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Review

Coastal and estuarine resources of Bangladesh: management and conservation issues

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Abstract : The coastal area of Bangladesh includes a number of bays into which different types of rivers empty, creating an estuarine ecosystem adjacent to the shore. The main estuarine systems are Brahmaputra-Megna (Gangetic delta), Karnaphuly, Matamuhuri, Bakkhali and Naf rivers, which are comprised of mangroves, salt marshes, seagrass, seaweeds, fisheries, coastal birds, animals, coral reefs, deltas, salt beds, minerals and sand dunes. The estuarine environment, which serves as feeding, breeding and nursery grounds for a variety of animals, varies according to the volume of discharge of the river and tidal range. It is highly productive in terms of nutrient input from different sources that promotes other living resources in the estuaries. Drought conditions exist during the winter months, i.e. November to February, and effective rainfall is confined to the monsoon period, i.e. May to June. Changes in salinity and turbidity depend on annual rainfall. The colour of most estuarine waters is tea brown or brown due to heavy outflows during the monsoon. The tidal mixing and riverine discharge governs the distribution of the hydrological parameters. The pH of these waters is reported to be slightly alkaline (>7.66) and dissolved oxygen (<6.0 mg/l) shows an inverse relationship to temperature. Studies of plankton have indicated two periods of maximum abundance, i.e. February-March and August-September. The abundance of fish and shrimp larvae varies in number and composition with season. Many marine and freshwater species are available in various types of coastal brackish water, which depend on monsoonal activities and local environmental conditions.

Keywords: coast, estuary, resources, ecology, Bangladesh

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Introduction

Bangladesh is blessed with an extensive coastline of about 710 Km [1]. The southeastern and southwestern coast of this country is mostly covered by a complex estuarine ecosystem with strong interactions of biotic and abiotic factors. According to Ketchum [2], an estuarine environment is a unique and important part of the aquatic habitat and forms the transition zone between the inland world of freshwater and the seawater lying offshore. Estuaries play a vital role in the life history development of many marine and brackish water coastal animals, and some live out their entire life cycle within the estuarine environment [3-4]. This estuarine ecosystem is dominated by a huge amount of living resources such as aquatic macrophytes (i.e. tropical moist forest, salt marshes, seagrasses and seaweeds), fisheries, avian fauna, animals and coral reefs.

In Bangladesh, the estuarine system is comprised mainly of the Brahmaputra-Megna (Gangetic delta), Karnaphuly, Matamuhuri, Bakkhali and Naf rivers (Figure 1). It is well established that this kind of estuarine environment is highly productive in terms of nutrient input from different sources, which promotes other living resources in the vicinity of the estuaries. These diverse living resources in the estuarine environment play an important role which is economically significant in many ways. In addition, the estuarine resources of this country greatly contribute to the national economy as well as promote the socio-economic well-being of the coastal and often poor communities. However, although coastal and estuarine resources contribute a vital role in terms of both the ecosystem and the economy, study of the estuarine coastal environment in Bangladesh is meagre. To date, no systematic investigations have been carried out on the eco-biology of the estuarine living resources in the country. Few scientific data on hydrology [3], seaweeds [5-7], zooplankton [8-13] and benthos exist [14]. Similarly, the common physical and chemical parameters of water and soil in the estuarine and coastal areas were conducted only recently [15]. Therefore, any form of critical investigation on estuarine living resources and their environment can be considered as an important study in Bangladesh. As part of the estuarine study, this paper deals with the living estuarine resources of Bangladesh and their usefulness, and is the first of a series dealing with estuarine habitats in the country.

Ecological Feature

Climate

The coastal and estuarine environment of Bangladesh has a maritime climate with temperatures buffered by the nearby ocean [16]. The maximum air temperature attained in summer ranges from 31.1-33.3º C and the minimum in winter ranges from 24.8-29.8º C [3, 17]. Drought conditions prevail during the winter months (November-February) and rainfall is confined to the monsoon period. Normally, 80-90% of the annual rainfall occurs during the monsoon months of June-September. Mahmood [17] recorded 3558 mm and 1638 mm annual rainfall in the coastal areas of Cox's Bazar and Satkhira respectively. The entire coastal and estuarine area of Bangladesh is prone to violent storms during the pre-monsoon (March-April) and post-monsoon (October-November) period. Sometimes, tidal bores associated with cyclones cause great loss of property and life.

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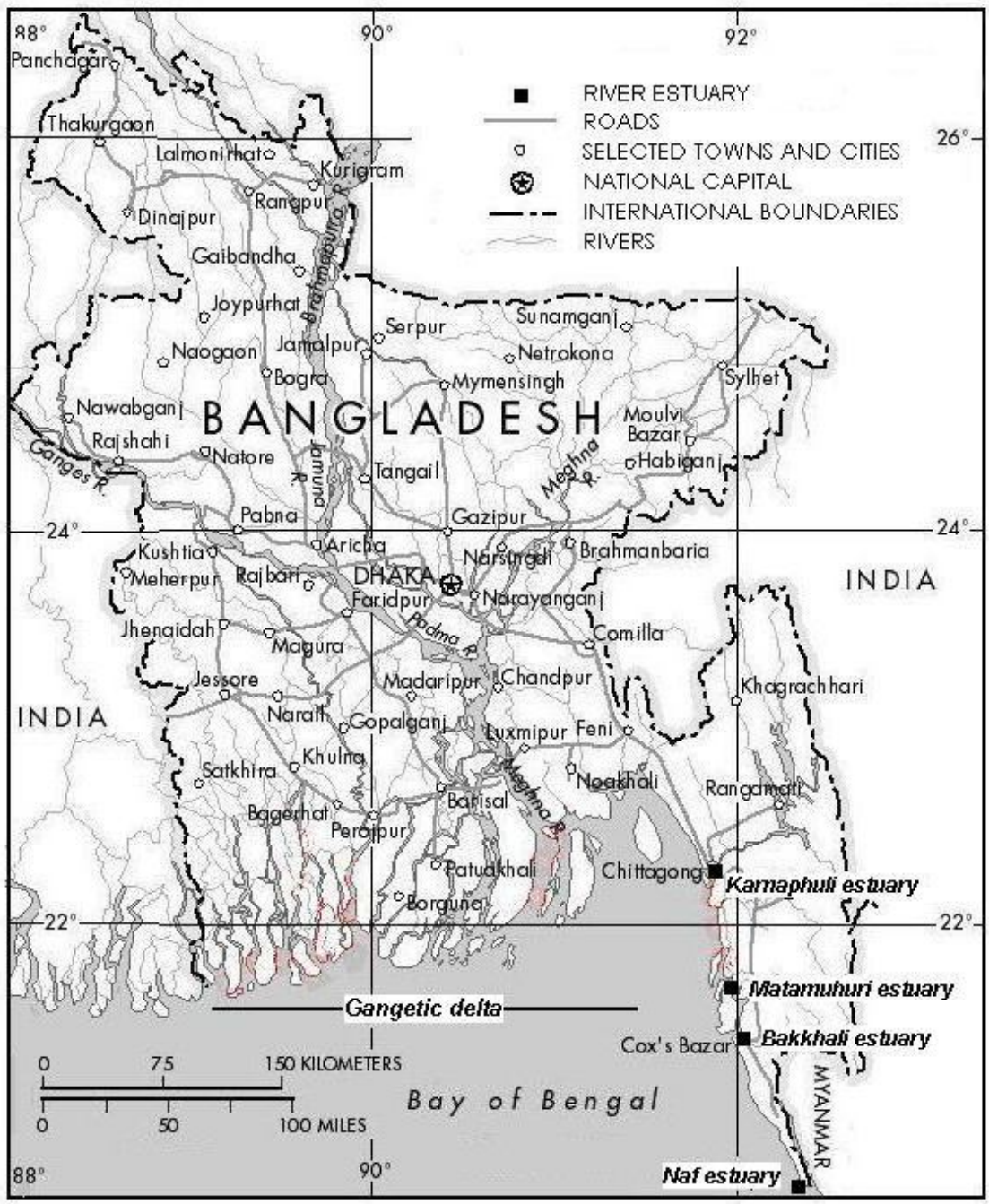

Figure 1. Major coastal and estuarine areas of Bangladesh

Hydrology of the coastal estuaries

The tides in the coastal and estuarine areas are semi-diurnal with two high and two low periods per day and have maximum amplitude of 3-4 m at spring tide [17]. The tidal activity is an important mechanism for the movement of water and nutrients especially in the estuarine areas, and this is probably a reason for the wide range of biodiversity in the estuarine water. The tidal range and river discharge are responsible for the extension of estuarine environment in the sea. The variation of tide level in the coastal areas may be attributed to the depth of the bay and varying topography of coastal water [18]. The tide penetrates up to 170 km in the south-west and 0-50 km in the south-east area of

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Bangladesh during lean period (April-May) depending on the topography and channels in the area [19]. The Bangladesh Inter Water and Transportation Authority [20] recorded 4.27 m neap tides and 6.10 m spring tides in the coastal area of Sandwip Island, Chittagong. However, the tidal range is reduced toward the south along the south-eastern coast of Bangladesh. In 24 years of tidal study, Chowdhury [21] observed that the monthly mean tidal range varies from 1.48 to 4.90 m with the mean value of 3.84 m in the coastline adjacent to the Karnaphuly River estuary.

The physico-chemical parameters of the estuarine environment show regular seasonal patterns of variation (Table 1 and Figure 2). The annual surface water temperature (<30º C) of the estuarine system is closely related to the annual cycle of air temperature. The cycle of dissolved oxygen (<6.0 mg/l) is mainly regulated by air temperature (<33º C) in some of the estuarine areas [22]. Mahmood et al. [3] observed an inverse relationship between dissolved oxygen and water temperature, and direct relationship between dissolved oxygen and pH. These relationships reveal that the influence of biological input/process, water discharge, temperature of neritic water and oxygen uptake in the chemical processes seem to be less important to change and long term variation in the dissolved oxygen and pH cycle in the estuarine environment.

Table 1. Physico-chemical parameters of the water of Bakkhali and Karnaphuli river estuary [3, 27]

	MONTH											
Factor	J	A	S	O	N	D	J	F	M	A	M	J
Water temp. (º C)	30.1	29.73	28.60	27.6	25.00	21.70	21.06	22.16	26.06	26.63	28.08	30.06
DO (mg/l)	3.21	3.56	4.23	3.15	3.55	5.37	3.14	2.74	1.89	2.33	2.47	3.79
pH	7.8	7.8	7.7	7.4	6.7	6.2	5.9	5.9	6.3	7.3	7.8	7.7
PO_4- P(mg/l)	0.17	0.13	0.13	0.08	0.11	0.09	0.11	0.13	0.14	0.12	0.17	1.5
MHW (m)	13.5	13.8	13.5	12.7	11.6	10.6	9.9	10	10.3	11	11.75	12.85
MLW (m)	3.07	3.24	3.05	2.62	2.01	1.4	0.92	0.69	0.8	1.33	2	2.65
Salinity (‰)	8.7	7.53	4.53	9.17	11.33	15.04	17.07	18.42	17.42	11.78	5.94	2.63
Air temp. (ºC)	31.7	30.1	29.1	28.26	25.13	23.13	22.03	21.8	26.26	27.18	29.06	30.83
Rainfall (cm)	56.52	29.49	16.43	12.29	2.54	0.076	0	0	0.18	2.77	31.22	51.16
BOD (mg/l)	2.02	1.12	1.04	1.37	1.51	1.61	1.02	1.86	3.38	3.13	3.51	2.22
NH_3 (mg/l)	2.26	2.31	1.44	1.06	1.15	0.49	0.25	1.0	1.17	1.52	2.30	2.58
TDS (mg/l)	300.5	264.3	443.4	385.7	285.7	322.0	408.2	527.4	457.5	474.4	530.24	582.9
TSS (mg/l)	109.81	97.69	99.28	108.74	98.17	124.05	208.15	199.45	147.52	204.93	111.44	104.50

Note: MHW = mean high water, MLW = mean low water, DO=dissolved oxygen, BOD = biological oxygen demand, TDS= total dissolved solids, TSS = total suspended solids

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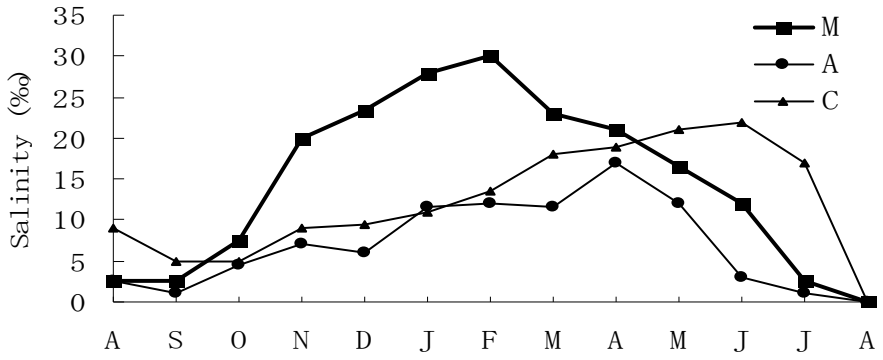

Figure 2. Seasonal variation (August 1982-August 1983) of salinity in the estuaries of the Mathamuhari River (M) of Chakaria, Chittagong; the Andermanik River (A) at Khepupara, Patuakhali; the Coxali River (C) at Satkhira, Khulna [17]

The most notable feature of the hydrology of the estuarine waters is the presence of a prolonged low salinity (<15‰) period mostly during the monsoon and certain period of post-monsoon. During the monsoon season, the water of the estuaries remains comparatively hyposaline due to heavy precipitation and freshwater discharge. This symptom persists for 5 months in the Matamuhuri estuary (Cox's Bazar), for 11 months in the Andhermanik estuary (Patuakhali) and 7 months in the Coxali estuary (Khulna) throughout the monsoon and post-monsoon period (Table 2 and Figure 2). The FAO of United Nations [23] recorded a wide variation in salinity (0-29%) at the estuarine system of Sunderban mangrove forest, Khulna. Salinity stratification is comparatively less during the monsoon than the other seasons of the year. Spencer [24] stated that the development of intensive chlorinity stratification under the influence of freshwater discharge is common to all estuarine tropical and subtropical systems. Similar results were observed by Ramanadham and Varadarajulu [25] in India. Based on the climatic factors, however, in the estuarine environment of Bangladesh, considerable salinity stratification exists during the non-rainy days when the evaporation rate is high during the dry seasons (November-February and April-May) and freshwater movement is not strong enough to create turbulent mixing with the tidal water.

Table 2. Variation in hydrological parameters of some of the estuaries of Bangladesh [17]

Parameter	Matamuhuri River (Chittagong)	Andhermanik River (Patuakhali)	Coxali River (Khulna)
Water temp. (° C)	21.38-31.60	22.50-31.88	21.07-31.16
DO (mg/l)	1.76-6.09	5.01-7.37	3.59-5.49
Salinity (%)	0.40-32.6	0.54-17.58	5.10-21.59
Transparency (cm)	22.8-97.5	9.0-31.0	7.4-14.3

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Horizontally, salinity variation is observed at the upper portion of the estuary [22] where fresh water flow dilutes with high tide. The vertical salinity distribution is always observed at the bottom; it appears that tidal water is more saline and heavier than the fluvial water-mass of the estuary, the probable reason for the heavier saline bottom water and the less saline surface water of the estuary. This phenomenon probably exists in all the coastal estuarine water systems in Bangladesh.

Based on universal relationships between climate and tide, the estuaries of Bangladesh are typical in that both freshwater discharge and tidal oscillation act together in creating a high mixing of neritic and fluvial water. This type of phenomenon occurs in the other estuaries elsewhere [2, 25, 26]. According to Mahmood et al. [3] the high circulation pattern is the dominant factor in the distribution of organisms especially the drifting forms in the estuarine systems of Bangladesh. Turbidity and total suspended solids (TSS) also depend on circulation pattern and freshwater discharge, and the range of TSS is 91.17-213.25 mg/l in the Bakkhali River estuary [27].

Biological Feature

Mangroves

Mangrove forests are usually found in the tropical and sub-tropical riverbanks, estuaries and along the coastlines, adapting to anaerobic conditions of both salt and freshwater environment. A mangrove community plays an important role to the stabilisation and maintenance of various closely linked ecosystems, such as seagrass, coral reef and marine ecosystems. It represents a unique ecological niche and habitat for a variety of marine and terrestrial animals. The amount of organic matter produced by a mangrove community supports not only the mangrove ecosystem itself but also its related ecosystems. Apart from providing an important coastal habitat for many types of species, a mangrove forest forms a community which helps to stabilise river banks and coastlines. Mangroves export detritus and nutrients into nearby systems that form a complex food chain which in turn supports valuable near-shore fisheries. In general, the mangrove forest of Bangladesh is divided into three zones, namely the Sunderban (largest continuous single productive forest of the world with an area of 577,040 ha), the Chakaria Sunderban in Cox's Bazar with an area of 8540 ha, and the planted coastal mangrove forests. The plantation of mangroves was introduced in the coastal area of Bangladesh in 1964 and is still carried out in the coastal belt of Cox's Bazar, Chittagong, Barisal, Patuakhali and off-shore islands, and now covers an area of 100,000 ha [28].

Small patches of mangroves are also found along the belt of nearly all coastal sub-districts. Different types of mangrove species dominate in different places of the coastal and estuarine areas of Bangladesh (Table 3). Fishing within the mangroves is one of the major activities in the coastal area. Several species of fish are found; common ones are mullet (*Mugil* spp.), marine catfish (*Mystus* spp.), seabass (*Lates calcarifer*) and black tiger shrimp (*Penaeus monodon*). Other species of shrimps are *Metapenaeus monoceros*, *M. brevicornis*, *P. indicus* and *Macrobrachium rosenbergii*. However, ever-expanding traditional culture of tiger shrimp has already led to the destruction of mangroves in Chakaria Sunderban, Moheskhali, Teknaf and Sonadia Island at the south-east coast of the country. In 2002-3, the destruction of mangroves for traditional shrimp culture in the south-eastern area was much higher than the previous years [Abu Hena, unpublished data]. The environmental damage and destruction of fishery resources is still unknown in those areas. According to available data of

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Mahmood [28] and Ahmad [29], the loss of mangrove wetland in Bangladesh during the last 25 years is about 50-70%. Similarly, in Sri Lanka an 11-65% [30] and in Thailand a 12-25% loss were estimated [31]. However, not all the blame for mangrove destruction lies in coastal aquaculture. Depending on the locality, the impact of the destructive uses is highly variable, though the scale of impact commonly found elsewhere [32] is similar to that found in Bangladesh, i.e. from (in descending order) clear cut for firewood and pool, conversion to agriculture (salt bed and aquaculture), conversion to human settlement, and diversion of fresh water or water quality changes.

Table 3. Mangroves of the coastal and estuarine areas of Bangladesh [61]

Family	Species
Acanthaceae	*Acanthus ilicifolius*
Pteridiaceae	*Acrosticum aureum*
Plumbaginaceae	*Aegialitis rotundifolia*
Myrsinaceae	*Aegiceras corniculatum*
Avicenniaceae	*Avicennia alba, A. marina, A. officinalis*
Rhizophoraceae	*Rhizophora mucronata, R. apiculata*
	Bruguiera grymorrhiza, B. seangula
	Ceriops decandra, C. tagal
	Kandelia candel
Euphorbiaceae	*Excoecaria agallocha, E.indica*
Sterculiaceae	*Heritiera fomes, H. littoralis (Extinct)*
Combretaceae	*Luminitzera racemosa*
Sonneratiaceae	*Sonneratia caseolaris, S. apetala*
Meliaceae	*Xylocarpus granatum, X. mekongensis*
Palmae	*Nypa fruticans*

Seaweeds

Sub-tidal macroalgal beds, i.e. *Sargassum*, *Dictyota* and *Codium*, play an important role in the life cycle of numerous important commercial species. Benthic forms of seaweeds are attached to the pneumatophores of the mangrove in inter-tidal areas of the coast. The rocky substratum of Saint Martin's Island is also a favourable place for seaweed growth and propagation. About 165 species belonging to 77 genera of seaweeds have been recorded in the coastal and estuarine areas (Table 4), whereas 1500 metric ton of red seaweed biomass are available around Saint Martin's Island [33]. However, they are often consumed elsewhere in the world and are not part of the daily tranditional diet in Bangladesh.

Table 4. Different groups of benthic marine algae of the coastal and estuarine areas of Bangladesh [33]

Division	No. of genera	No. of species
Chlorophyta	15	38
Chrysophyta	01	05
Phaeophyta	14	46
Rhodophyta	35	49
Cyanophyta	12	27
Total	77	165

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Salt marshes and seagrass

Salt marshes and seagrass are well recognised as important components of coastal productivity all over the world. These systems serve as feeding area for a variety of species including avifauna (birds), and contribute considerable quantities of leaf detritus to the water column. The detritus from seagrass plays an active part in nitrogen and phosphorus cycles that provide essential elements to the primary producers of all ecosystems. Seagrass also serves as a protective canopy, shielding the inhabitants of the bed from the effects of strong sunlight. When the bed occurs in the inter-tidal zone, the leaves may cover the bottom substrate during low tide, protecting the inhabitants from desiccation. Information on the existence of salt marsh and seagrass beds is lacking. No inventories have been conducted so far on salt marsh and seagrass resources in the coastal area of Bangladesh. Only 5 salt marsh plants (*Porteresia coarctata, Imperata cylindrica*, *Eriochloa procera*, *Myriostachya wightiana* and *Phragmites karka*), and five types of seagrass have been reported in the coastal and estuarine areas (Table 5) compared to nine species in Sabah, Malaysia.

Table 5. Seagrass of the coastal and estuarine areas of Bangladesh [36, 62-63] and Sabah, Malaysia [64]

Coastal and estuarine area, Bangladesh	Sabah, east Malaysia
Hydrocharitaceae	Hydrocharitaceae
Halophila decipiens	*Enhalus acoroides*
Halophila beccarii	*Halophila ovalis*
	Halophila minor
	Thalassia hemprichii
Cymodoceaceae	Cymodoceaceae
Halodule uninervis	*Cymodocea serrulata*
*Halodule pinifolia**	*Syringodium isoetifolium*
*Ruppia maritima**	*Halodule pinifolia*
	Halodule uninervis
	Cymodocea rotundata

* unpublished and newly recorded

Estuarine phytoplankton

Phytoplankton is a primary producer in the estuarine water. Phytoplankton produces organic compounds by utilising the solar energy during the photosynthesis process and releases oxygen into the estuarine water. This system controls the oxygen balance in any aquatic environment and mainly near the surface (0.4-0.6 m) where productivity is high [34]. It is well known that in any aquatic environment, the food chain starts with the phytoplankton. Thus, it plays a vital role in the estuarine food chain. Very little is known about the phytoplankton of the estuarine systems of Bangladesh. A few studies such as those of Salam and Khan [6], Ali et al. [35], Islam and Aziz [36], Hoque et al. [37] and Zafar [38] have been conducted on the seasonal abundance and distribution of phytoplankton in the estuarine environment (Table 6). The studies recorded that the major groups of phytoplankton are diatoms (88.60%), followed by dinophyceae (6.32%) and myxophyceae (5.10%). According to Ali et

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al. [35] higher production of phytoplankton was found in the dry season while the lowest one was recorded during the monsoon. However, its distribution and abundance in any estuarine environment is also influenced by the wind direction, current, nutrient input and freshwater discharge, which are not well studied in Bangladesh.

Table 6. Phytoplankton of the estuarine environment of Bangladesh [35, 66]

Group	Species
Diatoms	*Chaetoceros atlanticus, C. costatus, C. curvisetus*
	Coseinodiscus centrales, C. lineatus, C. excentricus, C. nitidus, C. radiatus, C. curvatulus, C. marginatus, C. gigas, C. perforatus, C. granii
	Biddulphia granulata, B. mobiliensis
	Lauderia sp.
	Nitzschia closterium, N. pacifica, N. longissima, N. pungens, N. sigma, N. seriala, N. paradoxa
	Thalasionema nitzschioides
	Rhizosolenia sp.
	Thalasiothrix longissima, T. frauenfeldi
	Encampia zoodiacus
	Melosira sulcata, M. nummuloides, M. moniliformis, M. varians
	Asterionella japonica
	Hemidiscus sp.
	Hemiaulus hauckii
	Anabaena circinalis
Myxophyceae	
	Oscillatoria tenuis, O. limosa
	Dinophysis sp.
Dinophyceae	
	Ceratium sp.

Estuarine fish and shellfish

The estuarine coastal and adjacent areas of Bangladesh support a variety of economically important fishes. The fishes are those that spend all or a major part of their lifetime in the estuarine environment; marine or freshwater species migrate seasonally into or through the estuaries. In the present state of investigation, a proper classification of fish species based on their period of life and availability in the estuaries is difficult. Mahmood and Khan [12], Ahmed [39-40] and Mahmood [28] described a tentative list of fishes and shrimps of the estuaries (Tables 7-8), while the FAO [23] gave a generalised list of the most common finfish for the estuaries.

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Table 7. Some of the shrimp fauna of the estuarine and mangrove ecosystem of Bangladesh [12, 28]

Family	Species
Penaeidae	
	Penaeus monodon, P. merguiensis, P. indicus. P. uncta
	Metapenaeus monoceros, M. lysianass, M. spinulatus, M. brevicornis, M. affinis
	Parapenaeopis sculptilis, P. stylifera, P. hardwickii, P. semisulcatus
Solenoceridae	
	Solenocera subnuda
Sergestidae	
	Acetes erythraeus, A. japonicus, A. indicus
Palaemonidae	
	Macrobrachium rosenbergii, M. lamarrei, M. rude, M. villosimanus,
	M. mirabile, M. birmanicum
	Palaemon Styliferus, P.(Nematopalaemon) tenuipes, P.(N) karnafuliensis
Alpheidae	
	Alpheus euphrosyne, A. crassimanus

Table 8. List of some ichthyofauna of coastal and estuarine environment of Bangladesh [12, 28]

Family	Species
Carcharhinidae	
	Scolidon lacticaudus
	Eusphyra blochii
Sphyrnidae	
	Carcharhinus melanopterus
Rhinobatidae	
	Rhynchobatus djiddensis
Dasyatidae	
	Dasyatis zugei
	Himatur uarnak, H. imbricata, H. fluviatilis
	Pastinachus sephen
Clupeidae	
	Escualosa thoracata
	Gudusia chapra
	Hilsa (Hilsa) kelee, H. (Tenualosa) ilisha, H. (T.) toil
	Anodontosoma chacunda
	Gonialosa manmina
	Dussumieria acuta
	Sardinella gibbosa, S. melanura, S. fembriat

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Table 8. (cont'd)

Family	Species
Pristigasteridae	
	llisha megaloptera, l. melastoma
	Rconda russelliana
Engraulidae	
	Thryssa dussumieri, T. hamiltonii
	Setipinna phasa, S. taty
	Coilia dussumieri, C. neglecta, C. ramcarati
	Stolephorus tri
Chirocentridae	
	Chirocentrus dorab, C. nundus
Elopidae	
	Elops machnata
Muraenesocida*e*	
	Congresox talabon
	Muraenesox cinereus
Cuchidae	
	Cuchia cuchia
Bagridae	
	Mystus gulio
Schilbeidae	
	Silonia silondia
Pangasiidae	
	Pangasius pangasius
Ariidae	
	Arius sona, A. gogora, A. maculatus, A. buchanani, A. caelatus, A. thalassinus, A. dussumieri, A. arius, A. nenga
Plotosidae	
	Plotosus canius, P. lineatus
Synodontidae	
	Saurida tumbil
Harpadontidae	
	Harpodon nehereus
Hemiramphidae	
	Hemiramphus georgii
Fistulariidae	
	Fistularia villosa
Syngnathidae	
	Hippocampus kuda

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Table 8. (cont'd)

Family	Species
Scorpaenidae	
	Pterois russeli, P. miles
Platycephalidae	
	Platycephalus crocodilus, P. scaber
	Rogadius asper
Ambassidae	
	Chanda nama
	Pseudambassis baculis, P. ranga
Centropomidae	
	Lates calcarifer
Serranidae	
	Cephalopholis miniatus
	Epinephelus fasciatus, E. tauvina
	Promicrops lanceolatus
Theraponidae	
	Therapon jarbua, T. theraps
Apogonidae	
	Apogon novemfasciatus, A. septemstiastus
Sillaginidae	
	Sillago domina, S. shihama
	Sillaginopsis panijus
Lactariidae	
	Lactarius lactarius
Carangidae	
	Alectis indica, A. melanoptera
	Alepes djedaba
	Megalaspis cordyla
	Atropus atropus
	Scomberoides commersonianus
	Carangoides malabaricus
	Selar boops, S. crumenophthalmus
Formionidae	
	Formio niger
Menidae	
	Mene maculata
Leiognathidae	
	Gazza minuta
	Leignathus bindus, L. equulus, L. fasciatus

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Table 8. (cont'd)

Family	Species
	Secutor ruconius, S. insidiator
Lutjanidae	
	Lutjanus johnii, L. sanguineus
	Pinjalo pinjalo
Nemipteridae	
	Nemipterus japonicus, N. nematophorus
Lobotidae	
	Lobotes surinamensis
Gerreidae	
	Gerres filamentosus
	Pentaprion longimanus
Haemulidae	
	Pomadasys argentus, P. maculates, P. hasta
Lethrinidae	
	Lethrinus ornatus
Sparidae	
	Acanthopagarus latua
	Argyrops spinifer
Sciaenidae	
	Atrobucca nibe
	Dendrophysa russelli
	Macrospinosa cuja
	Protonibea diacanthus
	Pama pama
	Panna microdon
	Johnius argentatus
	Johnius dussumieri
	Pterotolithus maculatus
	Otolithes ruber
	Pennahia macropthalmus
Mullidae	
	Upeneus sulphureus
	Parupeneus heptacanthus
Drepanidae	
	Drepane longimanus, D. punctatus
	Ephippus orbis
Scatophagidae	
	Scatophagus argus

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Table 8. (cont'd)

Family	Species
Mugilidae	
	Liza parsia, L. subviridis, L. tade
	Mugil cephalus, M. cascasia
	Valamugil speigleri
	Rhinomugil corsula
Sphyraenidae	
	Sphyraena barracuda, S. putnamiae
Polynemidae	
	Eleutheronema tetradactylum
	Polynemus paradiseus
	Polydactylus indicus, P. sexfilis, P. sextarius
Uranoscopidae	
	Uranoscopus quttatus
	lchthyscopus inermis
Eleotrididae	
	Eleotris fusca
	Butis melanostigma
Gobiidae	
	Brachygobius nunus
	Glossogobius giuris
	Pogonogobius planiformes
	Stigmatogobius sadanundio
	Apocryptes bato
	Boleopthalmus boddarti
	Parapocryptes batoides
	Pseudapocryptes lanceolatus
	Scartelaos viridis
	Periopthalmodon schlosseri
	Periopthalmus koelreuteri
Gobioididae	
	Odontamblyopus rubicundus
Trypauchenidae	
	Trypauchen vagina
Kurtidae	
	Kurtus indicus
Trichiuridae	
	Eupleurogrammus muticus
	Lepturacanthus savala

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Table 8. (cont'd)

Family	Species
	Trichiurus lepturus
Scombridae	
	Euthynnus affinis
	Rastrelliger brachysoma, R. kanagurta
	Sarda orientalis
	Scomberomorus commerson, S. quttatus
Stromateidae	
	Pampas argentaeus, P. chinensis
Psettodidae	
	Psettodes erumei
Bothidae	
	Pseudorhombus arius, P. elevatus, P. malayanus
Soleidae	
	Synaptura pan
	S.orientalis
	Zebreas altipinnis
	Cynoglossus bilineatus, C. cynoglossus, C. lingua, C. macrolepidotus,
	C. versicolor
	Paraplagusia bilineata
Triacanthidae	
	Triacanthus brevirostris
Balistidae	
	Abalistis stellatus
Tetraodontidae	
	Arothron stellaris
	Tetradon cutcutia
	Chelonodon fluviatilis, C. patoca

In the estuarine area of Sundarban, over 187 species are caught by commercial fishermen [28]. Out of 187 species only 22 species are most common throughout the year in the estuarine waters of Bangladesh (Table 9) [23]. Pillay [41-42] recorded over 120 species in the estuarine area of Sunderban, India and 128 species from 45 families in West African estuaries. About 138 species are recorded in Chilka Lake where many are only migrants or stray visitors [42]. In the estuary of the Rokan River in Sumatra, Hardenberg [43] recorded more than 150 species including occasional migrants. The number of individuals is, however, comparable.

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Table 9. General list of the most common fish and shrimp fauna available in the coastal environment of Bangladesh [23]

Family	Species
	Shrimp
Penaeidae	*Penaeus indicus* (H. Milne-Edw.), *P. monodon* (Fabricius)
	Metapenaeus brevicornis (H. Milne-Edw.), *M. monoceros* (Fabricius)
	Parapenaeopsis sculptilis (Heller), *P. stylifera* (H. Milne-Edw.)
Palaemonidae	*Macrobrachium dolicodaetylus* (Hi. lgendorf), *M. dyanus* (Henderson),
	M. rosenbergii (De Man), *M. villosimanus* (Tiwari)
	Palaemon karnafullensis (Khan-Fincham-Mahamood), *P. styliferus* (H. Miline-Edw.)
Sergestidae	*Acetes indicus* (H. Milne-Edw.)
	Fin fish
Polynemidae	*Eleutheronema tetradactylum* (Shaw)
	Polynemus paradiscus (Linn.)
Mugilidae	*Liza tade* (Forskal)
	Rhlnomugli corsula (Ham.)
Bagridae	*Mystus golio* (Ham.)
Clupediae	*Gonialosa manminna* (Ham)
	Tenualosa ilisha (Ham.)
	Ilisha megalopetra (Swainson)
Engrnulidae	*Collia ramcarati* (Ham. Buch)
	Septipinns phasa (Ham.)
	Stolephorus tri (Bleeker)
	Thrysssa purava (Ham.)
Gobiidae	*Apoeryptes bato* (Ham. Buch)
	Glossogoblus gluris (Ham.)
Taenioidae	*Odontamblyopus rubicundus* (Ham.)
Scatophagidae	*Scatophagus argus* (Linn.)
Centropomidae	*Lates calcarifer* (Bloch)
Sciaenidae	*Otolitholidaes pama* (Ham)
Cynoglossidae	*Cynoglossus cynoglossus*
Harpadontidae	*Harpodon nehereus* (Ham. Buch)
Sillaginidae	*Sillago domina* (Cuv. Val.)
Trichiuridae	*Lepturacanthus aavala* (Cuv.)

The fishery resources of the estuarine and coastal regions of Sunderban mangrove forest constitute 2-5% of the total capture fisheries of Bangladesh [44]. The common fishing method in almost all of the estuarine areas is by means of a fixed estuarine set bag net. Different sizes of the net are set against the current in shallow water areas by fastening the wings to bamboo poles driven into the bottom; the mouth of the net is kept open by means of bamboo poles. Other types of net used for

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fishing are gill net, drift net, larval net, trammel net, beach seine, marine set bag net, cast net, encircling net and drag net (Figure 3). In the estuarine areas of Bakkhali, Matamuhuri and Sunderban, narrow creeks or inter-tidal mud flats are often fenced off at high tide with walls of bamboo slats or netting. When the mud flat is drained dry at low tide, the fish are caught by hand. Cast nets are extensively used in the estuarine rivers in the country and catch a good amount of shrimps and fishes.

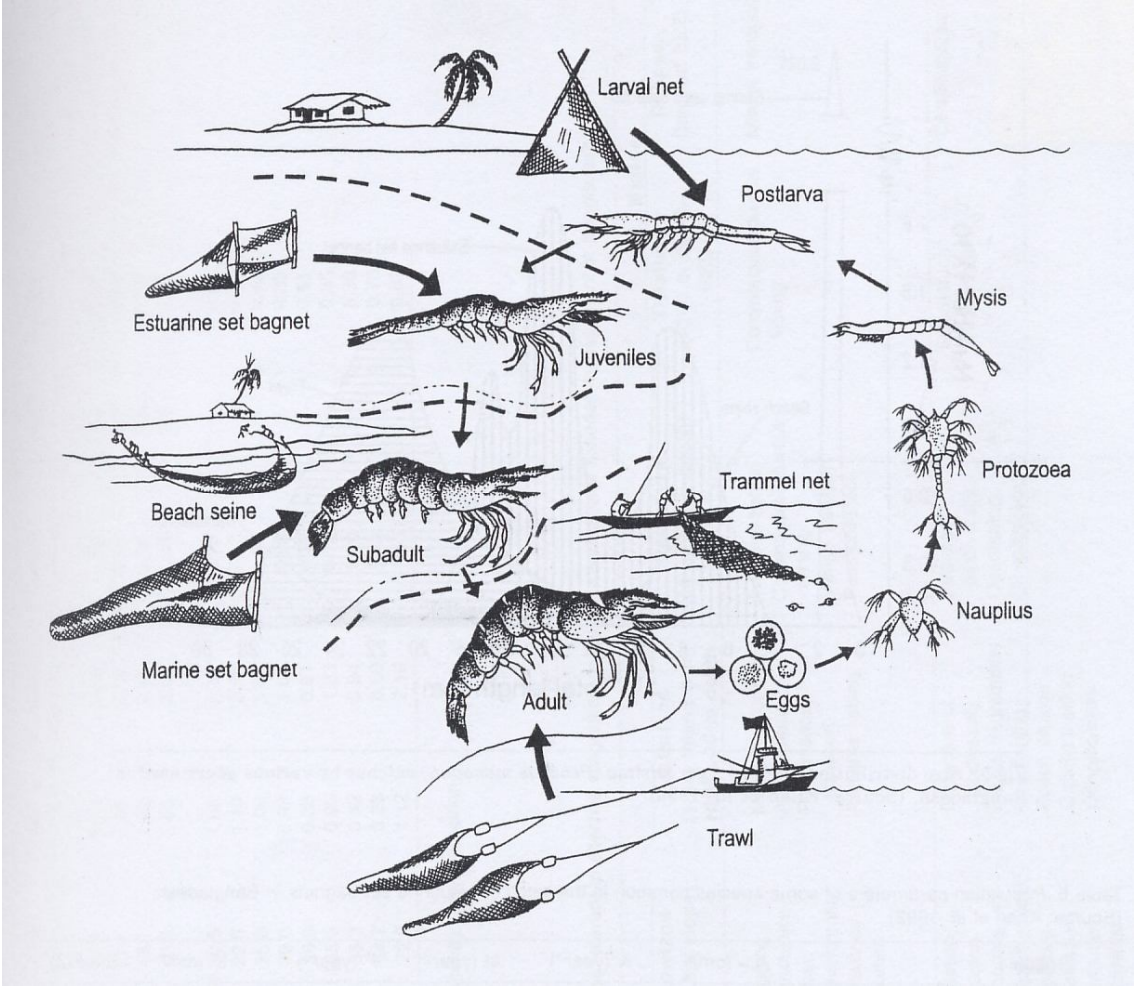

Figure 3. Fishing gears used at various stages in the coastal and estuarine fisheries of Bangladesh [66]

In the coastal and estuarine fisheries of Bangladesh, the increase in overfishing is a serious problem due to the use of huge numbers of push or larval nets and estuarine set bag nets (Table 10). Push and larval nets collect shrimp fry for the expanding shrimp aquaculture industry. In recent years, although a considerable number of shrimp hatcheries have been established, the wild fry collection is still practiced in the coastal area of the country. The loss of other species during the collection of tiger shrimp (*P. monodon*) post-larvae is well documented. It is notable that in catching a single species of tiger shrimp fry, about 26 other species, 29 finfish species and 70 other zooplankton were simultaneously destroyed [45] (Figure 4). The fry catchers carefully sort out *P. monodon* fry from the mixed catch and the rest of the plankton including fish and shellfish larvae are discarded anywhere on

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the shore. These activities cause great loss of the biodiversity and valuable fishery resources. In the case of estuarine set bag nets, area and seasonal closures for operation of the gears and the establishment of alternative livelihood projects in the context of integrated coastal community development projects have been proposed [46].

Table 10. Population parameters of some common species in the estuarine set bag net [65]

Species	L∞ (cm)	K ($year^{-1}$)	M ($year^{-1}$)	F ($year^{-1}$)	L_c (cm)	E (=F/Z)
Crustaceans						
Peneus monodon	31.4	0.72	1.42	8.38	13.8	0.86
Peneus indicus	22.8	0.55	1.30	3.70	5.9	0.74
Metapenaeus monocerous	19.8	0.44	1.17	3.65	5.9	0.76
Metapenaeus bervicornis	15.6	0.31	1.00	4.24	4.8	0.81
Metapenaeus spinulatus	20.1	0.39	1.08	5.90	5.3	0.84
Perapenaeopsis sculptilis	16.9	0.76	1.75	4.15	15.3	0.70
Perapenaeopsis stylifera	14.4	1.66	3.06	3.00	2.8	0.50
Acetes indicus	5.0	0.73	2.40	1.10	2.0	0.31
Macrobracium rosenbergii	35.5	0.34	0.84	1.96	7.3	0.70
Palaemon styliferous	15.4	0.63	1.59	3.20	3.74	0.67
Fish						
Raconda russelliana	23.6	0.43	1.10	2.10	2.90	0.66
Septinna taty	21.3	0.53	1.28	0.80	15.8	0.28
Stolephorus tri	16.8	0.65	1.59	9.00	3.4	0.85
Harpadon nehereus	34.9	0.38	0.91	3.75	6.3	0.80
Lepturacanthus savala	93.0	0.29	0.58	2.62	22.60	0.82
Eleutheronema tetradactyldum	38.1	0.1	0.85	3.50	5.3	0.87
Polynemous paradiscus	21.6	0.52	1.28	4.72	2.7	0.79
Sillaginopsis panijus	43.3	0.38	0.86	2.70	13.1	0.76
Sillago sihama	27.4	0.39	0.99	3.00	5.1	0.75

Note: L∞ = asymptotic length, K = growth co-efficient, M = natural mortality, F = fishing mortality, Lc = length at first capture, E= exploitation rate, Z = total mortality

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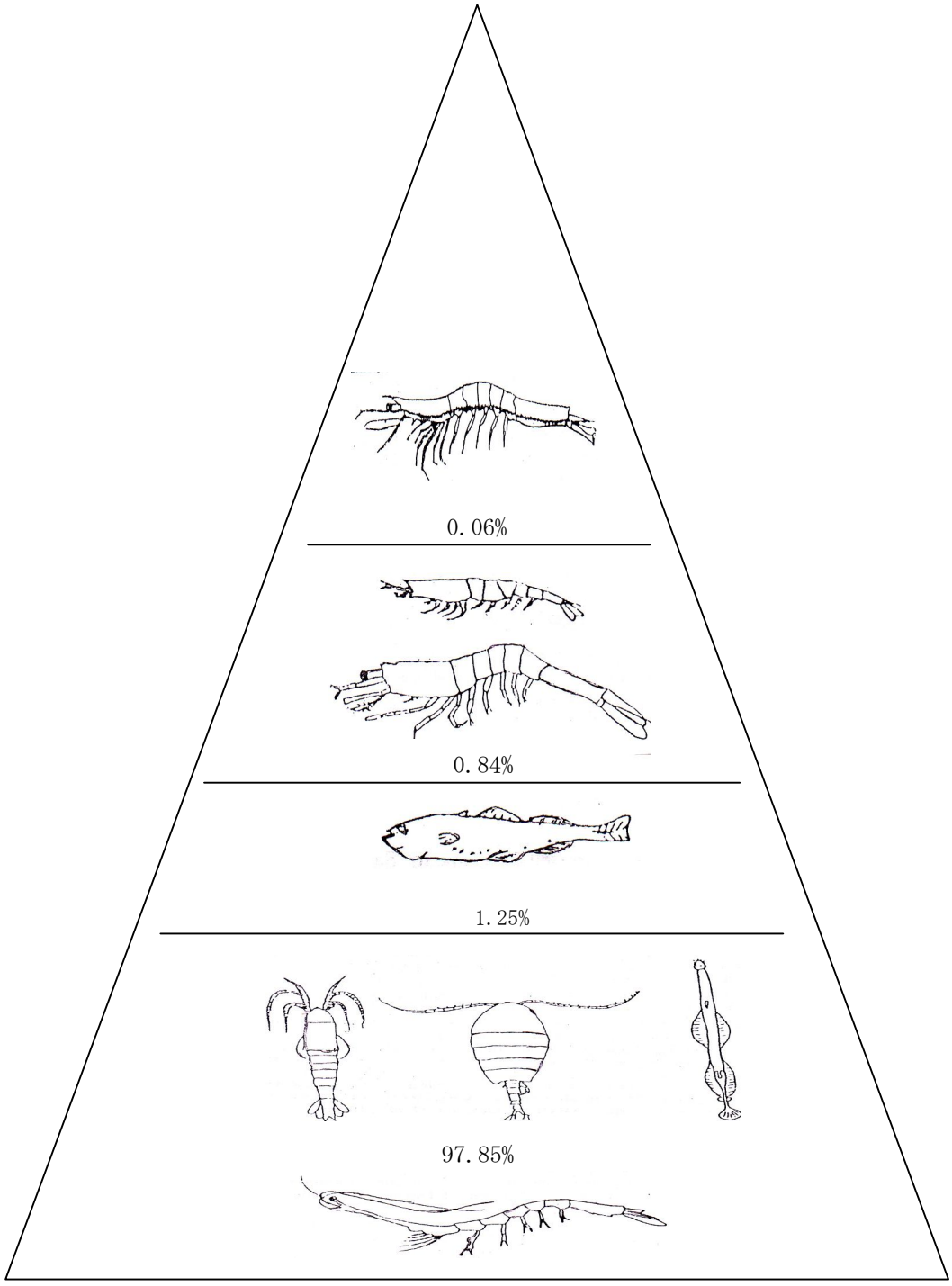

Figure 4. From top, showing average distribution (in percentage) of postlarvae of *P. monodon,* other shrimps, finfishes and all other zooplankton in the estuaries of Bangladesh (adopted from Mahmood [67])

Crabs belonging to different genera and species are widely distributed along the estuarine and coastal shores and swamps. Crabs, which are caught in cage traps or by a fishing rod, are one of the most important hidden living resources of Bangladesh. Siddiqui and Zafar [47] gave a check list of the coastal estuarine crabs of Bangladesh (Table 11). Due to religious prohibition on eating crabs, the mud

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crab (*Scylla serrata*) and swimming crab (*Portunus pelagicus*) fisheries are not popular in Bangladesh even though they have commercial importance in the world market. However, some rural Buddhists and Hindu people consume crabs as food locally. In some parts of the coastal areas, crabs are harvested naturally from the mangrove area and shrimp ponds as a by-product. The annual wild production of crabs in Bangladesh was about 2159 metric ton [48].

Table 11. Crabs of the estuarine and coastal areas of Bangladesh [44]

Family	Species	Economic importance
Portunidae	*Scylla serrata*	Used as food
	Portunus sanguinolentus	do.
	Portunus pelagicus	do.
Grapsidae	*Metopograpsus thukuhar*	No value
	Metopograpsus messor	do.
	Prasesarma plicatum	do.
	Sesaema lanatum	do.
	Episesarma versicolor	do.
Potamoniade	*Potamon wood-masoni*	As feed in aquaculture
	Potamon martensi	do
	Paratelphusa lamellifrons	Used for poultry feed
Ocypodidae	*Uca urvillei*	No value
	Uca annulipes	do.
	Ocypode ceratophthalmus	do.
Paguridae	*Anapagurus laevis*	do.
Leucosiidae	*Ebalia cranchii*	do.

Among the shellfishes, mollusks belonging to 187 genera of bivalves, clams, mussels and oysters have been recorded in the south-eastern coastal and estuarine areas of Bangladesh [49-51]. Three species of cephalopods (octopus, i.e. *Octopus aegina*, cuttlefish, i.e. *Sepia eculeata* and squid, i.e. *Loligo edulis*) are found in these coastal areas [52]. Some important gastropods (*Conus striatus, C. textile* and *C. geogrphes*) are abundant, and two economically important gastropods (*Trochus niloticus* and *Turbo marmoratus*) that are heavily depleted worldwide are also present in these coastal areas. One species of star fish, 5 species of lobster and a number of coelenterates are found in some of the estuarine parts [18, 50]. Seven species of edible oysters are found in the coastal areas of the country [18]. The green mussel *Perna viridis* is common in the estuarine waters, growing attached on any hard substrates or fishing poles. One of the most important shellfish, the pink pearl bearer bivalve *Lamelliden jenkinsianus var.obesa*, is also obtained around the coastal bays of the south-eastern area [18]. Shellfish grow and breed well when the water quality is good enough during the winter/dry season, because, as a filter feeder by nature, oyster or any other types of bivalves does not grow well in silted areas or turbid water environment. The *Meretix* spp. clams are found abundantly in the muddy coast of nearly all estuarine areas. Shells of these animals are collected in large quantities for lime production and manufacture of handicrafts which sell commonly in the local tourist markets.

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Estuarine and coastal water zooplankton

Zooplankton, the secondary consumer in an aquatic food chain, plays an important role in the estuarine and coastal water environment. The net fluxes of the water in the estuarine environment play an important role in the distribution of planktonic animals [53]. It is noted that there have been very limited published studies on the abundance of zooplankton and their ecology in the coastal and estuarine environment of Bangladesh [35]. On the other hand, a number of valuable investigations have been made in Indian waters by Krishnamurathy et al. [54], Santhanan et al. [55-56] and Menon and George [57]. Ali et al. [35] recorded a periodic variation of zooplankton in the coastal estuarine water of the south-eastern part of Bangladesh. The major groups of zooplankton, i.e. copepoda, decapoda, chaetognatha, cladocera, and fish and shellfish larvae were recorded by Ali et al. [35] and Ali [58], and are presented in Table 12. Studies have revealed a negative relationship between zooplankton abundance and NO_2-N concentration [35]. Furthermore, an inverse relationship between the abundance of phytoplankton and zooplankton has also been observed in Bangladeshi coastal waters [35]. Similar observations in Indian marine waters were also noted by Goswami and Singbal [59], who reported that tidal current, wind direction and river discharge can contribute to controlling the diversity of zooplankton in the estuarine environment [53].

Table 12. Zooplankton composition in the coastal and estuarine waters of Bangladesh [35, 55]

Group	Species
Copepoda	*Calanus* sp.
	Microsetella sp.
	Oncaea sp.
	Calanopia sp.
	Coryeacus sp.
	Oithona sp.
Crustacean	*Penaeus monodon, P. merguiensis*
	Metapenaeus monoceros, M. brevicornis
	Penaeus indicus
	Macrobrachium rosenbergii
	Acetes erythraeus, A. indicus, A. japonicus
Decapoda	*Lucifer* sp.
Chaetognatha	*Sagitta* sp.
Cladocera	*Evadue* sp.
Meropalankton	Nauplius
	Copepodite
	Zoea
	Hydromedusae

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Estuarine and coastal animals/wildlife

The estuarine and coastal environment supports a considerable size and variety of animal population. These animals spend at least a part of their life cycle in the coastal forest swamps which are subject to periodic tidal inundation. The wildlife of the coastal moist forest has been described by Blower [60], but the record for coastal forest faunas is still lacking. There are animals ranging from protozoa to birds, reptiles and mammals including tigers, deer and monkeys. Among the avian fauna, both migratory and indigenous birds are present. The common coastal and estuarine birds are gulls, terns, egrets, herons, bitterns, plovers, sandpipers and cormorants (Table 13). However, due to the population load on the coastal areas and severe destruction of coastal forests, almost all of the animal species are in danger, in particular, *Betagus basca* (River terrapin), *Lissemys punctata* (Indian flap-shelled turtle), *Panthera tigris* (Bengal tiger), *Python molorus* (Indian python), *Trionyx hururm* (Peacock soft shelled turtle) and *Vanaus flavescens* (Yellow monitor). However, a few of these together with some other reptiles have been protected by the Bangladesh Wildlife (Preservation) Act of 1973. It is worth mentioning that five major animal species, viz. *Axis procinus* (Hog deer), *Bubalis bubalis* (Water buffalo), *Cervus duvauceli* (Swamp deer), *Rhinoceros sondaicus* (Javan rhinoceros) and *Crocodylus palustris* (Mugger crocodile), have become extinct in the Bangladeshi coastal estuarine forests. The tidal waterways, varying in width from a few metres to 5 km, are inhabited by dolphin (4 species), otter and the saltwater crocodile (*Crocodylus porosus*), which are not well protected and conserved.

Table 13. Coastal and estuarine migratory and indigenous birds of Bangladesh

English name	Family	Generic name
	Dendrocygnidae	
Fulvous Whistling-duck		*Dendrocygna bicolor*
Lesser Whistling-duck		*Dendrocygna javanica*
	Anatidae	
Bar-headed Goose		*Anser indicus*
Ruddy Shelduck		*Tadorna ferruginea*
Common Shelduck		*Tadorna tadorna*
Comb Duck		*Sarkidiornis melanotos*
Cotton Pygmy-goose		*Nettapus coromandelianus*
Gadwall		*Anas strepera*
Falcated Duck		*Anas falcata*
Eurasian Wigeon		*Anas Penelope*
Mallard		*Anas platyrhynchos*
Indian Spot-billed Duck		*Anas poecilorhyncha*
Northern Shoveled		*Anas clypeata*
Northern Pintail		*Anas acuta*
Garganey		*Anas querquedula*
Common Teal		*Anas crecca*

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Table 13. (cont'd)

English name	Family	Generic name
Red-crested Pochard		*Netta rufina*
Common Pochard		*Aythya ferina*
Ferruginous Pochard		*Aythya nyroca*
Tufted Duck		*Aythya fuligula*
Greater Scaup		*Aythya marila*
	Rallidae	
White-breasted Waterhen		*Amaurornis phoenicurus*
Eastern Baillon's Crake		*Porzana pusilla*
Ruddy-breasted Crake		*Porzana fusca*
Watercock		*Gallicrex cinerea*
Purple Swamphen		*Porphyrio porphyrio*
Common Moorhen		*Gallinula chloropus*
Common Coot		*Fulica atra*
Spotted Crake		*Porzana porzana*
Water Rail		*Rallus aquaticus*
	Scolopacidae	
Pintail Snipe		*Gallinago stenura*
Common Snipe Fantail Snipe		*Gallinago Gallinago*
Greater Painted-snipe		*Rostratula bengalensis*
Eastern' Black-tailed Godwit		*Limosa melanuroides*
Bar-tailed Godwit		*Limosa lapponica*
Whimbrel		*Numenius phaeopus*
Eurasian Curlew		*Numenius arquata*
Spotted Redshank		*Tringa erythropus*
Common Redshank		*Tringa tetanus*
Marsh Sandpiper		*Tringa stagnatilis*
Common Greenshank		*Tringa nebularia*
Nordmann's Greenshank		*Tringa guttifer*
Green Sandpiper		*Tringa ochropus*
Wood Sandpiper		*Tringa glareola*
Terek Sandpiper		*Xenus cinereus*
Common Sandpiper		*Actitis hypoleucos*
Ruddy Turnstone		*Arenaria interpres*
Asian Dowitcher		*Limnodromus semipalmatus*
Red Knot		*Calidris canutus*
Great Knot		*Cakidris tenuirostris*
Sanderling		*Calidris alba*
Spoon-billed Sandpiper		*Calidris pygmea*

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Table 13. (cont'd)

English name	Family	Generic name
Little Stint		*Calidris minuta*
Red-necked Stint		*Calidris ruficollis*
Temminck's Stint		*Calidris temminckii*
Long-toed Stint		*Calidris subminuta*
Curlew Sandpiper		*Calidris ferruginea*
Broad-billed Sandpiper		*Limicola falcinellus*
Ruff		*Philomachus pugnax*
	Rostratulidae	
Greater Painted-snipe		*Rostratula benghalensis*
	Jacanidae	
Pheasant-tailed Jacana		*Hydrophasianus chirurgus*
Bronze-winged Jacana		*Metopidius indicus*
	Charadriidae	
Black-winged Stilt		*Himantopus himantopus*
Pied Avocet		*Recurvirostra avosetta*
Pacific Golden Plover		*Pluvialis fulva*
Grey Plover		*Pluvialis squatarola*
Common Ringed Plover		*Charadrius hiaticula*
Little Ringed Plover		*Charadrius dubius*
Kentish Plover		*Charadrius alexandrinus*
Lesser Sand Plover		*Charadrius mongolus*
Greater Sand Plover		*Charadrius leschenaultia*
Grey-headed Lapwing		*Vanellus cinereus*
Red-wattled Lapwing		*Vanellus indicus*
Yellow-wattled Lapwing		*Vanellus malabaricus*
River Lapwing		*Vanellus duvauceli*
	Glareolidae	
Small Pratincole		*Glareola lactea*
	Laridae	
Indian Skimmer		*Rynchops albicollis*
Heuglin's Gull		*Larus heuglini*
Steppe Gull		*Larus* [*heuglini*] *barabensis*
Pallas's Gull		*Larus ichthyaetus*
Brown-headed Gull		*Larus brunnicephalus*
Black-headed Gull		*Larus ridibundu*
Gull-billed Tern		*Gelochelidon nilotica*
Caspian Tern		*Sterna caspia*
River Tern		*Sterna aurantia*

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Table 13. (cont'd)

English name	Family	Generic name
Lesser Crested Tern		*Sterna bengalensis*
Great Crested Tern		*Sterna bergii*
Sandwich Tern		*Sterna sandvicensis*
Common Tern		*Sterna hirundo*
Little Tern		*Sterna albifrons*
Whiskered Tern		*Chlidonias hybridus*
White-winged Tern		*Chlidonias leucopterus*
Black belied Tern		*Sterna acuticauda*
Black Naped Tern		*Sterna sumatrana*
Lesser Noddy		*Anous tenuirostris*
Black Noddy		*Anous minuts*
	Phalacrocoracidae	
Little Cormorant		*Phalacrocorax niger*
Great Cormorant		*Phalacrocorax carbo*
	Ardeidae	
Little Egret		*Egretta garzetta*
Grey Heron		*Ardea cinerea*
Goliath Heron		*Ardea goliath*
Purple Heron		*Ardea purpurea*
Great Egret		*Casmerodius albus*
Intermediate Egret		*Mesophoyx intermedia*
Cattle Egret (Eastern)		*Bubulcus* (*ibis*) *coromandus*
Pond Heron		*Ardeola grayii*Indian
Little Heron		*Butorides striatus*
Black-crowned Night Heron		*Nycticorax nycticorax*
Cinnamon Bittern		*Ixobrychus cinnamomeus*
Little Bittern		*Ixobrychus minutus*
Yellow Bittern		*Ixobrychus sinensis*
Black Bittern		*Dupetor flavicollis*
	Threskiornithidae	
Black-headed Ibis		*Threskiornis melanocephalus*
Eurasian Spoonbill		*Platalea leucorodia*
	Ciconiidae	
Asian Openbill		*Anastomus oscitans*
Lesser Adjutant		*Leptoptilos javanicus*

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Conclusions

The coastal and estuarine areas of Bangladesh are covered by extensive mud flats, saline water, brackish water and protected bays. These places support huge numbers of important living resources, which are suitable for marine ranching. Local people indiscriminately utilise these natural resources and some are now completely destroyed, for example, the Chakaria Sunderban mangrove forest in Cox's Bazar. Most of the resources are being over-utilised (e.g. fish stock and shrimp fry) while some remain untouched or under-utilised (molluscs, seaweeds, crabs and offshore fishes). Therefore, sustainable practices, management and conservation of the estuarine and coastal resources and their related ecosystems are needed. The coordination of future research projects on ecology and conservation science of the coastal resources is required. The main problem facing Bangladesh is the limited capacity to enforce regulation and monitoring, as well as lack of knowledge on sustainable uses of coastal and estuarine resources. There are some management approaches and rules for coastal forests and fisheries of Bangladesh, which are not effective. Apart from this, there is a need for strong protection and conservation policies, which have to be incorporated into a management plan. Some of the plans should include: i) Major identification of coastal resources, ii) Monitoring activities, which contribute to the understanding of changes in coastal resources, iii) Improved management of existing reserves to correspond with their multipurpose usefulness, iv) Coordination of research project on conservation science and ecology of coastal resources, v) Creation of public awareness and promotion of local participation in managing natural coastal resources, vi) Strengthening and providing the required expertise on coastal zone management for existing coastal resources, vii) Participation by public bodies (non-government or trade organisations) in the planning of conservation strategies, and viii) Research on natural and human-induced treats to coastal resources and implementation of national coastal resource management programmes.

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