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The present status of ichthyofaunal diversity of river gGanga India: Synthesis of present v/s past

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ABSTRACT

In India, large rivers are experiencing serious threat to aquatic biodiversity, and therefore flagship projects are being executed on freshwater biodiversity conservation using various methods and strategies. Ganga River is the largest and longest river of India supporting rich commercial and artisanal fisheries for decades. Periodical and systematic assessments of fish biodiversity of the large river ecosystem are important for effective conservation planning. Although over the years, the ichthyofaunal diversity of the river has been assessed under different programmes, however current assessment of fish diversity across different zones are not adequately studied and reported. In the present study systematic re-explorations were carried out and changing pattern of fish diversity and distribution during the period 2016–19 was recorded. We described a total of 190 fish species (182 indigenous and 8exotics) belonging to 133 genera, 62 families and 23 orders from upper Ganga (Harsil) to the river mouth of Hooghly estuary (Fraserganj). The assessment of native species revealed about 10% and 14.21% of the total species are listed under threatened status of IUCN Red List (version 2020) and CAMP (1998) threatened category respectively. Among the exotics, common carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*) was found dominated in upper, middle and part of lower stretch. The study showed considerable dominancy of major and minor catfish followed by small indigenous fishes. The evaluation of species richness through biodiversity matrices resulted the lower stretch to be the richest zone forming a strong cluster relationship (>0.71) among all the stations. The analysis of similarity percentage (SIMPER) of all the stations revealed an average similarity of 4.59% between all the stations. Shift in distribution pattern of few fish species was also recorded in certain sections of the river. The study indicated drastic decline of commercially important major carps and catfishes in comparison to previous records. The present paper also discussed about the potential threats and important guidelines concerning sustainable fisheries of River Ganga. The comprehensive information presented in this paper on fish diversity, distribution, abundance, production trend of major fish group of the river in different zones have highlighted relative change as compared to previous studies that will be useful for monitoring biodiversity and future conservation planning of the river basin.

1. Introduction

Aquatic ecosystem constitutes a valuable natural resource comprising number of living organisms like plants, insects, fish, invertebrates and microorganisms. Freshwater fishes in particular, often act as a bioindicator susceptible to major alterations of the habitat [1]. Thus, in this recent challenging environment of fish diversity [2] water bodies particularly rivers require periodical study to generate adequate information on biodiversity. India is a global biodiversity hotspot [3] contributing a substantial percentage of important ecological services to the society. The river Ganga possesses an important attachment to the cultural, heritage and economic values of India [4]. The river traverses a long course of 2525 km from Gangotri to Gangasagar and is designated to be the fifth largest river in the world by discharge and the longest river in the country. Besides, being attached spiritually and emotionally, it is a major source of navigation and communication since ancient times. The river supports a large number of fish species on which thousands of people depend for livelihood. It is considered as the mainstay of riverine fisheries of India. The River Ganga originates from the western Himalayas draining effectively eight states of India covering

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an area of 1,051,540 square kilometerskm^2 before discharging into Bay of Bengal in the east. This allows the river to sustain varied fish fauna through the entire stretch ranged from cold-water species to warm-water species.Apart from its functional point of view, ichthyofauna diversity of River Ganga has been one of the prime areas of study for several zoologist and fisheries enthusiasts from ages. The Gangetic plain itself sustains around 11% of the total 522 endemic species reported from India [5]. The first comprehensive report on Gangetic fish fauna was documented by Hamilton (1822) [6] describing a total of 260 fish species. Subsequently, Francis Day (1888) [7] enlisted 1340 fishes under 342 genera from India, in which most of the fishes are in accordance with the River Ganga. Comprehensive studies were also advocated by [8] to reshape the works of Hamilton 1822 [6]. Consolidated efforts were also undertaken by Menon (1974) [9] enlisting 207 fish species from upper Ganga to Gangetic (Hooghly) estuary. Further investigation on the fish fauna of the Ganga river basin was initiated by Talwar and Jhingran (1991) [10], thereby, elucidating 266 fish species from the entire Gangetic basin and out of which 158 are reported to be freshwater and 108 marine species.Most recently, detail description and biogeographic distribution of 143 fish species (belonging 72 genera and 32 families) was reported by Sarkar et al. 2012 [11] extending from Gangotri (Uttarakhand) to Hooghly (West Bengal) emphasizing on freshwater zone of the river. However, no recent assessment has been reported from the large river covering long stretch of both freshwater and estuarine zone.

The fish diversity often shows a complex relationship with the habitat [12] thereby influencing fish species pattern altogether [13]. The impact is vivid in species composition of Ganga owing to its considerable modifications of river hydrology over the years. Reduced catches of important commercial fish group and significant increased landings of non major and exotics have certainly affected the riverine production a large way [11,14]. The species assessment and revision with respect to abundance and distribution at different habitat and conservation categorization is perhaps one of the most important criterions towards developing a database for sustainable fisheries, ecology restoration planning and biodiversity conservation. However, evaluation of species richness gradient across the geographical zones of River Ganga is required to perceive the considerable proportion of distinctive diversity status. The present paper develops updated and new information on the current fish faunal diversity, distribution, abundance and production patterns of major fish group of river Ganges along different biogeographic zones and discussed relative comparison with the previous reports. The outcomes of this research will certainly assist the fishery stakeholders and policy makers towards implementing sustainable management measures and revising conservation status of the species.

2. Materials and methods

2.1. Study area

River Ganga flows through the western to the eastern parts of the country stretching across 77° 58′ 47.44″ E longitude to 88° 30′ 37.89″ E longitude and 22° 18′ 6.43″ N latitude to 31° 2′ 49.31″ N latitude, travelling a vast distance of 2525 km. Nineteen different major fishing sites sprawling over four different states along the riverwas selected for the study. The sampling sites were further grouped on the basis of their hydrological characteristics and land use patterns. The entire course is divided into four segments (Table 1; Fig. 1) the upper stretch (Harshil to Haridwar), middle stretch (Bijnour to Varanasi), lower stretch (Buxar to Godakhali) and estuarine stretch (Diamond Harbour to Fraserganj).

2.2. Sampling methodology

Quarterly field surveys were performed for the collection of data within a span of four years from September 2016 to December 2020 covering approximately 2600 km. For assessing the ichthyofaunal diversity, samples were collected from the main river channel during fishing hours from comparatively undisturbed areas.Various selective and non-selective gears like multi meshed gill nets (mesh: 1.5 × 1.5 cm to 16.0 × 16.0 cm), mosquito nets (mesh: 0.2× 0.2 mm), bamboo traps (*locally termed as Ghuni,woka,aanta,arsi,duar*), cast nets (mesh: 0.6× 0.6 cm), drag nets (mesh: 0.8 × 0.8 mm), bag nets, etc. were used for the collection so as to represent the entire range of fish habitat from different water depths (Range: 2.5–31.2 m). In case of estuarine zones, fishes were collected following lunar cycle (new moon and full moon) owing to availability of maximum fish species. Fishes were counted, weighed and length of each species was measured using vernier calipers to the nearest 0.01 cm. The fish samples were identified on field or preserved in 7% formalin and transported to the laboratory for further analysis. The specimens were deposited in the Fish Biodiversity Repository of ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India. In addition, monthly data on landing of major

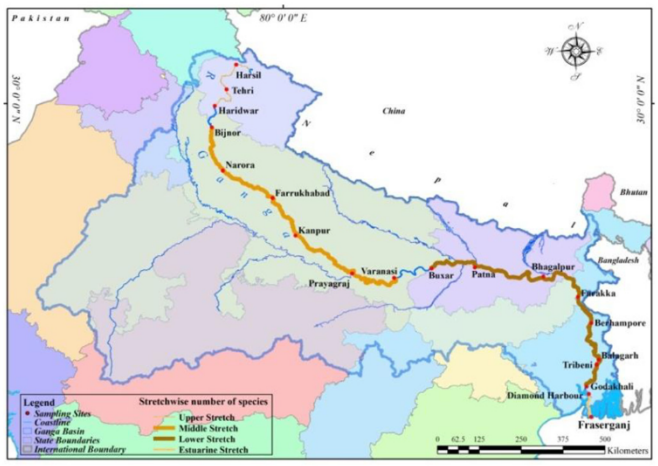

Fig. 1. Sampling points along River Ganga.

Table 1
The details of the sampling sites along river Ganga.

Stretch	Sites	Total river distance (km)	River segment	Land use pattern	Geographic coordinates
Upper stretch (Freshwater)	Harshil, Tehri, Haridwar	363.20	Upstream headwater	Protected forest zone, Barrage area	29° 56′ 3″ N to 31° 2′ 18″ N and 78° 9′ 55″ E to 78° 44′ 16″ E
Middle stretch (Freshwater)	Bijnour, Narora, Farukhabad, Kanpur, Prayagraj, Varanasi	1162.38	Upstream and midstream	Agriculture, semi urban and urban zone	25° 19′ 4″ N to 29° 21′ 32″ N and 78° 5′ 14″ E to 82° 58′ 26″E
Lower stretch (Freshwater)	Buxar, Patna, Bhagalpur, Farakka	668.86	Lower stream	Rural, urban and agricultural zone	24° 48′ 2″ E to 25° 33′ 53″ E and 83° 58′ 40″ E to 87° 54′ 32″ E
	Berhampore, Balagarh, Tribeni, Godakhali	155.64	Lower stream	Rural, semi urban, metropolitan area	22° 59′ 12″ N to 24° 5′ 56″ N and 88° 16′ 5″ E to 88° 24′ 9″ E
Estuarine stretch (Brackishwater)	Diamond Harbour and Fraserganj	232.20	Estuarine section (river draining site)	Rural agricultural and tourism spot	21° 34′ 57″ N to 22° 23′ 36″ and 88° 8′ 33″ E to 88° 15′ 30″

fish groups in different sites were collected and was raised to annual figures following the methods of random stratified sampling. Water parameter like temperature (°C) was measured using Aquaread portable multimeter (model no: multi probe- 2000).Water depth (m) was determined using Hondex BS-7-Echo-sounder whereas, the water flow (m sec^{-1}) was measured using flow meter (Global instruments make, model No: FP-111). Available literatures on Gangetic fish diversity were used to depict clear contrast between past and present. The habitat (Temperature, Depth and Flow) and juvenile variability along river Ganga were interpolated by IDW method using ArcGIS v.9.3 (The Environmental System Research Institute, USA).

2.3. Data analysis

Fish species diversity was assessed using different diversity indices viz. Shannon–Wiener diversity, Evenness, Margalef's richness index and Berger-Parker index. The Shannon Weiner diversity index [15] has been analyzed by considering the number of species along with the sharing of individuals among species. The Shannon Weiner index or the 'entropy' was calculated by following formulae, where p is the ratio (n/N) of individual of one particular species (n) recorded divided by the total number of individuals (N).

$$\text{Shannon Index } (H') = \sum_{i=1}^{n} pilnpi$$

Margalef richness index [16] was employed to compute species richness by using following formula: (S/1) = log (N)where S is total number of fish species and N is total number of individuals. For calculating species evenness, formulae E = eH/S was used [17]. Similarly, analysis of Berger-Parker dominance index [18] was performed using method, d = max(pi). The relative abundance (RA) of individual species was calculated by the following formula: RA = No. of fish species / Total no. of individuals collected from the study site ×100%

Software package namely Paleontological Statistics (PAST) version 3.0, was used for evaluating similarity percentage (SIMPER), rarefaction curves and Bray-Curtis analysis. Similarly, c-dominance plot was employed to assess the ecological stress between the fish community structure at various zones. The Cumulative relative dominance (y- axis) was plotted from a sampling zone over the rising species rank (x – axis). To assess the range of distribution of the exotic species in the river, distribution index was used using the formula: DR = L. st/ T. st × 100%; where DR = distribution range, L.st = total no. of sites where fishes were recorded, T. st = Total sampling sites. The catch per unit effort (CPUE) was evaluated as the weight or number of individual fish yielded during specified period of effort. The CPUE was estimated as follows;

$$\text{CPUE} = \frac{\text{Total weight of the fish (kg)}}{\text{Time taken for harvest (hr)}}$$

2.4. Taxonomic identification

The identification of the fish specimen from various sites of river Ganga was conducted based on morphometric and meristic taxonomical measures [19,20], [7,10,21]and [22]. For updated names, taxonomic classification and global conservation status of the collected fish species, Eschmeyer (2020) [23] and IUCN (2020) [24] were followed respectively.

3. Results and discussion

3.1. Habitat characterization

The habitat of river Ganga is very complex and characterized by considerable habitat diversity. The river being a snow fed perennial river exhibits typical hydrological, depth and climatic variations. After it origination, the river passes through the vast alluvial Gangetic plains before it terminates into the Bay of Bengal. During its course of flow, it travels through several urban settlements like Kanpur, Prayagraj, Varanasi, Patna and Kolkata, covering a distance of 2715 km [25].The main sources of river water are the rainfall, snow melt glaciers and adjoining tributaries. The entire river basin receives an average annual rainfall of 110 cm with maximum occurrence during monsoon months (June to October). In the uplands, from Harsil to Haridwar the river exhibits cold water regime with annual mean water temperature of 15.76 °C ± 7.39 (Fig. 2). At this point, the river displays increased depth (0.69–6.80 m; average 3.06 m) and fast flowing water with velocity of 1.2–0.12 m sec^{-1} (average 0.75 m sec^{-1} ± 0.56). The river bed in this area is mostly in the form of sand and rocky pebbles. This leads to poor nutrient release and plankton growth. Moreover, with the construction of Tehri dam at Tehri and Bhimgoda Barrage at Haridwar there has been hindrances in natural river flow resulting into sluggishness during dry months. The river after Haridwar maintains a warm temperature (average 23.35 °C ± 2.35) up to the middle stretch. Although majority of the tributaries meet at Prayagraj, not much flow (average 0.46 m sec^{-1} ± 0.05) is observed in the stretch due to evaporation, subsurface seepage and surface runoff. Low discharge from the northern and southern tributaries has also created an impact on the natural flow of river. During its course, the river substratum exhibit sandy bottom with no evidences of rocky bottom. Lower part of the Ganga also reveals similar type of environment with increased water temperature (average 25.78 °C ± 1.35). Construction of Farakka Barrage in river Bhagirathi has misbalanced the hydro-geo-morphological characteristics by releasing silt free water [25]. The region from Tribeni to Fraserganj experiences tidal influences. Below Godakhali, the main Hooghly estuary initiates. It is a positive mixohaline largest estuarine system in India forming the great Gangetic delta [26]. The maximum portion of river sediments is deposited into plains while rests of them are carried into the deltaic region. The entire geo-morpho-logical processes in the estuarine section are highly influenced by interactive environmental features i.e. freshwater influx and tidal activity. The portion of Fraserganj area carries estuarine clay. The salinity ranges from freshwater condition (below 0.1%) to above 30% during different seasons from the estuary head to the convergence points with the Bay of Bengal. The average depth and water velocity of zone remains 10.09 m (± 6.18) and 0.91 m sec^{-1} (± 0.44).

3.2. Pattern of ichthyofaunal diversity

In the present study, altogether 190 fish species (182 native and 8 exotics) belonging to 133 genera, 62 families and 23 orders was recorded from the entire stretch of River Ganga. The species are described along with their families as presented in Table 2. The description of the ichthyofauna distribution, origin and IUCN [24] (version 2020–3) status along all the sites are represented in Table 3. The review of previous literatures show evidence of the fish richness of the Ganga River are not homogeneous and changing trends are reported after the descriptions elucidated by Hamilton in 1822 [6] (Fig. 3). However, more or less similar pattern of fish species richness was observed during the studies conducted after 1990's in case of Indo Gangetic plain.

Overall, Cyprinidae the most well represented and commercially important family constituting carps and minnows was recorded in all the freshwater section (up to site S16). Out of the total of the 62 families, Cyprinidae was found to be the most species rich (28 spp., 14.28%) followed by Danionidae (19 spp., 9.69%), Sisoridae (10 spp., 5.10%) and Bagridae (9 spp., 4.59%) respectively. Zone wise distributions of families of the entire river stretch are presented in Fig. 4 As expected, Cypriniformes was recorded to be the richest order, contributing to 29% of the total fish species followed by species belonging to Siluriformes (22%). Further assessment revealed that the Ganga River supports substantial percentages of food fish (60.84%), followed by ornamental fish (35.44%) and sports fish (3.70%). The investigation has also further classified55.78% of the species to be solely freshwater inhabitants.

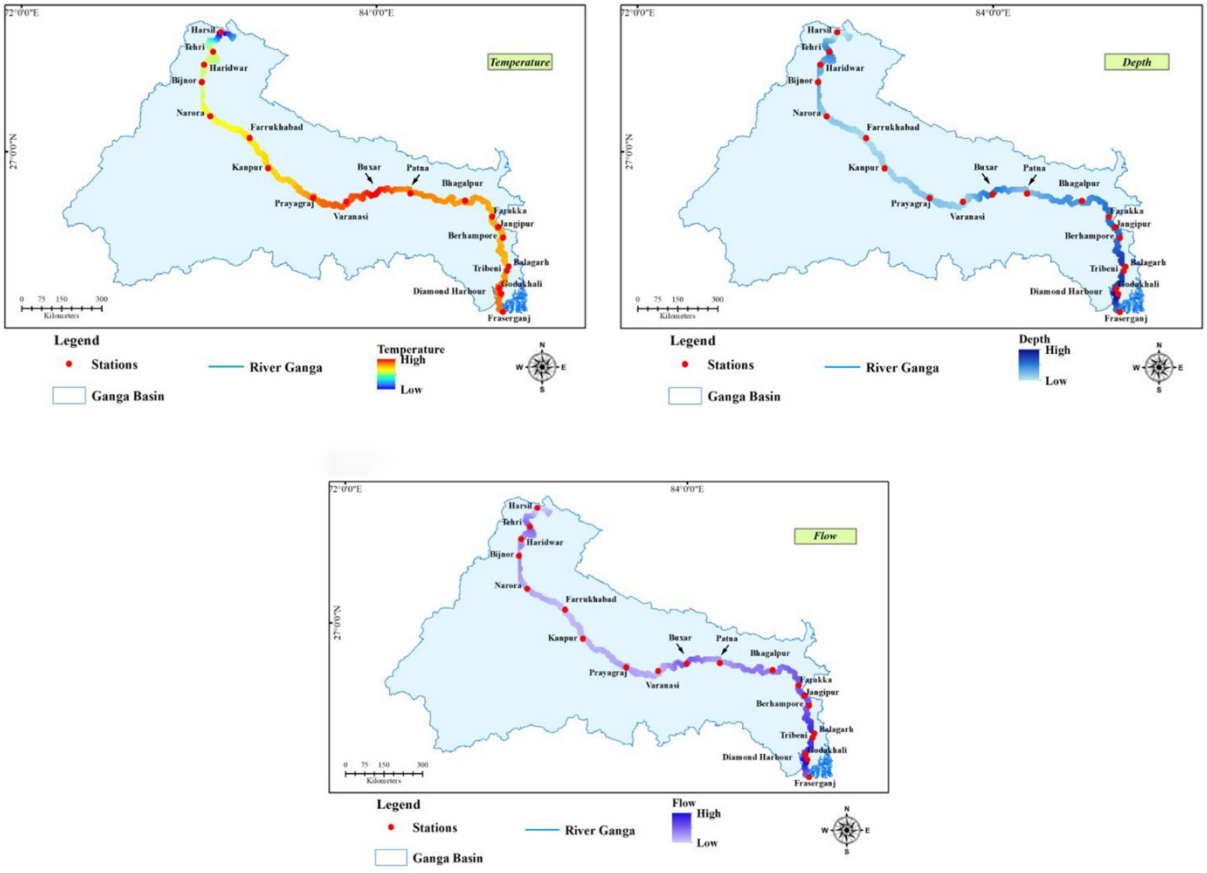

Fig. 2. (a-c) Habitat mapping of river Ganga in terms of temperature, depth and flow.

Around 15.26% of the fishes of the river are cosmopolitan in distribution inhabiting freshwater, brackishwater and marinewater ecosystems which includes 17 families and 26 genera. Subsequently, only 18.94% of the species belong purely to the brackishwater and marinewater habitat (24 families and 34 genera). About 10% of the fish fauna belongs to both freshwater and brackishwater environments that representing 14 families and 15 genera.

During the present study, wide diversity of fishes was recorded from different zones of Ganga. Cyprinidae is considered to be the richest family among all vertebrates accounting 3006 species [22]. The incredible diversity of Cyprindae was also recorded from upper (54.20%), middle (22.76%) and lower (20.07%) stretch of the river. Various member of the family are particularly food fish (*Labeo* spp., *Cyprinus* spp.) and aquarium fish (*Pethia* spp., *Puntius* spp.). The estuarine section of the river constitutes 45 different piscine families. Gobbidae was confirmed as species rich family (10.67%) followed by Engraulidae (9.70%).

3.3. Fish diversity and abundance

In this study, the rhithron zone of the river extending from Harshil to Haridwar has been recorded with the lowest number of fish belonging to hill stream species. The prominent characteristic species are the Barb, Baril and minnows. The keystone species of the hilly stretch are Mahaseer (*Tor putitora*) and Snow trout (*Schizothorax richardsonii*). Commercial fisheries activity in Ganga initiates from below Haridwar at Anupshahar [27] while the middle stretches of the river supports rich fishery resources. Downward of Haridwar to the plains up to Bhagalpur marks the appearances of commercially important fish groups of carps and catfishes. Species representing the higher economic value in the stretch are *Labeo rohita, L. catla, Cirrhinus mrigala, Labeo calbasu, Sperata aor, Sperata seenghala, Wallago attu, Chitala chitala, Rita rita, Eutropiicthys vacha* and *Clupisoma garua*. In another study, Nautiyal et al. 2013 [28] described 122 fish species along the plains from Haridwar to Kanpur stretch of the river. However, present study has revealed the presence of 111 fish species. This least dominance of the species in the region could be attributed to industrial pollution and anthropogenic stressors [29–31]. The area between Haridwar to Bijnor is the mix up of two diverse biogeographical regimes often regarded as transitional zone [28] has shown range extension of coldwater fish species like snow trout, *Glyptothorax cavia* and mahseer. Surprisingly, cold water species inhabiting mountain streams like *Labeo pangusia* was also noticed in the plains upto Bijnor. Incase of fish composition, a sharp dominance of major and minor catfish was observed in the entire middle and lower stretch of Ganga River in order of abundance, while, the abundance of Indian Major Carps (IMC) compared to catfishes showed a decreasing trend. In the present study, Bijnor (106) and Narora (93) recorded the highest number of species followed by Prayagraj (85), Varanasi (84) and Farakka (84). Seventy nine fish species (25 families) was described from Kanpur to Farakka stretch of the river [32]. However, the present study has documented 103 fish species (34 families) indicating an increase of 23% from the stretch. The lower zone of Ganga from Buxar (Bihar) to Tribeni (West Bengal) of the river is rich in from a biodiversity point of view supporting 123 fish species (118 native and 5 exotics). The shifting of river course in the midstream and upper Farakka barrage segments of Ganga has led to the formation of several ox bow lakes, small channels, pools of immense ecological wealth [33,34]. As a result, indication of higher richness in lower stretch of the river indicates a positive influence of open wetlands and aquatic macrophytes thereby creating added advantage for fish assemblage [35]. Moderate impairment in species richness was noticed at Bhagalpur compared to previous study elucidating 76 species [36].

Table 2
List of fish species collected from River Ganga, India. (¶ Exotic species).

Order	Family	Subfamily	Species	Common name	Total Length (cm)	
					Max	Min
Carcharhiniformes	Carcharhinidae		*Scoliodon laticaudus* Müller & Henle 1838	Spadenose shark	22.65	7.98
Myliobatiformes	Dasyatidae	Urogymninae	*Brevitrygon walga* (Müller & Henle 1841)	Scaly whipray	48.60 (disc length)	–
Anguilliformes	Ophichthidae	Ophichthinae	*Pisodonophis boro* (Hamilton 1822)	Rice-paddy eel	58.51	4.68
	Anguillidae		*Anguilla bengalensis* (Gray 1831)	Indian mottled eel	49.00	–
Osteoglossiformes	Notopteridae	Notopterinae	*Chitala chitala* (Hamilton 1822)	Clown knifefish	60.12	9.29
			Notopterus notopterus (Pallas 1769)	Bronze featherback	27.5	11.2
Clupeiformes	Clupeidae		*Anodontostoma chacunda* (Hamilton 1822)	Chacunda gizzard shad	17.6	9.8
			Corica soborna (Hamilton 1822)	Ganges river sprat	5.00	2.67
			Escualosa thoracata (Valenciennes 1847)	White sardine	9.52	4.19
			Gonialosa manmina (Hamilton 1822)	Ganges river gizzard shad	13.33	5.03
			Gudusia chapra (Hamilton 1822)	Indian river shad	14.69	3.60
			Tenualosa ilisha (Hamilton 1822)	Hilsa shad	45.00	3.58
	Engraulidae		*Coilia dussumieri* Valenciennes 1848	Gold spotted grenadieranchovy	10.00	3.22
			Coilia reynaldi Valenciennes 1848	Reynald's grenadier anchovy	12.55	9.80
			Setipinna phasa (Hamilton 1822)	Gangetic hairfin anchovy	24.62	5.2
			Setipinna brevifilis (Valenciennes 1848)	Short-hairfin anchovy	22.60	8.63
			Setipinna taty (Valenciennes 1848)	Scaly hairfin anchovy	18.08	7.61
			Setipinna tenuifilis (Valenciennes 1848)	Common hairfin anchovy	27.80	5.81
			Stolephorus baganensis Delsman 1931	Bagan anchovy	9.20	3.14
	Chirocentridae		*Chirocentrus dorab* (Fabricius 1775)	Dorab wolf-herring	42.00	15.19
	Pristigasteridae		*Ilisha elongata* (Anonymous [Bennett] 1830)	Elongate ilisha	31.55	12.83
			Ilisha megaloptera (Swainson 1838)	Bigeye ilisha	54.8	12.35
			Pellona ditchela Valenciennes 1847	Indian pellona	14.65	6.59
			Raconda russeliana Gray 1831	Raconda	16.16	10.09
Cypriniformes	Botiidae		*Botia dario* (Hamilton,1822)	Bengal loach	11.50	4.83
			Botia lohachata Chaudhuri 1912	Reticulate loach	11.62	3.60
			Botia rostrata Günther 1868	Gangetic loach	8.23	5.60
	Cobitidae		*Lepidocephalichthys guntea* (Hamilton,1822)	Guntea loach	9.41	5.44
			Pangio pangia (Hamilton,1822)	Pangia Coolie Loach	4.81	3.06
	Nemacheilidae		*Aborichthys elongatus* Hora 1921	Loach	6.96	4.21
			Paracanthocobitis botia (Hamilton 1822)	Leopard Loach	8.41	3.77
	Cyrpinidae	Labeoninae	*Bangana dero* (Hamilton 1822)	Kalabans	43.22	9.33
			Cirrhinus mrigala (Hamilton 1822)	Mrigal	87.53	4.28
			Cirrhinus reba (Hamilton 1822)	Reba carp	22.42	4.83
			Garra gotyla (Gray 1830)	Sucker head	18.00	10.94
			Labeo angra (Hamilton 1822)	Angra Labeo	16.34	9.11
			Labeo bata (Hamilton 1822)	Bata	15.14	9.00
			Labeo boga (Hamilton 1822)	Boga bata	11.30	10.33
			Labeo calbasu (Hamilton 1822)	Orangefin Labeo	66.40	4.06
			Labeo catla (Hamilton 1822)	Catla	97.00	11.80
			Labeo dyocheilus (McClelland 1839)	Brahmaputra Labeo	32.77	15.00
			Labeo gonius (Hamilton 1822)	Kuria Labeo	20.0	8.5
			Labeo rohita (Hamilton 1822)	Rohu Labeo	92.0	4.8
			Labeo pangusia (Hamilton 1822)	Pangasia Labeo	31.16	12.09
			Tariqilabeo latius (Hamilton 1822)	Gangetic latia	37.18	7.97
		Torinae	*Tor putitora* (Hamilton 1822)	Putitor Mahseer	49.90	12.21
		Smiliogastrinae	*Chagunius chagunio* (Hamilton 1822)	Chaguni	18.72	8.30
			Oreichthys cosuatis (Hamilton 1822)	Cosuatis	5.14	4.00
			Osteobrama cotio (Hamilton 1822)	Cotio	10.5	3.13
			Pethia conchonius (Hamilton 1822)	Rosy Barb	10.0	3.19
			Pethia gelius (Hamilton 1822)	Golden Barb	4.22	3.71
			Pethia phutunio (Hamilton 1822)	Spottedsail barb	4.30	3.52
			Puntius chola (Hamilton 1822)	Swamp barb	8.91	5.91
			Puntius sophore (Hamilton 1822)	Pool barb	10.96	3.40
			Pethia ticto (Hamilton 1822)	Ticto barb	6.44	5.63
			Systomus sarana (Hamilton 1822)	Olive barb	27.58	7.10
		Cyprininae	*Cyprinus carpio communis*(Linnaeus 1758)¶	Common carp	79.51	9.18
			Cyprinus carpio specularis (Linnaeus1758)¶	Common carp	64.78	12.09
		Schizothoracinae	*Schizothorax richardsonii* (Gray 1832)	Snow trout	38.08	26.25
	Danionidae	Chedrinae	*Barilius barila* (Hamilton 1822)	Barred Baril	8.26	3.50
			Barilius vagra (Hamilton 1822)	Vagra Baril	10.97	7.98
			Bengala elanga (Hamilton 1822)	Bengala Barb	15.63	8.49
			Cabdio morar (Hamilton 1822)	Morari	15.28	3.99
			Opsarius barna (Hamilton 1822)	Barna Baril	17.40	3.41
			Opsarius bendelisis (Hamilton 1807)	Hamiltons' Barila	18.0	3.43
			Opsarius tileo (Hamilton 1822)	Tileo Baril	21.16	12.05
			Raiamas bola (Hamilton 1822)	Trout Barb	28.09	11.76
			Salmostoma acinaces (Valenciennes 1844)	Silver razorbelly minnow	11.23	6.07
			Salmostoma bacaila (Hamilton 1822)	Large razorbelly minnow	13.40	3.60
			Salmostoma phulo (Hamilton 1822)	Finescale razorbelly minnow	12.06	4.44
			Securicula gora (Hamilton 1822)	Gora chela	16.16	8.41

(*continued on next page*)

Table 2 (*continued*)

Order	Family	Subfamily	Species	Common name	Total Length (cm)	
					Max	Min
		Rasborinae	*Amblypharyngodon mola* (Hamilton 1822)	Mola carplet	8.00	4.3
			Rasbora daniconius (Hamilton 1822)	Slender Rasbora	9.10	4.1
		Danioninae	*Devario devario* (Hamilton 1822)	Sind Danio	7.91	4.68
			Laubuka laubuca (Hamilton 1822)	Indian Glass Barb	8.88	4.83
		Esominae	*Esomus danrica* (Hamilton 1822)	Flying Barb	3.72	3.10
	Xenocyprididae	Xenocyprinae	*Ctenopharyngodon idella*[¶] (Valenciennes 1844)	Grass carp	38.19	24.27
			Hypophthalmicthys nobilis[¶](J. Richardson, 1845)	Big head carp	31.14	6.59
			Hypophthalmicthys molitrix[¶](Valenciennes, 1844)	Silver carp	24.09	8.91
Siluriformes	Loricariidae	Hypostominae	*Pterygoplichthys disjunctivus*[¶] (Weber 1991)	Vermiculated sailfin catfish	45.09	36.0
	Chacidae		*Chaca chaca* (Hamilton, 1822)	Squarehead catfish	24.35	–
	Allidae		*Ailia coila* (Hamilton 1822)	Gangetic Ailia	17.4	6.1
			Ailiichthys punctata Day 1872	Jamauna Ailia	16.9	8.2
			Clupisoma garua (Hamilton 1822)	Garua Bachcha	34.2	6.2
			Eutropiichthys murius (Hamilton 1822)	Murius vacha	26.2	9.4
			Eutropiichthys vacha (Hamilton 1822)	Batchwa vacha	27.4	4.0
			Silonia silondia (Hamilton 1822)	Silonid catfish	32.90	11.73
	Horabagridae		*Pachypterus atherinoides* (Bloch 1794)	Potasi	9.59	4.12
	Amblycepitidae		*Amblyceps mangois* (Hamilton,1822)	Indian torrent catfish	6.30	3.31
	Bagridae		*Hemibagrus menoda* (Hamilton 1822)	Menoda catfish	29.0	–
			Mystus bleekeri (Day,1877)	Days's mystus	12.60	6.11
			Mystus cavasius (Hamilton 1822)	Gangetic mystus	20.99	5.15
			Mystus gulio (Hamilton 1822)	Long whiskers catfish	19.60	8.65
			Mystus tengara (Hamilton 1822)	Tengara mystus	12.82	6.79
			Mystus vittatus (Bloch 1794)	Striped dwarf catfish	11.55	5.91
			Rita rita (Hamilton 1822)	Rita	55.28	5.50
			Sperata aor (Hamilton 1822)	Long whiskered catfish	71.20	6.10
			Sperata seenghala (Sykes 1839)	Giant river catfish	69.91	7.06
			Batasio batasio (Hamilton 1822)	Tista batasio	7.76	4.90
	Sisoridae	Sisorinae	*Bagarius bagarius* (Hamilton 1822)	Goonch	94.80	6.98
			Bagarius yarrelli (Sykes 1839)	Goonch	34.50	15.21
			Erethistes hara (Hamilton 1822)	Hara moth catfish	6.00	–
			Erethistes pusillus (Müller & Troschel 1849)	Gangetic erethistes	7.26	–
			Gagata cenia (Hamilton 1822)	Indian Gagata	10.77	5.0
			Gagata gagata (Hamilton 1822)	Gangetic Gagata	10.41	7.76
			Glyptothorax cavia (Hamilton 1822)	Mountain cavia catfish	18.05	8.46
			Glyptothorax garhwali Tilak 1969	Sisorid Rock catfish	7.88	6.00
			Gogangra viridescens (Hamilton 1822)	Huddah Nangra	6.70	4.20
			Sisor rabdophorus (Hamilton 1822)	Sisor catfish	18.19	12.64
	Pangasiidae		*Pangasius pangasius* (Hamilton 1822)	Pangas catfish	23.8	11.4
	Siluridae		*Ompok bimaculatus* (Bloch 1794)	Butter catfish	21.1	7.3
			Ompok pabda (Hamilton,1822)	Pabdah catfish	15.1	7.9
			Ompok pabo (Hamilton,1822)	Pabo catfish	10.0	8.4
			Wallago attu (Bloch & Schneider 1801)	Wallago	119.4	13.7
	Clariidae		*Clarias magur* (Hamilton 1822)	Asian catfish	18.81	10.69
			Clarias gariepinus (Burchell 1822)[¶]	North African catfish	48.00	28.00
	Heteropneustidae		*Heteropneustes fossilis* (Bloch 1794)	Stinging catfish	22.4	6.5
	Ariidae	Ariinae	*Arius arius* (Hamilton,1822)	Threadfin sea catfish	20.4	8.6
			Arius gagora (Hamilton,1822)	Gagora catfish	29.52	10.1
			Nemapteryx caelata (Hamilton,1822)	Engraved catfish	21.01	4.55
			Osteogeneiosus militaris (Linnaeus 1758)	Soilder catfish	12.10	5.62
Aulopiformes	Synodontidae	Harpadontinae	*Harpadon nehereus* (Hamilton 1822)	Bombay duck	26.00	5.91
Gadiformes	Bregmacerotidae		*Bregmaceros mcclellandi* Thompson 1840	Unicorn cod	8.64	5.11
Scombriformes	Trichiuridae	Lepidopodinae	*Eupleurogrammus muticus* (Gray 1831)	Small head hairtail	44.60	21.08
		Trichiurinae	*Trichiurus lepturus* Linnaeus 1758	Large head hairtail	*52.40*	*17.19*
Syngnathiformes	Syngnathidae	Nerophinae	*Microphis cuncalus* (Hamilton 1822*)*	Crocodile-tooth pipefish	5.50	4.42
Gobiiformes	Eleotridae	Eleotrinae	*Eleotris fusca* (Bloch & Schneider 1801)	Dusky sleeper	4.55	2.58
	Gobiidae	Gobiinae	*Glossogobius giuris* (Hamilton 1822)	Tank Goby	30.53	4.13
		Gobionellinae	*Brachygobius nunus* (Hamilton 1822)	Bumblebee Goby	12.46	5.09
		Oxudercinae	*Apocryptes bato* (Hamilton 1822)	Mudskipper	*10.52*	*4.29*
			Boleophthalmus boddarti (Pallas 1770)	Boddart's goggle-eyed Goby	11.80	5.00
			Oxuderces dentatus Eydoux & Souleyet 1850	Crocodile-face Goby	8.16	6.28
			Pseudapocryptes elongatus (Cuvier 1816)	Elongate mudskipper	13.90	3.13
		Amblyopinae	*Odontamblyopus rubicundus* (Hamilton 1822)	Rubicundus Eelgoby	26.34	4.20
Synbranchiformes	Mastacembelidae		*Mastacembelus armatus* (Lacepède 1800)	Zig-zag eel	62.08	11.28
			Macrognathus aral (Bloch & Schneider 1801)	One stripe spiny eel	17.44	6.03
			Macrognathus pancalus (Hamilton,1822)	Barred spiny eel	19.08	5.48
	Synbranchidae		*Ophichthys cuchia* (Hamilton 1822)	Gangetic mud eel	59.27	32.61
Anabantiformes	Anabantidae		*Anabas testudineus* (Bloch 1792)	Climbing perch	9.31	4.60
	Channidae		*Channa gachua* (Hamilton,1822)	Dwarf Snakehead	29.00	14.19
			Channa marulius (Hamilton,1822)	Great Snakehead	38.55	5.10
			Channa punctata (Bloch 1793)	Spotted Snakehead	22.82	4.92
			Channa striata (Bloch 1793)	Striped Snakehead	33.00	8.29
	Osphronemidae	Trichogastrinae	*Trichogaster chuna* (Hamilton,1822)	Honey gourami	5.11	–

(*continued on next page*)

Table 2 (*continued*)

Order	Family	Subfamily	Species	Common name	Total Length (cm)	
					Max	Min
			Trichogaster fasciata (Bloch & Schneider 1801)	Banded gourami	8.77	2.13
			Trichogaster lalius (Hamilton,1822)	Dwarf gourami	4.60	2.88
	Nandidae		*Nandus nandus* (Hamilton 1822)	Gangetic leaf fish	16.90	4.22
	Badidae		*Badis badis* (Hamilton,1822)	Blue dwarf	3.45	1.83
Carangiformes	Latidae		*Lates calcarifer* (Bloch 1790)	Asian sea bass	29.57	8.06
	Polynemidae		*Eleutheronema tetradactylum* (Shaw 1804)	Fourfinger threadfin	27.89	9.86
			Polynemus paradiseus Linnaeus 1758	Paradise threadfin	27.36	2.55
	Soleidae		*Brachirus pan* (Hamilton 1822)	Pan sole	11.10	2.39
	Cynoglossidae	Cynoglossinae	*Cynoglossus arel* (Bloch & Schneider 1801)	Largescale tongue sole	22.10	4.90
			Cynoglossus cynoglossus (Hamilton,1822)	Bengal tongue sole	10.90	8.83
			Cynoglossus lingua (Hamilton,1822)	Long tongue sole	17.78	7.60
	Carangidae		*Atropus atropos* (Bloch & Schneider 1801)	Cleftbelly trevally	10.62	4.12
			Alepes djedaba (Forsskål 1775)	Shrimp scad	12.13	8.51
			Megalaspis cordyla (Linnaeus 1758)	Torpedo scad	25.00	15.00
			Parastromateus niger (Bloch 1795)	Black Pomfret	24.8	12.6
Cichliformes	Cichlidae		*Oreochromis niloticus* (Linnaeus 1758)[¶]	Nile Tilapia	44.5	14.0
Cyprinodontiformes	Aplocheilidae		*Aplocheilus panchax* (Hamilton 1822)	Blue panchax	6.01	2.31
Beloniformes	Belonidae		*Xenentodon cancila* (Hamilton,1822)	Freshwater Garfish	25.52	7.23
	Hemiramphidae		*Hyporhamphus limbatus* (Valenciennes 1847)	Congaturi halfbeak	15.33	3.09
Mugiliformes	Mugilidae		*Chelon parsia* (Hamilton,1822)	Goldspot mullet	15.21	6.50
			Rhinomugil corsula (Hamilton,1822)	Corsula mullet	19.46	4.01
			Minimugil cascasia (Hamilton,1822)	Yellowtail mullet	6.14	3.15
			Planiliza tade (Forsskål 1775)	Tade mullet	16.81	6.10
Acanthuriformes	Lobotidae		*Lobotes surinamensis* (Bloch 1790)	Tripletail	16.28	9.81
	Drepaneidae		*Drepane punctata* (Linnaeus 1758)	Spotted sicklefish	11.89	9.19
	Leiognathidae		*Deveximentum insidiator* (Bloch 1787)	Pugnose ponyfish	9.22	4.68
			Nuchequula blochii (Valenciennes 1835)	Twoblotch ponyfish	2.88	1.82
	Scatophagidae		*Scatophagus argus* (Linnaeus 1766)	Spotted scat	10.91	5.67
	Siganidae		*Siganus javus* (Linnaeus 1766)	Streaked spinefoot	12.00	9.32
Tetraodontiformes	Tetraodontidae		*Leiodon cutcutia* (Hamilton 1822)	Ocellated pufferfish	8.56	3.60
			Lagocephalus lunaris (Bloch & Schneider 1801)	Lunartail puffer	18.29	6.57
Centrarchiformes	Terapontidae		*Terapon jarbua* (Fabricius 1775)	Tiger perch	20.8	6.9
Perciformes	Ambassidae		*Chanda nama* (Hamilton,1822)	Elongate glass perchlet	7.2	2.3
			Parambassis baculis (Hamilton,1822)	Himalayan glassy perchlet	2.1	2.9
			Parambassis lala (Hamilton,1822)	Highfin glassy perchlet	2.5	3.0
			Parambassis ranga (Hamilton,1822)	Indian Glass fish	6.5	2.5
	Serranidae		*Epinephelus coioides* (Hamilton, 1822)	Orange spotted grouper	29.7	10.2
	Sillaginidae		*Sillaginopsis domina* (Cuvier 1816)	Gangetic whiting	37.3	9.1
			Sillago sihama (Fabricius 1775)	Indian sand whiting	19.4	5.5
	Gerreidae		*Gerres oyena* (Forsskål 1775)	Common silver biddy	8.6	4.0
			Gerres filamentosus Cuvier 1829	Whipfin silver biddy	6.1	4.5
	Sciaenidae		*Johnius coitor* (Hamilton,1822)	Ganges croaker	14.1	8.5
			Johnius gangeticus (Talwar,1991)	Gangetic bola	15.5	2.5
			Otolithoides pama (Hamilton,1822)	Pama croaker	36.7	1.8
			Panna microdon (Bleeker 1849)	Panna croaker	24.3	6.7
	Platycephalidae		*Platycephalus indicus* (Linnaeus 1758)	Bartail flathead	18.6	2.9

The overall fish composition of river Ganga was divided into eight major groups (Table 4.). The abundance of carps was recorded analogous at Bhagalpur and Haridwar with 11%. The stretch from Farukhabad to Varanasi showed uniformity in carp abundance with 7.54%. The present study showed that the contribution of carps (major, medium and minor) has been reduced in river stretch where it constituted only 9.30% of the catch in comparison to catfish and miscellaneous fish group (25% and 61% respectively). However, catfish groups did not vary much and constituted a uniform catch percentage in almost all the sites. Haridwar recorded the least (11%) among the catfish abundance. The number of catfish was noticed highest in Bhagalpur and Farukhabad (30% and 28% respectively). Among the three major carps, all were available from site S4 (Bijnor) to S17 (Tribeni) except sites S17 and S18 which are brackishwater zone. Comparatively, the relative abundance of IMC was considerably poor while RA of another medium carp *L. calbasu* was highest 0.16% among all compared to *C. mrigala* (0.12%) and *L. rohita* (0.10%).

The analysis of species data the relative abundance of the indigenous fish species showedmaximum contributionofsmall indigenous fishes (SIF's) such as *Cabdio morar* (31.46%), *Salmostoma bacaila* (18.08%), *Puntius sophore* (6.95%), *Securicula gora* (3.96%), *Parambassis ranga* (2.82%), *Osteobrama cotio* (2.07%), *Barilius barila* (1.68%), *Gudusia chapra* (1.29%) and *Tariqilabeo latius* (1.05%).Similar report was observed by Sarkar et al. 2012. Increased abundance of small sized fishes in the river could be the result of excessive fishing pressure upon large size fishes like carps and catfishes. Among the catfishes, *Eutropiicthys vacha* (0.93%), *Heteropneustes fossilis* (0.90%), *Ailia coila* (0.44%) and *C. garua* (0.16%) was most abundant.

The available reports suggest the altered dynamics of Hooghly estuary after commissioning of Farakka barrage in 1975 [37–39]. Huge influxes of freshwater discharge from the barrage have restricted the true estuarine zone towards the river mouth [37]. The range of salinity extends from less than 0.1% to beyond 30% in several zones of the estuary and fluctuates along with the season. Regular tidal influences are experienced along the main channel of Hooghly River up to 220 km. Availability of true brackishwater species were reported from the present freshwater tidal stretches [40] thereby, indicating the confinement of fish faunal community more towards the marine zone. Review of literature indicates 133 species from the Hooghly Matlah estuarine system [41] while 172 fish species were reported during post Farakka period [42]. Present study recorded a total of 92 fish species along the tidal freshwater stretch (S15 to S17). The zone (S15) has high fish diversity (66) among freshwater tidal zones. Besides, influenced by minimum tidal influx, it is interconnected with number of smalllinks with

Table 3
Distribution pattern of recorded fishes in River Ganga.

Species	Upper stretch			Middle stretch						Lower stretch								Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Aborichthys elongatus Hora 1921‡	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–			LC	EN
Ailia coila (Hamilton 1822)†‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	NT	VU
Ailiichthys punctata (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–			NT	VU
Alepes djedaba (Forsskål 1775)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Amblyceps mangois (Hamilton,1822)‡	–	–	–	+	+	–	–	–	–	+		+	+	–	–	–	–	–	–	*	*	LC	LRnt
Amblypharyngodon mola (Hamilton 1822)†	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	LC	LRlc
Anabas testudineus (Bloch 1792)†	–	–	–	+	+	+	+	+	+	+	+	–	+	+	+	+	–	–	–	*	*	LC	VU
Anguilla bengalensis (Gray 1831)†	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	*	*	NT	EN
Anodontostoma chacunda (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*		LC	–
Aplocheilus panchax (Hamilton,1822)‡	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	+	–	–	–	*		LC	DD
Apocryptes bato (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*		LC	–
Arius arius (Hamilton,1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	*		LC	–
Arius gagora (Hamilton,1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	*		NT	–
Atropus atropos (Bloch & Schneider 1801)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Badis badis (Hamilton,1822)‡	–	–	–	+	+	–	–	–	–	–	–	–	–	+	+	+	+	–	–	*		LC	–
Bagarius bagarius (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	NT	VU
Bagarius yarrelli (Sykes 1839)†	–	–	–	–	–	–	–	–	–	+	+	–	+	–	–	–	–	–	–		*	NT	–
Bangana dero (Hamilton 1822)†	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	VU
Barilius barila (Hamilton 1822)‡	–	+	+	+	+	+	+	+	+	–	–	+	+	–	–	–	–	–	–	*	*	LC	VU
Barilius vagra (Hamilton 1822)‡	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	VU
Batasio batasio (Hamilton 1822)‡	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	*	*	LC	–
Bengala elanga (Hamilton 1822)‡	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	–
Boleophthalmus boddarti (Pallas 1770)‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*		LC	–
Botia dario (Hamilton,1822)‡	–	–	–	–	+	–	–	–	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Botia lohachata Chaudhuri 1912‡	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	–	–	–	–	*	*	NE	EN

(*continued on next page*)

Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch								Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Botia rostrata Günther 1868[‡]	–	–	–	–	–	–	–	–	–	+	–	–	+	+	+	+	–	–	–			NE	–
Brachirus pan (Hamilton, 1822)[‡]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*		LC	–
Brachygobius nunus (Hamilton 1822)[‡]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*		NE	–
Bregmaceros mcclellandi Thompson 1840[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			NE	–
Brevitrygon walga (Müller & Henle 1841)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			NT	–
Cabdio morar (Hamilton 1822)[†‡]	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Chaca chaca (Hamilton, 1822)[‡]	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	*		LC	–
Chagunius chagunio (Hamilton 1822)[†]	–	–	+	+	+	–	+	+	+	+	+	+	+	–	–	–	–	–	–	*	*	LC	–
Chanda nama (Hamilton,1822)[†‡]	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Channa gachua (Hamilton,1822)[†]	–	–	–	+	+	–	+	+	+	–	–	–	–	–	–	–	–	–	–	*		LC	VU
Channa marulius (Hamilton,1822)[†]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	LC	LRnt
Channa punctata (Bloch 1793)[†]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Channa striata (Bloch 1793)[†]	–	–	–	+	+	+	+	+	+	–	–	+	+	–	–	–	–	–	–	*	*	LC	LRlc
Chelon parsia (Hamilton,1822)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	NE	–
Chirocentrus dorab (Fabricius 1775)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	LC	–
Chitala chitala (Hamilton,1822)[†‡]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	NT	EN
Cirrhinus mrigala (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnT
Cirrhinus reba (Hamilton,1822)[†]	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	VU
Clarias gariepinus (Burchell 1822)[†]	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–		*	LC	–
Clarias magur (Hamilton,1822)[†]	–	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	*		EN	VU
Clupisoma garua (Hamilton 1822)[†s]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	VU
Coilia dussumieri Valenciennes 1848[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+			LC	–
Coilia reynaldi Valenciennes 1848[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+			LC	–
Corica soborna (Hamilton 1822)[†]	–	–	–	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	–	*		LC	–
Ctenopharyngodon idella (Valenciennes 1844)[†]	–	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–		*	NE	–
Cynoglossus arel (Bloch & Schneider 1801)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+			NE	–
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*		LC	–

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Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch									Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Cynoglossus cynoglossus (Hamilton,1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*			LC	–
Cynoglossus lingua (Hamilton,1822)†	–	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–		*		VU	–
Cyprinus carpio var. communis Linnaeus 1758†	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		*		NE	–
C. carpio var.specularis Linnaeus 1758†	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*		LC	LRnt
Devario devario (Hamilton 1822)‡	–	–	–	+	+	–	+	–	+	+	+	+	+	+	+	+	–	–	–				NE	–
Deveximentum insidiator (Bloch 1787)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+				LC	–
Drepane punctata (Linnaeus 1758)†‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+				LC	–
Eleotris fusca (Bloch & Schneider 1801)‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	+	*			LC	–
Eleutheronema tetradactylum (Shaw 1804)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*			NE	–
Epinephelus coioides (Hamilton, 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	*			LC	–
Erethistes hara (Hamilton 1822)‡	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	*	*		LC	–
Erethistes pusillus (Müller & Troschel 1849)‡	–	–	–	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–				LC	–
Escualosa thoracata (Valenciennes 1847)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+				LC	–
Esomus danrica (Hamilton 1822)‡	–	–	–	+	+	+	+	–	+	–	–	–	+	+	+	–	–	–	–	*	*		LC	–
Eupleurogrammus muticus (Gray 1831)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+				NE	–
Eutropiichthys murius (Hamilton 1822)†	–	–	–	+	+	+	+	+	–	+	+	+	+	–	–	–	–	–	–	*	*		LC	LRnt
Eutropiichthys vacha (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*		LC	EN
Gagata cenia (Hamilton 1822)†‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	*	*		LC	–
Gagata gagata (Hamilton 1822)†‡	–	–	–	–	–	–	–	–	–	+	+	–	+	–	–	–	–	–	–	*			LC	–
Garra gotyla (Gray 1830)†	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		*		LC	VU
Gerres filamentosus Cuvier 1829†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+				LC	–
Gerres oyena (Forsskål 1775)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+				LC	–
Glossogobius giuris (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*		LC	LRnt
Glyptothorax cavia (Hamilton 1822)†‡	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*			LC	EN
Glyptothorax garhwali (Tilak, 1969)†‡	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–				LC	CR
Gogangra viridescens (Hamilton 1822)	–	–	–	+	–	+	+	+	+	–	–	+	–	–	–	–	–	–	–	*			LC	LRnt

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Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch								Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Gonialosa manmina (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	*	*	LC	VU
Gudusia chapra (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRlc
Harpadon nehereus (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*		NT	–
Hemibagrus menoda (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	*	*	LC	
Heteropneustes fossilis (Bloch 1794)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	LC	VU
Hypophthalmicthys molitrix Valenciennes, 1844†	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–		*	DD	–
Hypophthalmicthys nobilis (J. Richardson, 1845)†	–	–	–	+	+	+	+	+	+	–	–	–	–	+	+	–	–	–	–		*	DD	–
Hyporhamphus limbatus (Valenciennes 1847)†‡	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	+	+	+		*	LC	–
Ilisha elongata (Anonymous [Bennett] 1830)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Ilisha megaloptera (Swainson 1838)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Johnius coitor (Hamilton,1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Johnius gangeticus (Talwar,1991)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+		*	DD	EN
Labeo angra (Hamilton 1822)†	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–		*	LC	LRnt
Labeo bata (Hamilton 1822)†	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Labeo boga (Hamilton 1822)†	–	–	–	+	+	–	–	+	+	+	–	–	+	+	–	–	–	–	–	*		LC	LRnt
Labeo calbasu (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Labeo catla (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	VU
Labeo dyocheilus (McClelland 1839) †	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–		*	LC	VU
Labeo gonius (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	–	+	+	–	–	–	–	–	–	*	*	LC	LRnt
Labeo pangusia (Hamilton 1822)†	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	NT	LRnt
Labeo rohita (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Lagocephalus lunaris (Bloch & Schneider 1801)‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Lates calcarifer (Bloch 1790)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*		LC	–
Laubuka laubuca (Hamilton 1822)‡	–	–	–	+	+	+	+	+	+	–	–	–	+	–	–	–	–	–	–	*	*	LC	
Leiodon cutcutia (Hamilton,1822)‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Lepidocephalichthys guntea (Hamilton,1822)‡	–	–	–	+	+	–	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–

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Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch								Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Lobotes surinamensis (Bloch 1790)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	
Macrognathus aral (Bloch & Schneider 1801)†‡	–	–	+	+	–	+	–	+	+	+	–	–	+	–	–	–	–	–	–		*	LC	LRnt
Macrognathus pancalus (Hamilton,1822)†‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Mastacembelus armatus (Lacepède 1800)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Megalaspis cordyla (Linnaeus 1758)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Microphis cuncalus (Hamilton 1822)‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	*		LC	–
Minimugil cascasia (Hamilton,1822)†	–	–	–	+	+	+	+	+	+	+	–	–	+	–	–	+	+	–	–	*	*	LC	VU
Mystus bleekeri (Day,1877)†	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	*	*	LC	VU
Mystus cavasius (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Mystus gulio (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	*		LC	–
Mystus tengara (Hamilton 1822)†	–	–	–	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–		*	LC	–
Mystus vittatus (Bloch 1794)†‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	*	*	LC	VU
Nandus nandus (Hamilton 1822)†‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	*	*	LC	LRnt
Nemapteryx caelata (Hamilton,1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+			NE	–
Notopterus notopterus (Pallas 1769)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Nuchequula blochii (Valenciennes 1835)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			NE	–
Odontamblyopus rubicundus (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	*		NE	–
Ompok bimaculatus (Bloch 1794)†	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	NT	EN
Ompok pabda (Hamilton,1822)†	–	–	–	+	+	+	+	+	–	–	–	–	+	+	–	–	–	–	–	*	*	NT	EN
Ompok pabo (Hamilton,1822)†	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	NT	–
Ophichthys cuchia (Hamilton 1822)†	–	–	–	+	–	–	–	–	–	+	+	–	+	+	+	–	–	–	–	*	*	LC	LRnt
Opsarius barna (Hamilton 1822)†‡	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	LRnt
Opsarius bendelisis (Hamilton 1807)†‡	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	LRnt
Opsarius tileo (Hamilton 1822)†‡	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	LC	LRnt
Oreichthys cosuatis (Hamilton 1822)†‡	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*		LC	–
Oreochromis niloticus (Linnaeus 1758)	–	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–		*	LC	–

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Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch								Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Osteobrama cotio (Hamilton 1822)†	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	*	*	LC	LRnt
Osteogeneiosus militaris (Linnaeus 1758)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+			NE	−
Otolithoides pama (Hamilton,1822)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	*		DD	−
Oxuderces dentatus Eydoux & Souleyet 1850†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+			NE	−
Pachypterus atherinoides (Bloch 1794)†‡	−	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	−	−	−	*	*	LC	EN
Pangasius pangasius (Hamilton 1822)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	*	*	LC	CR
Pangio pangia (Hamilton,1822)†	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	*		LC	VU
Panna microdon (Bleeker 1849)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+		*	LC	
Paracanthocobitis botia (Hamilton,1822)‡	−	−	−	−	−	−	−	−	−	+	+	+	+	+	+	−	−	−	−	*	*	LC	LRnt
Parambassis baculis (Hamilton,1822)†‡	−	−	−	+	+	+	+	+	+	−	−	−	−	−	−	+	+	−	−	*	*	LC	−
Parambassis lala†‡(Hamilton,1822)	−	−	−	+	+	+	−	+	+	−	−	−	+	+	+	+	−	−	−			NT	−
Parambassis ranga (Hamilton,1822)†‡	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	*	*	LC	−
Parastromateus niger (Bloch 1795)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+			LC	−
Pellona ditchela Valenciennes 1847†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	+			LC	−
Pethia conchonius (Hamilton 1822)†‡	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	*	*	LC	VU
Pethia gelius (Hamilton 1822)‡	−	−	−	+	+	−	−	−	−	−	−	+	+	+	−	−	−	−	−	*		LC	−
Pethia phutunio (Hamilton 1822)‡	−	−	−	−	−	−	−	−	−	−	−	−	+	+	−	−	−	−	−	*	*	LC	LRlc
Pethia ticto (Hamilton 1822)†‡	−	−	+	+	+	+	+	+	+	−	−	−	+	+	+	−	−	−	−	*	*	LC	LRnt
Pisodonophis boro (Hamilton 1822)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	+	+	*		LC	−
Planiliza tade (Fabricius 1775)†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	*		DD	−
Platycephalus indicus†(Hamilton 1822)	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	+	*		DD	−
Polynemus paradiseus Linnaeus 1758†	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	*		LC	−
Pseudapocryptes elongatus (Cuvier 1816) †‡	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	+	+			LC	−
Pterygoplicthys disjunctivus (Weber 1991)‡	−	−	−	−	−	−	−	−	−	−	−	−	+	−	+	−	−	−	−			LC	−
Puntius chola (Hamilton 1822)†‡	−	−	−	−	−	−	−	−	−	−	+	+	+	+	−	−	−	−	−	*	*	LC	VU
	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	*	*	LC	−

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Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch									Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Puntius sophore (Hamilton 1822)[†‡]																								
Raconda russeliana Gray 1831[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Raiamas bola (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	*		LC	VU
Rasbora daniconius (Hamilton 1822)[‡]	–	–	–	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	*	*	LC	
Rhinomugil corsula (Hamilton,1822)[†‡]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	*	*	LC	VU
Rita rita (Hamilton 1822)[†#]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRnt
Salmostoma acinaces (Valenciennes 1844)	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–			LC	
Salmostoma bacaila (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	LRlc
Salmostoma phulo (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	*	*	NE	–
Scatophagus argus (Linnaeus 1766)[‡]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	*		LC	–
Schizothorax richardsonii (Gray 1832)[† #]	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		*	VU	VU
Scoliodon laticaudus Müller & Henle 1838[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			NT	–
Securicula gora (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	*	*	LC	–
Setipinna brevifilis (Valenciennes 1848)[†]	–	–	–	–	–	+	+	–	–	+	+	–	+	–	+	–	–	–	–		*	DD	–
Setipinna phasa (Hamilton 1822)[†]				+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	*	*	LC	–
Setipinna taty (Valenciennes 1848)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Setipinna tenuifilis (Valenciennes 1848)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+			DD	–
Siganus javus (Linnaeus 1766)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
Sillaginopsis domina (Cuvier 1816)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	*		NE	–
Sillago sihama (Fabricius 1775)[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+			LC	–
Silonia silondia (Hamilton 1822)[†]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	*	*	LC	LRnt
Sisor rabdophorus (Hamilton 1822)[‡]	–	–	–	+	+	+	+	+	+	+	–	–	+	+	–	–	–	–	–	*	*	LC	EN
Sperata aor (Hamilton 1822)[† #]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Sperata seenghala (Sykes 1839)[† #]	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	LC	–
Stolephorus baganensis Delsman 1931[†]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+			LC	–
	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*	*	LC	VU

(*continued on next page*)

Table 3 (*continued*)

Species	Upper stretch			Middle stretch						Lower stretch									Estuarine stretch				IUCN status	CAMP (1998)
	Harshil	Tehri	Haridwar	Bijnour	Narora	Farukhabad	Kanpur	Prayagraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Berhampore	Balagarh	Tribeni	Godakhali	Diamond Harbour	Fraserganj	Hamilton (1822)	Sarkar et al. (2012)		
Systomus sarana (Hamilton 1822)†‡																								
Tariqilabeo latius (Hamilton 1822)†	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	*	*	LC	DD
Tenualosa ilisha (Hamilton 1822)†	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	*	*	LC	VU
Terapon jarbua (Fabricius 1775)†‡	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	*		LC	–
Tor putitora (Hamilton 1822)†‡ #	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	EN	EN
Trichiurus lepturus Linnaeus 1758†	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	*		LC	–
Trichogaster chuna (Hamilton,1822)‡	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–			LC	–
Trichogaster fasciata (Bloch & Schneider 1801)‡	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*		LC	LRnt
Trichogaster lalius (Hamilton,1822)‡	–	–	–	+	–	+	+	+	+	+	+	+	+	+	+	–	–	–	–	*		LC	–
Wallago attu (Bloch & Schneider 1801)†#	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	*	*	VU	LRnt
Xenentodon cancila (Hamilton,1822)†‡	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	*	*	LC	LRnt

(LC- Least concern, VU- Vulnerable, NT- Near threatened, EN- Endangered, CR- Critically endangered; NE- Not evaluated, DD- Data deficient; LRnt – Low Risk near threatened; LRlc- Low Risk least concern; '+' indicates presence and '-' indicates absence of a particular species in a given site, † Food fish, ‡Ornamental fish, # Sports fish).

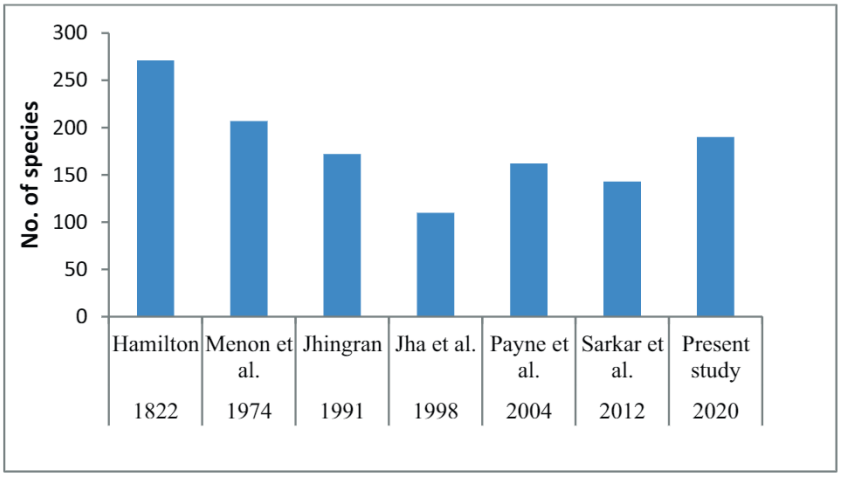

Fig. 3. Graphical representation of fish species richness during different time period of river Ganga.

the main channel, thereby forming a suitable habitat for fish breeding [43]. This zone was found dominated mostly by small indigenous freshwater fish species such as *P. sophore*(12.76%), *A. coila* (7.90%), *Pethia conchonius* (6.27%), *Corica soborna* (4.26%) and *Salmostoma bacaila* (3.29%). A combination of both estuarine and marine fish species were recorded from Site S16 to S17 as it is subjected to daily diurnal tidal influences. In lower stretch, Godakhali recorded the least number of species i.e. *32* as compared to other stretch.

In the present study a total of 72 fish species (37 families) were documented from the freshwater tidal zone. Clupeids like *C. soborna* (18.01%) and *Tenualosa ilisha* (17.78%) showed higher dominance in assemblage pattern followed by *Setipinna phasa* (16.37%), *Odontamblyopus rubicundus* (12.80%) and *Otolothoides pama* (7.06%). Site S19 is a high saline zone in close proximity of Bay of Bengal located nearly 10 km away from the sea mouth. The site represented 66 different fish species mostly of marine habitat. The dominance of marine species in the estuarine zone signifies their exploration behaviour as a part of their life cycle [44]. Correspondingly, the estuaries serve as a natural breeding spots for many marine species [45]. One species of shark (*Scoliodon laticaudus*) and ray (*Brevitrygon walga*) was also described from lower most high saline region. RA of *Harpadon nehereus* (24.33%), *Coilia dussumieri* (10.24%), *T. ilisha* (8.14%), *Setipinna taty* (6.24%) and *Anodontostoma chacunda* (5.19%) was recorded highest. However, rampant use of non-selective fishing nets [46] in the Hooghly River has created a drastic decline in overall fisheries. Intense fishing pressure in the coastal and estuarine zones [47] has resulted huge fishing imbalance including iconic Hilsa fisheries. Juvenile stocks of especially commercially important species like *Polynemus paradiseus* and *Otolithoides pama* are often considered as by catch and discard in the estuarine zone. Interestingly, *O. pama* (13.69%), *P. paradiseus* (11.07%) and *T.ilisha* (8.11%) contribute to maximum the juvenile landing in the Hooghly estuary. Large scale destruction of juveniles is not only detrimental to the fishery but also creates an impact on future recruitments of adult stocks [48]. The recent estimation on juvenile fishing of *T. ilisha* has depicted anannual economic deficit of 497.84 million (around US$ 7.8 million) from the Hooghly estuary [49].

Several literatures has documented that fish communities in riverine system follow a sequence of enhanced species richness, diversity and abundance from upstream to downstream [4,50,51]. Work done by Hamilton (1822) [6] was compared with the current study to understand the present available fish species in the river. Overall, 129 fishes were found in parity with the findings of Hamilton. Studies suggest that there is already a severe decline in major fish population due to loss of habitat, overfishing and other anthropogenic activities in Ganga [52–54]. Additionally, irrational fishing of adult and brood fish stocks using advanced armory of fishing practices has created a threatening condition for valuable species to survive, thereby, reflecting rising contributions of small indigenous fishes (SIF) in all the zones of Ganga River.

3.4. New distribution of fish species

In our study, range extension of exotic common carp (*Cyprinus carpio*) from cold water stretch Tehri to the plains in Buxar was documented during every sampling performed indicating threats to native fishes. This wide distribution range of the exotic carp specifies its sturdy temperature tolerance limits in the river. In contrast to the study conducted by Menon 1954, our findings indicate congregation of catfish *Bagarius bagarius* more in plains from upper colder section of Ganges. Likewise, common inhabitants of upland regions like *B. barila* and *Barilius vagra* are recorded from the middle stretch of the river signifying their extension affinity more towards the downstream. Range extension of few minor carps (*Cirrhinus reba, Labeo bata*) and minnows (*Systomus sarana*, *Amblypharyngodon mola*) in between Tehri and Haridwar stretch may also represent the possibility of temperature fluctuations. Moreover, a common coastal species *Hyporhamphus limbatus* mainly inhabiting the inshore tidal area have been encountered during the advent of monsoon months from Bhagalpur extending approximately 510 km upstream. Although, resolving the impact of climate modifications on fish species distribution is complex, several hypothesis has established the reason of global warming as a positive effect to the dispersal changes towards fish population [55–57]. A new distribution record of eel loach *Pangio pangia* was also reported from middle stretch of river Ganga by Sarkar et al. (2013) [58]. The results on systematic data on the global warming on river Ganga, indicates rise of temperature in the upper stretch by 1.5 °C during the period 1975–2005 [59] thus allowing shifting of fish species to the much colder reaches of the river.

3.5. Zonewise fish species composition

Determination of species richness in an aquatic ecosystem is the most accepted metric among the ecologist for determining species diversity [60]. The Shanon-Weiner (H′) index or the entropy analysis reflected the existence of similarity patterns in fish population between US-3 to MS-6 section of the river. The index represented an even distribution of fish community except Kanpur, Allahabad and Varanasi (Figs. 5, 6). The lower species richness and the index value at three sites may be attributed to the poor water quality [61]. However, the values of the site LS-1 up to LS-4 indices (Table 5.) ranged from 2.59–2.93 with no such significant alterations. Moderate increase of 20 fish species from Bhagalpur to Farrakka stretch may have been due to better habitat conditions. On the other side, from sites LS-5 to LS-7 the values ranged from 2.79–2.16.

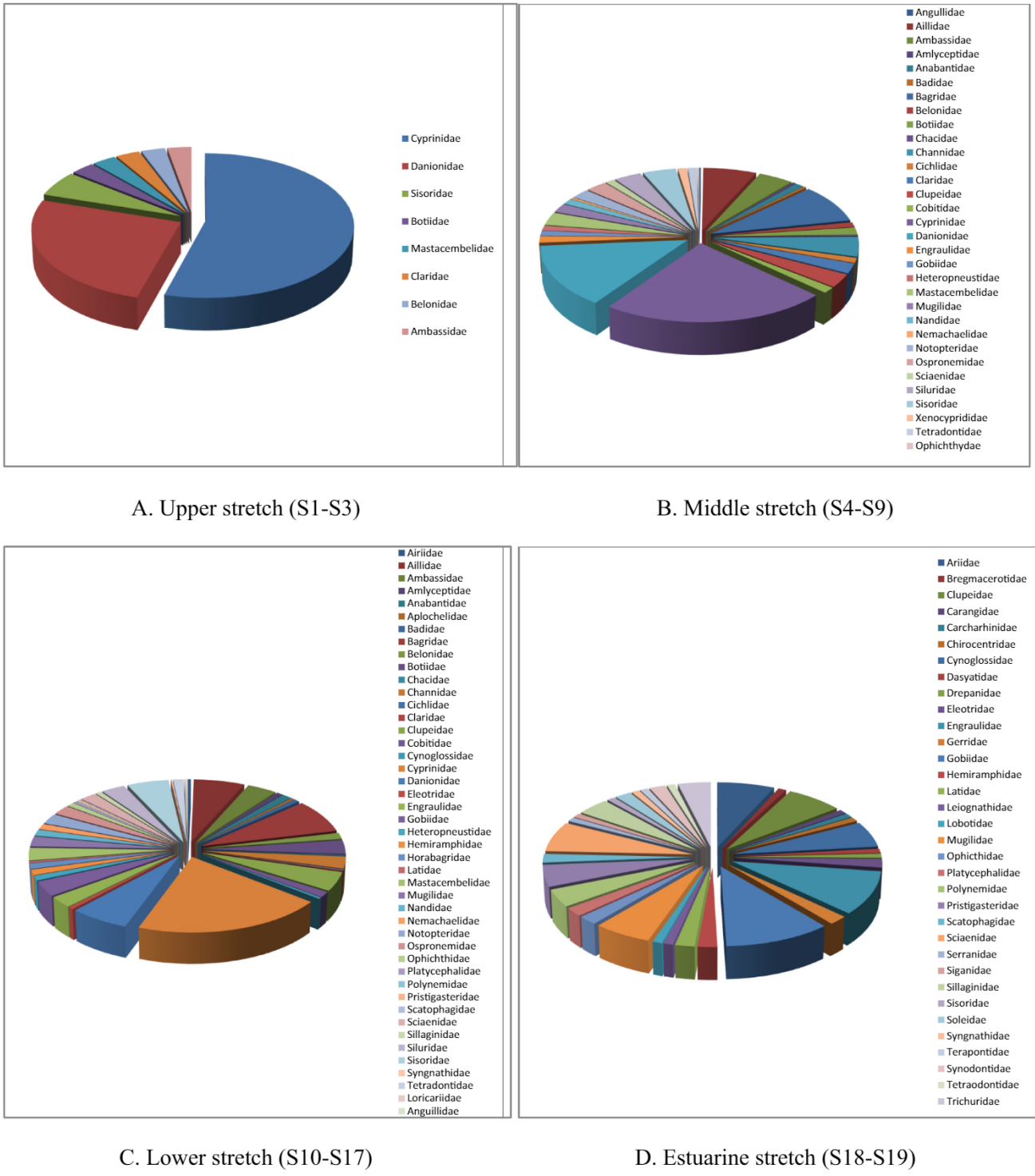

Fig. 4. (A-D) Family wise representation of fish species in River Ganga.

The lower stretch (LS) of Ganga particularly Farakka was recorded with highest value (2.93), indicating a congenial riverine environment and associated habitats for supporting stable fish population. Results on seasonal variability showed maximum abundance of fish during pre-monsoon (38%) followed by monsoon (35%) and post-monsoon months (27%) in Farakka. However, the richness values showed sharp decline from lower (LS-7) to estuarine section (ES-3) of the river. This might be due to the excessive fishing pressure exerted in the zone. The evenness index (J) values ranged from 0.13 to 0.22, which signifies that there was significant variation in the distribution of species between different stretches. This is mainly due to the result of selective fishing activity in the region. Moreover, as the river passes from Tribeni through the metropolitan city of Kolkata, by the time it reaches Godakhali only about 30 km south – east of the city, the pollution and contamination level can support only minimum fish species. The evenness index was confronted highest in the Upper stretch (US) sampling site S1 and S3 highlighting the dominance of only a few species with negligible variations. The diversity of fishes especially in the estuarine part of the river is complex as it is attributed to mostly euryhaline, freshwater and brackishwater fishes, respectively. The estuarine part of river (S19;

Table 4
Abundance of Major fish groups in different stretches of River Ganga.

Major fish groups	River stretch (sites)			
	S1-S3	S4-S9	S10-S17	S18-S19
Mahseer	1	1	0	0
Trout	1	0	0	0
Major carp	1	4	4	0
Medium & Minor carps	2	4	4	0
Catfish	2	29	31	7
Shads	0	3	4	3
Miscellaneous	18	65	75	60
Exotic species	3	5	5	0
Total species	28	111	123	70

Fraserganj) where the average salinity remains 28.18 ± 2.18 ppt inhabits 66 fishes classifying 45% as solely euryhaline, 7.57% as freshwater and 46.96% as brackishwater.

The literature shows that sample based rarefaction curves are the most widely used technique to compare the magnitude of species richness among different habitats [62,63]. In this study, refraction curves were employed to the large samples of River Ganga that represents the distribution of species over a specific habitat. Application of individual rarefaction shows increase in the number of shanon index in the lower stretch (LS) of the river (S10-S17) in comparison to the middle stretch (MS) and estuarine stretch (ES) (Fig. 7). This can be perceived due to rise of taxonomic levels (family and order) owing to combined habitat of both freshwater and brackishwater environments.

The c- plot for four different stretches of the river (Fig. 8) predicted on cumulative relative abundance suggest that the curve for Upper stretch is higher and do not follow similar pattern with the other plots. This indicates dominance of abundant species (*Cyprinus carpio*) reflecting less diversified habitat. Similarly, middle and estuarine stretch exhibited elevated curve less than upper stretch pertaining to partial biotic and abiotic disturbance. However a proper sigmoid curve (typical gradual rising) in the lower stretch of river Ganga indicates less disturbed sites.

3.6. Exotic species

During the course of study, eight different exotics (viz. *Ctenopharyngodon idella*, *Hypophthalmicthys molitrix*, *Hypophthalmicthys nobilis*, *Cyprinus carpio* var. communis, *C. carpio* var. *specularis*, *Oreochromis*

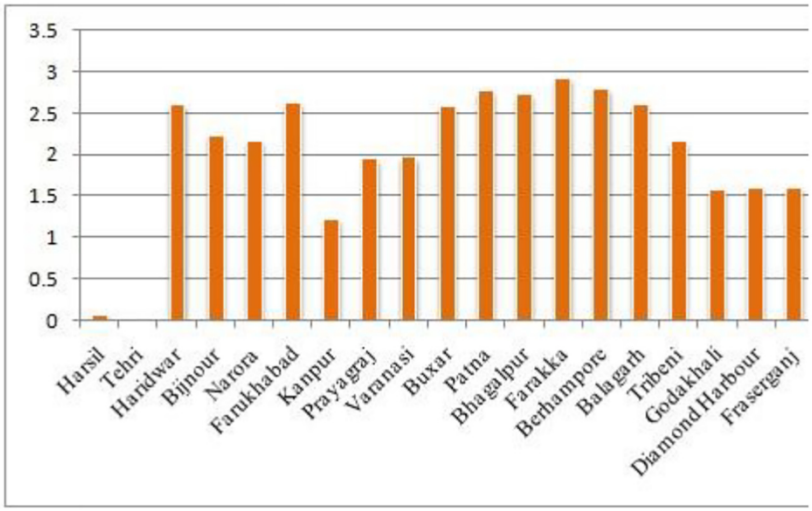

Fig. 5. Diversity richness (H′) in different sites of River Ganga.

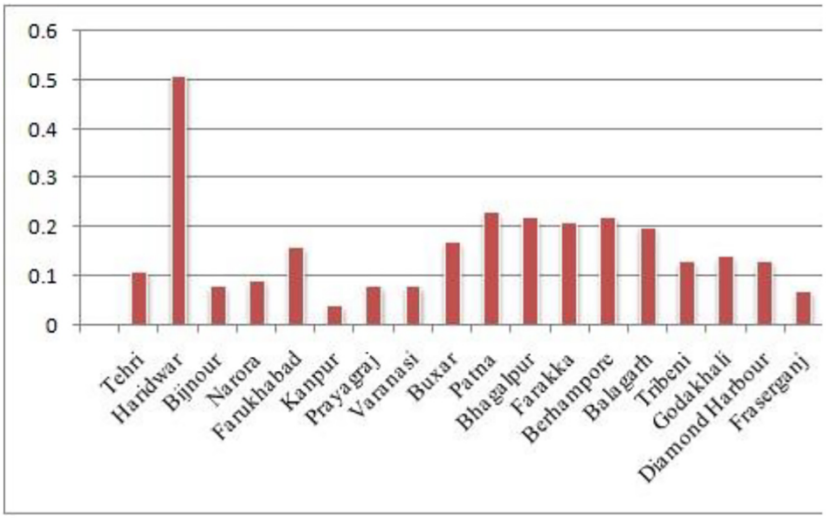

Fig. 6. Species eveness (J') in different sites of River Ganga.

Table 5
Diversity indices of ichthyofauna community in River Ganga (station wise).

Stretch	Sampling site code	Sampling stations	Number of taxa recorded	Shanon index (H′)	Evenness (J)	Margalef's richness index	Berger-Parker index
Upper stretch 1	S1	Harsil	2	0.08	0.54	0.15	0.98
Upper stretch 2	S2	Tehri	9	0.03	0.11	0.66	0.99
Upper stretch 3	S3	Haridwar	27	2.60	0.51	3.33	1.99
Middle stretch 1	S4	Bijnor	106	2.24	0.08	6.20	0.32
Middle stretch 2	S5	Narora	93	2.17	0.09	6.19	0.28
Middle stretch 3	S6	Farukhabad	83	2.64	0.16	6.56	0.24
Middle stretch 4	S7	Kanpur	83	1.23	0.04	5.58	0.66
Middle stretch 5	S8	Prayagraj	85	1.95	0.08	5.33	0.28
Middle stretch 6	S9	Varanasi	84	1.97	0.08	6.28	0.45
Lower stretch 1	S10	Buxar	78	2.59	0.17	5.77	0.24
Lower stretch 2	S11	Patna	66	2.77	0.23	5.23	0.24
Lower stretch 3	S12	Bhagalpur	64	2.73	0.22	5.31	0.18
Lower Stretch 4	S13	Farakka	84	2.93	0.21	6.50	0.16
Lower Stretch 5	S14	Berhampore	76	2.79	0.22	6.28	0.20
Lower Stretch 6	S15	Balagarh	66	2.61	0.20	5.19	0.25
Lower Stretch 7	S16	Tribeni	63	2.16	0.13	5.05	0.34
Lower stretch 8	S17	Godakhali	32	1.59	0.14	2.34	0.48
Estuarine stretch 1	S18	Diamond Harbour	37	1.61	0.13	2.58	0.49
Estuarine stretch 2	S19	Fraserganj	66	1.61	0.07	4.20	0.49

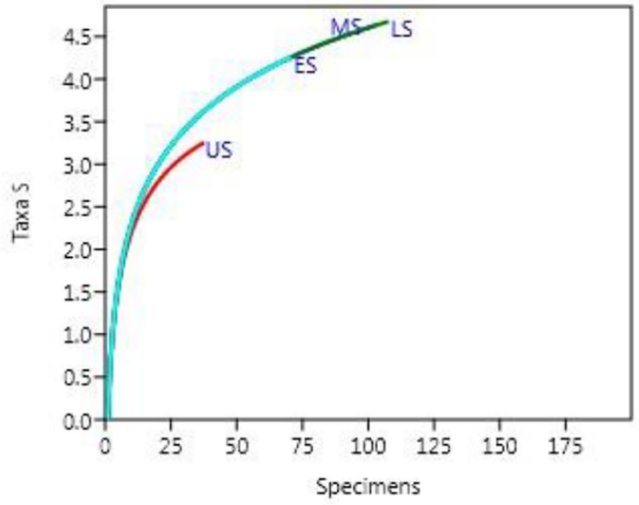

Fig. 7. Rarefaction curve (H′) in different zones of river Ganga.

niloticus, *Clarias gariepinus* and *Pterygopliicthys disjunctivus*) were recorded belonging to 7 genera, 5 families and 3 orders from all freshwater stretch. Although reported from different tributaries of Ganga [11], this study recordeda new exotic *Pterygoplicthys disjunctivus* from freshwater and tidal water areas of Ganga river. Theentryof thisalgivorous species might be due to illegal or unwanted introduction [64]. In accordance to the previous reports, ornamental exotics like *Pterygoplicthys anisitsi* [11] and *Barbonymus altus* [43] were not encountered. Previous reports convey the dominance of common carp in middle stretch of River Ganga [11,32,65,66]. Exploitation of common carp and Tilapia from the middle stretches of the river especially from Prayagraj to Buxar has created a commercial importance [65,67,68].Overall, the relative abundance of common carp (44.31%) and *O. niloticus* (30.15%) were in conformity with the report of Sarkar et al. 2012 [11].The upper stretch (S1-S3) was dominated by *C.carpio* var. *communis* (19.59%) and *C.carpio* var. specularis (13.61%).The increasing occurrence in the region might be due to natural recruitment and adaptation to lotic habitat. The middle stretch (S3-S9) was recorded highest abundance of *C.carpio*var. *Communis* (1.46%), *O.nloticus* (2.01%) and *C. gariepinus* (0.37%) respectively. Abundance of other exotics like *C.idella*, *Hypophthalmichthys molitrix*, *H. nobilis* was found below 0.10%. Sites like Kanpur, Prayagraj and Varanasi showed major abundance of common carp (7.31%; 16.49%;4.95%) and Tilapia (6.64%;7.36%;4.59%).

In the lower stretch (S 10-S17), dominance of *C.carpio* var. *communis* (7.68%) and *O.nloticus* (9.41%) was noticed at Buxar only. Sporadic availability of other exotic species was noticed below Bhagalpur to Tribeni stretch of river Ganga. The distribution pattern of exotic fish species in the river denotes that, *C. carpio*, was found omnipresent in ten sampling sites holding considerable local level distribution (52.63%) followed by *C. idella* (42.10%) (Fig. 9). However, *O. niloticus* was confronted in seven sites with the distribution range of 36.84%. The reduced water flow, high organic loadings and water abstraction are the favourable hydrobiological conditions for the exotics to establish at faster rate in some of the stretch of river Ganga.

3.7. Topological similarity of fish biodiversity

The analysis of similarity percentage (SIMPER) of all the stations revealed average similarity of 4.59% between all the sampling stations. Some of the important fishes supporting as maximum contributory species are *Cyprinuscarpio* var. communis (13.50%), *Cabdio morar* (10.69%), *Salmostoma bacaila* (7.15%), *Tor putitora* (6.39%), *Oreochromis niloticus* (5.43%), *Pisodonophis boro* (4.07%), *Puntius sophore* (3.94%), *Tenualosa ilisha* (3.77%), *Gudusia chapra* (2.91%), *Heteropneustes fossilis* (2.56%), *Eutropiicthys vacha* (2.39%), *Coilia dussumieri* (2.36%), *Harapadon nehereus* (2.33%), *Johnius coitor* (2.33%) and *Channa striata* (1.92%) (Table 6). Surprisingly, contribution of exotics like *C. carpio* var. communis and *O. niloticus* to the similarity indices in River Ganga has indicated their range of distribution and influence of hydrology over them. Among indigenous fishes, *Cabdio morar* revealed highest similarity patterns among the sites. The adaptive nature of small indigenous fishes might be due to the prolific breeding habit. Sites, S1 and S2 showed 5% of similarity with *Cabdio morar* (24.70%) as major species. Similarly, sites S2 and S3, S3 and S4, S4 and S5 exhibited resemblance of 10%, 12.50% and 20.21% respectively. Bray-Curtis analysis was performed to determine the fish assemblage pattern of river Ganga, based on the clusters formed with at least 50–80% similarity (Fig. 10). The plot clearly implies that there is a strong cluster with >0.71 similarity has been found in all lower stretch stations. Among lower stretch sites such as L2 (Patna), L3 (Bhagalpur) and L4 (Farakka) is forming a weak cluster (0.35) with middle stretch stations M3 (Farukhabad) and M6 (Kanpur). L8 (Godakhali) is forming a reasonable

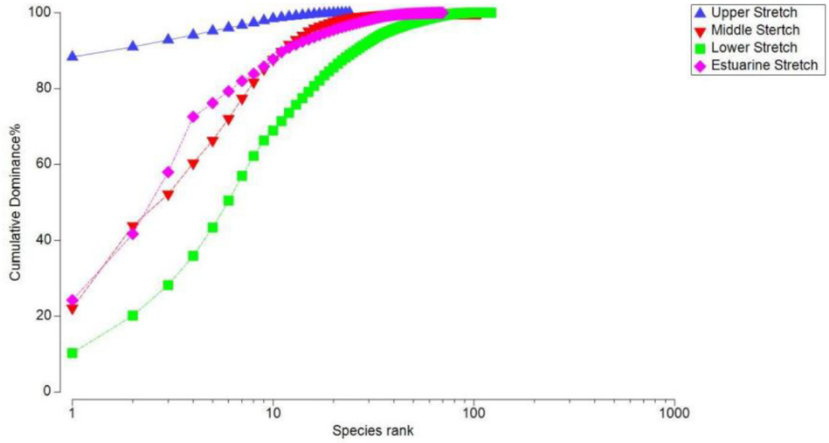

Fig. 8. C-dominance plot for the different sampling zones of river Ganga.

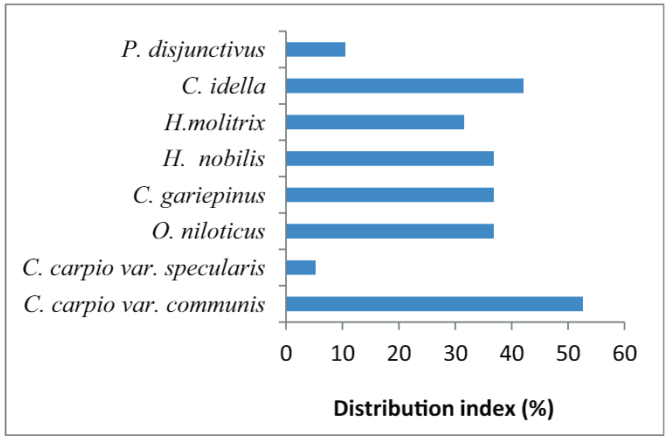

Fig. 9. Distribution index (%) of exotic species in river Ganga.

Table 6
Major similar fish species in each station (SIMPER analysis) of river Ganga.

Sl no.	Major species	Contribution (%)
1.	*Cyprinus carpio*	13.50
2.	*Cabdio morar*	10.69
3.	*Salmostoma bacaila*	7.15
4.	*Tor putitora*	6.33
5.	*Oreochromis niloticus*	5.43
6.	*Salmostoma phulo*	5.04
7.	*Pisidonophis boro*	4.07
8.	*Puntius sophore*	3.94
9.	*Tenualosa ilisha*	3.77
10.	*Gudusia chapra*	2.91
11.	*Heteropneustes fossilis*	2.56
12.	*Eutropiichthys vacha*	2.39
13.	*Coilia dussumieri*	2.36
14.	*Harpadon nehereus*	2.33
15.	*Johnius coitor*	2.33

cluster (0.58) with estuarine stretch station E2 (Fraserganj) indicating similarity in fish assemblage structure. However, no substantial cluster (<0.25) has been found in between middle stretch stations (M1, M2, M4 and M5). Similar cluster formation has been found in all three upper stretch stations. All four stretch of river Ganga highlights dissimilar structure of icthyofaunal diversity.

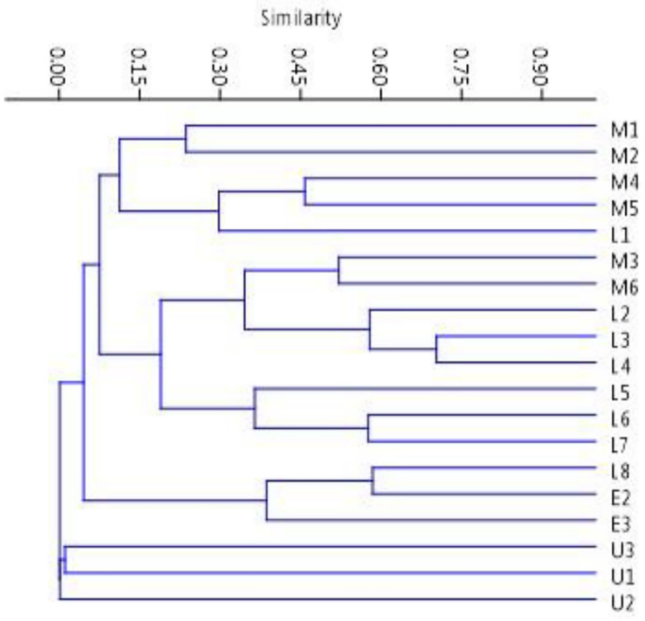

Fig. 10. Cluster of fish assemblage based on Bray-Curtis similarity index.

3.8. Assessment of conservation status

The conservation categorization of all native species of Ganga showed that 10% of the total species are considered under threatened category (15 near threatened, 2 vulnerable and 2 endangered) under IUCN red list (2020). Around 73.68% of the recorded species are least concerned which can be comprehensively utilized for human consumption after detailed assessment of its present population and nutritional condition. However, assessment as per CAMP workshop (1998) revealed 41 species has been listed under threatened category. This comprises of 27 vulnerable species (VU), 7 endangered species (EN) and one critically endangered (CR) species from the river. Conservation status of the fish species (site wise) is represented in Fig. 11. The data revealed highest percentage of fish species under near threatened category from sites S14 (Berhampore) and S6 (Farukhabad) with values 10.39% and 9.64% respectively. Assessment of site Haridwar (S1) was exempted due to least number of total individuals. S2 (Tehri) and S3

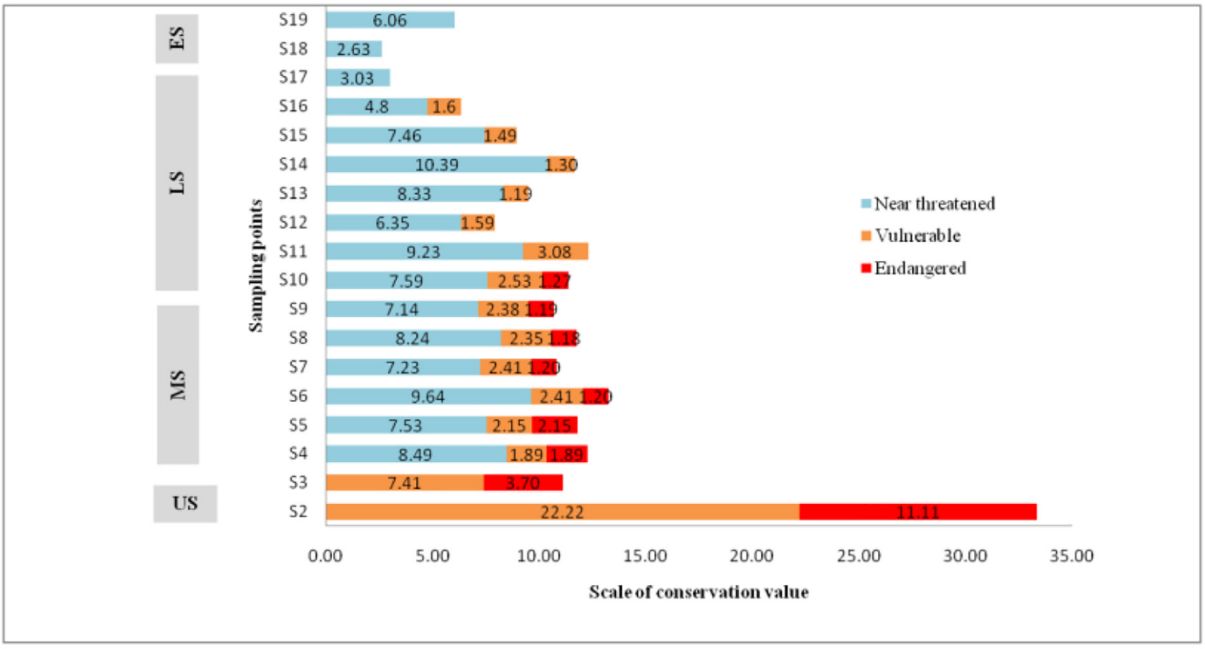

Fig. 11. Conservation status (%) of fishes in different sampling zones of Ganga as per IUCN 2020.

(Haridwar) exhibited maximum abundance of species belonging to vulnerable category (22.22% and 7.49% respectively). Similar results was obtained in case of endangered category from study points S2 (11.11%) and S3 (3.70%). About, 6.0% of the estuarine species from site S19 was also categorized under near threatened status. However, the current set of knowledge on the conservation categorization of fish species in India needs to be further developed for the Gangetic fish fauna as the risk assessment status of 12.10% of the indigenous species are yet to be established.

3.9. Status of fish production in river Ganga

The details of decadal fish landings of major commercial fish species from few significant landing centers of Ganga is presented in Fig. 12. Historically, middle stretch of the river has always been the principal fish production centre from years [27]. Gradual decline in valuable major carp productions has increased the abundance of small sized species [69]. Miscellaneous fish groups have increased manifolds from Buxar to Bhagalpur stretch as evident from the present data. Significant decrease in major carp production is evident from Praygraj region of Ganga where the landing came down from 35.82 t to 5.97 t during the period of 1981–90 to 2016–19. Impact on migratory species like Hilsa (*T.ilisha*) is tremendous. Hilsa fishery was the mainstay at Buxar stretch of Ganga during 1960's contributing 33.48% (22.35). However, the stock gradually got diminished after 1980's once Farakka barrage was commissioned. Post Farakka barrage has resulted sudden drop in catch of prized Hilsa from 160 to 9 kg km^{-1} in the middle stretches of Ganges [70]. The fishing practice as of now depends mainly on catfishes and other miscellaneous groups. The abundance of hilsa could be noticed below Farakka. In case of Patna, drastic decline in major carp landings was noticed from 1960's (23.35 t; 21.48%) to 2016–19 (2.16 t; 7.88%). Interestingly, rise in miscellaneous fish group was noticed during the same period. During the present study, reduced catches of major carp was observed at Bhagalpur 9.90% (1.98 t) compared to previous records of 20.18% (18.66 t) in 1980's. The pattern of annual landings was found similar when compared to previous reports from the site [36]. Higher appearances of small sized catfishes (*Clupisoma garua*, *Eutropiichthys vacha*, *A. coila*etc.) have significant effect on the total production. The group exhibited increasing trend in all of the sites studied with a range of 29–43%. Contribution of fish species towards commercial fisheries has always estimated through landings [14,36]. Previous studies on natural hydrological cycle of the river have highlighted the striking impact on the river integrity caused by severe anthropogenic loading, irrigation activities and manmade blockades [61,71,72]. The impact is more noticeable on the prized indigenous fish fauna of the river like Indian Major Carps which have been reduced to a great extent as evident from decline in spawn availability compared to other fish stocks [54]. Indiscriminate exploitation, pollution impacts and aquaculture needs may be attributed to the decreased production [27,36,38]. Besides, lowered precipitation, water restriction, deformed river bed has constituted change in water flow and turbidity in peak breeding seasons resulting in collapse of overall natural stock recruitments [14,54].The emergence and invasion of exotic species like common carp and tilapia has also added up to the rising trend in the overall production of the river. On the other hand, a shift in fish landing pattern was noticed during the period of 1950s and 1960s in the middle stretches of the river from major carps and large catfishes to catfishes, minor cyprinids, shads, croakers and spiny eels indicating new diverse assemblage structure [73].

The present assessment indicated a declining trend in fish landings especially of major carps. Therefore, for critical management of periodic species, judicial utilization of adult fish stocks and safeguarding of juveniles of all life stages play an important role towards sustainable restoration [74].

3.10. Trends in catch and catch per unit effort (CPUE)

In large river system like Ganga, limited information is available regarding CPUE from the entire river stretch. The present data revealed mean CPUE in the range of 0.06–1.9 kg hr^{-1} in upper reaches of the river (S1-S3) more or less similar to the trend reported by Pandey et al. 2018 [75]. In the middle and lower reaches of the river (S4-S17), the CPUE ranged from 0.16–1.04 kg hr^{-1} while in the estuarine zone the values depicted from 1.30–4.39 kg hr^{-1}. The increased catch in the lower section of the river may be attributed due to presence of tidal influence allowing varied spectrum of fish species to inhabit. In the middle stretch of the river, higher volume of CPUE can be confronted throughout the post monsoon months (average 3.129 kg hr^{-1}). On the contrary, pre monsoon months showed lowered CPUE (average 0.082 kg hr^{-1})

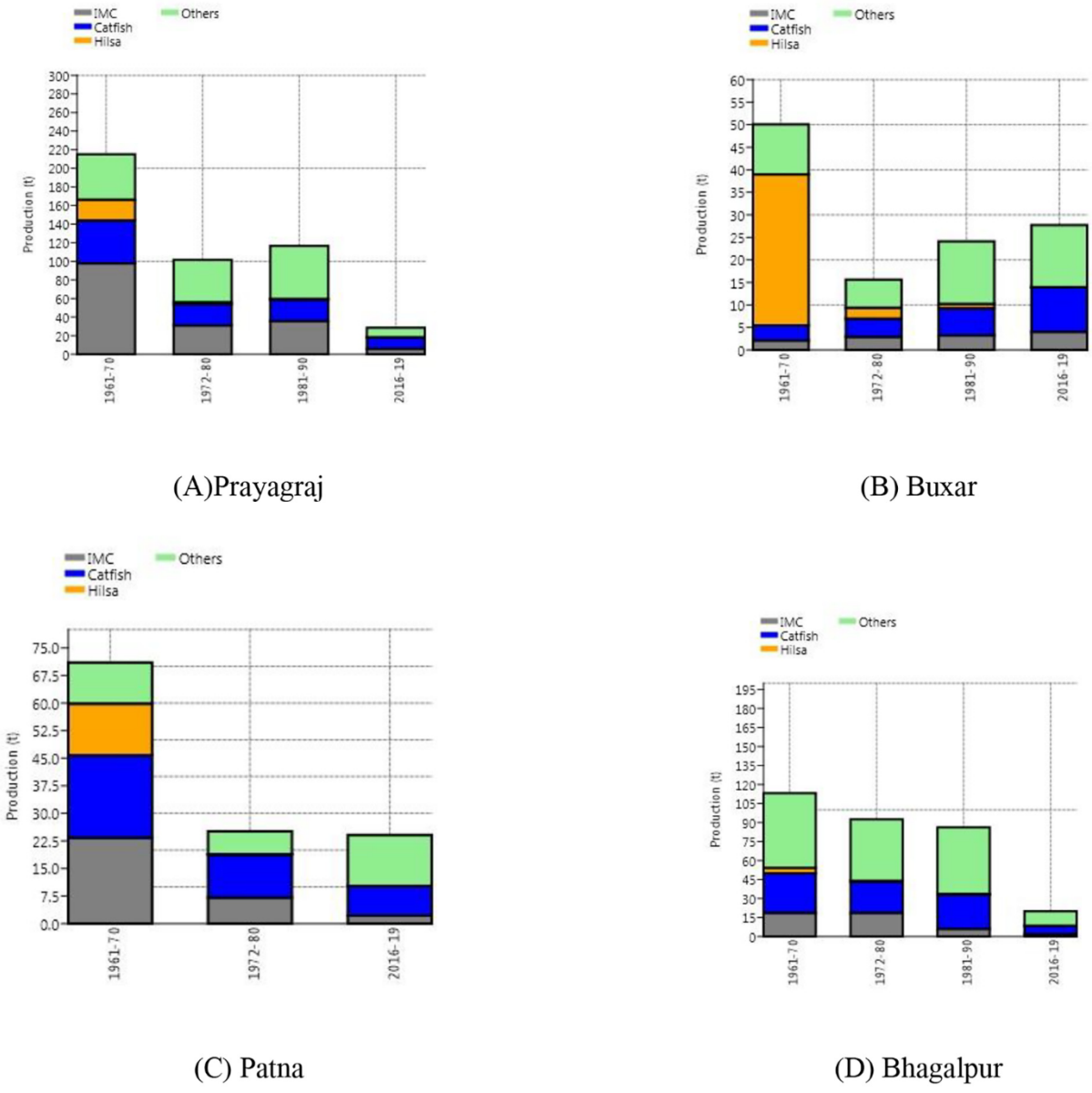

Fig. 12. (A-D). Decadal assessment of fish production from River Ganga (source: Vass et al. 2008).

indicating seasonal depletion of the fish stock which might be due to reduced flow ratein the main channel as well as in the river pockets like deep pools. A time series systematic relationship was established between the Catch per unit effort and fish production as presented in Fig. 13. Historical data on both the variables suggest a constant decreasing trend from 1960s to 2019. In the period of early 1960's to late 1970's the annual production of carps, catfishes and miscellaneous groups from Prayagraj resulted 192.7 t and 99.27 t respectively, which again rose to 115.93 t during 1981–1990. Subsequently, a higher degree of CPUE (33 kg hr^{-1}) which was observed in 1960's dropped significantly to 4.95 kg hr^{-1} at present. A considerable change was also noticed in both the aspect of production and CPUE in Bhagalpur stretch of the river. The production which was once 108.91 t (CPUE 18.90 kg hr^{-1}) came down to 19.87 t (CPUE 3.44 kg hr^{-1}). The investigation across the annual CPUE of Ganga for a period of 58 years indicated hyper depletion of fish stock where sequential decline is observed with respect to the production.

3.11. Occurrence of early life stage of major carps

The fishes in river Ganga breeds during the course of monsoon months extending from June to August. The river Ganga support potential habitat for the different early life stages of fish. The seasonal flood is crucial and enables them to breed in inundated flood plain areas of the river. In the present study, early life stages (spawn, fry, juvenile) of the major carps were identified during the spawning seasons from eleven different sites of river Ganga (Fig. 14). The occurrence of carp fry were noticed in eleven different sites of the river covering both middle and lower stretch during the period 2017–2019 indicating presence of suitable breeding and spawning ground. Larvae of *Labeo rohita* was found maximum in Bijnor (78%), Patna (66%) and Farukhabad (75%) during 2017, 2018 and 2019 respectively, Likewise, majority of Catla and Mrigal fry was observed from Kanpur (84%) and Prayagraj(89%) in 2019 and 2017. On the other hand, juveniles of *Labeo calbasu* was spotted maximum from the site Bijnor throughout the monsoon season

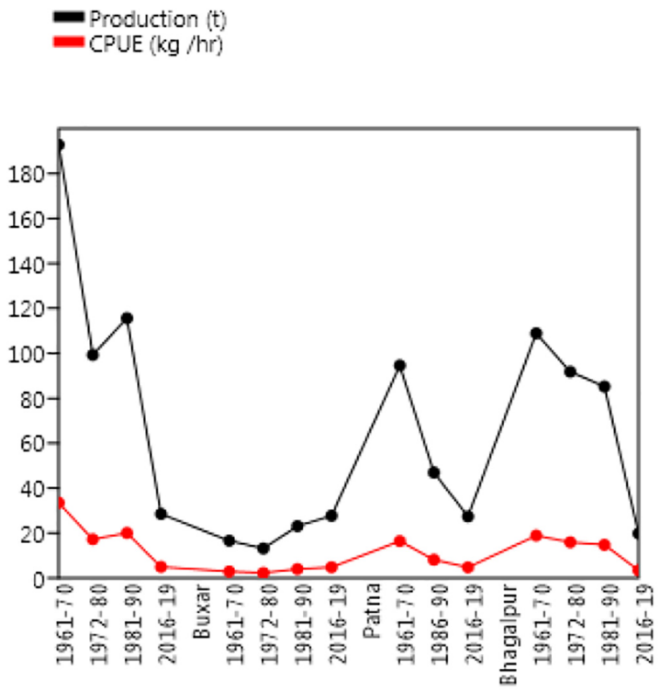

Fig. 13. Time series representation of fish production vs CPUE in river Ganga.

of 2018 and 2019. The studies of Das et al. 2013 [76] has explained the reduction in major carp spawn availability in river Ganga from 46% in the year 1965–1969 to 10% in 2005–2009 due to alteration in rainfall leading to inadequate flood and water flow.

3.12. Potential threats and issues to the fish diversity

River Ganga is experiencing tremendous challenges in relation to fish biodiversity due to several anthropogenic disturbances like construction of dams and barrages, pollution, over fishing, exotic invasion, climate change etc. The upper zone of river Ganga from Rishikesh to Narora is regulated by series of dams and barrages [77] diverting 90% of the flow during lean seasons, thereby, adversely affecting the ecosystem [25]. Decreased water flow in river Ganga has also created negative impact on the several migratory fish species [73]. The impact of damming is vivid in case of the migratory species like Indian Shad (*Tenualosa ilisha*) and Golden Mahseer (*Tor putitora*) in upstream. Availability of other migratory species like large prawns and *Pangasius pangasius* have also declined appreciably in upstreams. Moreover, blockade in water flow causes dwindling effect in turbidity to which species are adapted to the rivers. It also hinders the normal flooding of floodplain wetlands, thus, hampering fish diversity. Severe loading of silt in the river due to heavy deforestation and catchment activities also results in choking of wetlands impairing fish breeding and recruitment process [32]. Among all the point sources, municipal sewage and industrial effluent are the major pollution contributors in the river [78]. The rapid urbanization along the river bank has led to the discharge of 75% of untreated sewage in the river [79]. In addition to this, bioaccumulation of heavy metals in river water, sediment and fishes was found in the middle stretch of the river at Kanpur, Allahabad and Varanasi [80–82]. Increased catches of invasive species like common carp and tilapia has also altered the fishery dynamics of river Ganga replacing endemic fish species. Invasive species may benefit from anthropogenic pollution as they seem to be more resistant than native ones [83]. Most of the exotic species introduced in the river may be the result of escapements from the adjacent aquaculture practices and catchment areas when flooding conditions prevail. However, their innocuous entry in the natural river systems like Ganga has

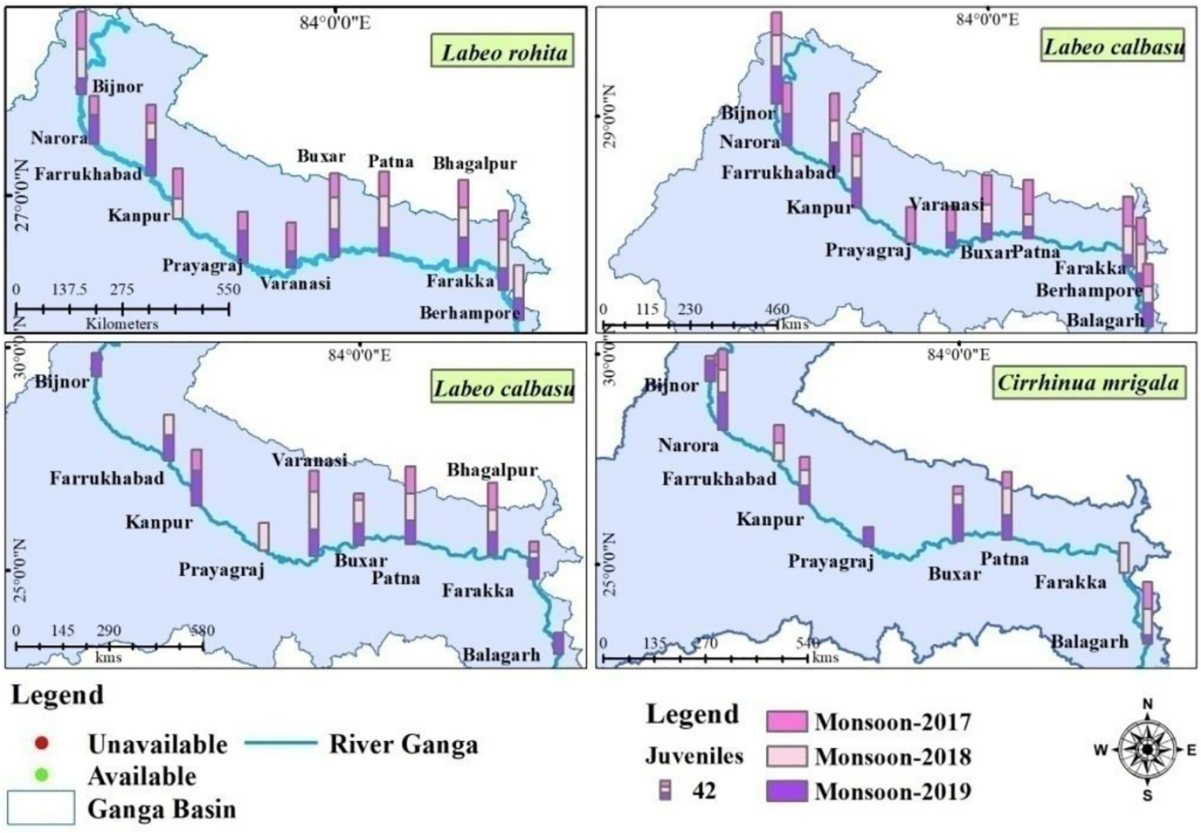

Fig. 14. Year wise (2017–2019) abundance of Indian Major Carp juveniles from different sites of river Ganga.

created an adverse impact towards the native fish species to manifolds. Seasonal flooding of floodplain wetlands during monsoon (July–September) has direct relationship with fish breeding in river Ganga. However, inadequate rainfall in entire Ganga basin in recent years [84] coupled with reduced water flow due to water abstraction has certainly resulted breeding failure of fish species and subsequent juvenile recruitment. Additionally, huge destruction of fish juveniles using mosquito nets and bag nets are one of the prime reason behind serial depletions of fish stocks in the river. This leads into considerable depletion in population of potential young ones from the fish population before attaining their complete biological maturity.

3.13. Guidelines for sustainable management of fish diversity in river ganga

In the light of potential threats to the fish biodiversity, proper management guidelines, conservation programme and effective implementation are imperative. Baseline information specifically on riverine ecology and fisheries must be delineated to encounter the ongoing trends. The present study recommend few significant points where the management interventions can be adopted, these are namely:

- *Continuity of minimum flow*: Maintenance of a minimum river flow in middle and lower stretches (Kanpur to Buxar) especially during pre-monsoon season (March–June) is important for sustainable fisheries.
- *Improved water quality*: Enforcement of strict regulation on the outfalls of untreated sewage and industrial effluent into river Ganga along with the other tributaries.
- *Restoration of floodplain wetlands*: Reduced discharge and heavy siltation has prevented the riverine connectivity of open wetlands along the main stem of the river. Wetlands serve as important fish breeding grounds thereby supporting fish stock recruitment process.
- *Encouraging fish pass*: Besides assessing the impacts of dams and barrages, improvement of fish pass are necessary in existing areas to recover negotiation of fishes towards upstream.
- *Banning of destructive fishing gear*: Absolute banning of destructive mosquito net and bag nets especially during post breeding months can considerably reduce growth overfishing.
- *Prioritization of potential zones:* Based on this study identification and prioritization of zones may be carried out for undertaking action based conservation and restoration programme in collaboration with the community.
- *Community awareness and participatory programme*: There is need to undertake long term mission mode programme to educate and sensitize fisher community and other stakeholder on conservation benefits.

4. Conclusion

Abundance, distribution and species richness play an important role towards understanding a community structure. Thus, an increasing pattern of all the variables of fish community is often noticed from upstream and downstream of a river system. However, a sharp inconsistency of the abundance, distribution and species richness was observed from all the zones of river Ganga. During the present examination, a total of 190 species of fish have been reported from 19 selected sites of river Ganga. The objectives of the study were fulfilled in developing an updated database of the spatio-temporal change analysis on fish diversity, distribution and occurrence covering larger geographical areas of river. The result of this investigation favours the concept of negative correlation between altitude and fish species diversity with recording the maximum diversity at Bijnour followed by Narora, whereas least number of species were recorded at Harsil. Paradigm shift in distribution of warm water fishes towards the colder reaches of the rivers also put forward the impact of anthropogenic factors and global warming. The synthesis of data indicated considerable variation in CPUE at temporal scale. During 1960's the stretch from Kanpur to Bhagalpur (S7-S12) marked increased level of annual fish yields (8180 Kg km^{-1}), of which Patna (S11) owned major share of 22.04% followed by Prayagraj 11.43% (S8) and Bhagalpur 9.54% (S12). However during the period of late 2000s, the yield rate came down to 368 Kg km^{-1} with distinct declination in major carp and large catfishes. Likewise, Catch Per Unit Effort (CPUE) is expressed to ascertain the change in commercial catch. Various factors are known to influence the CPUE other than the abundance. Variability in fishing gears, fishing zone accessibility is some of the major factors behind the change. It is apparent from the above discussion that water abstractions, reduced flow, water pollution, climate change along with the use of unscientific fishing gears have heavily impacted the fisheries of river Ganga. Moreover, induction of exotics and their contribution towards fish landings has become quite significant in the middle stretches of the river. The study will help in formulating restoration programme of the important species with conservation significance. Designing management framework for effective conservation of large number of threatened fish species in India is lacking. Therefore, strategies related of species specific conservation planning, habitat fingerprinting and landscape profiling is essential and should be implemented by Governmental agencies in close synchronization with the end users.

Declaration of Competing Interest

Authors declare no conflict of interest.

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