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Tidal bore induced upward shift of marine fish species in Hooghly estuary, India

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A total of ten different marine/brackish water fish species was recorded at Tribeni, a completely freshwater region located 212 km upstream from the sea in Hooghly estuary just after tidal bore, a natural high wave and high flow regime created during the spring tide around full moon/new moon days. A range of 85 – 179 km upstream shift of recorded marine fish species from their normal distribution range may be attributed to high turbulence, flow, and wave associated with bore tide as there is no sign of saltwater ingress in the Tribeni area as revealed through the analysis of associated environmental parameters. In addition to salinity, such extreme climatic events like tidal bore should also be considered to explain the fish species distribution in a tidal estuary.

[**Keywords**: Hooghly estuary, Marine fish distribution, Tidal bore, Water quality]

Introduction

The estuary is one of the most productive aquatic habitats that offer a congenial environment for breeding, survival, and growth of fresh, brackish, and marine water fishes[1]. It is the lowermost stretch of a river joining the sea where salinity gradient is created through the mixing of riverine freshwater discharge from upstream and tidal saline water intrusion from the sea. Water quality parameters of an estuary are highly dynamic where salinity and its related parameters are influenced more than any other parameters due to tidal influence[2]. Estuarine aquatic communities like fishes distribute themselves in the salinity gradient with seasonal upward/downward migration as per their physiological requirements especially during the breeding period. Tolerance to salinity variation is the major determining factor controlling the distribution of marine species in an estuary that generally resides in the lower estuarine zone except for some anadromous fish species[3]. However, this distribution of species may be changed upward or downward in case of extreme climatic events. The present article reports such a phenomenon of uncommon distribution of ten marine fish species in distant inland freshwater zone caused by tidal bore in Hooghly estuary, the longest estuary in India situated at the lowermost stretch of river Ganga. There are reports of the impact of tidal bore on different environmental, ecological, and cultural aspects of important rivers in the world[4]. However, no such literature is available on shifting of several marine species into the upper freshwater region of an estuary by tidal bore from any river in the world as described here.

Materials and Methods

Seasonal sampling was performed to assess the fish assemblage pattern in different stations of the Hooghly estuary (Fig. 1) along the salinity gradient which was mainly based on the catch analysis of bag net, an unselective fishing gear operated in the middle of the river. Preserved samples were taxonomically characterized following standard literature[5-7]. The recorded fish species were categorized by using fish guild approaches based on their estuarine use and feeding mode as Diadromous Species (DA), Marine Stragglers (MS), Marine Migrants (MM), Estuarine Species (ES), and Freshwater Stragglers (FS)[7,8]. Water quality parameters were also analyzed from the river at the same time following standard methods[9]. Sampling date was determined following year wise tide table published by the Shyamaprasad Mukherjee Port, Kolkata indicating date and time of tidal bore at different places of the estuary during the year[10]. One-way ANOVA between stations was performed to know the significant seasonal changes in water parameters at different stations using R-studio (2022.02.3; Build 492) software.

Results and Discussion

The Hooghly estuary on the Indian coast of the Bay of Bengal is the largest and most productive estuary in

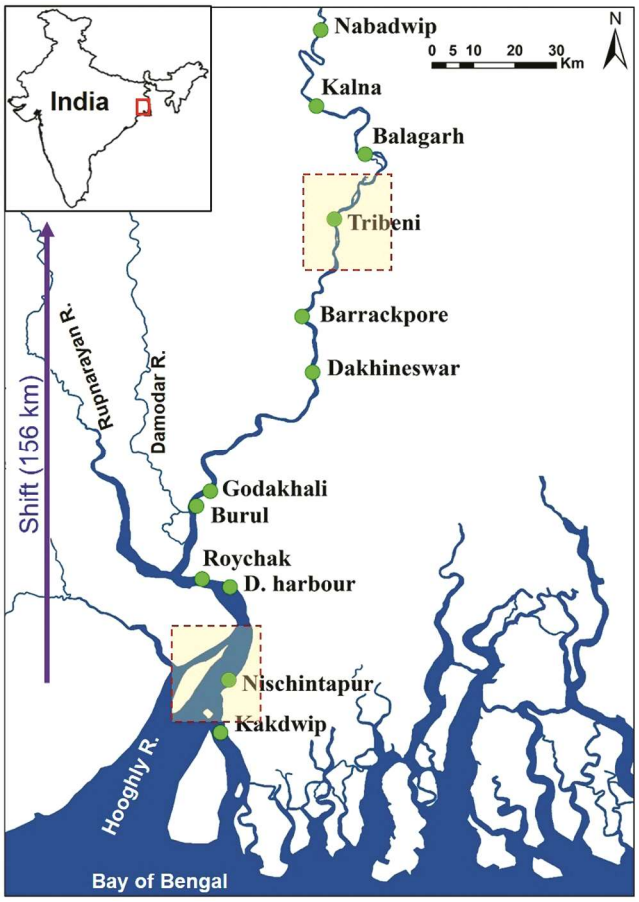

Fig. 1 — Sampling sites in Hooghly estuary showing shift of marine fishes caused by the tidal bore

the country, covering about 295 km from the sea face[11]. Fish diversity of Hooghly-Matlah estuary varied in different regions depending upon salinity and more than 90 % of fish caught from the estuary comes from the high saline zone[12,13]. The Hooghly is a positive estuary in the mixo-haline range, where salinity ranges from 0.1 to more than 30 ppt[14]. However, the salinity is variable depending upon the tidal cycle as well as the amount of seasonal freshwater discharge from upstream. Tidal cycle in the Hooghly estuary is semi-diurnal; high and low tide occurs about every six hours, alternatively[15].

A tidal bore is a unique natural phenomenon of extreme tidal surge when high tide (flood tide) progresses with heavy flow associated with a wave of higher amplitude at the tidal edge accompanied with gushing sound[16]. Bathymetry, bottom profile, river flow direction, width, etc., has its role in formation of such tidal bore in many estuaries of different rivers throughout the world[17]. In Hooghly estuary, it is locally known as *Baan* which starts from the Noorpur-Gadiara region (22°12'37" N; 88°03'25" E), where a major tributary Rupnarayana river joins the river Hooghly. But, its severity is apparent from Burul (22°21'50" N; 88°05'42" E) onwards[18] and 4 – 5 ft high wave continues up to the Tribeni-Kuntighat area (22°59'17" N; 88°24'20" E), a middle stretch of about 100 km during spring tide period for 3 – 5 days around the full moon and new moon. Though it occurs throughout the year, from full-moon day in the middle of March (popularly known as *Dol Purnima*) to full-moon day during the middle of July (popularly known as *Guru Purnima*), such tidal bores are more prominent in the Hooghly estuary. There are detailed studies regarding *Baan*-related hydrodynamics in the Hooghly estuary with mention of water rising and speed at different stations[18]. Water quality changes with the tidal cycle and hence bore tide have also received attention from the researchers[19]. There are recent reports on fish species distribution in Hooghly-Matlah estuary along the salinity gradient[12,20] as well as some earlier reports like by David (1956)[21]. However, no reports are available on impact of bore tide on fish species distribution in the Hooghly estuary. The present study confirmed that Tribeni, an entirely freshwater zone of the upper Hooghly estuary, recorded with ten marine and/or brackish water fish species which is a possible impact of the strong tidal bore as described below.

Record of marine fish species in freshwater dominated estuarine zone at Tribeni

A total of ten different marine and/or brackish water fish species have been recorded from Tribeni area from the catches of bag net operated just after tidal bore (Table 1). These fish species are *Alepes djedaba*, *Cynoglossus cynoglossus*, *Eleotris fusca*, *Ilisha megaloptera*, *Lates calcarifer*, *Nuchequula blochii*, *Platycephalus indicus*, *Rhabdosargus sarba*, *Scatophagus argus* and *Stolephorus indicus*. Habitat of *Alepes djedaba* and *Stolephorous indicus* was reported as totally marine; whereas, *Cynoglossus cynoglossus*, *Nuchequula blochii*, *Platycephalus indicus* and *Rhabdosargus sarba* has their habitat as marine to brackish. Other four fishes *viz. Eleotris fusca*, *Ilisha megaloptera*, *Lates calcarifer* and *Scatophagus argus* can inhabit all three types of environments *i.e.*, marine, brackish, and freshwater as reported. Ecological guild characterization revealed that four fishes are Marine Migrants (MM), two species each as Marine Stragglers (MS), Diadromous (DA), and Estuarine species (ES) (Table 1). The

Table 1 — Categorization of recorded fish species according to habitat preference and ecological guild

Species	Common name	Reported habitat	Ecological categorization	Migration pattern
Alepes djedaba (Forsskål, 1775)	Horse mackerel / Shrimp scad / Djeddaba crevalle	M	MM	AM
Cynoglossus cynoglossus (Hamilton, 1822)	Bengal tonguesole	M + B	MM	AM
Eleotris fusca (Forster, 1801)	Dusky sleeper	M + B + F	ES	AM
Ilisha megaloptera (Swainson 1838)	Bigeye ilisha	M + B + F	DA	AN
Lates calcarifer (Bloch 1790)	Barramundi / Asian seabass	M + B + F	DA	CA
Nuchequula blochii(Valenciennes, 1835)	Twoblotch ponyfish	M + B	MM	AM
Platycephalus indicus (Linnaeus, 1758)	Bartail flathead	M + B	MS	OC
Rhabdosargus sarba (Forsskål, 1775)	Goldlined seabream	M + B	MS	OC
Scatophagus argus (Linnaeus 1766)	Spotted scat	M + B + F	ES	AM
Stolephorus indicus (van Hasselt, 1823)	Indian anchovy	M	MM	OC

Note: M = Marine, B = Brackish water, F = Freshwater; ES = Estuarine species, MM = Marine migrants, MS = Marine stragglers, DA = Diadromous; AM = Amphidromous, OC = Oceanodromous, CA = Catadromous, AN = Anadromous

Table 2 — Upward shift (in km) of the recorded marine fish species in Hooghly estuary

Fish species	Normal uppermost distribution area	Distance from sea (km)	Place of record under present study after tidal bore	Distance from sea (km)	Upward shift (km)
Alepes djedaba, Rhabdosargus sarba	Kakdwip	36	Tribeni	212	176
Ilisha megaloptera, *Nuchequula blochii*	Nischintapur	56	Tribeni	212	156
Cynoglossus cynoglossus, *Lates calcarifer*, *Scatophagus argus*, *Stolephorus indicus*	Roychak	95	Tribeni	212	107
Eleotris fusca, *Platycephalus indicus*	Godakhali	127	Tribeni	212	85

comparatively fewer numbers of ES than MM confirms that fewer numbers of species use tropical estuaries for spawning, or shelter[22,23]. As per migration behavior is concerned, five fish species are amphidromous *i.e*., migrate without the need for breeding; whereas, two are diadromous *i.e*., migrate for breeding purposes. Rest three are reportedly oceanodromous *i.e*., they migrate within salt water.

Shift of the recorded fishes from the area of their natural availability

Estuarine fishes remain distributed in different regions as per their physiological need; whereas, marine fishes generally remain in the lower estuarine zone. However, all the ten marine fish species were recorded from the Tribeni area, a freshwater zone located at 212 – 215 km from the sea (Table 2). Maximum drift (176 km) was observed in the case of *Alepes djedaba* and *Rhabdosargus sarba* which are normally not available above Kakdwip (21°53'27" N; 88°08'54" E) area, 36 km distant from the river mouth. *Nuchequula blochii* and *Ilisha megaloptera* have been shifted 156 km upstream beyond their normal distributional area of Nischintapur; thus now they may be located at a distance up to 212 km from river mouth at Tribeni. Similarly, *Cynoglossus cynoglossus*, *Lates calcarifer*, *Scatophagus argus* and *Stolephorus indicus* which are mostly available in the middle to lower estuary have been confronted with a shift of 107 km upstream from Roychak (22°12'06" N; 88°07'04" E), a lowermost station of a freshwater stretch of Hooghly estuary. Now the extended distribution range of these fishes is 212 km from river mouth up to Tribeni. *Eleotris fusca* and *Platycephalus indicus*, sometimes available in the lower freshwater zone of Godakhali region (127 km from river mouth), observed drift of 85 km upstream resulting in their extended distribution range of 212 km from lower estuarine zone. Roshith *et al*.[20] reported 155 types of fish species from 168.9 km tidal freshwater stretch of Hooghly estuary *i.e.* from Godakhali (located at a distance of 127 km from river mouth) to Nabadwip (295.9 km from river mouth) through an exhaustive seasonal study. Tribeni area is located at the midpoint of this 168.9 km freshwater stretch. Out of ten fish species reported in the present study, three species namely *Cynoglossus cynoglossus*, *Eleotris fusca* and *Platycephalus indicus*, have been reported from upper and middle freshwater stretch (Barrackpore to Nabadwip including Tribeni) by Roshith *et al*.[20]. Additionally, out of ten species recorded in this study, five species have been recorded by Roshith *et al*.[20] from Godakhali area (127 km distant from river mouth and 85 km downward to Tribeni). These species are *Ilisha megaloptera*, *Lates calcarifer*, *Nuchequula blochii*, *Scatophagus argus* and *Stolephorus indicus.* Two fish species *Alepes djedaba*

and *Rhabdosargus sarba* have not been reported so far from freshwater zone. The study by Roshith *et al*.[20] included pre-monsoon season also in their study when maximum tidal bore event occurs in the Hooghly estuary; and hence recorded five marine or brackish water fishes as mentioned above from the Godakhali area, the lower zone of a freshwater stretch in Hooghly estuary.

Size and abundance of the recorded fish species

Analysis of fish samples revealed that all the marine fishes in the catch are in juvenile stages or small-sized fishes (Table 3). This may be because juvenile fishes generally remain in near shore areas and are unable to negotiate the thrust of the high flow and strong wave regime during tidal bore formation as the associated wave formation happens in shallower near shore areas. As the tide is the main driver of estuarine ecosystem dynamics, banks plays an important role in influencing fish distribution with shallow pelagic schools of fishes concentrated near the banks as reported by Embling *et al*.[24]. The percentage share of the marine fishes in the total catch (0.4 – 1.6 % by number) at Tribeni revealed that only a portion of the trapped fishes (in the tidal bore) are forced to drift up to such a long distance; while most of the marine fishes (especially the adult fishes) can manage to move downstream. A similar observation was made by David[21] in 1954, where he has explained the appearance of brackish water fishes in Barrackpore region in the summer months because of the influence of strong flood tides (including tidal bore) driving mostly small and feeble swimmers upstream. Additionally, the absence of *Lates calcarifer* at Barrackpore in the study of David[21] was explained based on the ability of fish species as a strong swimmer. The present study could able to record *Lates calcarifer*, an important fish in the Hooghly estuary from Tribeni area but only very small sized juveniles (83 – 115 mm; 7.81 – 20.12 g). Smaller fishes are more impacted by flow regime in rivers as reported by Del Signore *et al*.[25]. Caught in the bore turbulence, smaller fishes became easy prey for predatory birds and other aquatic animals (Seal, crocodile) of higher trophic level in different rivers of the world as reported by Chanson[4]. Larval fishes are influenced more by tidal surges in estuaries and near shore areas[26]. Though flood tide in Hooghly estuary is felt up to Nabadwip, appearance of marine/brackish water fishes only up to Tribeni-Kuntighat area (up to the area where tidal bore is observed in Hooghly estuary) is an indication of the impact of tidal bore on such shift of marine fishes in the upper estuarine freshwater area. Impact of tidal bore on fisheries are reported from many rivers and estuaries of the world where fishers took the advantage of the strong impact of the tidal bore surge on fishes to catch them easily from the water surface as observed in Dordogne River (France)[4] and Qiantang River, China by Dai & Zhou[27]. In Hooghly estuary, tidal bore impacted fishes with all types of swimming behaviour, both pelagic and demersal as given in Table 3 revealing the severe thrust of the tidal bore.

Water quality *vis-à-vis* fish species occurrence

Water quality (salinity as a controlling factor) of the Hooghly river always received the attention of the researchers over the years along with its influence on fish species distribution. Hora[28] mentioned increasing salinity in Hooghly estuary over the years from the reporting of marine species *Hilsa toli* at Falta (near Roychak), about 95 km from sea mouth. However, he has hypothesized the possibility of a bottom wedge of heavier brackish water penetrating deeper into the river Hooghly behind the appearance of a marine fish deep inside the estuary[29]. No vertical stratification of salinity with salt wedge at bottom was able to be recorded from the Hooghly estuary, instead absence of any stratification was attributed to violent tidal mixing and river morphology including tidal bore and

Table 3 — Length and weight of the recorded marine fish species at Tribeni

Fish species	Sample size	Length range (mm)	Weight range (g)	Abundance (%) by number	Swimming behaviour
Alepes djedaba	5	85-97	10.12-14.83	0.4	Pelagic
Cynoglossus cynoglossus	23	143-17.9	12.01-25.03	0.5	Demersal
Eleotris fusca	17	71-87	5.02-9.03	0.2	Demersal
Ilisha megaloptera	15	77-125	7.62-17.91	0.8	Pelagic
Lates calcarifer	11	83-115	7.81-20.12	0.8	Demersal
Nuchequula blochii	51	36-56	0.41-2.52	1.6	Demersal
Platycephalus indicus	7	91-155	4.30-22.72	0.8	Demersal
Rhabdosargus sarba	12	73-10.3	5.72-15.76	0.8	Demersal
Scatophagus argus	21	34-39	1.25-2.22	1.2	Pelagic
Stolephorus indicus	39	61-79	1.21-2.82	0.4	Pelagic

silting pattern[30]. Biswas[31] identified strong turbulence caused by high tidal range as a preventive mechanism for the possible establishment of vertical salinity gradient in the Hooghly estuary. However, Rao[15] reported partial stratification during high discharge conditions in monsoon. Increased salinity was also evident when David[21] reported several marine and brackish water fishes from Barrackpore, 185 km deep inside the estuary during the pre-Farakka barrage period. The environmental situation of Hooghly estuary changed completely after the operation of the Farakka barrage in 1975 with diversion of more freshwater from the river Ganga into the Hooghly river[32,33]. A 45 – 60 km downward shift of salinity gradient as an impact of Farakka barrage was reported along with the estuarine fish species which seldom cross Godakhali region now[32,34]. During post-monsoon and winter, tidal bore occurrence in Hooghly estuary is either absent or mild. Whereas, the pre-monsoon months observe bore tide periodically impacting different water parameters. Hence, a comparative data of water quality parameters has been given depicting salinity and its related parameters like conductivity, hardness recorded during post-monsoon (absence of tidal bore) and pre-monsoon, just after tidal bore occurrence (Table 4). Turbidity, an indicator of high flow/turbulence caused by tidal bore is also mentioned in the table.

Analysis of variance of salinity and other water parameters revealed that seasonal salinity varied significantly in three lower stations *viz*. Raichak, Kakdwip and Fraserganj (Table 5). But, in the upper stretch *i.e*., freshwater zone, there were no significant changes in salinity occurred between the seasons. So, tidal bore-induced salinity increase did not show any impact in the freshwater zone. However, other parameters especially total hardness and conductivity showed significant variations between pre-monsoon and post-monsoon seasons at different stations.

Bore tide occurrence in Hooghly estuary is accompanied by a significant increase in salinity (53.2 % from the neap tide period) and other physicochemical parameters at Diamond Harbour as mentioned by Nath & De[2,19]. Significant differences in water quality parameters especially salinity at middle and lower Hooghly estuary between pre-monsoon and post-monsoon were reported both in pre-and post-Farakka barrage periods[34,35]. Less freshwater discharge along with strong tidal bore formation in Hooghly estuary may be attributed to significantly higher salinity regime during pre-monsoon months. However, that increased salinity does not reach above Godakhali as revealed by data given in Tables 4 and 5. Hence, the occurrence of marine/brackish water fishes in completely freshwater area at Tribeni (75 km upstream from Godakhali) indicated that it is not the ambient condition of the river but the tidal influence (here caused by bore tide) that played a major role behind shifting of marine fish species to Tribeni in Hooghly estuary, similar to the

Table 4 — Important salinity-related water quality parameters in Hooghly estuary (2021-22)

	Salinity (ppt)		Conductivity (mS/cm)		Total hardness (mg/l)		Turbidity (NTU)	
	Post-mon	Pre-mon	Post-mon	Pre-mon	Post-mon	Pre-mon	Post-mon	Pre-mon
Nabadwip	0.0352±0.001	0.0363±0.001	0.376±0.002	0.329±0.002	156±2.0	120.7±3.1	61.1±24.4	47.1±1.54
Tribeni	0.0379±0.002	0.0370±0.001	0.389±0.007	0.330±0.004	158±2.0	130.0±4.0	48.5±13.24	39.5±2.14
Godakhali	0.0418±0.004	0.0571±0.010	0.387±0.007	0.378±0.031	161±1.0	122.7±4.1	156.5±74.62	201.0±77.38
Roychak	0.2380±0.006	0.9385±0.126	0.476±0.008	1.802±0.079	550±50.0	356.7±20.8	75.3±5.54	79.8±16.24
Kakdwip	5.1400±0.937	10.830±0.156	6.900±1.232	17.14±0.306	873.3±110.2	2600.0±435.9	65.3±32.65	262.0±39.58
Fraserganj	23.847±0.075	28.608±0.090	31.40±0.100	47.30±0.100	5000.0±608.3	5233.3±76.4	19.9±5.67	67.2±14.81

Table 5 — ANOVA analysis of salinity and other water parameters between different seasons

Station	*P*-value			
	Salinity	TH	Conductivity	Turbidity
Nabadwip	0.154	7.43e-05 ***	3.98e-06 ***	0.377
Tribeni	0.482	0.00041 ***	0.000191 ***	0.308
Godakhali	0.0712	0.000101 ***	0.632	0.513
Roychak	0.000661 ***	0.00348 **	8.41e-06 ***	0.671
Kakdwip	0.000487 ***	0.00265 **	0.000152 ***	0.00267 **
Fraserganj	2.46e-07 ***	0.546	4.17e-09 ***	0.0067 **

Note: '***' denotes highly significant, '**' denotes significant at 99 % confidence level, '*' denotes significant at 95 % confidence level

observation made by David[21] in his fish assemblage study at Barrackpore.

Conclusion

The distribution of fishes in an estuary is mostly linked by the researchers to the salinity gradient and other related parameters. Extreme climatic events may jeopardize such a simple relationship as revealed in this study. Hence, estuarine fish assemblage study should also consider extreme variables like tidal bore events which may influence the distribution of fishes. Even spring tide associated with strong floods may have an influence in controlling fish species distribution and assemblage in the Hooghly estuary. Present observation on appearance of marine fishes in the completely freshwater zone of the upper Hooghly estuary at 212 km distant from the river mouth will be helpful for future studies related to estuarine fish species distribution where physical parameters like tidal pulse can also be considered along with the chemical parameters like salinity.

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Conflict of Interest

The authors declare that there is no conflict of interest in this manuscript.

Ethical Statement

We declare that the research and preparation of the manuscript was carried out according to the procedures of Animal Ethics Committee guidelines of ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), Barrackpore to avoid any harm to any animal.

Author Contributions

RKM: Collection of field data and information, conceptualization, and drafting of manuscript; DB: Collection of field data and information, input for improvement; SMN: Analysis of fish samples for any residue; CJ: GIS map and statistical analysis; SM: Analysis of water samples in field and laboratory; SS: Input for improvement of the draft manuscript; BKD: Project planning, implementation and editing of manuscript.

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