

Seasonal fish diversity under tidal influence in the intertidal mudflats of Indian Sundarbans

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ABSTRACT

The seasonal fish diversity and assemblages in intertidal mudflats in the Indian Sundarbans were compared between the two tidal phases (high tide and low tide). In terms of number of species per family, Gobiidae was most diverse followed by Engraulidae, Congridae and Muraenidae in submerged mudflats. A total species richness of 31 was recorded in the present study. Two-way analysis of variance was applied to assess the differences in species richness, fish diversity, density and standing stock amongst tidal phases and seasons, while fish assemblage composition was analysed using multivariate analysis (MDS, ANOSIM, SIMPER). The analysis indicated significant fluctuations in fish assemblage during monsoon and post-monsoon seasons supporting specialised and recognisable fish assemblages at low tide. Post-monsoon season, irrespective of tides, was characterised by high species richness, fish density and standing stock. The findings indicated that the intertidal mudflat is a unique system and provides a favourable environment for large variety of estuarine species assemblages. The sustainability of diversified fish assemblages in mudflats depends on constant monitoring and conservation efforts of this unique habitat.

Keywords: Estimators, Fish density, Indian Sundarbans, Intertidal mudflats, Species richness, Standing stock, Taxonomic diversity

Introduction

Intertidal mudflats are dominant features of many estuaries and forms significant proportion of the estuarine habitat available to fish (Morrison *et al.*, 2002). Mudflats are structurally less complex compared to mangroves but they contain great abundance and diversity of invertebrates. These ecosystems are periodically immersed and emerged in each tidal cycle and are, therefore, mostly available to nekton during tidal inundation which implies tidal migration to use this habitat (Morrison *et al.*, 2002; Nagelkerken and van der Velde, 2002; Pihl and Wennhage, 2002; Weerts and Cyrus, 2002; Mumby *et al.*, 2004; Kanou *et al.*, 2005; Vinagre *et al.*, 2006). The dominance of a few species is a general feature in fish communities of salt marshes, mudflats and their creeks (Kneib, 1997; Jin *et al.*, 2007). Fishes that occupy the intertidal and the upper subtidal zones of estuaries have proven to be difficult to classify in terms of their habitat use. Some species spend most of their life therein, others descend to deeper waters as they grow larger, and still others enter this zone only during high tide periods. Seasonal utilisation of these habitats by fishes are commonly observed (Rountree and Able, 1992; Cattrijsse *et al.*, 1994; Salgado *et al.*, 2004). Tidal shifts in fish assemblages have also been reported by several authors

(Sogard *et al.*, 1989; Rountree and Able, 1993; Gray *et al.*, 1998; Griffiths, 2001; Methven *et al.*, 2001; Morrison *et al.*, 2002; Guest *et al.*, 2003).

The Sundarbans mudflats (Banerjee, 1998; Bose, 2004) are found in the estuary and on the deltaic islands, where low velocity of river and tidal current occurs. The flats are exposed in low tides and submerged in high tides, thus being changed morphologically even in one tidal cycle. The interior parts of the mudflats are magnificent home of luxuriant mangroves. The Sundarban mudflats control the food chain in the estuarine ecosystem. However, no systematic approach towards studying the ichthyofaunal diversity of different habitats of Indian Sundarbans for conservation purpose has been attempted so far (Saha *et al.*, 2001; Alongi, 2002; Gopal and Chouhan, 2006; Hoq *et al.*, 2006).

The maintenance of mudflats is important in preventing coastal erosion. However, mudflats worldwide are under threat from predicted sea level rises, land claims for development, dredging due to shipping purposes, and chemical pollution. The present study aims to characterise the nekton assemblage of a mudflat area of the Indian Sundarbans and to assess its structure and seasonal

distribution patterns during high and low tide conditions in terms of taxonomic composition, species richness, fish diversity, fish density and standing stock.

Materials and methods

Study area

The present study was undertaken at 12 randomly selected sites located in the mudflats (35 km²) along a 10 km stretch of Matla River, Bidya River and Boro Herobhanga Rivulet in Sunderbans (22° 01' N, 88° 40' E). The Boro Herobhanga Rivulet is a small creek, about 150 m wide which joins two mighty rivers of Sunderbans namely the Matla River on the west and the Bidya River in the east. Matla is connected to Bidya and ultimately flows to the Bay of Bengal. The freshwater connection and discharge to this river has been lost in recent times. Salinity of the river water is relatively high owing to freshwater cut off from upstream region (Manna *et al.*, 2010) (Fig. 1). The study site was a broad (up to 1 km wide) gently-sloping tidal platform, composed predominantly of well-packed soft mud.

Fish sampling and environmental data collection

Sampling was conducted seasonally during pre-monsoon, monsoon and post-monsoon seasons, between October 2008 and September 2011. Samples were collected fortnightly from each site during new and full moon periods. Fish sampling was performed during high tide employing i) a gillnet of 20 m length with 1 cm spacing between adjacent knots, ii) cast net of 1.2 m radius and iii) with hook and line of 50 m length having 50 hooks each at 1 m interval. Twenty four nettings were undertaken at each site, per season. During low tide, 100 m transects were

established at each site for studying the amphibious fishes. Along the transects, 1 m quadrats constructed from nylon ropes and bamboo sticks were temporarily established at intervals of 10 m. Hand nets (dot net) were also used for sampling during low tide.

Subsequent to netting, the specimens were retrieved from the net, identified and species abundance was recorded to investigate species assemblages. Live fishes were measured for total length (L_T in cm) and weighed for total mass (M in g) (Table 1) and released, after preserving individuals representing each fish species in 5% formalin. Fish specimens were identified to the lowest taxonomic level following existing literature (Shaw and Shebbeare, 1937; Day, 1958; Talwar and Jhingran, 1991).

Prior to netting, important hydrological parameters (dissolved oxygen, water temperature, pH, total dissolved solids and salinity) from the sampling sites were measured following standard methods (Strickland and Parsons, 1972; Grasshoff, 1983; Grasshoff *et al.*, 1983). The soil parameters (soil organic matter and soil organic carbon) were recorded in each sampling station following Brower *et al.* (1998).

Data analyses

Fish density and standing stock were calculated by dividing the total number and biomass of each species by the area sampled (35 km²). To compare the diversity between three seasons during inundated and exposed conditions, Shannon-Weiner diversity index (H') (Shannon and Wiener, 1949) and species richness (S) (Margalef, 1957) were calculated.

Statistical estimations such as Jackknife method (Heltshe and Forrester, 1983), Bootstrap method (Smith and van Belle 1984) and Chao's estimator, Chao 1 (Chao, 1984) were applied to the data collected from the samplings to check for differences in the estimation of the species richness. Comparisons of species richness across tidal scales (high tide and low tide) and seasonal scale (*i.e.*, pre-monsoon, monsoon and post-monsoon) were carried out using the method of rarefaction (Sander 1968; Hurlbert 1971). Species accumulation curves were generated using the EstimateS (version 8) software. Multiple and pair wise differences were tested by non-parametric statistics (Kruskal-Wallis tests) (Zar, 1984).

Two-way analysis of variance (ANOVA) was used to assess habitat differences in total fish density, standing stock, species richness and fish diversity. Duncan's test was used for post-hoc comparisons. Statistical analyses were carried out using SPSS 17 software.

Bray-Curtis similarity coefficient was calculated on the fish density and standing stock data to generate

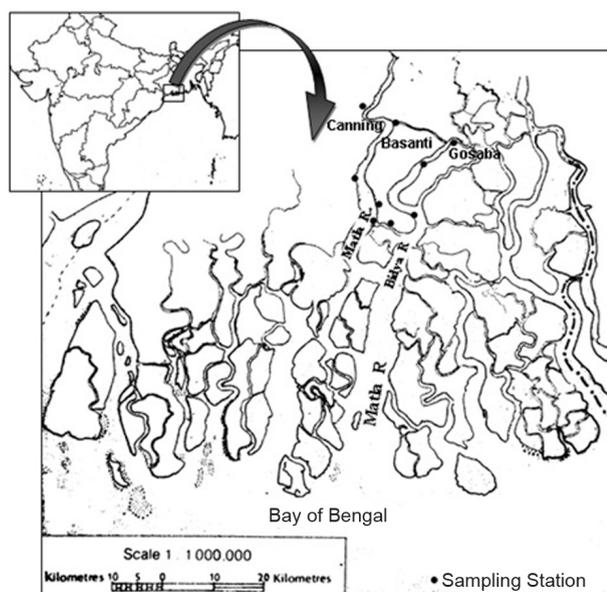


Fig. 1. Map of Indian Sunderbans showing the study locations and sampling stations

similarity matrices (Clarke, 1993). For each season, an analogue of multivariate analysis of variance with a randomisation test for significance (ANOSIM) was used to compare habitats in terms of their fish assemblage composition. Multidimensional scaling (MDS) was used to plot the relationships amongst habitats for each season where significant differences occurred. Similarity matrices used for MDS were also analysed for the individual species making the greatest contribution to between-group differences (SIMPER; Clarke, 1993). Seasonal differences were investigated by performing ANOSIM for each habitat. All multivariate analyses were performed using PRIMER (Clarke and Warwick, 1994).

Results and discussion

Species richness, diversity, fish density and standing stock

A total of 4891 individuals belonging to 31 species were collected from the mudflats of Indian Sundarbans at high and low tides. The diversity was higher compared to the reports from other studies in mudflats of Raby Bay (Williamson *et al.*, 1994), Negombo Estuary of Sri Lanka (Pinto and Puchihewa, 1996), Australian Estuary (Morrison *et al.*, 2002), mudflats in France (Amara and Paul, 2003) and mudflats of Tagus Estuary (Salgado *et al.*, 2004). In terms of number of species per family, Gobiidae (6 species) was the most diverse followed by Engraulidae (3 species), Congridae (2 species) and Muraenidae (2 species) (Table 1; Fig. 2, 3). Amongst 31 species, 12 were found both during high and low tides. Ten species in both pre-monsoon and

monsoon and 12 species in post-monsoon contributed 95% of the total fish density during high tide. In contrast, 95% of the density during low tide was contributed by 3, 5 and 6 species during pre-monsoon, monsoon and post-monsoon respectively (Table 2). The range of hydro-edaphic factors during the study period were also recorded (Table 3).

The transient nature of many species is one of the characteristics of an estuarine fish population that influences diversity. Emigration and immigration of adults and young fish can directly affect the population diversity (Cardoso *et al.*, 2011). In the present study, diversity index (H') and species richness (S) showed significant variation across seasons (H' : $F = 22.19$, $p = 0.000$; S : $F = 18.87$, $p = 0.000$) as well as amongst tides (H' : $F = 200.90$, $p = 0.000$; S : $F = 276.24$, $p = 0.000$), with higher values in high tide and post-monsoon (Fig. 4). Fish density and standing stock were also significantly higher at high tide than at low tide (FD: $F = 38.65$, $p = 0.000$; SS: $F = 108.58$, $p = 0.000$). With respect to seasonal variations, post-hoc test showed that both fish density and standing stock were significantly higher (FD: $F = 9.83$, $p = 0.003$; SS: $F = 16.09$, $p = 0.000$) in the post-monsoon than in the other seasons though they did not vary significantly when both tide and season were considered (FD: $F = 3.02$, $p = 0.087$; SS: $F = 2.52$, $p = 0.122$). Significant interactions between tide and seasons were detected by the ANOVA for Shannon Weiner and species richness (H' : $F = 9.049$, $p = 0.004$; S : $F = 7.362$, $p = 0.008$). The species diversity index (1.4), recorded for the mangrove lined mudflat in Raby Bay located in the

Table 1. List of fish family and species collected during the study showing the IUCN status

Family	Species	IUCN status	L_T (mm)	W (g)	EI	Occur.		DLHI
						HT	LT	
Bagridae	<i>Mystus gulio</i> (<i>My.gu</i>)	LC	285.00 ± 29.20	241.70 ± 55.08	Commercial	P, M, Po	-	DA
Belontiidae	<i>Strongylura strongylura</i> (<i>Str.st</i>)	NE	265.00 ± 20.34	42.70 ± 8.46	Commercial	M, Po	-	J,DA,A
Bregmacerotidae	<i>Bregmaceros maclellandi</i> (<i>Br.mc</i>)	NE	81.25 ± 50.31	2.10 ± 0.05	Commercial	P, Po	-	A
Clupeidae	<i>Gudusia chapra</i> (<i>Gu.ch</i>)	LC	100.10 ± 40.86	9.20 ± 2.62	Subsistence fisheries	P, M	-	DA,A
Congridae	<i>Muraenesox bagio</i> (<i>Mu.ba</i>)	NE	570.40 ± 20.08	744.47 ± 179.58	Commercial, game fish	P, M, Po	M, Po	A
Congridae	<i>Uroconger lepturus</i> (<i>Uroc.le</i>)	NE	360.0 ± 50.50	69.00 ± 5.71	Commercial	P, M, Po	P, M, Po	DA
Cynoglossidae	<i>Cynoglossus lingua</i> (<i>Cy.li</i>)	NE	253.20 ± 7.70	94.00 ± 17.99	Commercial	P, M, Po	-	DA,A
Dasyatidae	<i>Himantura walga</i> (<i>Hi.wa</i>)	NT	2950.00 ± 462.75	41.00 ± 15.47	Commercial	P, M, Po	-	J,DA,A
Eleotridae	<i>Butis butis</i> (<i>Bu.bu</i>)	LC	130.20 ± 40.10	17.3 ± 3.16	Commercial	M, Po	-	DA
Engraulidae	<i>Coilia neglecta</i> (<i>Coi.ne</i>)	LC	85.60 ± 6.30	33.75 ± 1.85	Subsistence fisheries	M	-	J,DA,A
Engraulidae	<i>Coilia ramcarati</i> (<i>Coi.ra</i>)	NE	91.50 ± 7.50	40.00 ± 3.35	Subsistence fisheries	P, M, Po	-	J,DA,A
Engraulidae	<i>Setipinna taty</i> (<i>Se.ta</i>)	NE	164.10 ± 31.30	57.33 ± 12.15	Minor Commercial	P, M, Po	-	J,DA,A
Gerreidae	<i>Glossogobius giurus</i> (<i>Gl.gi</i>)	NE	145.50 ± 5.50	56.15 ± 4.56	Commercial	P, M, Po	-	DA
Gobiidae	<i>Boleophthalmus boddarti</i> (<i>Bo.bo</i>)	NE	110.76 ± 22.20	35.55 ± 2.70	Of no interest	P, M, Po	P, M, Po	DA,A
Gobiidae	<i>Oxudercus dentatus</i> (<i>Ox.de</i>)	NE	120.90 ± 27.80	15.50 ± 3.12	Of no interest	P, M, Po	M, Po	DA
Gobiidae	<i>Periophthalmus novemradiatus</i> (<i>Pe.no</i>)	NE	50.50 ± 11.17	3.45 ± 1.52	Of no interest	P, M	P, M, Po	J,DA,A
Gobiidae	<i>Pseudapocryptes elongatus</i> (<i>Psp.el</i>)	LC	142.50 ± 12.20	13.71 ± 0.69	Minor Commercial	P, M, Po	P, M	DA,A
Gobiidae	<i>Trypauchen vagina</i> (<i>Try.va</i>)	NE	162.18 ± 7.50	11.73 ± 0.81	Minor Commercial	P, M, Po	M, Po	DA,A

(LC, least concern; NT, near threatened; NE, not evaluated);

L_T , total length; W, body weight;

EI, species of economic importance;

Occur., occurrence at high tide (HT) and low tide (LT) (P, Pre monsoon; M, Monsoon; Po, Post monsoon); and DLHI, dominant life history intervals (J, juveniles; DA, developing adult; A, adults)

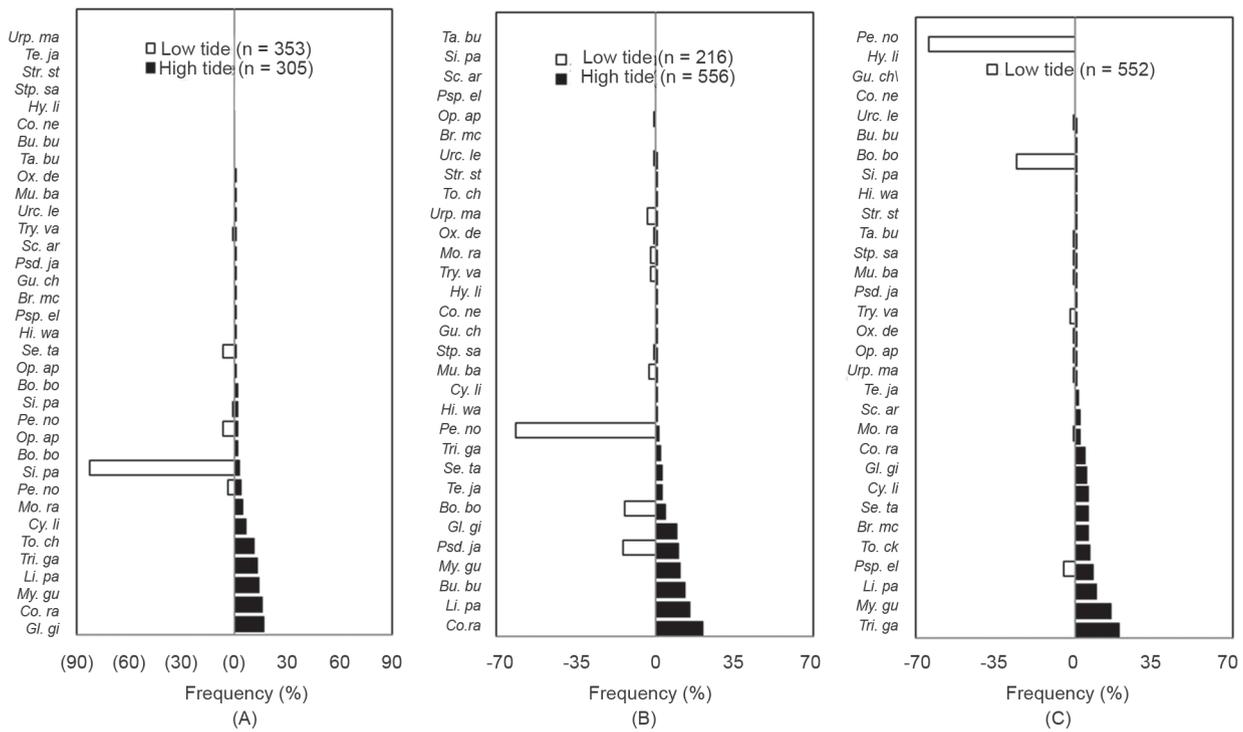


Fig. 2. Percentage abundance of species during pre-monsoon (A), monsoon (B) and post-monsoon (C) seasons at high tide and low tidal conditions

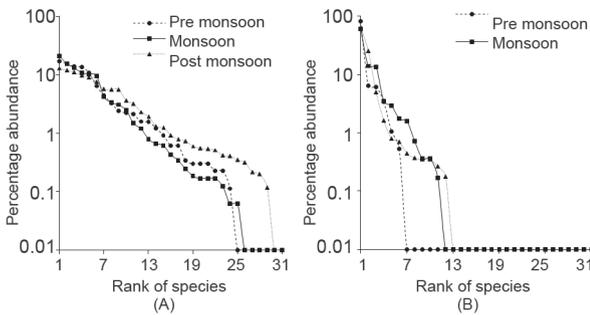


Fig. 3. Species rank abundance curve in a mudflat of Sundarbans at high tide (A) and low tide (B)

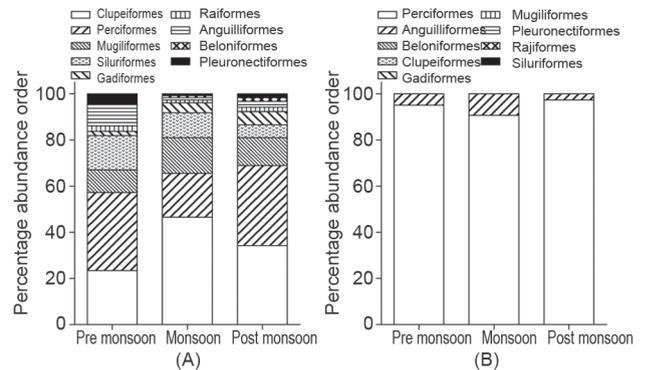


Fig. 4. Percentage abundance of orders in a mudflat of Indian Sundarbans at high tide (A) and low tide (B)

sub tropical Moreton Bay, Queensland, Australia (Williamson *et al.*, 1994), was lower than that from the current study ($H' = 1.55, 2.13, 2.42$ during pre-monsoon, monsoon and post-monsoon seasons respectively) at high tide but higher than the low tidal values ($H' = 0.66, 1.30, 1.10$ during pre-monsoon, monsoon and post-monsoon seasons respectively). Six species represented 90% of individuals collected by Williamson *et al.* (1994) in a similar study. In comparison, the number of species in Sundarban mudflats representing 90% of individuals was variable during pre-monsoon (11 and 3), monsoon (9 and 4) and post-monsoon (12 and 3) at high tide and low tide respectively. The results of high tide corroborated with the study by Ikejima *et al.* (2003) who collected 58 species

from a mangrove creek in the tropical Trang Province of Thailand, but had a diversity index of 3. A total of 22 species comprising 90% of individuals indicated a relatively more number of individuals of each species. In contrast, Pinto and Puchiheva (1996) recorded a Shannon diversity index of 1.1 and a Pielou's evenness index of 0.3 in their study of fish community of a mangrove-lined shore in the tropical Negombo Estuary of Sri Lanka. Even though Pinto and Puchiheva (1996) documented more species than the current study, their low diversity and evenness values signified greater dominance of a few species. Similar observations were reported by Shervette *et al.* (2007) in a mangrove wetland and an adjacent tidal river in Palmar, Ecuador.

Table 2. Fish density (FD) and standing stock (SS) for fish taxa collected in pre-monsoon (P), monsoon (M) and post-monsoon (Po) high tide and low tide

Species	High tide						Low tide					
	P FD	P SS	M FD	M SS	Po FD	Po SS	P FD	P SS	M FD	M SS	Po FD	Po SS
<i>Boleophthalmus boddarti</i> (Bo.bo)	0.100	0.003	0.029	0.001	0.100	0.004	0.64	0.019	0.83	0.025	4.04	0.121
<i>Bregmaceros mccllelandi</i> (Br.mc)	0.029	0	0.986	0.002	0.814	0.002	0	0	0	0	0	0
<i>Butis butis</i> (Bu.bu)	0	0	0	0	0.071	0.002	0	0	0	0	0	0
<i>Coilia neglecta</i> (Coi.ne)	0	0	1.529	0.008	0.943	0.005	0	0	0	0	0	0
<i>Coilia ramcarati</i> (Coi.ra)	0.986	0.009	3.929	0.026	1.229	0.008	0	0	0	0	0	0
<i>Cynoglossus lingua</i> (Cy.li)	0.557	0.008	0.157	0.016	0.186	0.021	0	0	0	0	0	0
<i>Glossogobius giuris</i> (Gl.gi)	0.029	0.001	0.100	0.004	0.014	0	0	0	0	0	0	0
<i>Gudusia chapra</i> (Gu.ch)	1.114	0.009	0.957	0.007	1.400	0.010	0	0	0	0	0	0
<i>Himantura walga</i> (Hi.wa)	0.057	0.229	0.129	0.439	0.243	0.507	0	0	0	0	0	0
<i>Hyporhamphus limbatus</i> (Hy.li)	0	0	0.057	0.001	0.114	0.001	0	0	0	0	0	0
<i>Liza parsia</i> (Li.pa)	0.814	0.037	2.729	0.069	1.629	0.076	0	0	0	0	0	0
<i>Moringua raitaborua</i> (Mo.ra)	0.371	0.004	0.014	0	0	0	0.19	0.003	0.09	0.001	0.03	0.001
<i>Muraenesox bagio</i> (Mu.ba)	0.029	0.014	0.129	0.053	0.071	0.036	0	0	0.11	0.046	0.06	0.029
<i>Mystus gulio</i> (My.gu)	1.700	0.067	1.086	0.028	0.743	0.076	0	0	0	0	0	0
<i>Ophichthus apicalis</i> (Op.ap)	0.129	0.001	0	0	0	0	0.06	0.001	0.01	0	0.04	0.001
<i>Oxuderces dentatus</i> (Ox.de)	0.029	0	0.014	0	0.057	0.001	0	0	0.01	0	0.06	0.001
<i>Periophthalmus novemradiatus</i> (Pe.no)	0.114	0	0.143	0	0.443	0.001	8.53	0.026	3.80	0.011	10.13	0.030
<i>Pseudapocryptes elongates</i> (Psp.el)	0.043	0	1.943	0.021	1.271	0.019	0.63	0.009	0.91	0.014	0.79	0.005
<i>Pseudorhombus javanicus</i> (Psd.ja)	0.043	0	0	0	0.043	0.005	0	0	0	0	0	0
<i>Scatophagus argus</i> (Sc.ar)	0.014	0.009	0	0	0.443	0.120	0	0	0	0	0	0
<i>Setipinna taty</i> (Se.ta)	0.200	0.003	0.714	0.011	0.771	0.008	0	0	0	0	0	0
<i>Sillaginopsis panigus</i> (Si.pa)	0.114	0.028	0	0	0.029	0.005	0	0	0	0	0	0
<i>Strongylura strongylura</i> (Str.st)	0	0	0.143	0.009	0.100	0.042	0	0	0	0	0	0
<i>Strophidon sathete</i> (Stp.sa)	0	0	0.014	0.007	0.071	0.033	0	0	0.03	0.014	0.07	0.021
<i>Taenioides buchanani</i> (Ta.bu)	0.014	0	0	0	0.057	0.001	0	0	0	0	0.06	0.001
<i>Terapon jarbua</i> (Te.ja)	0	0	0.614	0.018	0.314	0.009	0	0	0	0	0	0
<i>Toxotes chatareus</i> (To.ch)	0.814	0.020	0.029	0.004	0.043	0.004	0	0	0	0	0	0
<i>Trichiurus gangeticus</i> (Tri.ga)	1.371	0.021	0.357	0.026	1.771	0.102	0	0	0	0	0	0
<i>Trypauchen vagina</i> (Try.va)	0.014	0	0.043	0.001	0.086	0.001	0	0	0.11	0.001	0.26	0.004
<i>Uroconger lepturus</i> (Uroc.le)	0.014	0	0.014	0	0.029	0.001	0.03	0	0.01	0	0.11	0.001
<i>Uropterygius marmoratus</i> (Urop.ma)	0	0	0.014	0.004	0.171	0.051	0	0	0.23	0.057	0.13	0.043

Table 3. Water and soil parameters (abbreviations given in parenthesis) recorded from the study area of intertidal mudflats in Indian Sundarbans

Parameter	Pre-monsoon	Monsoon	Post-monsoon
Dissolved oxygen (DO) (mg l ⁻¹)	7.24 – 7.91	7.41 – 8.22	7.01 – 10.10
Salinity (Sal) (PSS)	21.73 - 35.46	12.79 - 28.45	14.80 - 28.60
Water temp. (W. tm) (°C)	30.50 - 37.50	27.20 - 32.50	21.80 - 28.20
pH (pH)	6.90 - 8.50	6.60 - 8.10	6.90 - 8.10
TDS (TDS) (g l ⁻¹)	1.30 - 2.17	1.04 - 4.53	1.10 - 7.04
Soil organic carbon (S OC) (%)	0.78 - 2.17	1.66 - 1.79	0.70 - 2.14
Soil organic matter (S OM) (%)	0.45 – 1.20	0.87 – 1.04	0.65 – 1.24

Based on four non-parametric methods of species richness estimations, the expected species richness for the mudflats during three distinct seasons at high tide and low tide were calculated (Fig. 5). The result showed that a total

of 31 species were enumerated from this region during high tide and low tide, while the Jackknife 1 and Chao1 estimators gave similar estimates of 24, 25, 29 species, and the Bootstrap method gave 25, 26 and 29 species during

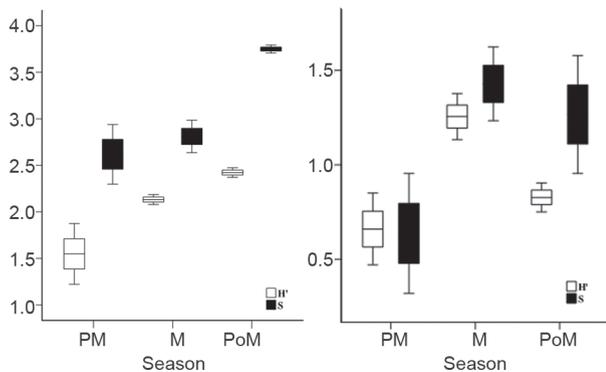


Fig. 5. Boxplot of Shannon Weiner (H) and Species richness (S) during three pre-monsoon (PM), monsoon (M) and post-monsoon (PoM) seasons in the study site of Indian Sundarbans at high tide (A) and low tide (B)

pre-monsoon, monsoon and post-monsoon seasons respectively. On the other hand, during low tide, the above three estimators gave the same estimates of 6 and 12 species during pre-monsoon and post-monsoon respectively, while bootstrap estimated the highest (14 species) and jackknife indicated the lowest values (12 species) during monsoon season. Palmer (1990) conducted a comparative study on some methods of species richness estimation by extrapolation, integration of log-normal distributions and non-parametric estimates (Bootstrap and Jackknife method) on plant species data for a given area. He found that the non-parametric estimators (and especially the Jackknife method) gave the most precise estimate. The current study showed that all of the three estimators showed more or less similar estimate of species during pre-monsoon and monsoon seasons irrespective of tidal cycle, but the Jackknife method showed the highest estimate of 26 species at ebb tide and 14 species at low tide. Hence, the estimate from the Jackknife method seems to be a 'safe' upper limit for the actual species richness of the fishes of the region.

Several global patterns in fish species richness exists that may help in explaining the higher species richness (Alongi, 2002). The mangrove fish communities of the Indo-western Pacific are more speciose compared to Atlantic estuaries (Alongi, 2002) and the same trend may apply to eastern Pacific estuaries. Moreover, connectivity between mangrove and mudflat ecosystems as well as with other adjacent ecosystems such as coral reefs, tidal creeks, rivers and seagrass beds may influence composition of fish community (Robertson and Blaber, 1992). The mudflats under study are in close proximity to other species rich systems and hence, harbour a higher diversity of species, particularly during post-monsoon under both the tidal conditions. The results are in agreement with earlier reports from certain mangrove lined shores (Flores-Verdugo *et al.*, 1990; Laroche *et al.*, 1997; Barletta *et al.*, 2003).

Fish assemblage

The fish assemblage at low tide was dominated by the mudskipper, *Periophthalmus novemradiatus* with percentage abundance ranging from 61.11 to 82.50% throughout the year. *Boleophthalmus boddarti* was also abundant at low tide during monsoon (13.54%) and post-monsoon seasons (25.51%). *Coilia ramcarati*, *Glossogobius giuris*, *Liza parsia* and *Mystus gulio* were ubiquitous during high tide when mudflats are submerged under water and abundant across seasons. They together comprised 18.54%, 56.62% and 35.49% of the total number of individuals caught in pre-monsoon, monsoon and post-monsoon respectively. *Pseudorhombus javanicus* was well represented at both high tide (10.39%) and low tidal (13.99 %) conditions but was restricted during monsoon season only. *Butis butis* was abundant (13.13%) at high tide only during monsoon. In contrast, *Trichuirus gangeticus*, *Toxotes chatareus* and *Cynoglossus lingua* were found during pre-monsoon and post-monsoon seasons at high tide (Fig. 6).

The non-metric multidimensional scaling analysis provides a clear distinction of fish samples between high and low tide (Fig. 7) from cumulative data obtained during three year study period. The fish density and standing stock data showed no significant differences ($p = 0.1$) amongst season during high tide. In contrast, significant seasonal fluctuations ($p = 0.05$) in the fish standing stock were detected for low tide by means of pair-wise comparison by ANOSIM. Using SIMPER, the species that most contributed to these seasons were identified. Two gobiid fishes (*Oxuderces dentatus* and *Trypauchen vagina*), two species of Muraenidae family (*Strophidon sathete* and *Uropterygius marmoratus*), three species each from Congridae, Moringuidae and Muraenisocidae (*Muraenesox bagio*, *Moringua raitaborua*, *Ophichthus apicalis*) determined the difference between the post-monsoon season and monsoon.

Several studies have documented that mangrove habitats provide unique resources for juvenile fish compared with adjacent habitats such as seagrass meadows and mudflats (Robertson and Duke, 1987; Chong *et al.*, 1990; Laegdsgaard and Johnson, 1995; Ikejima *et al.*, 2003). Halliday and Young (1996) found that juveniles of economically important species contributed more than 76% of individuals from a subtropical mangrove forest in Tin Can Bay, Australia. Bell *et al.* (1984) documented that 38% of the fish density in a temperate tidal mangrove creek in Botany Bay, New South Wales, was represented by juveniles of commercially important species. Morton (1990) reported that 75% of the fish density in a subtropical mangrove area was comprised of economically important species. Little *et al.* (1988) also collected a high proportion

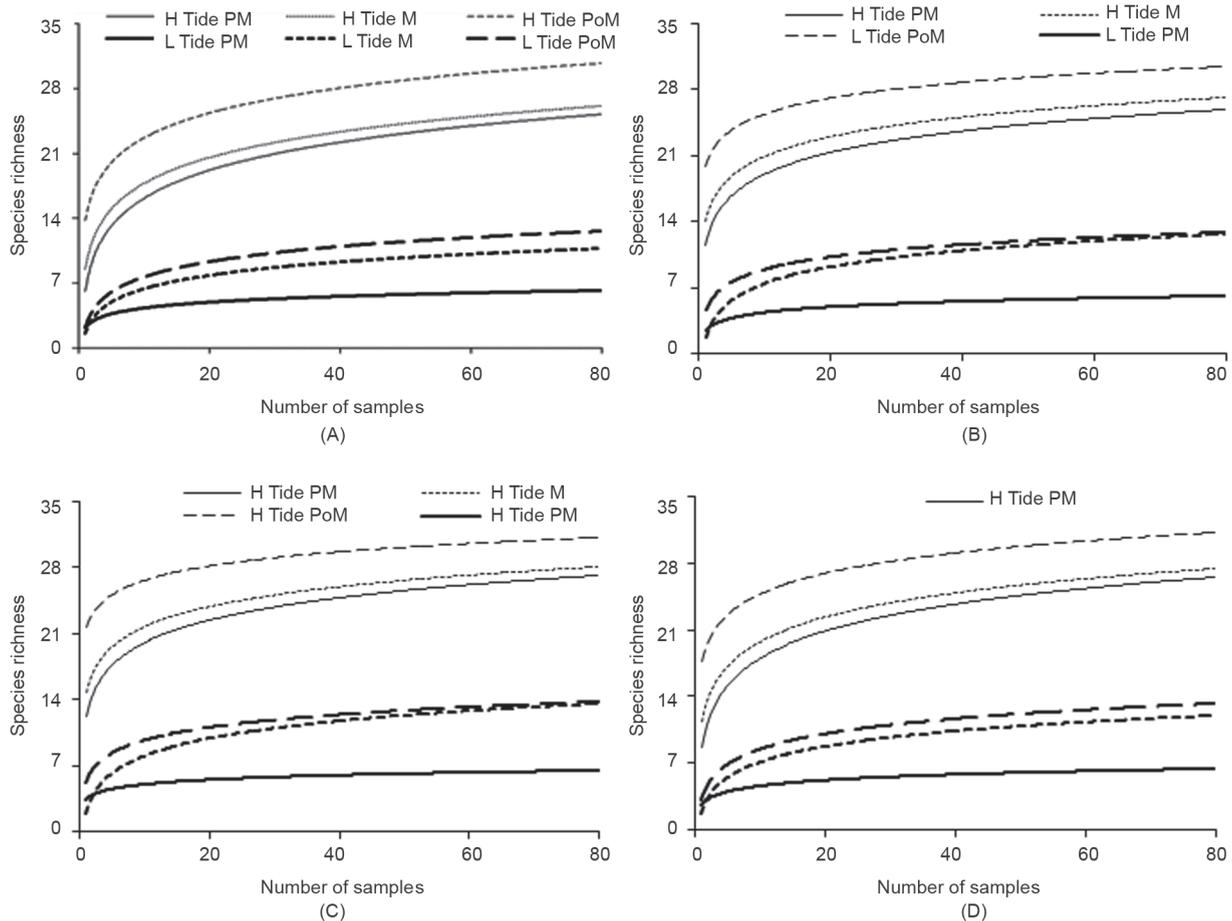


Fig. 6. Species accumulation curves generated by various species richness estimators (A: Species accumulation curve, B: Chao1, C: Jackknife1, D: Bootstrap) during high tidal (H Tide) and low tidal (L Tide) conditions. PM: Pre-monsoon; M: Monsoon, PoM: Post-monsoon

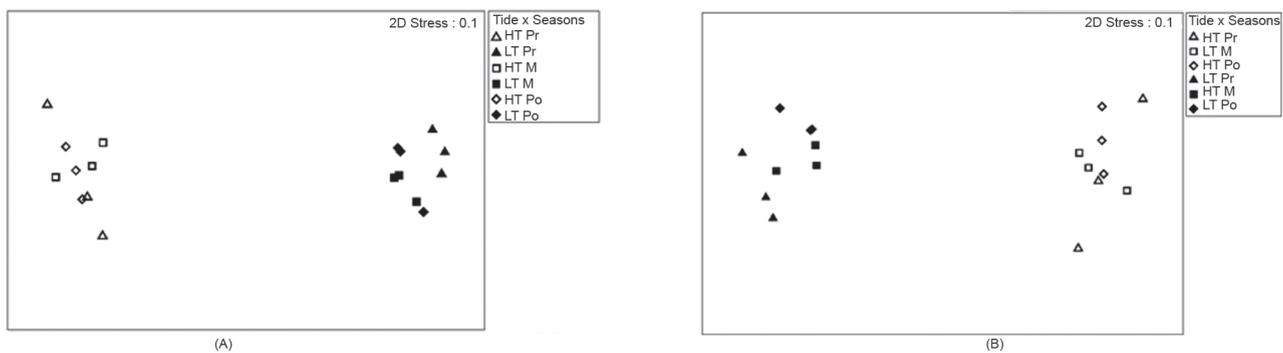


Fig. 7. Non-metric multidimensional scaling (MDS) ordination of fish communities in three different seasons at high tide and low tide based on fish density (A) and fish standing stock (B)

of juvenile individuals (46%) in a mangrove creek on the coast of Kenya and noted a similar trend from other mangrove studies including Stoner (1986) with 55% of individuals collected being juveniles. Yáñez-Arancibia *et al.* (1980) documented 46% of individuals collected as juveniles. In the present study, 15 species of the 31 collected from both high and low tidal conditions comprised

juveniles and developing adults. The collected species belong to families Bagridae, Gerreidae, Mugilidae, Teraponidae, Toxotidae *etc.*, many of which are economically important and are known to inhabit estuaries at early life history stages (Robertson and Blaber, 1992; Halliday and Young, 1996; Blaber, 1997; Ikejima *et al.*, 2003; Shervette *et al.*, 2007). From the results of the present

investigations it is evident that the mudflats of Indian Sundarbans provide an important nursery area for a variety of economically valuable fish species. The fish assemblages comprised species which are found throughout the seasons during both low and high tides. Therefore, it may be suggested that sparsely unvegetated mudflats act probably as 'buffer zones' and seasonal migration routes for many fish species.

The results also point out that the tidal conditions and seasonal fluctuations are relevant in structuring the small-sized or juvenile fish assemblages of the mudflat habitats of Indian Sundarbans due to different ecological reasons. The inundated mudflats during post-monsoon sustain high diversity as these habitats come under strong influence of the communication channels with open sea. The marine influence contributes significantly to increased species diversity in the lagoonal systems supporting the confinement theory (Guelorget and Perthuisot, 1983). Lower ichthyofaunal diversity in the exposed mudflats can be reasoned from the said fact of hydrological connectivity. Therefore, the sustainability of diversified fish assemblage in mudflats depends on a constant monitoring and conservation efforts of this unique habitat. With hardly anything known about the aquatic fauna of the region (some of the species are yet to be described), much of the fauna in these habitats could be lost forever even before they are known to us.

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