Research article

Appraisal of different attributes of fish community in Andharmanik River of coastal Bangladesh and socio-economic conditions of fishermen

Dulon Roy a,*, Nishat Binte Didar a, Smita Sarker b, Md. Arafat Rahman Khan a, Gulshan Ara Latifa c

a Department of Zoology, Faculty of Life and Earth Sciences, Jagannath University, Dhaka, 1100, Bangladesh
b Department of Statistics, Faculty of Science, Jagannath University, Dhaka, 1100, Bangladesh
c Department of Zoology, Faculty of Biological Science, University of Dhaka, Dhaka, 1000, Bangladesh

ARTICLE INFO

Keywords:
Coastal river
Conservation status
Diversity status
Fish community
Socioeconomics

ABSTRACT

The purpose of this study was to determine the fish species composition and appraise the status of fish diversity through sampling in six sample locations and to observe the socio economic conditions of the fishermen surrounding the river during the study period. There were 81 fish species found, classified into 13 orders, 40 families, and 69 genera. The most dominant order was Perciformes (55.42 %), followed by Clupeiformes (20.44 %), Cypriniformes (8.96 %), Siluriformes (8.13 %), and others (7.05%). To illustrate the species diversity, fish species richness and evenness in sampling areas, indices of fish community viz. Shannon-Wiener's Index (H), Simpson's Dominance Index (D), Simpson's Diversity Index (1-D), Margalef's Index (d) and Gibson's Evenness (€) were used and 3.29–3.48, 0.05–0.069, 0.93–0.95, 6.88–8.43 and 0.39–0.49 respectively were the overall values of the indices. S1 station is significantly differ in species richness from the rest of the five stations (P < 0.05). The analysis of similarity (ANOSIM) displayed significant (P-value < 0.05) variations in fish community among stations and months. In compliance with similarity percentage (SIMPER) analysis, 35.8% similarities were observed among the fish species from different stations, while 59.36% similarities were detected among the fish species from different months. One species is critically endangered (CR), three species are nearly threatened, eight species are endangered (EN), and eight species are vulnerable among the 81 fish species recorded at various sampling locations. The socioeconomic conditions of fishermen were determined on the basis of a personal interview and focus group discussion. Unfair fishing practices as well as environmental instabilities such as reduced water volume, increased sedimentation, water abstraction, and pollution have ravaged fish habitat and diminished fish diversity over time. As a result, fish preservation in the Andharmanik River has become imperative, and an integrated management plan should be designed and executed as soon as possible.

1. Introduction

Due to the existence of large numbers of rivers spread throughout the region, Bangladesh is considered a riverine country (Rahman, 2015; USAID, 2016). It has numerous inland bodies of water rich in biodiversity. About 800 rivers with their tributaries and distributaries cross the country and create a waterway of approximately 24,140 km in length (DoF, 2014) of which 710 km is coastline area. In Bangladesh, the southeastern and the southwestern coast constitute a complex coastal and estuarine ecosystem. The rivers provide enormous opportunities and possibilities for enhancing fish production and improving the living conditions of the people living around them (Rahman et al., 2015). The coastal rivers of southern Bangladesh are recognized for a large quantity of commercial fish catch which influences the national economy of the country (Sharker et al., 2015) and the Andharmanik River is one of them. The Bangladeshi Government has declared five sanctuaries where fishing of ‘Jatka’ or juvenile Hilsha fish is forbidden for a particular period. The Andharmanik River is one of the five sanctuaries (Wahab and Golder, 2016) and contains a large number of aquatic resources. Fish diversity refers to the number of species present in the given location as well as their relative abundance. In Asia, Bangladesh has the third-highest aquatic fish diversity after China and India with about 800 species in freshwater, saltwater and coastal waters (Shamsuzzaman et al., 2017).

* Corresponding author.
E-mail addresses: dulonroy@gmail.com, dulon.roy@zool.jnu.ac.bd (D. Roy).

https://doi.org/10.1016/j.heliyon.2022.e09825
Received 1 February 2022; Received in revised form 21 March 2022; Accepted 24 June 2022
2405-8440/ © 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
The diversity of species can be measured in a variety of ways e.g. number of species, functional diversity and genetic diversity. The coastal zone is inhabited by 35 million people, or 29% of the total population (Ahmad, 2019). Coastal zone as a part of the fisheries sector in Bangladesh contributes significantly to the country's socioeconomic development by providing opportunities for income, empowering women, supplying nutrition and gaining money from overseas through exporting fish, shrimp, and other fisheries products. For the overall planning and development of the fisheries sector, sound knowledge of the livelihood patterns of the associated people is very important.

Fish biodiversity and environmental management are two of the most pressing issues today, and the ability to measure the effects of habitat change and other factors on the fish population require detailed assessments of the fishery (Dudgeon et al., 2006). A major problem in Bangladesh is the decline in the abundance or stocks of freshwater as well as coastal water fish species. IUCN Bangladesh (2015) evaluated a total of 253 fish species, of which 64 species (25.3%) were found to be endangered (Rihanom et al., 2016). The diversity of fish species in water bodies such as rivers, estuaries, and beels is rapidly dwindling, as evidenced by various studies (Mia et al., 2015; Rahman et al., 2015, 2016a and 2016b; Islam et al., 2016; Roy et al., 2016; Galib et al., 2013; Hossain et al., 2014; Alam et al., 2013; Mohsin et al., 2013 and 2014. But less is known about the species composition and livelihood patterns of the local fishers. Storm surges, cyclones, sea level rise, coastal inundation, land erosion, and other climate change-related occurrences are major factors in fish diversity loss, which ultimately determine the fate of fishers in the coastal zone (Karim and Mimura, 2008). As a result, a thorough understanding of fish community structure and biodiversity patterns is required in order to develop sustainable management or conservation measures in coastal areas and assess their effects (Sarkar and Bain, 2007). For all of these reasons, the current research intends to evaluate the fish community composition, diversity status and socio-economic conditions of fishers in the Andharmanik River. The findings of this research will help to develop ecosystem-based riverine fisheries management in coastal areas.

2. Materials and methods

2.1. Study area

The Andharmanik River is a coastal river of the Ganges–Padma system and it is one of the major rivers of Kalapara Upazila in Patuakhali District. Because of its proximity to the Bay of Bengal, the Andharmanik River in southern Bangladesh is an ichthyofaunal resourceful coastal water body and currently declared as fish sanctuary. For a total length of 40 km, at least 25 km of the river have been permanently dried out due to deposition of sediment and siltation. The Andharmanik river has been divided into six sampling stations to explore the entire length of the river and to determine how seasonal fish diversity affects local river fisheries and fisherman's socioeconomic status. Six sampling stations have been the focus of the present investigation such as Khepupara (S1), Nahipur (S2), Fatapur (S3), Hajipur (S4), Nizampur (S5) and Alipur (S6) (Figure 1). The related data were collected on a quarterly basis to meet the objectives of the current research, i.e., twice a month for a period of one year from May 2019 to February 2020.

2.2. Fish specimen collection

During the catch, fish samples were gathered from local fish landing stations and previously notified fishers. In the study region, different types of fishing gear (seine net, gill net, cast net, hooks, trapes etc) are employed by local Fishers which vary in terms of target species, size, and

![Figure 1. Sampling area with different sampling stations in Andharmanik River.](https://example.com/figure1.png)
performance (Kundu et al., 2019). The collection methods were the same in different sampling stations. On each sampling day, the total number of individual species found at these six locations was tallied.

2.3. Identification of collected fish samples

Collected fishes were organized based on their key morphological features. Species that were tough to recognize on the site were stored in a 5–10% buffered formalin solution and transported to the lab of Department of Zoology, Jagannath University, Dhaka, Bangladesh. Then they were identified by evaluating their morphometric and meristic features as well as the color of the specimens. In accordance with Rahman (2005), Talwar and Jhingran (1991), and IUCN Bangladesh (2015), the taxonomic analysis was carried out. After identification, the fish species were persistently classified according to Nelson (2006).

2.4. Species assemblage and fish diversity analysis

The two most widely used diversity indices are species richness and evenness (Magurran, 2004). We selected a variety of diversity indicators because they provide a solid foundation for assessing and comparing biodiversity across communities. Species diversity was calculated using different indices such as Shannon Weiner diversity index (Shannon, 1949; Shannon and Weaver, 1963; Ramos et al., 2006), Simpson’s index of diversity, Simpson’s dominance index, Margalef’s index and Gibson’s evenness were considered for both the number of species and the distribution of individuals.

The Shannon–Wiener diversity index was used to take into account for the number of species as well as the apportionment of individuals within species. The Shannon Weiner diversity (H) was calculated by following formula:

\[ H = -\sum_{i=1}^{S} \left( p_i \times \ln p_i \right) = -\sum_{i=1}^{S} \left( \frac{n_i}{N} \times \ln \frac{n_i}{N} \right) \]

Where pi is the proportion of the sample represented by species i, N is total number of individuals of all species in community, S is the sum values for each species and ln is the natural logarithm.

Simpson’s (1949) Index of Diversity (1-D):

\[ 1 - D = 1 - \frac{\sum n_i(n_i - 1)}{N(N - 1)} \]

Where, ni is the total number of individuals of a particular species, S is the sum values for each species and N is the total number of individuals of all species.

Simpson’s dominance index (D) is a commonly used method for quantifying biodiversity of habitat, which takes into consideration both the number of species and their abundance.

\[ D = \frac{\sum n_i(n_i - 1)}{N(N - 1)} \]

The following formula was used to calculate the Margalef index (d) (Margalef, 1968) to determine species richness.

\[ d = \frac{(S - 1)}{\ln N} \]

Where S is the number of species in a sample and N is the total individuals and ln is the natural logarithm.

Buzas and Gibson’s evenness (Harper, 1999) was used to estimate the relative number of individuals in the sample by using the following formula:

\[ E = e^{\frac{1}{S}} \]

2.5. Socio-economic conditions of fishermen

The survey questionnaire is an important instrument for data collection. A draft questionnaire with some predefined questions was prepared in conjunction with the objectives of the study in such a way that it could cover all factors relevant to the socio-economic status of fishermen and to the fish diversity (Hossain et al., 2015). A simple random sampling procedure for 50 fishermen of different age in each village was used for questionnaire interviews. In light of specific and realistic experiences, the draft questionnaire was then modified, reordered and updated. Each fisher was interviewed near the river when fishing and sometimes by visiting home. Each fisher was interviewed for half an hour in a single session. To assess the socioeconomic condition, participatory rural appraisal tools such as focus group discussion (FGD) were also conducted with these 50 fishers. For verification of the relevant information, cross-check interviews were performed with key individuals such as the DFO and relevant NGO staff.

2.6. Statistical analysis

During the first step of data analysis, fish diversity was quantified and statistical comparisons were then carried out. MS Excel and Statistical Packages for Social Sciences (SPSS) version 20.00 were used to perform this statistical analysis. R Programming version 4.1.1 was used to perform Analysis of Variance (ANOVA) to determine the spatial variation of average species richness. Tukey’s multiple comparison test also used to determine which station amongst the six stations differs from the rest of the remaining stations. Paleontological Statistics (PAST) version 3.22, a software package for paleontological data analysis (Hammer et al., 2001) was used to execute the Analysis of Similarities (ANOSIM) and Similarity Percentages analysis (SIMPER). The assemblage similarity and significant differences among the fish species of different stations and months were assessed employing ANOSIM (Clarke, 1993; Clarke and Warwick, 2001). SIMPER (Clarke, 1993) was performed to observe the degree of similarity among the fish species of from various locations and months. This analysis is also used to estimate the percentage of major fish species during different months and stations. The hierarchical clustering (Clarke and Warwick, 2001) was also calculated to generate a dendrogram for analyzing similarities among months and stations.

3. Results

3.1. Fish species assemblage and distribution

A variety of economically important fishes are found in the estuarine coastal and nearby areas of Bangladesh. The assessment encompassed 81 fish species classified into 13 orders, 40 families, and 69 genera, along with their scientific names, English names, local names, and IUCN red list status in Bangladesh (Table 1). Perciformes was the most prevalent order (55.42%), trailed by Clupeiformes (20.44%), Cypriniformes (8.96%), and Siluriformes (8.13%). Anguilliformes, Aulopiformes, Beloniformes, Mugiliformes, Ostegocephaliformes, Pleuronectiformes, Scorpaeniformes, Synbranchiformes and Tetraodontiformes were least adequate and constituted 7.05% of overall species composition (Figure 2). Among the six stations, a maximum of 80 species recorded in station 6 (S6) and a minimum of 63 species recorded in station 3 (S3).

3.2. Fish diversity status

The concept of a biodiversity index is to use a single number to describe the diversity of a sample or community. Figure 3 depicts the average species richness in six sampling points under several orders along the Andharmanik River in coastal Bangladesh. During the entire sample period, the Shannon-Weiner index (H), Simpson’s dominance index (D), Simpson’s index of diversity (1-D), and Margalef’s index were calculated.
| Order                       | Family                  | Scientific Name                            | English Name          | Local Name | Number of Individuals | Total | IUCN Red List Status |
|-----------------------------|-------------------------|--------------------------------------------|-----------------------|------------|-----------------------|-------|----------------------|
| Anguilliformes              | Muraenesocidae          | Congresox talabon (Cuvier, 1829)           | Yellow pike-conger    | Kamila     | 84                    | 390   | NE                   |
| Aulopiformes                | Synodontidae            | Harpadon nehereus (Hamilton, 1822)         | Bombay-duck           | Loitta     | 352                   | 1948  | NT                   |
| Beloniformes                | Belonidae               | Xenetodon cancila (Hamilton, 1822)         | Freshwater Garfish    | Kakila     | 46                    | 288   | LC                   |
| Clupeiformes                | Clupeidae               | Corica soborna (Hamilton, 1822)            | Ganges river sprat    | Kachki     | 172                   | 881   | LC                   |
|                           |                         | Gudusia chapra (Hamilton, 1822)            | Indian river shad     | Chapila    | 104                   | 578   | VU                   |
|                           |                         | Elisha megaloptera (Swainson, 1839)        | Bigeye ilisha         | Choukka    | 274                   | 1638  | LC                   |
|                           |                         | Tenualosa liihsa (Hamilton, 1822)          | Hilsa shad            | Ilish      | 670                   | 3042  | LC                   |
|                           |                         | Tenualosa toli (Valencienes, 1847)         | Toli shad             | Chandana   | 116                   | 620   | VU                   |
| Engraulidae                 |                         | Setipinne phassa (Hamilton, 1822)          | Gangetic hairfin anchovy | Phasa     | 286                   | 1406  | LC                   |
|                           |                         | Setipinne taty (Valencienes, 1848)         | Scaity hairfin anchovy | Teli phasa | 124                   | 722   | LC                   |
|                           |                         | Csilia neglecta (Whitehead, 1967)          | Neglected grenadier anchovy | Olia     | 446                   | 2251  | LC                   |
|                           |                         | Csilia ramcarati (Hamilton, 1822)          | Ramcarat grenadier anchovy | Megha olua | 90                   | 406   | DD                   |
| Pristigasteridae            |                         | Pellona ditchela (Valencienes, 1847)       | Indian pellona        | Choukka    | 76                    | 356   | LC                   |
| Cypriniformes               | Cobitidae               | Lepidocephalichthys guenta (Hamilton, 1822) | Guntea loach          | Gutum      | 34                    | 161   | LC                   |
|                           |                         | Puntius sophore (Hamilton, 1822)           | Spot fin swamp barb   | Jat punti  | 26                    | 156   | LC                   |
|                           |                         | Puntius ticto (Hamilton, 1822)             | Ticto barb            | Tit punti  | 93                    | 451   | VU                   |
| Osteobrama cotio           |                         | (Hamilton, 1822)                           | Cooto                 | Dhela      | 36                    | 206   | LC                   |
| Salmonostoma bacaila       |                         | (Hamilton, 1822)                           | Large razorbelly minnow | Narkali chela | 24                | 138   | LC                   |
| Exomus danricus            |                         | (Hamilton, 1822)                           | Flying barb           | Darkina    | 98                    | 466   | LC                   |
| Laboe bata (Hamilton, 1822) |                         | Bata                                       | Bata                  | 24         | 152                   | 152   | LC                   |
| Laboe rohita (Hamilton, 1822) |                     | Rui                                        | Rui                   | 16         | 88                    | 88    | LC                   |
| Gibelion catla (Hamilton, 1822) |                     | Catla                                      | Catia                 | 12         | 41                    | 41    | LC                   |
| Amblypharygodon mola       |                         | Mola carplet                              | Mola                  | 648        | 3004                  | 3004  | LC                   |
| Amblypharygodon microlepis |                         | (Bleeker, 1853)                           | Indian carplet        | Mola       | 72                    | 352   | LC                   |
| Mugiliformes               | Mugilidae               | Rhinomugil consula (Hamilton, 1822)        | Corsula               | Khalla     | 10                    | 40    | LC                   |
|                           |                         | Mugi cephalus (Linnaeus, 1758)             | Flathead grey mullet  | Korol      | 8                     | 34    | LC                   |
|                           |                         | Chelon parisa (Hamilton, 1822)             | Goldspot mullet       | Parse Bata | 0                     | 8     | NE                   |
| Osteoglossiformes           | Nototpteridae           | Nototerus notopterus (Pallas, 1769)        | Bronze featherback    | Foli       | 20                    | 100   | VU                   |
|                           |                         | Nototerus chinula (Hamilton, 1822)         | Clown knifefish       | Chital     | 14                    | 48    | EN                   |

(continued on next page)
| Order            | Family               | Scientific Name                  | English Name                  | Local Name       | Number of Individuals | IUCN Red List Status |
|------------------|----------------------|----------------------------------|------------------------------|------------------|-----------------------|----------------------|
|                  |                      |                                  |                              |                  |                       | S1      S2 S3 S4 S5 S6 |                      |
| Perciformes      | Ambassidae           | Chanda nama (Hamilton, 1822)      | Elongate glassy perchlet     | Nama chanda      | 48 24 40 30 32 42     | 216     LC            |
|                  |                      | Chanda nama (Hamilton, 1822)      | Elongate glassy perchlet     | Nama chanda      | 48 24 40 30 32 42     | 216     LC            |
|                  |                      | Parambassis ranga (Hamilton, 1822)| Indian glassy fish          | Lal chanda       | 22 29 36 0 24 28      | 139     LC            |
|                  | Anabantidae          | Anabas testudineus (Bloch, 1792) | Climbing perch              | Koi              | 26 20 22 18 0 26      | 112     LC            |
|                  | Carangidae           | Parastromateus niger (Bloch, 1795)| Black pomfret               | Kala chanda      | 18 0 0 12 0 16        | 46      LC            |
|                  | Channidae            | Channa punctatus (Bloch, 1793)    | Spotted snakehead           | Taki             | 18 20 18 20 12 16     | 104     LC            |
|                  |                      | Channa marulius (Hamilton, 1822)  | Giant snakehead             | Gozar            | 12 16 14 22 8 18      | 90      EN            |
|                  |                      | Channa striatus (Bloch, 1793)     | Striped snakehead           | Shol             | 12 16 14 10 18 12     | 82      LC            |
|                  | Gobiidae             | Glossogobius giuris (Hamilton, 1822)| Tank goby                | Bele             | 182 146 162 108 106 176 | 880     LC            |
|                  |                      | Pseudapocryptes elongatus (Cuvier, 1816) | Lanceolate goby        | Chewa            | 112 82 107 0 67 96    | 464     LC            |
|                  | Osphronemidae        | Trichogaster fasciata (Bloch and Schneider, 1801)| Banded gourami   | Khalisha         | 94 66 72 54 56 104    | 446     LC            |
|                  | Polynemidae          | Polyergus paradiseus (Linnaeus, 1758) | Paradise threadfin      | Tapasi           | 146 126 154 106 107 136 | 775     LC            |
|                  |                      | Eleutheronema tetractylum (Shaw, 1804) | Fourfinger threadfin     | Tailla           | 46 0 38 40 42 52      | 218     NE            |
|                  | Scatophagidae        | Scatophagus argus (Linnaeus, 1766) | Spotted scat              | Bishtara         | 834 642 470 646 390 942 | 3924    LC            |
| Sciidae          | Macrognathus cuja (Hamilton, 1822) | Cuja croaker                 | Kuizza poa               | 82 64 52 48 70 98 | 414     DD            |
|                  |                      | Otolithoides pama (Hamilton, 1822)  | Pama croaker               | Pox/Bhola poa   | 1680 1542 1324 1110 1448 1242 | 8346    DD            |
|                  |                      | Pana microdon (Bleeker, 1849)     | Pana croaker               | Chotta lambu     | 106 92 128 112 102 120 | 660     LC            |
|                  |                      | Johnius coitor (Hamilton, 1822)   | Coitor croaker             | Koitor           | 896 678 1094 566 589 967 | 4790    LC            |
|                  | Pterolatilus maculatus (Cuvier, 1830) | Blotched tiger-toothed croaker | Gutipoo/lombu          | 124 107 132 104 99 128 | 694     LC            |
| Sillaginidae     | Sillaginis spinius (Hamilton, 1822) | Flathead sillago            | Tular dandi              | 125 157 114 128 106 146 | 776     NE            |
|                  |                      | Sillago sihama (Forskal, 1775)    | Silver sillago            | Tool bele/Sunda  | 64 46 42 38 36 56      | 282     LC            |
| Sparidae         | Acanthopagrus latus (Houttuyn, 1782) | Surf bream               | Datina                    | 206 216 186 164 218 251 | 1241    DD            |
| Teraponidae      | Terapon jarbua (Forskal, 1775) | Jarbua terapon              | Borguni                   | 52 38 46 0 52 44   | 232     LC            |
| Trichiuridae     | Trichura mutica (Gray, 1831)    | Ribbon Fish                    | Churi                     | 1148 1064 1142 1014 1022 1122 | 6512    NE            |
| Pleuronectiformes| Cynoglossidae        | Cynoglossus arel (Bloch and Schneider, 1801) | Largescale tonguesole  | Kukur jeeb       | 36 0 42 0 40 38       | 156     DD            |
|                  |                      | Cynoglossus cynoglossus (Hamilton, 1822) | Bengal tongue sole       | Kukur jeeb       | 32 18 28 12 20 27     | 137     LC            |
| Soleidae         | Brachirus pan (Hamilton, 1822) | Pan sole                      | Kathal pata              | 22 0 18 0 0 24     | 64      LC            |

(continued on next page)
from the research areas to evaluate the fish diversity status, evenness, and species richness (Table 2, Figure 3 and Figure 4). S6 had the highest H value (3.49), S1 had the second highest (3.42), and S2 had the lowest (3.29). In case of months, the highest value was found in January (3.44) followed by July (3.38) and lowest was found in October (3.23).

The Simpson’s dominance index (D) values ranged from 0.05-0.07 which indicates the smaller diversity in studied areas. From the studied areas to evaluate the fish diversity status, evenness, and species richness (Table 2, Figure 3 and Figure 4). S6 had the highest H value (3.49), S1 had the second highest (3.42), and S2 had the lowest (3.29). In case of months, the highest value was found in January (3.44) followed by July (3.38) and lowest was found in October (3.23).
stations 2, 4 and 5. Likewise, stations 2, 4, and 5 also exhibited significant differences from stations 1 and 6. Noticeable difference was not observed for station 3 with other stations. In case of months, May, June, July, and August showed a significant dissimilarity with November. June showed major difference in contrast to October, November and December. October showed a significant difference from June. Similarly, the months of November showed significant difference with May, June, July and August. December differed significantly from June, July, and August, whereas September and January exhibited no significant changes from the other months.

In conformity with the similarity percentage (SIMPER) analysis (Table 4), 35.8% similarity was found among the fish samples of different stations and dominating species were Otolithoides pama (18.06%), Trichiurus muticus (12.71%), Scatophagus argus (11.9%), Johnius coitor (11.67%), Tenualosa ilisha (8.84%), Amblypharyngodon mola (7.76%), Mystus vittatus (7.19%), Coilia neglecta (5.46%), Setipinna phasa (4.65%), Ilisha megaloptera (4.63%), Harpadon nehereus (4.08%) and Acanthopagrus latus (3.01%).

On the contrary, 59.36% similarity was observed among the fish samples of different months and dominating species were Otolithoides pama (19.77%), Trichiurus muticus (15.83%), Amblypharyngodon mola (11.11%), Johnius coitor (10.97%), Coilia neglecta (8.92%), Scatophagus argus (8.66%), Harpadon nehereus (5.81%), Mystus vittatus (5.33%), Acanthopagrus latus (4.11%), Tenualosa ilisha (3.96%), Setipinna phasa (2.95%) and Ilisha megaloptera (2.57%).

At the similarity level 29% separation, either for month or station, was identified by cluster analysis (Figure 5). Two major clusters were obtained—first cluster consists of fish samples of station 4 with October, November and December, fish samples of station 5 with August, June, July, October, November and December, and fish samples of station 6 with November, December, June, July, August and October, and second cluster consists of fish samples of station 1 with October, July, November, August, December and June, fish samples of station 2 with June, July, August, October, November and December, and fish samples of station 4 with August, June and July.

3.3. Conservation status

Of 81 fish species found in the studied area, 1 species are critically endangered (CR), 3 species are nearly threatened (NT), 8 species are endangered (EN) and 8 species are vulnerable (IUCN 2015) (Figure 6). A maximum number of the threatened species was recorded at sampling site S6, followed by S1 and S5 (Figure 7). Rahman et al. (2016a) recorded 3 endangered, 3 critically endangered and 8 vulnerable fish species in a community of 48 species. On the other hand, Mohsin et al. (2014) found 3 endangered, 2 critically endangered, and 5 vulnerable fish species in Andharmanik River. Both of these findings are lower than the current one.
Table 2. The species status in the Andharmanik River was determined using different diversity indexes.

| Sampling stations | No of Species | No. of individuals | Variables |
|-------------------|---------------|--------------------|-----------|
|                   |               |                    | Shannon Wiener Diversity index (H) | Simpson's dominance index (D) | Margalef's index (d) | Simpson's index of diversity (1-D) | Gibson's Evenness (E) |
| S1                | 77            | 11493              | 3.42      | 0.057 | 8.13   | 0.943 | 0.397 |
| S2                | 64            | 9024               | 3.29      | 0.066 | 6.92   | 0.934 | 0.419 |
| S3                | 72            | 9882               | 3.38      | 0.059 | 7.72   | 0.941 | 0.408 |
| S4                | 63            | 8197               | 3.32      | 0.060 | 6.88   | 0.940 | 0.439 |
| S5                | 66            | 7904               | 3.31      | 0.069 | 7.24   | 0.931 | 0.415 |
| S6                | 80            | 11722              | 3.48      | 0.050 | 8.43   | 0.950 | 0.406 |

| Months           | No of species | No. of individuals | Variables |
|------------------|---------------|--------------------|-----------|
| May              | 56            | 4868               | 3.31      | 0.056 | 6.48   | 0.944 | 0.489 |
| June             | 67            | 5640               | 3.36      | 0.061 | 7.64   | 0.939 | 0.430 |
| July             | 66            | 6396               | 3.38      | 0.056 | 7.42   | 0.944 | 0.445 |
| August           | 73            | 7407               | 3.37      | 0.058 | 8.08   | 0.942 | 0.398 |
| September        | 74            | 7547               | 3.35      | 0.061 | 8.18   | 0.939 | 0.385 |
| October          | 67            | 7594               | 3.23      | 0.069 | 7.39   | 0.931 | 0.377 |
| November         | 66            | 6936               | 3.29      | 0.064 | 7.35   | 0.936 | 0.407 |
| December         | 62            | 6049               | 3.29      | 0.067 | 7.00   | 0.933 | 0.433 |
| January          | 65            | 5735               | 3.44      | 0.055 | 7.40   | 0.945 | 0.480 |

Threatened fish made for 24.69% fish species in the Andharmanik River. Among them 1.23% were critically endangered, 3.70% were near threatened, 9.88% were endangered and 9.88% were vulnerable. 33.92% of fish species in the Mahananda River (Mohsin and Haque, 2009), 42.5% in the Padma River (Rahman et al., 2012), 41.27% in the river Choto Jamuna (Galib et al., 2013), 32% in the Talma River (Rahman et al., 2015), and 6.65% in the Shiba River (Khanom et al., 2016) were reported as threatened.

3.4. Socio-economic conditions of fishermen

This result indicates that the fishing community relies on fishing and fishing-related activities for its livelihood. Several criteria were considered in order to clearly understand the whole scenario regarding their socio-economic status such as sex, marital status, religion, age group, family size, education, fishermen type, housing condition, health facility, drinking water facilities, sanitation, electricity facilities, credit access, annual income etc.

Both male and female fishermen were seen in the study sites. Among them 7% of females and 93% of males were involved in fishing. Most of the respondents of that site were married (96%) and 4% were unmarried. Muslims were featuring as the absolute majority of the fishermen in the study area. 86% of the fishermen were Muslim and the rest of the fishermen were Hindu in their religion. Knowing the age structure of fishermen is essential for calculating prospective productive human resources. The study found that the largest age group that was involved in fishing was 31–40 years old (35%) followed by 41–50 years old (30%), 51–60 years old (23%), and those older than 60 years old (12%) (Figure 8). The study revealed that 50% of fishermen had 5–7 family members, 40% had above 7 family members and only 10% of fishermen had 4–5 family members (Figure 9). In the current study, it was found that the majority of the fishermen in the selected areas were illiterate (46%) and could only sign 32%, 18% had only primary education, and 4% had only received junior (class eight) education (Figure 10). About 74% of fishermen were full-time fishermen, about 22% of fishermen were part-time fishermen and 4% were subsistence fishermen (Figure 11). Among part-time fishermen, many of them are engaged in agriculture and day labor activities. It was evident from the data that 72% of fishermen had kacha, 28% had a tin-shed house. Fishermen’s health facilities were poor in the study areas and it was found that 60% of fishermen’s households were dependent on village doctors who did not have adequate knowledge of medical science, 30% of fishermen received health services from the Upazila health complex and the remaining 10% received health services from MBBS doctors. According to the study, 100% of fishermen’s households drink from tube wells, with 54% using their own tube well, 42% using a shared tube well, and 4% utilizing tube well from a neighbor. It was observed that the sanitary conditions of the fishermen were not enough satisfactory. In the study area, it was found that 60% of toilets were semi-paka while 32% were kacha and 8% of the fishermen had paka sanitation found in the investigation (Figure 12). From the present survey, it was found that there were 78% of fishermen had electricity facilities and the rest 22% had no electricity facilities. National and local NGOs such as BRAC offer credit for the purchase of fishing gear and boats only to the organized poor members. After repayment only 42% became self-sufficient who did not need financial help but 14% borrowed money from their neighbors, 16% from relatives, 22% from NGO s and 6% from co-operatives for their fishing business (Figure 13). Annual incomes of the fishermen were varied from BDT 24000 to 50000. The selected fishermen were divided into two classes based on their annual incomes, with around 60% of the respondents earning between BDT 24000 and 35000 and 40% earning between BDT 35001 and 45000. The fishermen did not receive any kind of government’s assistance as a result their living conditions were found as so poor. The activities of NGOs were also not so active.

4. Discussion

Within a river in different sampling stations, we compared the diversity pattern and community organization. During the study period, a total of 81 fish species were discovered. Because of the different kinds of environmental conditions in coastal water systems, different kinds of organisms were found at different locations in the research area. The species composition revealed a mixture of freshwater, marine and estuarine species as the river is a convergence of freshwater, brackish-water and coastal waters. Mohsin et al. (2014) conducted a one-year study of the fish fauna of the Andharmanik River and discovered 53 fish species belonging to 28 families while Rahman et al. (2016) reported a total of 48 species under 10 orders and 26 families which is signifying the enhancement in biodiversity in the coastal river for the last few years. In fact, the abundance of fish species has increased dramatically as a result of some recent incentive-based management initiatives, and fishermen are catching more species (Islam et al., 2016, 2017).
Moreover, the number of fish species recorded was much fewer than in other research in Bangladesh. For example, Shaﬁ and Quddus (1982) found 139 fish species from Marine and Brackish water of Bangladesh, Kundu et al. (2019) recorded 97 ﬁsh from two riverine sanctuaries, Roy et al. (2016) identiﬁed 103 ﬁsh species in Netrakona district’s designated locations, Hanif et al. (2015) recorded 98 species from southern coastal waters, Hossain et al. (2014) reported 128 ﬁsh species from Greater Noakhali, and Chowdhury et al. (2010) reported 98 species from Naaf River. Furthermore, the current ﬁndings revealed a large number of species when compared to Islam (2005), who identiﬁed 48 ﬁshes from Bangladesh’s Chittagong coast, Nabi et al. (2011), who identiﬁed 45 ﬁsh species from the Bakkhali estuary, and Joadder et al. (2015) documented 71 species from river Padma, Rahman et al. (2012) discovered 80 species in the Ganges River, whereas Galib et al. (2013) discovered 63 species in the Choto Jamuna river. Only 63 species were found in the Noakhali Coastal area, according to Ullah et al. (2016). The depletion of the biodiversity of ﬁsh is regarded as a troubling challenge and the only solution to this issue is its conservation. The same causes of decreasing biodiversity from the Padma and Tetulia Rivers were stated by Hossain (2010) and Hossain et al. (2015a) respectively.

The diversity and richness indices revealed that the diversity of ﬁsh fauna in different sampling points and in different months was practically identical (Figure 3 and Figure 4). The Shannon–Wiener diversity index calculates the number of species or the diversity of species, as well as their proportion. Contrastingly, Dominance and the Evenness indices quantify the fraction of common species and the relative number of Figure 4. Different attributes of ﬁsh community during different months and sampling stations of Andharmanik River.
from 1.63 to 3.41 (Chowdhury et al., 2011). The Shannon-Weiner values \((H)\) in the Naaf River estuary range slightly pollution of coastal water (Table 2). Rahman et al. (2016a) recorded Shannon-Weiner index \((H)\) from 1.06 to 1.51 from Talma River (Rahman et al., 2015). Galib et al. (2013) found Shannon-Weiner index \((H)\) was 3.71 in the Choto Jamuna River. Alam et al. (2013) in the Halda River found \(H\) values to be from 3.29 to 3.49. Seasonal fluctuations in nutrients at seagrass beds which affect the cohabitation of several fish species, atmospheric wind patterns, and periodic fish migrations for breeding and reproduction are the major reason for disparities in biodiversity indices in the coastal areas. The Margalef index \((\text{d})\) is used to assess pollution levels and species richness throughout sampling locations; it reveals inconsistency based on the number of species present (Vyas et al., 2012). Site S6 and the month of September represented the highest index value of Margalef (Table 2), suggesting a substantially higher number of individuals than other sampling stations. The observed value of \(d\) in the current study is greater than that of 4.72–5.24 by Rahman et al. (2016) and comparable to Hanif et al. (2015) who documented a high Margalef's index \((\text{d})\) of 7.48–8.67 in the southern coastal waters of Bangladesh. The dominance diversity index \((0.055–0.069)\) value and evenness value \((0.377–0.480)\) were almost the same among different stations and in different months during the study period (Table 2). Rahman et al. (2016a) recorded Simpson's dominance index \((\text{D})\), Simpson's index of diversity \((1-\text{D})\) and evenness \((\text{E})\) range from 0.042-0.048, 0.952–0.958 and 0.67–0.73 respectively in three stations of the Andharmanik River. Rahman et al. (2016) reported the Simpson’s dominance index \((\text{D})\) value range from 0.064 to 0.0133 on the Bishkhali River. Galib et al. (2013) found about 63 species from Choto Jamuna River and calculated values of Margalef’s index and evenness \((\text{E})\) were 6.954 and 0.897 respectively in the southern coastal waters of Bangladesh. The dominance diversity index \((0.055–0.069)\) value and evenness value \((0.377–0.480)\) were almost the same among different stations and in different months during the study period (Table 2). Rahman et al. (2016a) recorded Simpson's dominance index \((\text{D})\), Simpson's index of diversity \((1-\text{D})\) and evenness \((\text{E})\) range from 0.042-0.048, 0.952–0.958 and 0.67–0.73 respectively in three stations of the Andharmanik River. Rahman et al. (2016) reported the Simpson’s dominance index \((\text{D})\) value range from 0.064 to 0.0133 on the Bishkhali River. Galib et al. (2013) found about 63 species from Choto Jamuna River and calculated values of Margalef’s index and evenness \((\text{E})\) were 6.954 and 0.897 respectively. There was no significant difference in Shannon \((\text{H})\), Simpson's \((1-\text{D})\), Evenness \((\text{E})\), Dominance index \((\text{D})\), and Margalef \((\text{d})\) diversity. As a result, it is possible to conclude that seasonal differences in species diversity are a typical occurrence in the study area.

The current study, the occurrence of finfish assemblages was found to be nearly identical across stations and months. Although their percentage of contribution varies, the major contributing species for both locations and months are comparable. Several studies on the temporal and spatial pattern of fish diversity and assemblage structures in coastal ecosystems have been conducted throughout the world (Goswami et al., 2012). However, the current study gives a broad perspective of the spatial and temporal patterns of fish communities, a more extensive sampling technique is used to clarify a complete representation of the coastal ecosystem.

Fish biodiversity conservation is currently concentrated mostly on endangered and economically important fish species. It has made a number of steps to conserve fish biodiversity in Bangladesh and around the world, but we observed that such initiatives were insufficient in coastal areas. The environments rich in endemic fish species should be designated as nature reserves in order to restore fish assemblages in the

### Table 3. One-way ANOSIM (significant levels) results for various stations and months.

| Stations | S1 | S2 | S3 | S4 | S5 | S6 |
|----------|----|----|----|----|----|----|
| S1       |    |    |    |    |    |    |
| S2       |    | 0.035 |    |    |    |    |
| S3       |    |    |    |    |    |    |
| S4       |    | 0.0063 |    |    |    |    |
| S5       |    | 0.015 |    |    |    |    |
| S6       |    |    |    |    |    | 0.0065 |

| Months | May | June | July | August | Sep | Oct | Nov | Dec | Jan |
|--------|-----|------|------|--------|-----|-----|-----|-----|-----|
| May    |    |    |    |        |     |     |     |     |     |
| June   |    |    |    |        |     |     |     |     |     |
| July   |    |    |    |        |     |     |     |     |     |
| August |    |    |    |        |     |     |     |     |     |
| Sep    |    |    |    |        |     |     |     |     |     |
| Oct    |    | 0.0464 |    |        |     |     |     |     |     |
| Nov    | 0.0278 | 0.0120 | 0.0176 | 0.0274 |     |     |     |     |     |
| Dec    |    | 0.0062 | 0.0052 | 0.0077 |     |     |     |     |     |
| Jan    |    |    |    |        |     |     |     |     |     |

### Table 4. SIMPER analysis was used to find the average similarity and distinguishing fish in each sampling station.

**SIMPER**

**Average Similarity**

| Stations (35.8%) | Months (44.8%) | Contributory Species | Contributory Species |
|------------------|---------------|----------------------|----------------------|
| Otolithoides pama (Hamilton, 1822) | 18.06 | Otolithoides pama (Hamilton, 1822) | 19.77 |
| Trichurus muticus (Gray, 1831) | 12.71 | Trichurus muticus (Gray, 1831) | 15.83 |
| Scatophagus argus (Linnaeus, 1766) | 11.90 | Amblyparyngodon mola (Hamilton, 1822) | 11.11 |
| Johnius coitor (Hamilton, 1822) | 11.67 | Johnius coitor (Hamilton, 1822) | 10.97 |
| Trinilus lalis (Hamilton, 1822) | 8.84 | Coilia neglecta (Whitehead, 1967) | 8.92 |
| Amblyparyngodon mola (Hamilton, 1822) | 7.76 | Scatophagus argus (Linnaeus, 1766) | 8.66 |
| Mystus vittatus (Bloch, 1794) | 7.19 | Harpadon nehereus (Hamilton, 1822) | 5.81 |
| Coilia neglecta (Whitehead, 1967) | 5.46 | Mystus vittatus (Bloch, 1794) | 5.33 |
| Setipinna phasa (Hamilton, 1822) | 4.65 | Acanthopagrus latus (Houttuyn, 1782) | 4.11 |
| Ilisha megaloptera (Swainson, 1839) | 4.63 | Tenualosa ilisha (Hamilton, 1822) | 3.96 |
| Harpadon nehereus (Hamilton, 1822) | 4.08 | Setipinna phasa (Hamilton, 1822) | 2.95 |
| Acanthopagrus latus (Houttuyn, 1782) | 3.01 | Ilisha megaloptera (Swainson, 1839) | 2.57 |

individuals respectively in the sample (Hossain et al., 2012). The calculated value of \(H\) in the present study among different sampling stations and months was significantly higher due to a large number of species and slight pollution of coastal water (Table 2). Rahman et al. (2016a) recorded Shannon-Weiner index \((H)\) ranges 3.33–3.42 in Andharmanik River. The Shannon-Weiner values \((H)\) in the Naaf River estuary range from 1.63 to 3.41 (Chowdhury et al., 2011). The \(H\) values are recorded as 1.06 to 1.51 from Talma River (Rahman et al., 2015). Galib et al. (2013) found Shannon-Weiner index \((H)\) was 3.71 in the Choto Jamuna River. Alam et al. (2013) in the Halda River found \(H\) values to be from 3.29 to 3.49. Seasonal fluctuations in nutrients at seagrass beds which affect the cohabitation of several fish species, atmospheric wind patterns, and periodic fish migrations for breeding and reproduction are the major reason for disparities in biodiversity indices in the coastal areas.
riverine estuaries. The IUCN regulatory regime for assessing the conservation status of fish was used in the study. Fish diversity must be conserved in order to keep environmental, nutritional, and socioeconomic balance (Lakra, 2010).

The age structure, family size and type, occupation status, level of education, dwelling condition, drinking water facilities, hygiene practices, health services, access to credit, and monthly income of fishermen were all investigated. Fish farmers in the research area have a poor socio-

Figure 5. Spatial and temporal cluster of fish assemblage based on Bray–Curtis similarity matrix.

Figure 6. The status of fish species documented in the Andharmanik River is on the red list.
economic situation and a poor livelihood structure. Few studies on the socio-economic condition of fishermen in different regions of Bangladesh were performed by Uddin et al. (2020), Hossain et al. (2015) and Hossain et al. (2014a) and the present findings agreed with them with few exceptions. The majority of fishermen (34%) are between the ages of 31 and 40, roughly 42% are illiterate, 72% have a hut, just 30% have a sanitary latrine, 34% are malnourished, 82 percent seek disease care from surrounding pharmacies, and only 14% have a monthly salary of more than $200 (Paul et al., 2018).
5. Conclusion

The results of this study showed the spatial and temporal patterns of fish diversity and community structure, as well as the role of different species in these patterns. It is evident from the current study that the status of the diversity of the fish fauna in the Andharmanik River is stable. The coastal areas consist of a collection of essential living resources, which are indiscriminately exploited by inhabitants. As a result, sustainable management and conservation of estuarine and coastal resources, as well as their connected ecosystems are required. There is no proper management scheme for capture fishery of the Andharmanik River and the adjacent Bay of Bengal. So many species are shrinking drastically due to human interference, excessive tourism, contamination, and even global climate change. That is why appropriate rules and regulations should be implemented in a planned way to increase production, to save the endangered species and improve the livelihood status of the people in the coastal area.

Declarations

Author contribution statement

Dulon Roy: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Nishat Binte Didar & Arafat Rahman Khan: Performed the experiments; Analyzed and interpreted the data.

Smita Sarker: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gulshan Ara Latifa: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Acknowledgements

The authors would like to convey their heartfelt gratitude to the fishermen and fishing community who assisted in data collecting in many ways to ensure the success of this study.

References

Ahmad, H., 2019. Bangladesh coastal zone management status and future. J. Coast. Zone. Manag. 22, 1.
Alam, M.S., Hossain, M.S., Monwar, M.M., Hoque, M.E., 2013. Assessment of fish distribution and biodiversity status in upper Halda River Chittagong Bangladesh. Int. J. Biodivers. Conserv. 5 (6), 249–257.
Chowdhury, M.S.N., Hossain, M.S., Das, N.G., Barua, P., 2011. Environmental variables and fishes diversity of the Naaf River estuary, Bangladesh. J. Coast Conserv. 15, 163–180.
Clarke, K.R., 1993. Non parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18 (1), 117–143.
Clarke, K.R., Warwick, R.M., 2001. Change in Marine Communities: an Approach to Statistical Analysis and Interpretation, second ed. PRIMER-E, Ltd., Plymouth Marine Laboratory, Plymouth.
Dhaka, 2014. National Fish Week 2014 Compendium (in Bengali). Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh, p. 44p.
Dudgeon, D., Arthington, A.H., Gesmer, M.O., Kawabata, Z.I., Knowler, D.J., et al., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. Camb. Phil. Soc. 81 (2), 163–182.
Gali, S.M., 2015. Fish fauna of the Brahmaputra River, Bangladesh: richness, threats and conservation needs. J. Fish. 3 (3), 285–292.
Gali, S.M., Naser, S.M.A., Mohsin, A.B.M., Chaki, N., Fahad, M.F.H., 2013. Fish diversity of the river Choto Jamuna, Bangladesh: present status and conservation needs. Int. J. Biodivers. Conserv. 5 (6), 389–395.
Goswami, U.C., Basistha, S.K., Bora, D., Shyamkumar, K., Saikia, B., Changsan, K., 2012. Fish diversity of North East India, inclusive of the Himalayan and Indo Burma biodiversity hotspots zones: a checklist on their taxonomic status, economic importance, geographical distribution, present status and prevailing threats. Int. J. Biodivers. Conserv. 4 (15), 592–615.
Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol. Electron. 4 (1), 1–9. http://pal eoelectronica.org/2001_1/past/issue1_01.htm.
Hari, M.A., Siddik, M.A.B., Chaklader, M.R., Nahar, A., Mahmud, S., 2015. Fish diversity in the southern coastal waters of Bangladesh: present status, threats and conservation perspectives. Croatian J. Fish. 73 (4), 148–161.
Harper, D.A.T., 1999. Numerical Palaeobiology. John Wiley & Sons.
Hossain, M.Y., 2010. Morphometric relationships of length-weight and length-length of four cyprinid small indigenous fish species from the Padma River (NW Bangladesh). Turk. J. Fish. Aquat. Sci. 10, 131–134.
Hossain, M.S., Das, N.G., Sarker, S., Rahman, M.Z., 2012. Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. Egypt J. Aquat. Res. 38 (3), 213–226.
Hossain, M.S., Sarker, S., Rahman, M.Z., Hoque, M.E., 2014. Freshwater fish diversity at greater Noakhali Bangladesh. CMU J. Nat. Sci. 13 (2), 207–225.
Hossain, S., Hasan, M.T., Alam, M.T., Mazumder, S.K., 2014a. Socio-economic condition of the fishermen in jelepara under pahartoli of Chittagong district. J. Sylhet Agril. Univ. 1 (1), 65–72.
Hossain, F.I., Miah, M.I., Hosen, M.H.A., Pervin, R., Haque, M.R., 2015. Study on the socio-economic condition of fishermen of the punovaba river under sadar Upazila, dinajpur. J. Fish. 3 (1), 239–244.
Hossain, M.Y., Sayeed, S.R.M., Rahman, M.M., Ali, M.M., Hossen, M.A., Elgorban, A.M., Ahmed, Z.F., Ohtomi, J., 2015a. Length-weight relationships of nine fish species from the Tenulta River, southern Bangladesh. J. Appl. Ichthyol. 31 (5), 967–969.

Funding statement

This work was supported by ‘NST Fellowship’, Ministry of Science and Technology, and partially from Grants from Jagannath University, Dhaka-1100, Bangladesh.

Data availability statement

Data available on personal reasonable request.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.
Islam, M.M., 2005. Catch Composition of Set Bag Net Fishery with Emphasis on the Population Dynamics of Two Commercial Important Fish Species from Chittagong Coastal Waters in the Bay of Bengal. MSc Thesis, Institute of Marine Sciences, University of Chittagong, Bangladesh.

Islam, M.K., Habil, K.A., Ahsan, M.E., Ali, M.M., Banik, S.K., 2016. Fish biodiversity at silsa river in southwestern Bangladesh: status and conservation requirements. Int. J. Fish. Aquat. Stud. 4 (1), 24-26.

Islam, M.M., Shamsuzzaman, M.M., Monaram, M.M.H., Xiangmin, X., Ming, Y., Jewel, M.A.S., 2017. Exploitation and conservation of coastal and marine fisheries in Bangladesh: do the fishery laws matter? Mar. Pol. 76, 143–151.

IUCN Bangladesh, 2015. Red Book of Threatened Fishes of Bangladesh. IUCN. The world conservation union, Dhaka, Bangladesh.

Joadder, M.A.R., Galib, S.M., Haque, S.M.M., Chaki, N., 2015. Fishes of the river Padma Bangladesh: current trend and conservation status. J. Fish. 3 (2), 259–266.

Karim, M.F., Mimura, N., 2008. Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. Global Environ. Change 18 (3), 490–500.

Khanom, D.A., Khatun, T., Jewel, M.A.S., Hossain, M.D., Rahman, M.M., 2016. Present status of fish biodiversity and abundance in Shila river Bangladesh. Univ. J. Zool., Rajshahi Univ. 35, 7–15.

Kundu, G.K., Islam, M.M., Hasan, M.F., et al., 2019. Patterns of distribution of hilsa shad conservation. Ecol. Freshw. Fish 29, 364–376.

Lakra, W.S., 2010. Fish biodiversity of Uttar Pradesh: issues of livelihood security, threats and conservation. National Conference on Biodiversity, Development and Poverty Alleviation. Uttar Pradesh State Biodiversity Board, India, pp. 40–45.

Margalef, R., 1968. Perspectives in Ecological Theory. University of Chicago Press, Malden, MA, p. 256.

Margalef, R., 1968. Perspectives in Ecological Theory. University of Chicago Press, Chicago, IL, p. 111.

Mia, M.S., Yeamin, F., Nesa, N.V., Kafi, M.F.H., Miah, M.I., Haq, M.S., 2015. Assessment and monitoring fish biodiversity of Meghna River in Bangladesh. Int. J. Nat. Social Sci. 2, 13–20.

Moinh, A.B.M., Haque, M.E., 2009. Diversity of fishes of Mahananda River at chapai nawabganj district. Res. J. Biol. Sci. 4 (7), 829–831.

Moinh, A.B.M., Haque, S.K.M.M., Galib, S.M., Fahad, M.F.H., Chaki, N., Islam, M.N., Rahman, M.M., 2013. Seasonal abundance of fin fishes in the Padma River at Rajshahi district, Bangladesh. World J. Fish Mar. Sci. 5 (6), 680–685.

Nabi, M.R.U., Mamun, M.A.A., Ullah, M.H., Mst. Akhter, M.N.R., 2016. Assessment of biodiversity in Talma River at northern part of Bangladesh. Int. J. Fish. Aquat. Stud. 5 (1), 341–348.

Rahman, M.B., Huque, S., Rahman, M., 2016. Identification of fishing technologies and their probable impacts on fish folk diversity in the Bishkhali River of Bhaklakhali District in Bangladesh. Acad. J. Agric. Res. 4 (2), 72–81.

Rahman, M.M., Rahman, M.B., Okaizaki, E., Mst. Akhter, M.N.R., 2016a. Assessment of species specificity of fishing gears and fish diversity status in the Andhmarikan River of coastal Bangladesh. J. Fish. Aquat. Sci. 11, 361–369.

Rahman, M.M., Rahman, M.B., Rithu, M.A.A., Huque, M.S., 2016b. Observation on selectivity of fishing gears and ichthyofaunal diversity in the Faiza River of Southern Bangladesh. Int. J. Fish. Aquat. Stud. 4 (1), 95–100.

Rahman, B.M., Huque, Z.M.D., Rahman, M.M., Nahar, A., 2017. Exploration of fishing gear and fisheries diversity of Aghumuka river at galachipa Upazila in Pataukhali district of Bangladesh. Jpn. J. Fish. Sci. 16 (1), 108–126.

Ramos, S., Cowen, R.K., Re, P., Bordak, A.A., 2006. Temporal and spatial distribution of larval fish assemblages in the Lima estuary (Portugal). Estuar. Coast Shelf Sci. 66, 303–314.

Roy, D., Masud, A.A., Sarkar, A., Latifa, G.A., 2016. Diversity of fish fauna in some selected area of a haor system in Khaliyajri thana of Netrakona district Bangladesh. Int. J. Fish. Aquat. Stud. 4 (2), 427–432.

Sarkar, U.K., Bain, M.B., 2007. Priority habitats for the conservation of large river fish in the Ganges river basin. Aquat. Conserv. Mar. Freshw. Ecosyst. 17, 349–359.

Shafl, M., Quddus, M.M.A., 1982. Fisheries Resources of Bay of Bengal (Bangostopagar Matshaya Sampad, in Bengali). Bangla Academy, Dhaka.

Shamsuzzaman, M.M., Islam, M.M., Tania, N.J., Al-Mamun, M.A., Barman, P.P., Xu, X., 2017. Fisheries resources of Bangladesh: present status and future direction. Aquac. Fish. 2, 145–156.

Shannon, C.E., 1949. Communication in the presence of noise. Proc. Inst. Radio Eng. 37, 10–21.

Shannon, C.E., Weaver, W., 1963. The Mathematical Theory of Communications. University of Illinois Press, Urbana, IL, p. 125.

Sharker, M.R., Mahamud, S., Siddik, M.A.B., Alam, M.J., Alam, M.R., 2015. Livelihood status of hilsa Fishers around Mohipur Fish Landing site, Bangladesh. World J. Fish Mar. Sci. 7 (2), 77–81.

Simpson, E.H., 1949. Measurement of diversity. Nature 163, 688.

Talwar, P.K., Jhingran, A.G., 1991. Inland Fishes of India and Adjacent Countries. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi Calcutta, p. 1158.

Uddinn, K.M., Hasan, R.M., Paul, S.K., Sultana, T., 2020. Socio-economic condition and livelihood status of the fisherman community at Murudangarh Upazila in Cumilia. Fish. Aquacult. J. 11, 279.

Ullah, M.K., Uddinn, M.N., Hossain, M.S., Hossain, M.B., Hossain, M.A., 2016. Fish diversity in three selected areas of mid-coastal region, Bangladesh. J. Fish. Aquat. Sci. 11, 174-184.

USAID, 2016. United States agency for international development. Bangladesh Tropical Forests and Biodiversity Assessment 73.

Vyas, V., Damde, V., Parashar, V., 2012. Fish Biodiversity of Betwa River in Madhya Pradesh, India with special reference to a sacred ghat. Int. J. Biodivers. Conserv. 4 (2), 71–77.

Wahab, M.A., Golder, M.L., 2016. Hilsa Fisheries Management Action Plan. ECOFISH-Bangladesh Project, World Fish, Bangladesh & South Asia Office and Department of Fisheries, Dhaka, Bangladesh, p. 14 (updated Short Edition).