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ORIGINAL ARTICLE

Understanding enviro-climatological impact on fish biodiversity of the tropical floodplain wetlands for their sustainable management

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Abstract

Inland open water fisheries around the world are threatened due to growing anthropogenic pressures, climate change and overexploitation of the germplasm resources. Understanding how the floodplain wetland fish diversity responds to these unprecedented challenges is critical for developing alternative management and mitigation strategies in vulnerable wetland ecosystems. This communication elucidates the changing pattern of fish diversity in three moderately impacted tropical floodplain wetlands namely Bhomra, Mathura and Chandania in the lower Ganges basin during the year 2017–2019. Experimental fishing using gill net, drag net and cast net was carried out monthly to assess the fish diversity pattern in the three wetlands. Enviro-climatological parameters were assessed, and the important parameters influencing fish diversity were identified. Most of the critical environment parameters including pH, DO, water temperature were in the favourable range for fish. ANOVA indicated that pH, TDS, conductivity, salinity, transparency, depth and hardness showed significant difference ($p < 0.05$) among the three wetlands. Thirty-six fish species were recorded from the three wetlands out of which 2 species were vulnerable (VU) and 1 species was near threatened (NT). Species richness declined in all the studied wetlands ranging from 22.85 to 54% from the year 2002. The Canonical Correspondence Analysis showed a varying relationship of climatic and environmental parameters with the occurrence of fishes indicating species-specific adaptive capacity. The study also revealed a decrease in fish production (1991 to 2017) with the decreasing trend in rainfall and the increasing trend in temperature showing enviro-climatological influence. The new information generated would help to manage the wetland resources for sustainable fisheries enhancement and biodiversity conservation.

Keywords Climate change · Wetlands · Fish diversity · Ecology · Impact · Sustainability

Introduction

Freshwater ecosystems and its associated flora and fauna are threatened by factors such as degradation of habitats, abstraction of the natural flow of water for hydro-power generation, pollution, harmful agricultural activities and introduction of invasive species to natural system etc (Carpenter 2011). In addition to these, unfavourable climatic condition poses a major threat to freshwater habitats and fish diversity (Sharp 1987; Sarkar and Borah 2017). Erwin (2009) opined that the consequences of climate change such as increased temperature and reduced rainfall pattern altered the eco-hydrology of wetlands. According to Duraiappah et al. (2005), many freshwater species are threatened due to climatic variability. Wrona et al. (2006) also mentioned that climate change-induced threats such as flood, drought condition, and cyclone are responsible for alteration in the global biogeochemical cycle, nature and structure of food chain and food web, productivity potential of the aquatic system, causing changes in adaptive capabilities of species and thus the fish diversity.

Climate change is projected as an important driver of change in wetland ecosystem throughout the globe (UNESCO 2007). Freshwater ecosystems and the associated fish diversity and fisheries are changing under the pressure of unprecedented threats including climate change (Woodward et al., 2010). Inland wetlands, particularly floodplain wetlands of India, are indispensable resources in fisheries sector that provide a natural habitat for different economically important and migratory species (Mitsch and Gosselink 1986; Whiting and Pomeranets 1997; Takatert et al. 1999;

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Hupp 2000). Although 85 fish species belonging to 33 families were reported from the floodplain wetlands of India a decade ago (Suresh and Chitranshi 2011), but reports on the current status of fish diversity and the impact of enviro-climatological on fish diversity in floodplain wetland are scanty (Sarkar et al. 2020).

Inland water bodies of West Bengal harbour around 190 varieties of native fishes which is about 23% of total freshwater fishes are found in India (Mahapatra et al. 2014). This state is also enriched with a considerable number of floodplain wetlands, which are highly productive. Since last few years, these wetlands are facing climatic variability which includes temperature rise, uncertainty in rainfall, and occurrence of extreme climatic events along with anthropogenic threats. In changing climatic and environmental scenario, management of these aquatic resources and its associated habitats requires long-term data to identify the threats that are responsible for a decline in overall fish diversity, production trend as well as ecological profile.

There is a lack of systematic quantified information on climatic and hydrological influences on floodplain wetland fish diversity as well as on fish production trends. Most of the previous studies that have been conducted are mainly confined to the assessment of present fish diversity of different floodplain wetlands (Dey 2017; Ghosh et al. 2018a, b). West Bengal is very resourceful in floodplain wetlands which are being used effectively for fisheries to maintain their livelihood by many rural communities (Sarkar et al. 2020). In this backdrop, the aim of the present study was to generate comprehensive information on the impact of climate change on the status of fish diversity as well as production trends of some selected tropical floodplain wetlands of West Bengal, India, for developing suitable conservation management and adaptation strategies.

Materials and methods

The selected floodplain wetlands are Bhomra located in Nadia district, whereas Mathura and Chandania are located in North 24 Parganas district of West Bengal, India (Fig. 1, Table 1). The water spread area of each wetland was divided into three equal strata for sample collection which were designated as sampling sites (site 1–3). The GPS coordinates of each sampling site along with area, land use pattern, etc., are shown in Table 1. Fish diversity and enviro-climatological samples were collected monthly from the three sampling sites of each wetland for two years during 2017 to 2019. Experimental fishing was conducted monthly in the three sampling sites of the three wetlands for two years using gill net, cast net and dragnet. Gill net was employed in wetlands for 12 h, drag nets were operated for 3 h, and cast net was casted five times in each site of the three wetlands. Enviro-climatological parameters were also collected monthly from the three sampling sites of each wetland in the morning time between 8 and 10 AM.

The water quality parameters were analyzed following standard protocol (APHA 1998). Time series data on air temperature and rainfall were collected from the Indian Metrological Department (IMD), Kolkata, for Nadia and North 24 Parganas District of West Bengal, India, from the period 1985 to 2018. Trend analysis was carried out to see the trend of rainfall and temperature across the years for the two districts.

The collected fish samples were preserved in 10% formalin solution and identified based on specific morphometric and meristic characteristics given by Talwar and Jhingran (1991), Jayaram (1999) and Vishwanath et al. (2011). The conservation status has been documented based on the information given in IUCN Red List of Threatened Species (IUCN 2020) and Threatened Freshwater Fishes of India, NBFGR (Lakra et al. 2010a, b).

Fish diversity was assessed using the Shannon–Weiner index, Simpson's index and Jacquard index. Canonical correspondence analysis (CCA) was carried out to establish the relationship between fish diversity vs. ecological and climatic parameters for the data collected for two years using PAST software (Hammer et al. 2001). The available historical data on fish production of the three wetlands were collected from the respective Primary Fishermen Co-operative Societies (PFCSs) using standard data collection questionnaire developed by ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), India. Trend analysis was carried out to assess the pattern of fish production of the three wetlands. The temporal variation of the number of species or the species richness was assessed by comparing the number of species in the present study with the previously recorded species by Sugunan et al. (2000) and Chakraborty (2002) and confirmed it by cross verification with the local fishermen through a standard questionnaire prepared by ICAR-CIFRI.

Results

Ecological and climatic parameters

In the present study, the pH values ranged from 7.94 to 8.86 in the three wetlands. The highest pH value was recorded in Mathura during post-monsoon period (9.26), whereas in Chandania (8.34) and Bhomra (8.46) the highest pH values were recorded during pre-monsoon period. Water conductivity and total dissolved solids were comparatively higher in Chandania (757.62 µS/cm and 513.17 mg/l) than Bhomra (394 µS/cm and 263.628 mg/l) and Mathura (331.312 µS/cm and 234.587 mg/l). Maximum water depth was recorded

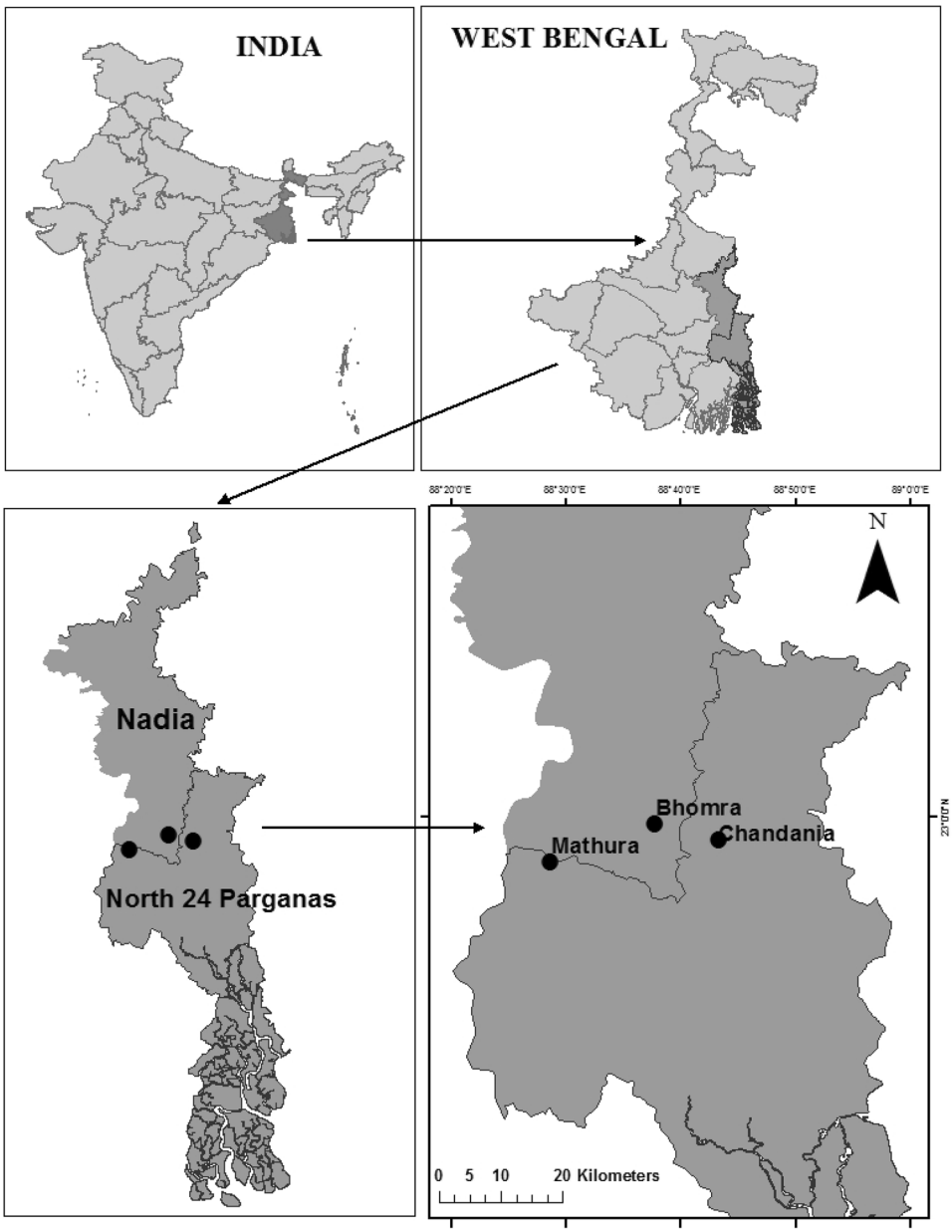

Fig. 1 Details of the study area indicating sites

from Chandania (2.70 m) and Bhomra (2.40 m), while the lowest water depth was recorded from Mathura (1.42 m). Water transparency was higher in Bhomra (1.21 m) during pre-monsoon period, while in Chandania it was during post-monsoon period (0.94 m). The mean dissolved oxygen (DO) concentration showed similar trends in the studied wetlands. The annual mean of other ecological parameters such as salinity (372.32 mg/l), free CO_2 (7.42 mg/l) and hardness (245.12 mg/l) was higher in Chandania as compared to Bhomra (194.0 mg/l, 5.238 mg/l and 173.602 mg/l) and Mathura (159.241 mg/l, 6.772 mg/l and 155.25 mg/l), respectively (Table 2). ANOVA indicated that pH, TDS, conductivity, salinity, transparency, depth, nitrate and hardness showed significant difference ($p < 0.05$) among the studied wetlands (Table 2). Seasonal analysis indicated that air temperature, water temperature and hardness showed a significant difference ($p < 0.05$) across the seasons.

The annual mean temperature of the study area showed a gradually increasing trend from the year 1985 to 2018 as indicated by trend line in Nadia and North 24 Parganas district (Fig. 2), whereas the annual mean rainfall showed a decreasing trend in both the districts (Fig. 3).

Fish species diversity

In the present study, 36 fish species were recorded from the 3 wetlands. Maximum species richness was recorded in Bhomra (31 species), followed by Mathura (29 species)

Table 1 Basic profile of the studied three floodplain wetlands of West Bengal, India

Wetland	Sampling sites GPS location	Total area (ha)	Wetland type/characteristics	Land-use pattern	Fishing practices
Bhomra	**Site 1** 22°59′9.26″ N 88°38′8.99″ E **Site 2** 22°58′50.45″ N 88°37′28.17″ E **Site 3** 22°58′26.40″ N 88°37′51.83″ E	45.7	Closed, water stress, moderate macrophyte infestation	Wetland fisheries, irrigation, agriculture	Capture and culture-based fishery, moderate fishing pressure
Mathura	**Site 1** 22°56′9.91″ N 88°29′30.91″ E **Site 2** 22°59′9.26″ N 88°29′30.90″ E **Site 3** 22°56′5.77″ N 88°28′2.88″ E	184	Closed, peri-urban, siltation, low macrophyte infestation	Wetland fisheries, agri-horticulture, jute retting, ecotourism	Capture and culture-based fishery, high fishing pressure
Chandania	**Site 1** 22°57′30.44″ N 88°43′13.49″ E **Site 2** 22°57′46.12″ N 88°43′18.91″ E **Site 3** 22°58′3.19″ N 88°42′57.17″ E	51.5	Closed, low macrophyte infestation, deep water	Fisheries, irrigation agriculture, jute retting	Capture and culture-based fishery, moderate fishing pressure

Table 2 Ecological parameters (Mean ± Standard Error) of Bhomra, Mathura and Chandania wetland

Parameters	Bhomra (Mean± SE)	Mathura (Mean ± SE)	Chandania (Mean ± SE)	*p*-value (ANOVA)
pH	7.93 ± 0.638	8.86 ± 0.614	7.99 ± 0.382	0.001
TDS (mg/l)	263.62 ± 36.53	234.58 ± 30.06	513.17 ± 215.54	0.001
Conductivity (µS/cm)	394 ± 64.02	331.31 ± 39.61	757.62 ± 299.85	0.001
Salinity (mg/l)	194 ± 32.89	159.24 ± 19.51	372.32 ± 150.86	0.001
Air temperature (ºC)	29.44 ± 2.61	29.97 ± 3.37	30.97 ± 3.85	0.527
Water temperature (ºC)	28.42 ± 2.55	28.90 ± 3.33	29.93 ± 3.60	0.509
Transparency (m)	1.23 ± 0.43	0.51 ± 0.2	0.95 ± 0.27	0.001
Depth (m)	2.40 ± 0.61	1.42 ± 0.59	2.70 ± 0.71	0.001
DO (mg/l)	7.71 ± 2.00	8.16 ± 1.37	8.29 ± 2.24	0.664
Alkalinity (mg/l)	198.41 ± 1.38	174.35 ± 43.01	173.76 ± 58.56	0.387
Phosphate (mg/l)	0.029 ± 55.02	0.053 ± 0.08	0.08 ± 0.10	0.375
Nitrate (mg/l)	0.105 ± 0.04	0.11 ± 0.04	0.06 ± 0.04	0.025
CO_2 (mg/l)	5.238 ± 0.044	6.772 ± 5.416	7.42 ± 3.363	0.394
Hardness (mg/l)	173.60 ± 42.01	155.25 ± 41.93	245.12 ± 58.50	0.001

(Fig. 4) and Chandania (23 species) (Table 3). In the present study, 3 exotic carps *H. molitrix, C. idella* and *C. carpio* were described. Among them, *H. molitrix* was present in all the three wetlands, *C. idella* was present in both Bhomra and Chandania wetland, whereas *C. carpio* was present only in Bhomra wetland. The overall fish diversity was found to be the highest during monsoon and lowest during the pre-monsoon season. The order Cypriniformes was the most dominant in all the three wetlands, contributing 39% of the total fish species in Bhomra, 38% in Mathura and 35% in Chandania. There were 16, 15 and 14 family in Bhomra, Mathura and Chandia wetlands out of which cyprinidae contributed 35%, 34% and 35% in Bhomra, Mathura and Chandia wetlands, respectively.

The fish species composition and fish production varied considerably between the three different wetlands (Figs. 5 and 6) studied in the Ganga basin. The analysis of temporal variations of species richness indicated the loss of about 40% of the species from the year 2002 in Bhomra, 22.85% loss in Mathura from the year 2002 and 54% loss from the year 2002 in Chandania (Fig. 7). In Bhomra, *A. mola (*15.88%), *N. nandus* (7.74%), *G. giuris* (4.13%), *P. sophore* (3.73%),

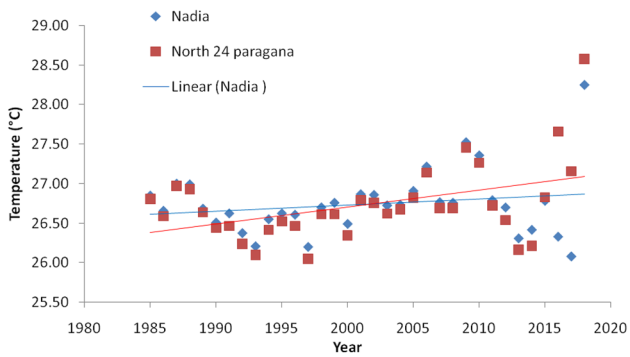

Fig. 2 Trend of temperature in Nadia district and North 24 Parganas (1985–2018)

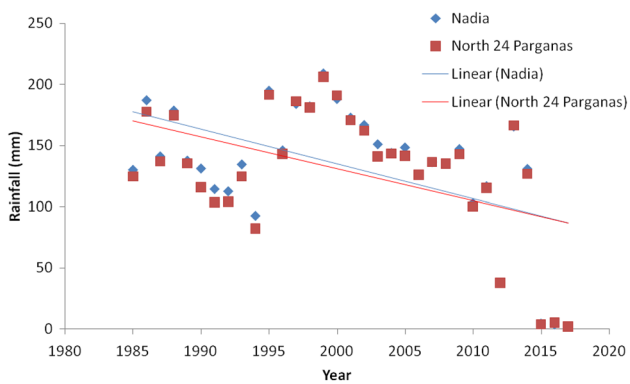

Fig. 3 Trend of rainfall in Nadia district and North 24 Parganas (1985–2018)

M. vittatus (3.60%), *C. punctata* (3.20%) and *X. cancila* (2.26%) were the most abundant fish species. Species like *G. chapra* (17.50%), *P. sophore* (14.37%), *G. giuris* (5.83%), *T. fasciata* (5%) and *S. bacaila* (2.91%) contributed 45.60% of the total fish diversity in Mathura while in Chandania, *T. fasciata* (13.96%), *C. nama* (7.97%), *P. sophore* (7.12%), *S. bacaila* (6.83%) and *A. mola* (4.84%) contributed maximum to the overall species composition. Percentage relative abundance of all species is shown in Table 4. Three Indian major carps (IMC), minor carps as well as exotic carps were present in all the studied wetlands and a noticeable variation in their relative abundance was recorded among the studied wetlands. In Bhomra, Mathura and Chandania, the relative abundance of *L. rohita* (6.68%, 5.21% and 7.41%) was relatively higher than *L. catla* (6.01%, 5.21% and 6.55%) and *C. mrigala* (5.87%, 3.75% and 5.13%).

The Shannon–Weiner diversity index ranged from 2.89 to 3.09 in three wetlands (Table 3). Shannon–Weiner index value was highest in Bhomra (3.09) as compared to Mathura (2.93) and Chandania (2.89). Simpson's index was found to be the highest in Bhomra (0.94) followed by Chandania (0.93) and Mathura (0.93) (Table 3). The similarity in species diversity was calculated by using Jacquard index, and the value was highest between Bhomra and Chandania (0.7), while the lowest value was observed between Mathura and Chandania (0.58).

Assessment of conservation status of fish species in Bhomra revealed that out of 31 species, 26 species were under least concern category (LC), 1 species under near threatened (NT), 2 species under vulnerable (VU), and 2 species were not evaluated (NE). In Mathura out of 29 species, 27 species were under LC, 1 species under VU and 1 species under NE. In Chandania out of 23 species, 20 species were under LC, 1 species under VU and 2 species under NE (Table 4 and Fig. 8).

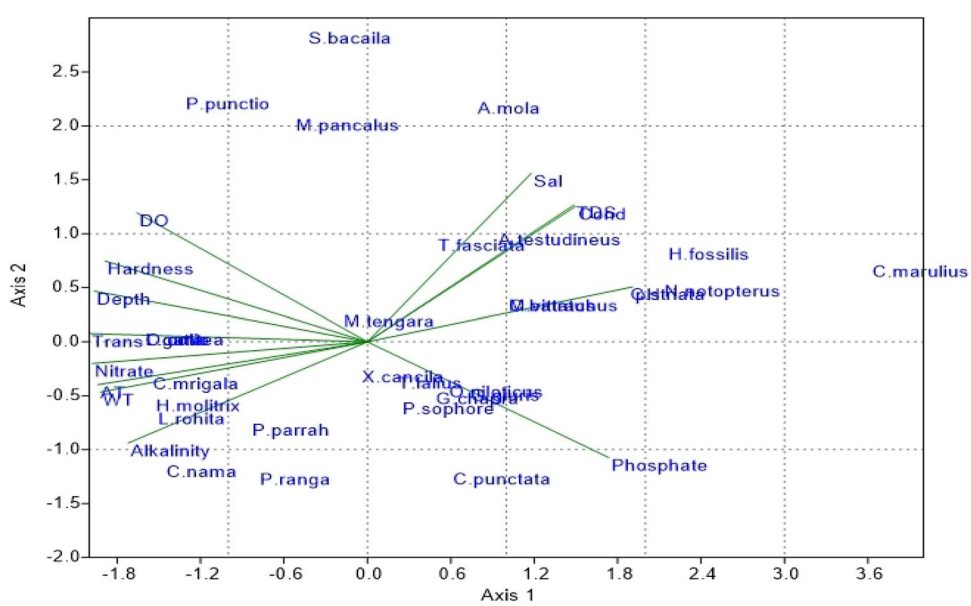

Fig. 4 Relationship of fish diversity of Mathura wetland with environmental and climatic parameters

Table 3 Overall diversity and diversity indices of fishes in the studied wetlands

Parameters	Bhomra	Mathura	Chandania
Number of species	31	29	23
Shannon–wiener index	3.09	2.93	2.89
Simpson's index	0.94	0.93	0.93
Jacquard index	(Bhomra & Mathura) 0.65	(Mathura & Chandania) 0.58	(Bhomra & Chandania) 0.7

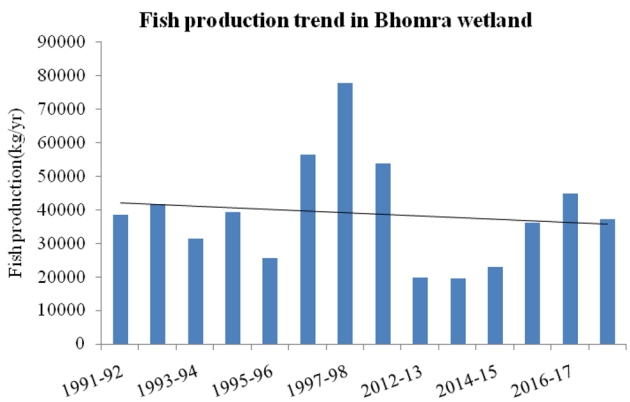

Fig. 5 Fish production trend in Bhomra wetland

Enviro-climatological influences on wetland fish diversity

The CCA analysis revealed the varied response of fishes to selected ecological parameters in the three wetlands. The analysis of data showed that in Bhomra, *L. guntea*, *X. cancila, G, giuris* and *M. pancalus* showed positive correlation with dissolved oxygen (DO), pH and transparency. *A. mola* showed a positive relationship with TDS and water hardness.

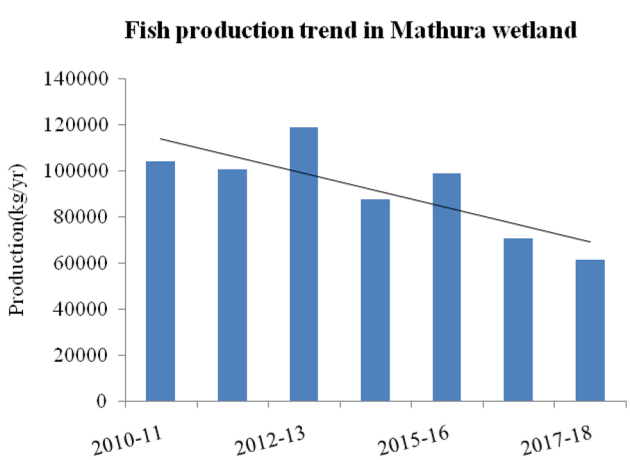

Fig. 6 Fish production trend in Mathura wetland

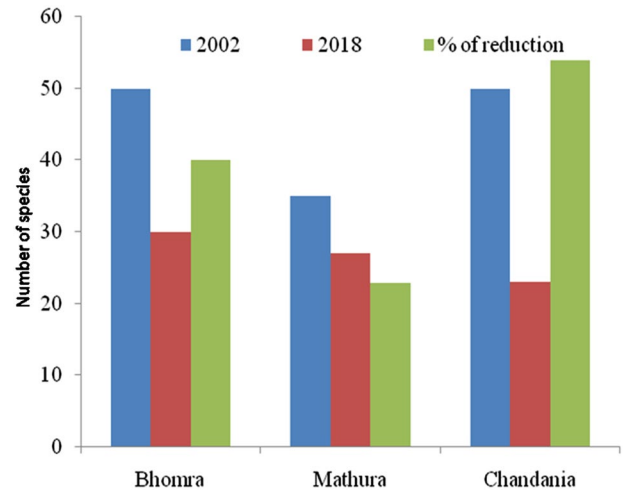

Fig. 7 Loss of fish diversity in the studied wetlands of West Bengal

L. rohita and *C. mrigala* showed a positive relationship with water depth (Fig. 9). In Chandania, small indigenous species like *G. chapra, T. fasciata* and *C. nama* showed a strong positive relation with nitrate. However, spiny eel *M. pancalus* showed a positive correlation with water depth and phosphate. Featherback *N. notopterus* showed a positive correlation with DO and hardness (Fig. 10). In Mathura the species viz. *X. cancila*, *P. sophore* and *C. punctata* showed positive relationship with phosphate. Major carp *L. rohita* and exotic species *H. molitrix* had a positive relationship with alkalinity. Guntea loach *L. guntea* showed positive relationship with water transparency. The other species like *M. tengara, T. fasciata* and *A. testudineus* also showed a positive relationship with TDS (Fig. 4). Among climatic parameters, air and water temperature showed a positive relationship with a few fish species of Bhomra viz. *C. punctata* and *T. lalius* (Fig. 9). Similarly, in Chandania *X. cancila* and *A. testudineus* (Fig. 10) and in Mathura *L. rohita, H. molitrix* and *C. mrigala* showed a positive correlation with temperature (Fig. 4).

Fish production trends and influence of climatic variables

The trend analysis indicated the decreasing trend of fish production in Bhomra and Mathura wetland. In Bhomra, the total fish production showed a decreasing trend from the year 1991 to 2017 (Fig. 5). The fish production ranged from 19,438 kg in 2014–15 to 77,762 kg in 1998–99. In Mathura, the total fish production showed a decreasing trend from the year 2010 to 2018 (Fig. 6). The fish production ranged from 61,247.1 kg in 2017–2018 to 118,804.5 kg in 2013–2014. In both the wetlands, IMCs contributed the maximum to the overall catch. The changing trend in regional (Nadia and

Table 4 Occurrence, distribution and conservation status of fish species in Bhomra, Mathura and Chandania wetlands of West Bengal

S. No	Order	Family	Species name	Bhomra	Mathura	Chandania	Conservation status
1	Osteoglossiformes	Notopteridae	*Notopterus notopterus*	0.93	1.45	1.70	LC
2	Clupeiformes	Clupeidae	*Gudusia chapra*	2.26	17.50	4.84	LC
3	Cypriniformes	Cyprinidae	*Labeo catla*	6.00	5.00	6.55	LC
4		Cyprinidae	*Cirrihunus mrigala*	5.87	3.75	5.12	LC
5		Cyprinidae	*Ctenopharyngodon idella*	4.00	0	4.27	NE
6		Cyprinidae	*Cyprinus carpio*	4.27	0	0	VU
7		Cyprinidae	*Hypopthalmichthys molitrix*	2.26	2.50	4.55	NE
8		Cyprinidae	*Labeo bata*	4.53	0	0	LC
9		Cyprinidae	*Labeo rohita*	6.67	5.20	7.40	LC
10		Cyprinidae	*Osteobrama cotio*	0	0.41	0	LC
11		Cyprinidae	*Puntius sophora*	3.73	14.37	7.12	LC
12		Cyprinidae	*Pethia ticto*	0.26	0	0	LC
13		Cyprinidae	*Puntius punctio*	0	3.95	0	LC
14		Cyprinidae	*Puntius parrah*	0	3.33	0	LC
15		Cyprinidae	*Salmostoma bacaila*	2.00	2.91	6.83	LC
16		Cobitidae	*Lepidocephalichthys guntea*	0.80	0.83	0	LC
17		Cyprinidae	*Amblypharyngodon mola*	15.88	2.08	4.84	LC
18	Siluriformes	Bagridae	*Mystus vittatus*	3.60	0.83	0	LC
19			*Mystus tengara*	2.80	2.29	1.13	LC
20		Siluridae	*Ompok bimaculatus*	0.13	0	0	NT
21		Clariidae	*Clarias batrachus*	0	0.83	0	LC
22		Heteropneustidae	*Heteropneustes fossilis*	0.66	2.29	1.13	VU
23	Beloniformes	Belonidae	*Xenentodon cancila*	2.26	1.45	3.70	LC
24	Perciformes	Ambassidae	*Chanda nama*	3.20	0.62	7.97	LC
25		Ambassidae	*Parambassis ranga*	2.26	1.66	1.70	LC
26	Gobiiformes	Gobiidae	*Glossogobius giuris*	4.13	5.83	2.56	LC
27	Perciformes	Nandidae	*Nandus nandus*	7.74	0	1.99	LC
28	Anabantiformes	Anabantidae	*Anabas testudineus*	1.46	2.50	1.70	LC
29	Anabantiformes	Osphronemidae	*Trichogaster fasciata*	1.86	5.00	13.96	LC
30	Anabantiformes	Osphronemidae	*Trichogaster lalius*	1.46	2.50	0	LC
31	Anabantiformes	Channidae	*Channa punctata*	3.20	6.45	1.99	LC
32		Channidae	*Channa striata*	1.86	1.25	0	LC
33		Channidae	*Channa marulius*	0.66	0.41	0.28	LC
34	Synbranchiformes	Mastacembelidae	*Macrognathus pancalus*	2.26	1.66	5.12	LC
35		Mastacembelidae	*Mastacembelus armatus*	0.80	0	3.70	LC
36	Cichliformes	Cichlidae	*Oreochromis niloticus*	0	1.04	0	LC

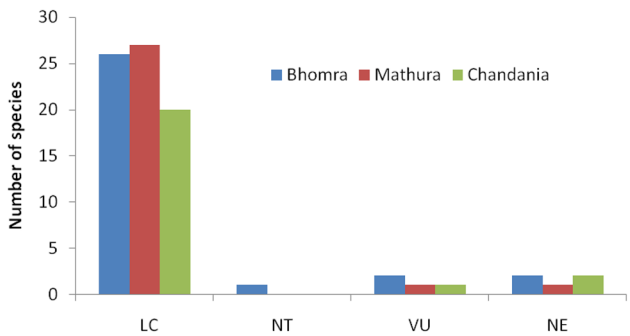

Fig. 8 Conservation status of fishes in Bhomra, Mathura and Chandania wetland

North 24 Parganas districts) temperature, precipitation and the fish production pattern of Bhomra and Mathura is graphically represented (Figs. 2, 3, 5 and 6). In both the wetlands, a gradual decline in total fish production, decreased rainfall and elevated temperature were observed.

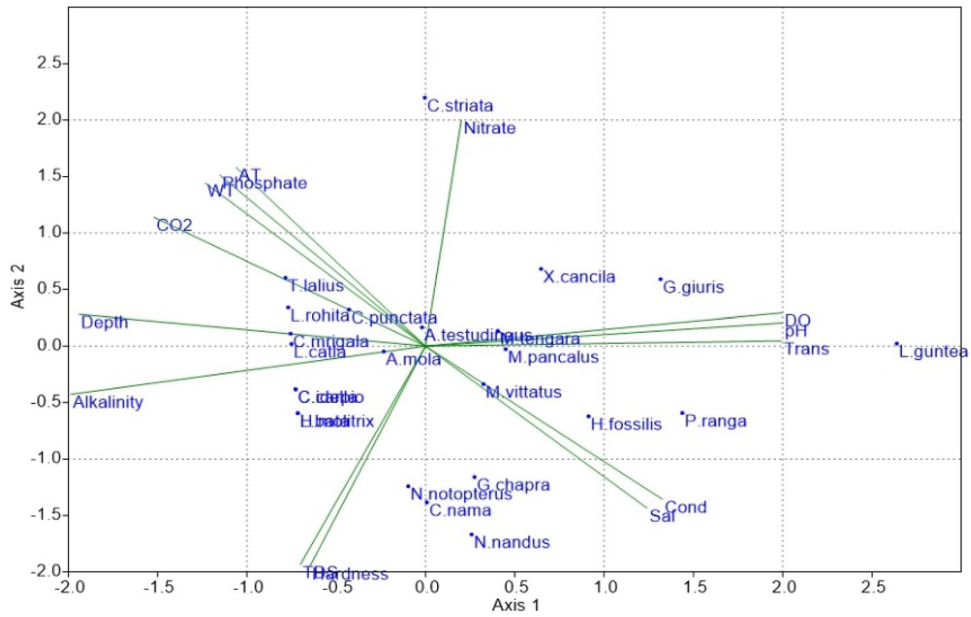

Fig. 9 Relationship of fish diversity of Bhomra wetland with environmental and climatic parameters

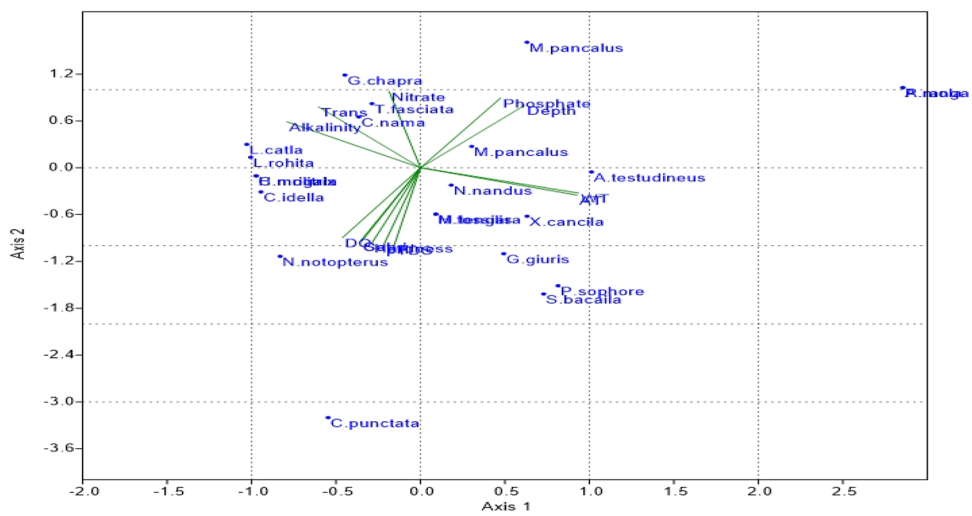

Fig. 10 Relationship of fish diversity of Chandania wetland with environmental and climatic parameters

Discussion

Among the three studied wetlands, family Cyprinidae was found to be the major contributor to the overall wetland fish diversity. A similar result was also reported by Prasad et al. (2009) in major wetlands of Mysore, Mondal and Kaviraj (2009) in Gopalnagar and Dumar wetland of North 24 Parganas, West Bengal, and Mistry (2016) in Ahiran wetland of Murshidabad district, West Bengal, India. In the present study, 36 species were observed from the three wetlands which clearly indicated a significant decline in the species richness from the last decade as recorded by Sugunan et al. (2000) in the wetlands of West Bengal. Mondal and Kaviraj (2009) recorded 49 species from two floodplain wetlands of North 24 Parganas which was significantly higher as compared to the present findings. Chakraborty (2002) observed 35 species from Mathura which was higher than the number of species 29 recorded in the present study indicating a reduction in overall fish diversity. Ghosh and Biswas (2017) recorded 33 species from a wetland in Nadia district, West Bengal, which is comparable with the present findings. The declining of fish species richness in the present study may be due to several factors including habitat degradation, siltation, loss of connectivity with the parent rivers, climate change, introduction of exotic species, pollution due to unfavourable anthropogenic activity like agricultural runoff and sewage discharge. Mustapha (2013) also mentioned that combining effect of elevated temperature, changes in aquatic habitat and other natural extreme events causes reduction in species abundance, fish yield and breeding penology. Though the species richness was declining from the last

decade, Simpson's index (0.93–0.94) clearly indicated the fish species were evenly distributed and none of the species dominated in the present study. The species richness and diversity index like Shannon–Weiner index and Simpson's index indicated that Bhomra is having better fish diversity pattern as compared to other two wetlands. The higher species richness and diversity in Bhomra may be due to better habitat for indigenous fishes and better connectivity with the river. The Jacquard index indicated that the fish abundance pattern was more similar between Bhomra and Chandania, but Mathura was distinct which may be due to the combine effect of enviro-climatological parameters and the land use pattern. The assessment of conservation status shows a few species in the near threatened (NT) and vulnerable (VU) categories which require attention for their protection and conservation. In the present study, we have also recorded a few exotic fishes from the wetlands which also pose a threat to native species. Sarkar et al. (2010) reported the introduction of exotic species causes a threat to the riverine native fish species of river Ganga basin.

The review of literature showed that no systematic studies have been reported so far on changing pattern of fish diversity and fisheries of floodplain wetlands concerning climate change in India except a few studies on ecology and reproductive phenology (Sarkar et al. 2012, 2016; Sarkar and Borah 2017; Karnatak et al. 2018). The inherent ecological profile, intensity of management and anthropogenic pressures led to varying influences. Larka et al. (2010a; b) reported that physical variables are responsible for the changes in the distribution pattern of fishes. Negi and Mamgain (2013) and Stalnaker (1979) also reported that fish diversity of any aquatic ecosystem is influenced by a few ecological parameters such as air and water temperature, DO, free CO_2 and pH. Limited study on the impact of climate change on wetlands in India suggests that high altitude wetlands and coastal wetlands are some of the most vulnerable classes to climate change (Patel et al. 2009). Although specific information on the assessment of climate change impact on floodplain wetlands is scanty, it is obvious that change in climate will bring about irreparable change in the ecology of the floodplain wetlands too, as evident from a study on potential changes in floodplain inundation and connectivity between river and floodplain wetlands under projected future climates, conducted in the river catchment area in Western Australia (Karim et al. 2015). A study on the river Brahmaputra basin of India indicated that climate change manifested by increased temperature may have a profound impact on the connecting floodplain wetlands, as the rising temperature may trigger melting of glaciers in the Himalayas, which along with rising actual evapo-transpiration and erratic rainfall pattern may cause repercussions on the river hydrology (Sharma 2013).

The increasing trend of temperature and the decreasing trend in rainfall marked the incidence of climate change phenomena in the districts where the three wetlands are located. Climate change-induced rising temperature and declining rainfall pattern presents a potential danger to the already disappearing lakes in the Gangetic plains (Sinha 2011). Decreased precipitation will exacerbate problems associated with already growing demands for water and hence alter the freshwater inflows to wetland ecosystems (Bates et al. 2008; Erwin 2009). A rise in temperature can aggravate the problem of eutrophication, leading to algal blooms, expansion of aquatic macrophytes, fish kills and dead zones in the surface water (Gopal et al. 2010). The review of literature indicated the scarcity of information linking climatic variability and its influence on fish diversity and fisheries of the wetlands (Sarkar et al. 2020; Sarkar and Borah 2017; Karnatak et al. 2018). According to Woodward et al. (2010), changes in climatic parameters are one of the major threats for freshwater ecosystem and its associated biodiversity. Ficke et al. (2007) and Macusi et al. (2015) also mentioned that changing pattern of temperature and aquatic environment led to reduced fish abundance. Among climatic parameters, temperature strongly influences the distribution pattern, breeding behaviour, survival of young ones, body metabolism, and growth rate (Jain et al. 2013). Negi & Mamgain (2013) reported that water and air temperature strongly influence the fish aggregation and distribution pattern. Das et al. (2013) mentioned that climatic variability causes a shift in the geographical distribution of some warm water fish species along with a decline in spawn availability of IMC in river Ganges.

The environmental parameters including DO, TDS, pH, transparency, nitrate, phosphate, hardness and alkalinity influenced the fish assemblage pattern in the present study as per CCA. Limited researchers studied the relationship of environmental parameters and climatic parameters with fish abundance pattern and fish biology in the inland water bodies of India. The fish production was found to be positively correlated with total alkalinity, DO, pH, transparency and specific conductivity in Nanaksagar reservoir of Uttrakhand, India (Raveendar et al. 2018). Lianthuamluaia et al. (2019) also observed that environmental parameters have a profound influence in fish assemble pattern in Chandil reservoir, Jharkhand, India, where pH and nitrate were the most important parameters influencing fish assemblage. However, many scientific studies on the relationship of environmental parameters with fish abundance have been done in different water bodies in different parts of the world. Nsor and Obodai (2016) reported the relationship of fish and environmental parameters of wetlands of Northern Region Ghana where nitrate-nitrogen, phosphate, conductivity, temperature and turbidity influenced fish community structure. Vega-Cendejas et al. (2013) also observed that environmental parameters influenced fish

assemblage in karstic pools in southern Mexico, while Roy et al. (2018) reported that temperature and photoperiod were the two main parameters controlling fish activity and spatial distribution in Bariousses reservoir, France.

The detailed studies on the influence of climatological and environmental parameters on floodplain wetland biodiversity, fisheries and fish production have not been studied systematically except some basic information on ecology and taxonomic aspects. The analysis in this study indicated decreasing of fish production in Bhomra and Mathura wetlands which may be due to ecological and climatic stressors. There were an increasing trend of temperature and a decreasing trend of rainfall in the region where the wetlands were located which could be the reason for the decline of fish production in the wetlands. O'Reilly et al. (2003) observed that changes in climatic variability had more impact on the productivity of Tanganyika Lake rather than any other threats. Chu et al. (2005) opined that in some freshwater lakes of Canada, climate change-driven threats were responsible for the reduction in freshwater fish of a particular aquatic environment. Loss of river connectivity with wetlands, ramification of aquatic weed, excess deposition of silt, shrinkage of water area (Naskar et al. 2018), harmful agricultural activities, discharge of municipal and domestic wastes (Mukherjee et al. 2015), and anthropogenic stress (Ghosh et al. 2018a, b) are the other probable reasons behind the gradual decline in fish diversity of floodplain wetlands.

Climate change-induced temperature variation will have a strong impact on the spatial distribution of fishing and fish farming activities, and on their productivity and yield. The yield of aquatic product will vary through changes in the ecosystem, species distribution, seasonality and habitat (Sarkar and Borah 2017). Fish biodiversity, as well as the overall fish yield from the studied wetlands, reduced due to direct or indirect consequences of climate change. Threat status of wetland fishes draws attention for framing suitable conservation and management action plans to sustain the wetland fisheries. Altered rainfall pattern and temperature regime influence the ecological parameters and habitat quality, which ultimately creates a negative impact on wetland fish diversity as well as fish production trend. Conservation, restoration and wise use of the wetlands will be a cost-effective strategy for climate change adaptation with strong benefits for poverty reduction and biodiversity conservation. Concerted attention for conservation and revamping of the productivity of these potential resources of India is urgently required to protect the vulnerable bioresources. The information generated in this study will serve as a baseline which could be used for conservation and management planning and developing adaptation strategies in future.

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