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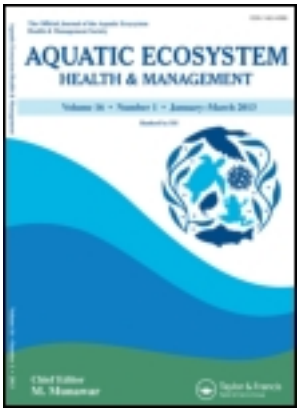

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Ichthyofaunal diversity, assemblage structure and seasonal dynamics in the freshwater tidal stretch of Hooghly estuary along the Gangetic delta

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Ichthyofaunal diversity, assemblage structure and seasonal dynamics in the freshwater tidal stretch of Hooghly estuary along the Gangetic delta

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The tidal freshwater areas of estuaries have received little attention in ecological research although they are often heavily stressed by environmental impacts. These critical habitats contribute significantly to the biodiversity of the entire estuarine system. The present study aims to describe the fish diversity, assemblage structure and seasonal dynamics through data collected by intensive sampling of the tidal freshwater stretch of the Hooghly estuary (June 2010 to June 2012), the largest estuary in India formed in the Gangetic delta. The tidal freshwater zone of Hooghly has gained importance due to ecological changes during the post-Farakka period since this zone covers 74% of the total estuarine stretch. During the study, a total of 155 fish species belonging to 49 families and 15 orders were recorded from the tidal freshwater zone of the Hooghly estuary. The exotic ornamental fish Barbonymus altus *(Tinfoil Barb) has been recorded from the tidal freshwater zone which is the first record of these species in Indian inland waters. A detailed analysis of the fish diversity revealed that of the total 155 species recorded from the study, 19 species have been listed in category of threatened fishes by National Bureau of Fish Genetic Resources (Lakra et al., 2010). This includes 16 vulnerable (VU) species and 4 endangered (EN) species. This signifies the role of tidal freshwater zone as an essential fish habitat due to its rich fish diversity and as a sheltered area which favours the growth and survival of larval and juvenile fish assemblages.*

Keywords: ecological guild, essential fish habitat, Farakka barrage, river islands

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Introduction

Estuaries constitute one of the most productive ecosystems of the world as they are naturally characterized by increased availability of nutrients and abundance of primary producers. These transitional water bodies are among the most modified and threatened environments (Blaber, 1988). Estuaries have long been regarded as important sites for fish, both as nursery and overwintering grounds, migration routes and areas which naturally support large number of fishes. Even-though extensive studies were conducted on the estuarine fish fauna, much of the works focussed on the high saline portions of the estuaries and estuarine-dependent fish species (Odum, 1978). The tidal freshwater areas of estuaries have received little attention in ecological research although they are often heavily stressed by environmental impacts.

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It was Fairbridge (1980) who first included 'tidal freshwater areas' as a distinct part of an estuarine system. Freshwater tidal areas are those places where there is no saline influence and the tidal water movement occurs through hydrostatic changes further down the estuary (Elliot and Mc Lusky, 2002). They are found in upper estuaries of major river systems where there is sufficient freshwater flow to maintain salinities of less than one percent, but insufficient flow to dampen the upstream tidal movement (Simpson et al., 1983). Hence, the biota of tidal freshwater reaches of estuary experiences tidal fluctuations, without the influence of salinity. It is thus possible to define the tidal freshwater reach of the estuary as a separate biotope with specific community structure and these are important sites of physical, chemical and biological processes which may alter riverine input considerably before it reaches the freshwater-seawater interface (Schuchdart et al., 1997). The freshwater tidal stretches of the estuaries can be extensive, particularly in systems with high riverine input and these areas can support abundant fish and active fisheries (Odum, 1978). In upstream, often freshwater areas of estuaries, freshwater fish species may not only persist but dominate the fish communities. Tidal freshwater reaches are important areas for fish occurring in lowland waters and therefore, the protection of these habitats is a matter of major concern since they contribute significantly to the total biodiversity of the entire estuarine ecosystem (Maes et al., 1997).

In India, the various estuarine systems spreading over 300,000 ha form an important component of the fisheries resources and contribute significantly to the production (Sugunan and Sinha, 2001). Hooghly is the largest estuary in India covering a distance of about 295 km from the sea face (confluence point with the Bay of Bengal) to Nabadwip in the district of Nadia, West Bengal. This estuary, along with the Matla estuarine system on its east, forms one of the largest estuarine systems of the world and serves as the mainstay of inland capture fisheries of India. The main channel of the Hooghly is a positive estuary of mixohaline nature where the salinity ranges from freshwater condition (salinity values even below 0.1‰) to above 30‰ in different parts during different seasons and it covers about 14.05% of the total length of the River Ganga in India. The Hooghly estuary forms the western border of the Gangetic delta and has special significance for detailed hydrobiological studies as the tidal influence is seen all throughout the estuary due to its funnel shaped sea face which is well suited for optimum tidal flux.

Most of the observations on fisheries of the Hooghly estuary relate to the period before the commissioning of the Farakka barrage. In the pre-Farakka period (before 1975), the Ganga delivered almost its entire discharge into the Padma River (which flows through Bangladesh), thereby depriving a perennial supply of freshwater to the Bhagirathi-Hooghly River system. This resulted in heavy siltation and when coupled with the ingress of salt water from the Bay of Bengal during high tides, many estuarine and marine species started extending their distribution towards the upper stretches of the estuary and displaced the freshwater fishes which were not able to cope up with the changed ecological conditions and thus converting the fish fauna of the Hooghly estuary into predominantly a marine element (Nandy et al., 1983).

Farakka barrage was commissioned in 1975 (at the border of Malda and Murshidabad districts in West Bengal, India) with the objective of increasing the volume of freshwater discharge in River Bhagirathi, and consequently in the Hooghly estuary so as to protect the Calcutta port from siltation. The increased freshwater influx to the Hooghly estuary resulted in the extension of freshwater zone, thereby pushing the true estuarine zone towards the mouth and the marine zone getting restricted to the area near the mouth of the estuary (Sinha et al., 1996). Several species of freshwater fishes and prawns started appearing in the tidal freshwater zone during the post-Farakka barrage period.

No comprehensive studies have been conducted so far on the fish communities of the Hooghly estuary in general and its tidal freshwater zone in particular, during the post-Farakka period. Presently, the information regarding fish fauna is available in the form of species checklists or observations on the landings of certain commercially important species. Moreover, the previous studies on the fisheries of Hooghly estuary either concentrated on the estuarine and marine zones which contributed to more than 80% of the total fish landings from the system or on the economically significant Hilsa Shad (*Tenualosa ilisha*) fishery. With the alteration of ecological conditions due to freshwater release from Farakka barrage, the studies on the fish community structure of the tidal freshwater zone has gained importance since this zone covers the major part of Hooghly estuary at present and significantly contributes to the

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fish diversity and production. This article aims at a detailed analysis of the fish community structure of the tidal freshwater zone of the Hooghly estuary by studying the diversity, distribution, abundance and variations in the fish faunal assemblages under the current ecological regime.

Methods

Study area

Hooghly estuary (Figure S1) is the lower part of the Bhagirathi River (lower stretch of the Ganges in India), which is subjected to tidal action. Since tidal impact is felt up to Nabadwip which is located at about 295 km from the estuarine mouth; this region is regarded as the head part of the Hooghly estuary. In the northern reaches, the Hooghly is joined by tributaries, viz., Jalangi (joins Hooghly at Nabadwip) and Churni Rivers which originate from Bangladesh. The tributaries such as Damodar, Rupnarayan and Haldi join Hooghly in its lower course. The main channel of Hooghly estuary lies between 21° 31′–23° 30′ North latitude and 87° 45′–88° 45′ East longitude, covering the districts of Nadia, Hooghly, North and South 24 – Parganas, Howrah and East Midnapore in the state of West Bengal (Nath et al., 2004).

The entire region experiences tropical climate with reversal of winds during summer (South-West) and winter (North-East) monsoons. The yearly weather conditions of the region can be categorized into three distinct seasons, viz., the pre-monsoon (March–June) characterised by little or no rainfall and prevalence of high temperatures, the monsoon (July–October) with heavy precipitation and relatively lower temperatures and the post-monsoon (November–February) season where there is occasional rainfall and prevalence of lower temperatures. Annual rainfall varies between 188 cm to 245 cm and 75–85% of the total annual rainfall occurs during monsoon months (Mukhopadhyay et al., 2006). The freshwater discharge from Farakka barrage ranges from a lower value of 1000 $m^3\ s^{-1}$ (pre-monsoon) to a peak value of 4000 $m^3\ s^{-1}$ in September (monsoon). The average values for monsoon and post-monsoon seasons were 2975 $m^3\ s^{-1}$ and 1875 $m^3\ s^{-1}$, respectively (Mukhopadhyay et al., 2006).

Due to wide variations in salinity in different parts of the estuary, many workers (Dutta et al., 1973) proposed zonations based on salinity for the purpose of biological studies. In general, the freshwater zone extended from Nabadwip to Barrackpore during pre-Farakka period. But the whole scenario changed after the construction of Farakka barrage. Presently, the tidal freshwater zone extends from Nabadwip (head part of the Hooghly) to Nurpur near Diamond Harbour (Figure S1), with a length of about 220 km (74% of the total length of estuary) and true estuarine conditions begin to appear from Diamond Harbour onwards.

The present study pertains to the 168.9 km stretch of tidal freshwater zone from Nabadwip to Godakhali. The channel width varies from 321.3 m at the head part of Hooghly (Nabadwip) to 1347 m at Godakhali and shows steady increase from Nabadwip – Godakhali, reflecting the funnel-shaped structure of the estuary. As the zone is subjected to frequent dredging for inland water transport, the channel depth is highly variable within a sampling station. Minimum depth (3.4 m) was observed at Nabadwip and maximum (16.9 m) at Dakshineswar, with an average value of 7.9 m. Both channel width and depth exhibit seasonal variations reached their maxima in monsoon due to heavy freshwater influx while the minimum levels were observed during pre-monsoon season when the freshwater flow was lowest.

Throughout tidal freshwater zone, the bed soil is more or less loamy in texture with 42.8% sand, 44% silt and 13.2% clay.

The tidal freshwater zone of Hooghly is highly vulnerable to anthropogenic stresses due to its proximity to the Kolkata Metropolitan Zone, the Kolkata port and multifarious industrial establishments (includes paper, leather, chemicals, pesticides, jute, textiles, plastics, etc.) resulting in the introduction of hazardous and toxic substances to this critical aquatic habitat through industrial effluents along with the huge organic load emanating from agricultural activities as well as from several non-point sources (such as the domestic run-off from adjacent land masses).

Sampling methodology

The samplings were carried out in the freshwater tidal stretch of the Hooghly estuary which was divided into 8 sampling stations, viz., Nabadwip (S1), Kalna (S2), Balagarh (S3), Tribeni (S4), Hooghlyghat (S5), Barrackpore (S6), Dakshineswar

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(S7) and Godakhali (S8). The present study was carried out during June 2010 to June 2012. The whole study period was divided into three distinct phases according to seasons, viz., pre-monsoon (March–June), monsoon (July–October) and post-monsoon (November–February).

The major constraint in fish sampling of a tropical estuary such as Hooghly is the wide variation in fishing gears and methods in different areas with respect to seasons, which makes it difficult to adopt a standard sampling methodology for all the sampling stations. Remesan et al. (2009) reported 23 different types of fishing gears from the freshwater stretch of Hooghly with about 31 local variants based on the locality and targeted species/resource. In describing the abundance pattern and seasonality of fish communities we adhered to the catches of non-selective fishing gears such as seine nets, bag nets, set barriers and cast nets which were operated by hired local fishermen in the various sampling stations. However, in the fish diversity studies, catches of selective fishing gears such as hook and line, traps and gill nets were also considered. For studying the seasonal dynamics of the fish communities to make meaningful comparison, we stratified the eight sampling stations into three sampling zones based on the similarities in fish assemblages, physical habitat structure and fishing methodologies. These zones include, Zone I (S1–S3), Zone II (S4–S5) and Zone III (S6–S8).

The fishes caught were counted, weighed and majority of the fish species were identified on the field itself. Unidentified fish samples were preserved in 10% formalin and taken to the laboratory for further analysis. We followed Nelson (2006) in determining the families of fish species collected during the study. For proper assessment of the fish assemblages and for deriving meaningful conclusions, all the fish species were categorized in to different groups based on the ecological guild approach as per Elliot et al. (2007). The abundance data of the fish samples were subjected to cluster analysis (Clarke and Warwick, 2001) to study the similarities in fish assemblage pattern among various sites. For comparison of fish community structure between the sampling zones, we relied on the c-dominance plot where the cumulative relative abundance/dominance (y – axis) of fish species from a sampling zone is plotted against the increasing species rank on x – axis. The c-dominance curves for all zones were compared to determine whether the fish community structure exhibit any signs of ecological stress.

Results and Discussion

The mean monthly tidal amplitude (height) of the tidal freshwater zone varied from 2.84 m (meters) in January to a peak value of 3.45 m in August. The averages values of tidal amplitude for the various seasons were, 3.2 m (pre-monsoon), 3.34 m (monsoon) and 2.9 m (post-monsoon) respectively during the sampling period with Garden Reach as the reference point which is located within Zone III (Kolkata Port Trust, 2011).

Eventhough salinity plays a major role in structuring the fish assemblages along the gradient and marine zones of Hooghly estuary, this was not evident with respect to tidal freshwater zone where the salinity almost remained constant (0.04 ppt) with very little seasonal variation (0.03–0.06 ppt). The water temperature ranged from a lower value of 17.8°C in winter (post-monsoon) to a peak value of 35.2°C in summer (pre-monsoon) during our study. The minimum temperature range (17.8–20.1°C) was observed during cool winter months of December –January and the maximum range (32.4–35.2°C) during the summer (May–June). Thermal stratification has not been evident, presumably due to tidal effect.

Since the zone receives a huge amount of silt from the Ganga-Bhagirathi system, water was generally turbid with an average transparency of 35.8 cm. Transparency exhibited seasonal variation and was highest during post-monsoon (63.8 cm) due to low turbidity and prevailing calm weather conditions. The heavy influx of silt laden riverine water during monsoon results is high turbidity and thereby reduces the transparency to its lowest (12.7 cm). The tidal freshwater zone has relatively high dissolved oxygen content (7.3 ppm) as it is heavily impacted by fluvial inputs. The dissolved oxygen content was maximum during post-monsoon (9.6 ppm) and minimum in monsoon (5.7 ppm).

A thorough analysis of the physico-chemical parameters along with the fish community structure revealed that the physical habitat structure and tidal intensity is the most dominant factor in structuring the fish assemblages in the tidal freshwater zone since there were no major variations in the chemical parameters especially the salinity since the entire zone exhibits freshwater conditions throughout the year. Eventhough the transparency, dissolved oxygen and temperature showed seasonal variations; there were no significant differences between the sampling stations during a particular season.

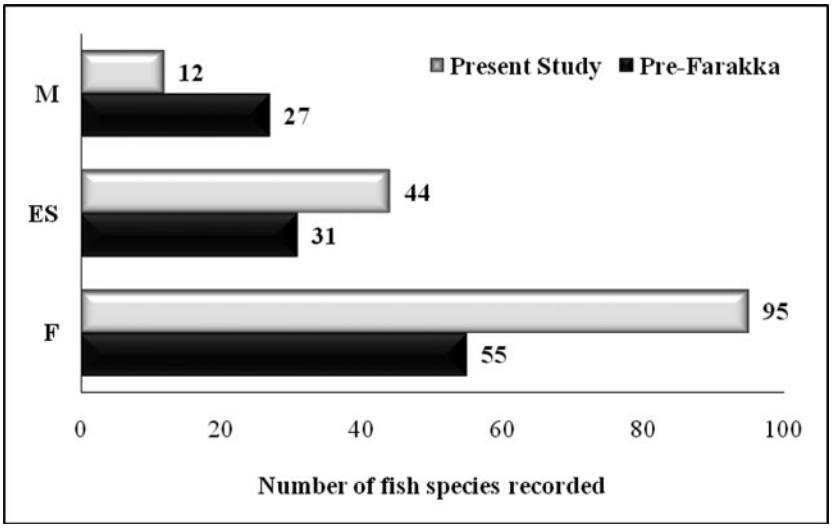

Figure 1. Changes in ecological guild of fishes from pre-Farakka period to the present study.

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During the study, a total of 168,075 fishes were collected from the tidal freshwater zone which comprised of 156 species belonging to 49 families and 15 orders (Table S2). Cyprinidae was the most speciose family with 34 species followed by Gobiidae (12 species), Bagridae (8 species) and Clupeidae (7 species). Among the sampling stations, Tribeni (S4) had the highest diversity with 113 species and Nawabganj (S6) with the lowest (75 fish species). In comparison with the previous works related to the fishes of the Hooghly estuary (David, 1954; Gopalakrishnan, 1971; Menon et al., 1972; Sen, 1992; Talwar et al., 1992 and Amitabha Ghosh, 2008), 18 fish species were recorded for the first time in the Hooghly estuary (Table S2). With respect to the exotic fish fauna, five species were recorded from the study area of which the most significant was the Tinfoil Barb *Barbonymus altus* (Figure 1). This fish has been considered as being endemic to the Mekong River system (Rainboth, 1996) and is a popular species in aquarium trade. We have observed both juveniles and adults of this species from the Hooghly system and this is the first record of the species in Indian inland waters. In terms of ecological guild based on estuarine use functional groups; the tidal freshwater zone is dominated by freshwater fishes (F) with 95 species followed by estuarine fishes (ES) with 44 species, marine migrants (M) with 12 species, one anadromous species (AN), two semi-anadromous (SA) species and two catadromous (CA) species (Table S2). In comparison with studies conducted during the pre-Farakka period (David, 1954; Gopalakrishnan, 1971; Menon et al., 1972), it has been observed that the number of freshwater fish species has increased from 55 in the pre-Farakka period to 95 in the present study while the number of marine species has reduced from 27 (pre-Farakka) to 12 in the present period (Figure 2).

The cluster analysis of the fish abundance data showed clear demarcation of the various sampling sites in terms of fish assemblage structure (Figure 2). There were three distinct clusters, viz., Nabadwip-Kalna-Balagarh (Zone I), Tribeni-Hooghlyghat (Zone II) and Nawabganj-Dakshineswar-Godakhali (Zone III).

Zone I is subjected to minimum tidal influence and is structured by the riverine influx resulting in the formation of 'river islands' due to siltation thereby resulting in the growth of aquatic macrophytes of marginal variety (the most dominant genus being *Phragmitis* spp.). These islands reduce the damaging force of the flood waters and have several minor channels that are connected with the main river thus forming sheltered areas which are used by fishes as refuge areas and breeding grounds. The high fish diversity in this zone (105 species) and the abundance of juvenile fishes (34 species) signifies its role as an essential fish habitat. This zone is dominated by small indigenous freshwater fish species (Table S1) such as *Puntius sophore* (7.44%), *Amblypharyngodon mola* (6.82%), *Pseudambassis ranga* (6.55%), *Gudusia chapra* (5.21%) and *Corica soborna* (5.14%). The fish community structure

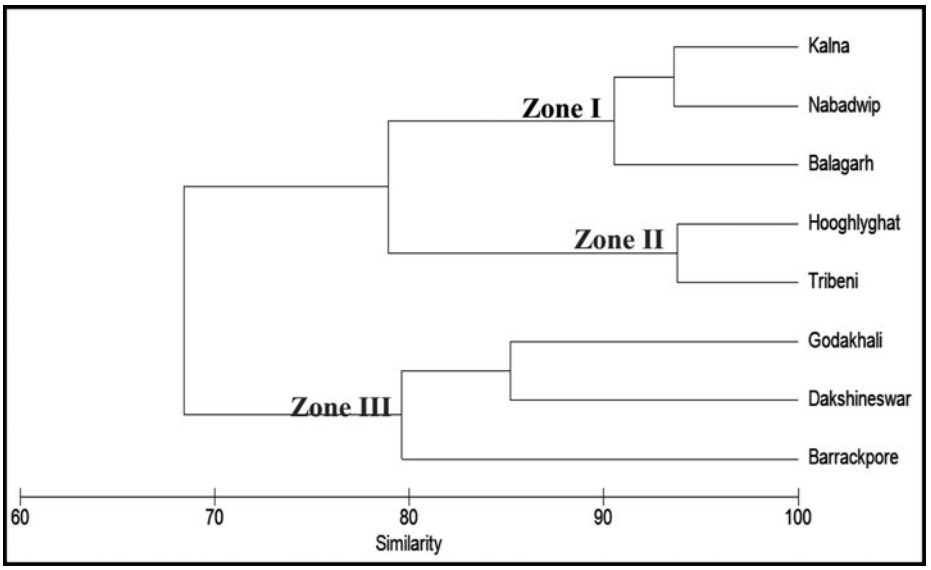

Figure 2. Cluster dendrogram of fish abundance data.

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of Zone I is more or less similar to typical riverine freshwater stretch with the dominance of freshwater fishes (contributing to about 87% of the catches).

Zone II is subjected to regular tidal influence (diurnal tides) and reversal of flow. Like Zone I, this zone also has islands infested with marginal weeds. The influence of tides and abundance of weed infested river islands (dense marginal vegetation occur in the islands and moderately dense vegetation in the main channel) makes this zone the most species rich zone in terms of fish biodiversity with 131 species. Several estuarine and marine fishes have been recorded from this zone. The catch composition of Zone II (Table S1) reflected a gobiid dominated fish assemblage with *Odontamblyopus rubicundus* (30.34%) and *Apocryptes bato* (21.56%) contributing a major share, followed by other small indigenous fishes such as *Corica soborna* (9.21%), *Salmophasia bacaila* (5.67%) and *Setipinna phasa* (4.92%). In general, the fish assemblage showed more estuarine affinities with estuarine species dominating the catches (64.4%) followed by freshwater species (30.4%).

Zone III is that part of the tidal freshwater stretch which is most vulnerable to anthropogenic impacts due to its proximity to the urban agglomeration of Kolkata and the Kolkata port. This zone is an open channel with very limited areas of aquatic vegetation and is dredged regularly for shipping and other inland water transport. Eventhough the zone recorded 108 fish species most of them are stray visitors either during monsoon flooding (freshwater species) or during tidal bores (marine and estuarine species). Moreover, the average number of species per sampling site was also low in this zone (79 species) when compared to Zone I (97 species) and Zone II (102 species). The true resident population (species recorded throughout the year) of Zone III comprised of only 27 species which is very low when compared to Zone I (61 species) and Zone II (45 species). The cumulative dominance (c-dominance) plot for the different zones (Figure 3) based on cumulative relative abundance indicates that the curve for Zone III is elevated (J – shaped) which clearly reflects the stressed habitat conditions due to pollution, i.e. there is higher dominance of abundant species. Zone II also produce an elevated curve, but less elevated then Zone III whereas Zone I is represented by a sigmoid curve (rises gradually) which is typical to that of an undisturbed site. The resident fish population of Zone III is dominated by gobiids such as *Odontamblyopus rubicundus* (13.26%), *Apocryptes bato* (2.28%) and *Glossogobius giuris* (2.06%) even though the overall catch (Table S1) represented a major contribution by the seasonally abundant *Tenualosa ilisha* (28.42%), *Corica soborna* (23.22%) and *Polynemus paradiseus* (12.54%) due to massive juvenile aggregations during pre-monsoon season. The Zone III also represents a fish assemblage with dominance of estuarine species (42.84%), but the anadromous Hilsa Shad (*Tenualosa ilisha*) forms the second

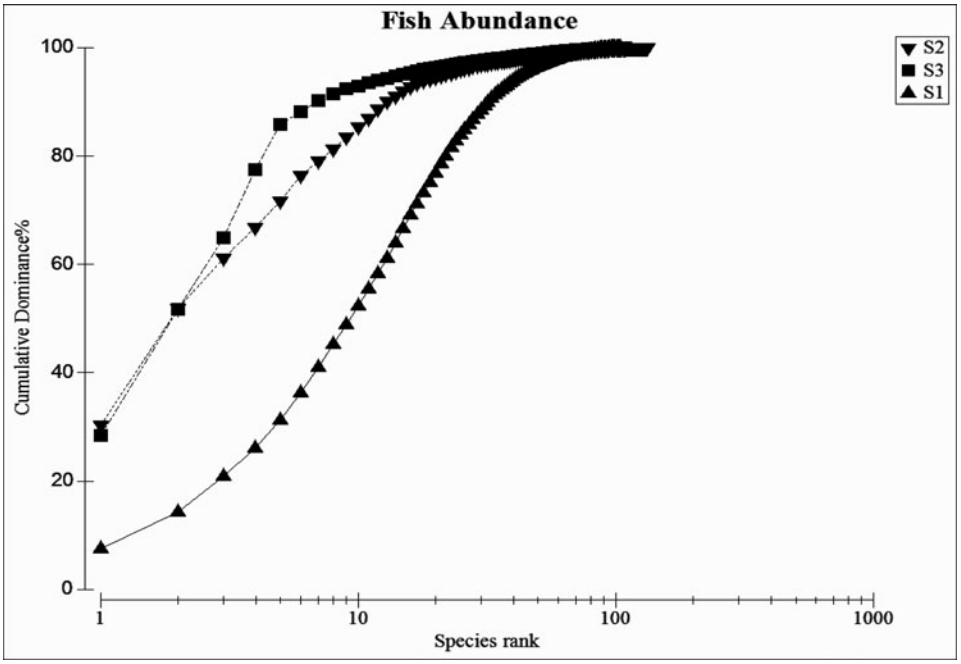

Figure 3. C-dominance plot for the various sampling zones (S1: Zone I, S2: Zone II and S3: Zone III).

major component (28.42%) and this makes the zone distinct from Zone II.

The cumulative value of relative abundances of all species (irrespective of the sampling zones and sampling seasons) throughout the study (Figure 4) clearly depicts that the fish fauna of the tidal freshwater stretch of the Hooghly estuary is dominated by species, viz., *Odontamblyopus rubicundus* (15.89%), *Corica soborna* (13.17%), *Tenualosa ilisha* (12.76%), *Apocryptes bato* (9.59%), *Setipinna phasa* (5.36%) and *Polynemus paradiseus* (4.84%). Seasonal variation in fish diversity and

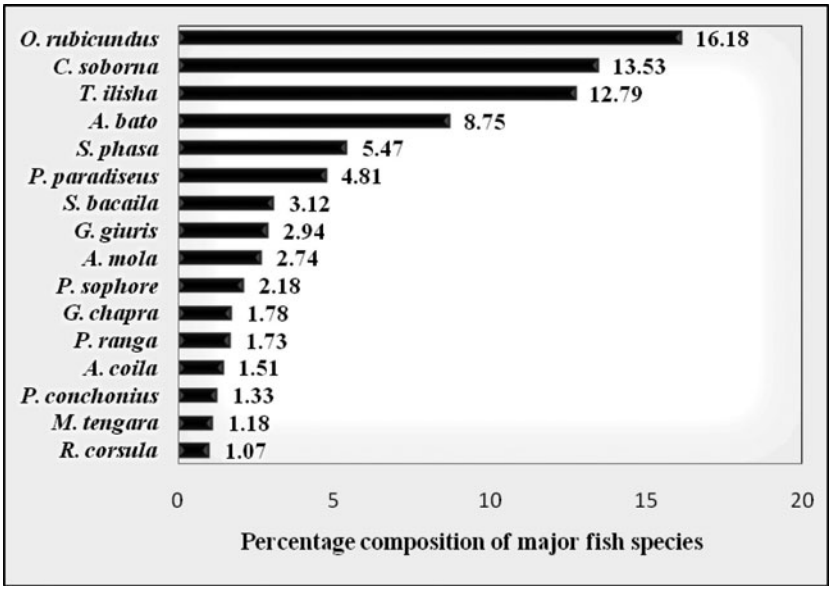

Figure 4. Overall percentage contribution of the dominant fish species in the tidal freshwater stretch.

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abundance was prevalent in all the sampling zones. The mean number of species per site was highest during monsoon (69 species) followed by pre-monsoon (59 species) and reached its lowest (44 species) in post-monsoon/winter period. During pre-monsoon period, the most abundant fish species of the tidal freshwater zone include *Tenualosa ilisha* (24.35%), *Corica soborna* (21.37%), *Odontamblyopus rubicundus* (13.28%), *Polynemus paradiseus* (10.14%) and *Setipinna phasa* (7.90%). With the onset of monsoon along with its heavy freshwater influx the whole scenario changes, resulting in a fish assemblage dominated by cyprinids (carps, minnows and barbs) such as *Amblypharyngodon mola* (11.20%), *Puntius sophore* (8.40%), *Salmophasia bacaila* (7.11%), *Puntius conchonius* (5.91%), *Labeo calbasu* (4.55%) and *Labeo rohita* (3.63%). Majority of these freshwater fishes are introduced into the system through monsoon flooding and they utilize the sheltered areas within the river islands as spawning and nursery grounds. During post-monsoon season, the water flow recedes and most of the species leave the system leading to a drastic reduction in fish diversity and resulting in an assemblage dominated by gobiids such as *Odontamblyopus rubicundus* (27.88%), *Apocryptes bato* (26.44%) and *Glossogobius giuris* (5.52%). This signifies the role of freshwater flow in maintaining the fish community structure of the estuarine tidal freshwater stretch.

Conclusions

It has been established in many parts of the world that tidal freshwater ecosystems serve as the connection between true freshwater ecosystems and adjacent marine areas, thereby providing essential passage as well as nursery areas for commercially important migratory fish species (Sousa et al., 2008). Due to their intermediate position between the spheres of interest of limnologists and marine biologists, tidal freshwater estuaries have received little attention in ecological studies (Odum, 1978). Several studies have been initiated in the recent past around North America and Europe, but tidal freshwater areas still remain as one of the most neglected habitats within estuarine ecosystems and the scientific communities in many countries still do not consider them as a part of the estuarine system.

Even though India is blessed with a vast expanse of estuarine/transitional water bodies, no comprehensive studies have been carried out on the tidal freshwater reaches of Indian estuaries thus far. The present study reported 155 fish species, of which 29 species has been listed in category of threatened fishes by the Conservation and Management Plan (CAMP) (1998). This includes 19 vulnerable (VU) species, 9 endangered (EN) species and one critically endangered (CR) species. This signifies the role of tidal freshwater zone as an essential fish habitat due to its rich fish diversity and as a sheltered area which favours the growth and survival of larval and juvenile fish assemblages. This study emphasises the need for taking up intensive, as well as exploratory, research on the tidal freshwater areas of different estuarine systems of India which will help in formulation of management plans in conserving this critical habitat which has been generally excluded in biodiversity conservation programmes.

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