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Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh

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Abstract

Bangladesh has vast coastal and marine resources along its south edge. Due to the geographical position and climatic condition, the coastal area of the country is known as one of the highly productive areas of the world. Bangladesh is rich not only in terms of its vast water areas but also in terms of the biological diversity. One of the unique features of the coastal areas is the influence of the mangrove forests, which support a high number of fishes and other commercially important aquatic organisms. The biological and ecological values of the Bay of Bengal have been pointed out by many authors. The coastal and marine fisheries have been playing considerable roles not only in the social and economic development of the country but also in the regional ecological balance. A large number of commercially important fishes have long been exploited which are of high export values. Shrimp aquaculture has become a highly traded export-oriented industry for the last few decades. In spite of having bright prospects, marine aquaculture on a commercial basis as well as marine stock enhancement and sea ranching are yet to be developed. The marine fisheries sector has been suffering from chronic disintegration and mismanagement that have led to many consequences. Most of the commercially important fish stocks are either overexploited or under threat. Marine pollution has reached a level that could create an unmanageable situation in the near future; coastal shrimp farming has generated considerable debates due to its adverse environmental and socioeconomic impacts. The Bay of Bengal and its coastal areas are one of the most poorly studied areas of the world although it possesses high potential for further stock improvement. Proper attention is needed in every aspect of exploitation, handling and processing, export and marketing as well as in biological and institutional management strategies. The Bay of Bengal has been increasingly important for local development as well as for a global perspective. The coastal and marine fisheries of the Bay of Bengal are briefly reviewed in this paper to provide a salient feature of the available information and resource base and to identify future research and management needs.

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1. Introduction

The state of exploitation of the main fish stocks of the world has remained more or less unchanged since the early 1990s. Recent information suggests that among the major fish stocks, an estimated 445 are either fully exploited or reaching their maximum limit with no room expected for further expansion [1]. The main areas where the total catches still follow an increasing trend and where some potential for increase still exists are the Eastern and Western Indian Ocean [1], of which the Bay of Bengal is an important part.

The Bay of Bengal, arm of the Indian Ocean, 2090 km long and 1600 km wide with an average depth of more than 2600 m, occupying an area of about 2,172,000 km^2 is bordered on the West by Sri Lanka and India, on the North by Bangladesh, and on the East by Myanmar and Thailand; the Andaman and Nicobar Islands separate it from the Andaman Sea, its eastern arm. The bay receives many large rivers including the Irawaty, Ganges–Brahmaputra, Mahanadi, Godavari, Kristna, and Kaveri, all forming fertile, heavily populated deltas. Sediment from the rivers has made the bay a shallow sea, and the waters have reduced the salinity of surface waters along the shore. Monsoon rains and destructive cyclone storms often cause great loss of life along the bay's northern coast. The main ports are Vishakhapatnam, Paradip, Madras, and Calcutta, India; Chittagong, Bangladesh; and Sittwe, Myanmar. The coastal and marine waters of the Bay of Bengal including the coastal shrimp farming areas and the mangrove forest are shown in Fig. 1.

Bangladesh has a coastline of 480 km along the North and Northeast part of the Bay of Bengal. It has an internal estuarine water area of 7325 sq. nautical miles upto 10 fathom of baseline depth, an EEZ of 41,040 sq. nautical miles and the continental shelf of 2480 sq. nautical miles; the total marine water area is about 48,365 sq. nautical miles which is almost as big as the country itself [2]. The coastal and marine zone of Bangladesh is one of the world's richest ecosystems characterized by higher productivity and unique mangrove influences. The coastal landmass is very fertile due to regular flush of nutrient rich silts and supply of organic matters from mangrove liter falls. As a result, the Bay of Bengal has become one of the richest areas in terms of biological diversity and productivity. However, the Bay of Bengal is probably one of the most poorly studied areas in the world although this is one of the potential areas for stock improvement as well as for developing commercial mariculture. Study of the Bay of Bengal started in the middle of 1880s through the Indian Ocean Expedition. However, no recent and comprehensive knowledge is available on different biological and ecological aspects of the coastal and marine fisheries, which, to some extent, limit the utilization and management of the resources. Some reports are available describing different aspects of the Bay of Bengal [3–10] but such information is extremely fragmentary and incomplete. Reports on experimental studies on specific aspects of biology and the life history of commercially important fish species are rarely available.

Recent reports suggest that most of the commercially important fish stocks of the Bay of Bengal are overexploited and are, therefore, under threat although no reliable estimates as to the exact size of stock are available. Pollution of coastal and marine

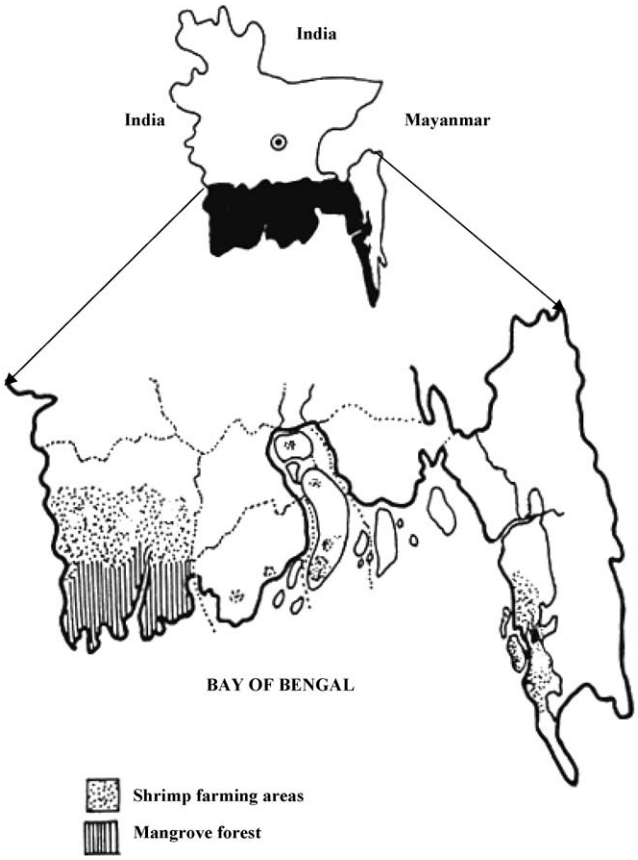

Fig. 1. Map showing the coastal and marine waters of the Bay of Bengal, Bangladesh including the coastal shrimp farming areas and the mangrove forest.

ecosystems poses an additional threat to the sustainability of the resources. The present paper reviews the existing information on the different aspects of the coastal and marine fisheries of the Bay of Bengal, points out to the research needs in the future and puts forward suggestions and recommendations for the overall development of the resources.

2. Ecology and productivity

Data on the oceanographic features and the organic productivity are not adequate for the Bay of Bengal and its estuary because no comprehensive survey was made to determine these features. However, the Indian Ocean Expedition reports some fragmentary data on the primary productivity [11,12]. The average production was found to be 0.19 g C/m^2/day in the deeper part and 0.63 g C/m^2/day in the shelf area. The estimated net organic productivity was 15 million tones of carbons per year.

Data available on the physico-chemical and geological features of the coastal and marine environment are very poor and fragmentary. No comprehensive survey or well-designed experiment on ecological parameters was reported [13]. Ecological parameters given in this paper were taken from some Bengali literatures [14] published on the basis of theoretical information and from some unpublished works obtained from the Marine Fisheries Technology Discipline, Khulna University, Bangladesh. Temperature, rainfall, relative humidity and evaporation (Fig. 2) clearly indicate the features of a typical tropical climate. The mangrove dominated coastal areas have developed on soil formations of recent origin consisting of alluvium washed down from the Himalayas. The surface geology consists of category sediment, sands and silts mixed with tidal marine sediments containing silts and clays. However, the surface soil is a silty clay loam overlying alternating layers of clay and sands. Silts appear to be the most common textural class and the grain size is larger in the eastern part of the coast than its western part. In areas with localized depressions, prolonged stagnation of saline water sometimes creates conditions of pyritic and acid sulfate soils. The cation exchange capacity (CEC) of the coastal soil mineral particles was reported to be very high ranging from 9.94 me/100 g to 22.87 me/100 g in different regions. Recent information about the geology and sedimentation patterns can be obtained from Davies et al. [15] and Alam and Curray [16].

Mangroves, locally known as 'Sundarbans' are one of the major important coastal features and a major component of the vegetative cover in the coastal region of the country. At one time, mangrove forest in Bangladesh was distributed along much of the coastal belt of the southwestern region, but is now confined to the Sundarban Reserve Forest and offshore islands stretching as Far East as the relic forest of

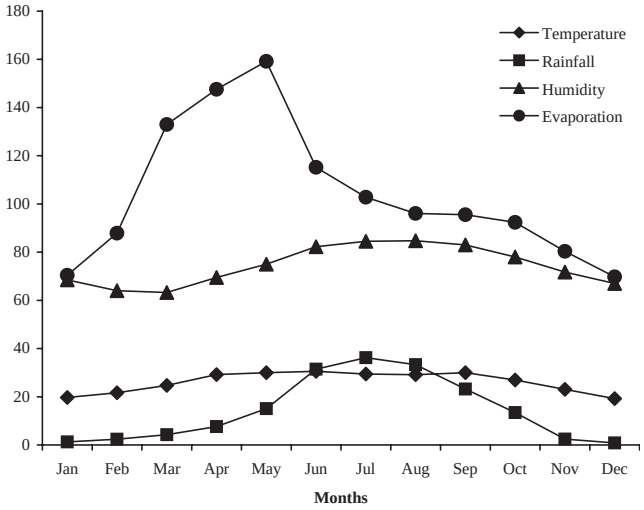

Fig. 2. Some ecological parameters in the coastal areas of the Bay of Bengal (temperature, °C; rainfall, cm; relative humidity, %; and evaporation, mm).

Chakaria in Cox's Bazar District (the Chakaria Sundarbans) situated at the Matamuhuri River delta. The Sundarbans was regarded as the largest continuous natural mangrove forest in the world [17], covering an area of 10,000 km^2 of which 62% fall within the territory of Bangladesh, covering an area of 4020 km^2 [18].

The four main seasons are pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and the dry winter season (December–February). Each of the seasons has its distinct characteristic features and influence on mangrove ecology. The area inundated by tidal water increases and, due to increasing maritime influence, the salinity of river water also reaches a maximum during the post-monsoon season because of its characteristic southern winds, high temperature and higher evaporation rates with occasional heavy thunderstorms. The monsoon brings high rainfall and cloudy cover resulting in rise in water levels and increased sediment loads in upper catchment areas. During the monsoon and the post-monsoon season, the estuarine hydrology is characterized by a prolonged low-saline regime. A semi-diurnal tide is typical of the coastal waters. Very low or no tidal inundation resulting in a dry, exposed period is characteristic of the winter season.

The coastal area is intersected by an elaborate network of rivers, channels and creeks. These waterways are of varying width and length and occupy a substantial part of the forest. The larger rivers, passing through the forest, join together forming estuaries at the confluence where they meet near the sea. The surface water flow in the rivers of the coastal areas mainly comes from the Ganges–Padma River Systems through Garai–Madhumati Rivers and from the lower Meghna through the Swarupkati–Kocha Rivers. The other source of surface water flow in the rivers is the runoff from the local catchment area.

The coastal mangrove is a deltaic swamp and low-lying area drained by a network of small creeks, which flow into the main watercourses on the ebb-flow of the tide. These are, in some instances, eroded by the tide to form saucer-shaped depressions in which there may be standing water. For about seven months of the year, from November to May, potential evaporation exceeds precipitation by nearly 500 mm. For more than half of the year, therefore, the vegetation is heavily dependent on soil-water, which is recharged largely by tidal intrusion and the reduced overflow. During this period of precipitation deficit, soil salinity temporarily increases. The forest receives large volumes of freshwater from inland rivers and of saline waters from the twice-daily tidal inundation from the sea creating in the mangrove forests an open ecological system. The freshwater charged with alluvium that contains plant nutrients and which, together with the salinity of the tidal water, is a major factor affecting the forest ecosystem. The bulk of the freshwater reaches the forest in the monsoon season. During the dry season the freshwater flow decreases progressively, resulting in a prolonged saline condition, which persists until the freshwater flow increases again.

The distribution of depths in the Bay of Bengal has many irregularities due to the presence of submarine canyons, ridges and other topographic features. A huge discharge of freshwater runoff from numerous large rivers is a dominant feature that influences the seasonal dynamics of the coastal and marine environment [70].

The continental shelf receives a great amount of sediment carried out by the rivers, which amount to as high as 13 million tones per day during monsoon [19]. Higher organic loads resulting from mangrove leaves and litter falls are the primary feature for higher productivity and that is for why the estuaries of Bangladesh differ from typical estuarine systems and serve as the home for numerous estuarine-dependent species.

3. Fish and related biotic diversity

3.1. Plankton

Algal flora is a poorly studied component of the estuarine ecosystem. Algae can be seen attached to the pneumatophores and roots of mangrove plants, tree trunks and on the mud floor. Mangrove algae can also be found in some areas forming red, brown or green mats on intertidal mud flats. Due to muddy shorelines and low saline conditions, typical eurihaline benthic marine algae are negligible in the region. Islam [20] recorded 165 species of benthic marine and brackish water algae from the coast of Bangladesh. Most of the specimens were collected from water, muddy banks and shore mainly from pneumatophores, twigs and fallen logs.

Although far from complete, so far, 34 species of phytoplankton have been recorded along the coastal regions of Bangladesh and Mridha [14] reported 103 species of phytoplankton in the Bay of Bengal including the North Indian Ocean. Belonging to the families Volvocaceae, Palmelaceae, Ulvaceae, Cladephoraceae, Zygnemaceae, and Codiaceae, the Division Chlorophyta is represented by nine species under six genera. Division Cyanophyta is represented by 16 species under nine genera belonging to the families Chroococcaceae, Oscillatoriaceae, Nostocaceae, and Rivulariaceae. Division Bacillariophyta is represented by 16 genera and 35 species and the Euglenophyta is represented by two genera consisting of two species. It was observed that most of the members of Bacillariophyta and Cyanophyta occur in abundance in the lower littoral zone. The distribution and abundance of algae in the mangrove areas are greatly influenced by the ecological characteristics, particularly the mixing of saline and freshwater resulting in salinity fluctuation and the silt carried by rivers.

The complex mangrove ecosystems are highly suitable to support very complex food chains and for organisms of all trophic levels and niches to occur. The mangroves of Bangladesh are extraordinarily rich in zooplankton production. Thirteen major taxa of zooplankton namely, Copepods, Amphipodes, Mysids, Acetes, Chaetognaths, Polychaetes, Lucifers, Hydromedusae, Shrimp larvae, Fin fish larvae, Crab larvae, Squilla, and Horse-shoe crab larvae were found to occur in this region.

3.2. Fishes

A total of 475 species of fish belonging to 133 families have so far been identified from the coastal and marine waters of the Bay of Bengal [21]. However, FAO

fisheries database [101] reported as many as 629 fish species in the Bay of Bengal. A complete list and description of the coastal and marine fish species of the Bay of Bengal are not available yet. So far, Hussain [21] and Quddus and Shafi [22] have provided the most comprehensive list and taxonomic description of the fishes. Lists of fish and other commercially important organisms found in the coastal mangrove areas are provided also in Hussain and Archarya [23] and Rahman et al. [24]. Mridha [14] also discussed in detail the different aspects of fish and fisheries in the Bay of Bengal. The major groups of fishes are catfish, pomfret, grunter, Indian salmon, shad, snapper, jewfish, mackerel, threadfin bream, lizard fish, goatfish, ribbon fish, hairtail species, ponnyfishes, sharks, skates and rays, mixed small fishes, etc. [25–27].

Several studies [28–30] reported that the mangroves of Bangladesh support at least 120 species of commercially important fishes. The mangrove waters support 53 species of pelagic fish belonging to 27 families and 124 species under 49 families of demersal fish. Diadromous species such as *Pangasius pangasius, Hilsa ilisha, Lates calcarifar* are common in the low saline zone. The moderately saltwater zones are dominated by *Hilsa ilisha, Pomadasys hasta, Polynemus* spp., *Coilia* spp., *Johnius* spp., etc. The highly saline zones are likely to support species such as *Harpodon nehereus, Trichiurus savala, Setipinna* spp., *Pampus* spp., *Sardinella* spp., *Salar* spp., etc [21]. Being a transitional zone between freshwater and seawater the mangrove estuary serves as a seasonal habitat for many freshwater and marine species and, as such, richer than either of the two in terms of its biological genetic resources. Many species, both freshwater and marine, are dependent on the mangroves for their nursery areas.

3.3. Shrimps

Besides the large number of fish species, the mangroves also support many species of shrimps with high commercial value. These include 24 species of shrimps belonging to five families [21,29]). However, the tiger shrimp, *Penaeus monodon*, outstands the other in terms of its commercial importance and availability. The bottom trawling industries of Bangladesh aims mainly to catch shrimps, particularly *Penaeus monodon*. Lists of the shrimp species of the coastal and marine waters of Bangladesh have been given by Hussain and Archarya [23].

3.4. Crabs

As many as 50 species of crabs have so far been identified in the coastal and marine habitats of the Bay of Bengal [31] of which 11 are purely marine. Only three species, namely *Scylla serrata* (mud crab or mangrove crab), *Portunus pelagicus*, and *P. sanguinolentus* are reported to be commercially important [22,31,32]. The mud crab, *Scylla serrata* is abundantly available and is reported to be suitable for coastal aquaculture. The seeds of this species are also available throughout the coastal belt [33]. However, no report is available on the standing stock of the crab resources.

3.5. Molluscs, bivalves and reptiles

Molluscs of a variety of forms are available in the Bay of Bengal and adjacent areas. They include bivalves, clams, oysters, scallops, snails and slugs, cuttlefish, squids, octopuses, etc. Ahmed [34] reported 301 species of marine mollusks in Bangladesh. However, very little is known about their biology, occurrence, production and management. Two types of clams are available—the blood clams and the thick-shelled clam. Sarker and Alam [35] identified two species of blood clams, namely, *Anadara granosa* and *A. rhombea*. These species are reported to occur from the intertidal, mangrove areas upto a depth of 10 m in the sea [36]. The blood clams are utilized in animal feed industries, shell handicrafts, and lime production. The thick-shelled clam (*Meretrix meretrix*) are reported to inhabit the estuarine and marine waters but the majority occur in the intertidal areas, buried in the sand. Recently, the blood clam is cultured in experimental trials and it is the only bivalve exported from Bangladesh [37]. No reliable information on the amount of catch is available but the annual production is roughly estimated to be 80–100 t [33].

Oysters are sedentary animals that grow on gravel, rocks, tree roots, and hard objects in the littoral and intertidal zones. Three types of oysters are reported to occur in the coastal waters of the Bay of Bengal, namely, the edible oyster, the pearl oyster, and the windowpane oyster. The most important group of edible oyster in Bangladesh is *Crassostrea*. Pagcatipunan [36] reported that the highest natural abundance occur in Cox's Bazar and Teknaf area. No well-studied report is available on the production and utilization of the oyster in Bangladesh except that of Sarker and Alam [35] who reported an annual production of shell weight of 50–70 mt. in 1984. The pearl oyster *Pinctada fucata* occurs sporadically around St. Martins Island attached with corals and rocks [33]. The windowpane oyster and the green mussel occur on hard surfaces, cement blocks, asbestos, string of coconut shells, split bamboo poles, mangrove roots and branches, bivalve shells, etc. They occur in the intertidal areas along the estuaries and are collected during the dry season.

Cuttlefish and squids are reported to occur in plenty in the Bay of Bengal. Quddus and Shafi [22] reported seven species of squids and two species of cuttlefish from the Bay. However, no report is available on their production and stock size. Three species of turtles, namely, *Caretta caretta*, *Chelonia* sp., and *Dermochelys* sp. Have been identified from the seawater of Bangladesh and these species have been reported as commercially important [31].

3.6. Seaweeds

In Bangladesh, the natural abundance of commercially important seaweeds is reported to be very low [33]. Only small portion of the southeastern part of the mainland covering about 30 km of the coastline and another offshore island, St. Martin Island have got rocky substratum and are suitable natural growth of seaweeds. Islam [20] and Islam and Aziz [38] conducted taxonomical studies on the seaweeds in these areas and reported that the major groups of naturally growing seaweeds in St. Martin Island represents 20–22 species. *Hypnea* was reported to be

Table 1
Seaweed resources in the Bay of Bengal and its coast [34]

Species	Type	Monthly abundance				
		Dec.	Jan.	Feb.	Mar.	Apr.
Actinotrichia fragilis	Red	+	+	+		
Asperogapsis taxiformes	Red		+	+ +	+ +	+
Calliblepharis sp.	Red	+ +	+			+
Caulerpa sp.	Red	+	+	+	+	+
Caramiun sp.	Red	+		+	+	+
Chrysymenia sp.	Red		+	+	+	+
Cthonoplastis sp.	Red	+	+ +	+ +	+ +	+ +
Victyota sp.	Brown	+	+	+		+
Eucheuma sp.	Red		+			
Galauxara sp.	Red	+	+			+
Halymenia sp.	Red		+	+	+	+
Hydroclathara sp.	Brown	+ +	+	+	+	+
Hypnea sp. (a)	Red		+	+	+ +	+ +
Hypnea sp. (b)	Red		+ +	+ + +	+ + +	+ + +
Hypnea sp. (c)	Red		+ +	+ + +	+ + +	+ + +
Hypnea sp. (d)	Red		+	+ +	+ +	+ +
Liagora sp.	Red	+	+			+
Lobophara sp.	Red	+	+	+	+	+
Padina sp.	Brown	+	+	+	+	+
Sargassum spp.	Brown		+ +	+ +	+ +	+ +
Scinnaia complanta	Red	+	+			+
Vanvorstrea coccinea	Red	+				

+: Normally available.
+ +: Moderately available.
+ + +: Commercially available.

the most abundant species [39]. However, identification of upto species level for most of the seaweeds is yet to be done [33]. Also very little is known about utilization of the seaweeds in Bangladesh. Kamal [33] reported that mainly *Hypnea* spp. are collected during February–April for commercial purpose. In St. Martin Island, the fishermen, women and their children are engaged in collecting seaweeds. The collected weeds are dried in the sun spreading on the open beach. Because there is no industrial set up for seaweed processing and utilization in Bangladesh, the dried seaweeds are sold to the marketing agents and it has been reported that about 200 t of dried seaweeds are disposed from Bangladesh to Myanmar through various marketing intermediaries [33]. Table 1 provides a list of commonly occurring seaweed species in the Bay of Bengal and its islands and coasts.

4. Stock assessment

Since 1958, several surveys have been conducted to evaluate the abundance and promote the exploitation of the marine fisheries resources of the Bay of Bengal.

Among the surveys, the most comprehensive one was the UNSF/PAK-22 Project conducted by BFDC in collaboration with FAO/UNDP from 1968 to 1971 which covered an area of about 26,000 km^2 and identified four major fishing grounds in the Bay of Bengal.

Several reports are available on the standing stock of penaeid shrimp, but there are large variations in the reported values, ranging between 1000 and 9000 t. Some authors reported that the penaeid shrimp stock range is 2000–4000 t [40–42]. Khan et al. [27] reported the maximum sustainable yield (MSY) of shrimp within the range of 7000–8000 t upto a 10 m depth.

Surveys on the demersal resources so far conducted also give several different estimates. West [43] reported the standing stock of demersal fish in the continental shelf of 264,000–373,000 t and a potential yield of 175,000 t while Penn [40] after observing the landings of commercial trawlers evaluated the standing stock of demersal fish of 39,000–54,900 t. However, the results of the three recent surveys are rather closer. The R.V. Dr. Frdtjof Nansen survey during 1979–1980 reported a stock of 160,000 t [44], the R.V. Anusandhani survey during 1981–1983 reported a standing stock of 152,000 t [45] and the third survey by the same vessel during 1984–1986 estimated the standing stock of 157,000 t [26] within the exploited 10–100 m shelf area. There are many controversies about the stock of pelagic fishery resources within the EEZ of Bangladesh [33]. It has not been possible yet to assess the pelagic resources of the Bay of Bengal [46]. Acoustic survey by R.V. Dr. Frdtjof Nansen gave an estimate of 60,000–120,000 mt., which, however, was termed as underestimate by Saetre [44].

5. Resource utilization

5.1. *Industrial trawl fishery*

The marine catch increased from 95,000 t in 1975–1976 to 250,480 t in 1992–1993, which is an increase of about 265% [33]. Yet there remain some unexplored areas for development of offshore pelagic fishing [21]. Commercial exploitation of deep sea fishing trawlers started in 1972 when Bangladesh Fisheries Development Corporation (BFDC) introduced 11 modern fishing trawlers and three more trawlers were added in 1974. On a promising abundance of penaeid shrimp resources, shrimp trawling on the continental shelf was introduced in 1978 after the Mitsui Tayo survey in 1976–1977 [47]. However, commercial shrimping was based mainly on the export-oriented markets. After a joint venture with Thailand in 1979–1980, commercial trawling gained momentum in the private sector and the number of trawlers increased. In 1980–1981, about 131 trawlers including 80 Thai fleet operated in Bangladesh seawater. Later the number of trawlers for shrimping increased gradually. The number of Bangladesh owned shrimp trawlers increased from 8 in 1980–1981 to 31 in 1985–1986 but the fishing trawlers reduced from 46 in 1983–1984 to 14 in 1985–1986 [48]. However, there are controversies in the reported number of trawlers between Shimura [49], White and Khan [50] and Shahidullah [48]. At

present, 30 shrimp trawlers and 19 fish trawlers are operating in Bangladesh seawater [33]. However, [70] reported 41 shrimp and 12 fish trawlers giving an annual effort of about 5000 standard days. They also reported that the shrimp production has been much below the MSY level and the present annual effort is about 1000 days less than the optimum. Similar reports were also made by Rahman and Khan [46]. The catch of finfish was also reported to be much lower than the MSY [70], which is 85,000 mt. [26]. The fish trawls are mostly high opening bottom trawls operated from the stern side and with the cod-end mesh of 60–65 mm. The shrimp trawlers usually operate twin nets with cod-end mesh of 45–50 mm [33]. Almost all the vessels are reported to be equipped with modern facilities [46].

5.2. *Artisanal fishery*

The estuarine and marine capture fisheries activities of the country are mainly based on artisanal fishing, which is estimated to contribute about 95% of the total marine production [51]. An analysis on the trend of marine production over the last two decades reveals that the production from artisanal sector has been growing more rapidly than the industrial sector (Fig. 3).

Artisanal fisheries include a number of different types of fishing gears and crafts which are mostly traditional. Some of the gears are operated by mechanized boats, but mostly with country boats some are even operated without any boat. The gear types include different types of gillnets (drift gillnet, large mesh gillnet, fixed gillnet, bottom set gillnet, and mullet gillnet), set bag nets (estuarine set bag net, marine set

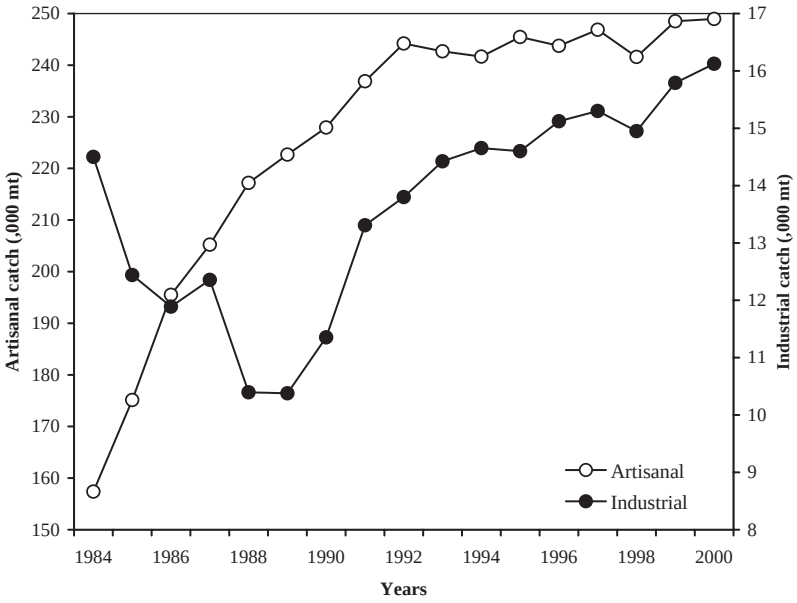

Fig. 3. Trends in fish landings from artisanal and industrial sectors of marine fisheries in different years.

bag net, and large mesh set bag net), trammel net, bottom longline, beach seine net and many other scattered throughout the coast and estuaries. Among the total production from artisanal sector, 55% is contributed by drift net and gill nets and 30% by estuarine set bag net [52]. The catches of the ESBN are mainly juveniles and young of fishes and other aquatic animals [33]. At present, 14,014 non-mechanized and 3317 mechanized boats are operating in marine and coastal artisanal fishing activities.

5.3. Shrimp seed fishery

Shrimp seed fishery has been one of the most important coastal fisheries, which gained momentum during the 1970s when commercial shrimp culture started in the coastal areas of Bangladesh on an industrial scale. For stocking in the farms, thousands of people—men, women and children—exhaust their energy to collect shrimp post-larvae along the nursery areas. Many types of gears are used but push nets are the predominant. Among the total collection of the shrimp seeds, more than 60% comes from push net operation [53]. The main collection areas are estuaries of Cox's Bazar, Teknaf, Khulna and Satkhira. Although there has been a tremendous decrease in the shrimp fry fishery these days, it resulted in a boon in the socio-economic condition of the poor fisherfolk community.

5.4. By-catch

By-catch is another significant part of the total landings of fishes in the Bay of Bengal, which includes landed by-catch and discards. A significant proportion of the by-catch comes from the shrimp fishery comprising 80–90% of the catch volume in the shrimp fisheries [33]. The post-harvest losses from discards by the Bangladesh trawlers are roughly estimated at around 50,000 metric tons per year [54]. Everything but shrimp less than 20 cm is discarded by the shrimp trawlers [55]. Species composition of shrimp by-catch are presented in Table 2.

Table 2
Species composition of shrimp by-catch [34]

Species	Family	Composition (%)
Catfish	Ariidae	25.1
Lizardfish	Synodontidae	23.2
Ponyfish	Leiognathidae	18.3
Jewfish	Sciaenidae	8.9
Hardtail scad	Carangidae	5.1
Solefish	Cynoglossidae	3.8
Threadfin bream	Nemipteridae	3.0
Goatfish	Mullidae	2.3
Squid and cuttlefish	Sepiidae/Ommastrephidae	2.2
Shad	Clupeidae	2.2
Miscallaneous		5.9
Total		100

6. Coastal aquaculture

6.1. Shrimp culture

In Bangladesh, coastal aquaculture is almost exclusively represented by shrimp culture. Many areas of coastal districts such as Khulna, Barisal, Patuakhali, Bagerhat, Chittagong, and Cox's Bazar, which were once covered with dense mangrove vegetation are now converted to aquaculture farms. In the southeast part in the delta of Matamuhuri River, one of the oldest mangrove forest of the subcontinent, the 'Chakaria Sundarbans' had an area of 18,200 ha which was dramatically reduced to 5446 and the rest of the area are used for shrimp cultivation.

The ecology of coastal areas and the climatic condition of Bangladesh are extremely suitable for shrimp culture with a very low production costs. Shrimp culture is mostly practiced in low-lying tidal flats within Bangladesh Water Development Board (BWDB) polders. The polders were originally constructed to prevent the land from brackish water inundation and to use the reclaimed land for agriculture. Prior to the construction of the coastal embankments, shrimp culture was done traditionally in a limited scale in the coastal district of Satkhira.

As a result of increasing demand and price, shrimp culture started to expand in 1970s aiming mainly the export markets. Shrimp culture area has expanded from 20,000 ha in 1980 to over 140,000 ha in 1994 and production has increased form 2220 t in 1982–1983 to 57,000 t in 1994–1995 [54]. About 75% of this land is located In Khulna, Bagerhat and Satkhira districts in the south and the rest in the Cox's Bazar district in the southeastern region of the country. Reliable sources suggest that the area suitable for shrimp culture in Bangladesh is around 0.2 million ha. In Khulna areas, shrimp is cultured in the dry season alternating with paddy in the rainy season, and in the Cox's Bazar area, shrimp and salt are produced alternately. Although shrimp culture technology in Bangladesh has been intensified to some extent over the last few years, the production level has not increased satisfactorily; one of the main causes is irregular and unscientific input supply. The average per hectare production in the shrimp farms is very poor, not exceeding about 200–250 kg/yr [51].

Shrimp culture is practiced mostly in the areas where the land is low and tidally inundated. Excavation of relatively high land to make its level lower and allow tidal inundation for shrimp is not common. Use of pump to supply surface water can be seen rather exceptionally in some areas. These farms are usually small in size, from fraction of a hectare to a few hectares, and are completely pump-fed. In some areas, small domestic ponds are connected with tidal creeks; these ponds are originally used for household purposes such as bathing, washing of cloths and dishes and are also used for brackish water aquaculture with varying degree of intensity.

Although more advanced culture technologies than that of the early stages are now in use in most of the shrimp farms, by no way, they can be treated as true scientific. The development itself took place in a speculating and traditional manner. Because of unscientific management, water quality problems are common in almost all farms in each year, which are further compounded by surprisingly higher stocking

density which results from the intention of getting more production. However, at the end, very poor production with respect to the total input is obvious. Frequent occurrence of disease and mortality of shrimps is another consequence of poor water quality.

On the basis of fry stocking rate and the degree of management applied, shrimp culture techniques that seem to exist in Bangladesh are traditional or extensive, semi-intensive, and intensive [56,57]. The traditional or extensive type is the predominant culture type currently in practice. An estimated 75% of the brackish water culture area is under extensive culture. The ponds are fed tidally and size varies from a few hectares to hundreds. The ghers are stocked by trapping the shrimp fry from the wild at high tide. No liming, fertilization and feeding is practiced although sometimes some water is exchanged at spring tide. Production is very low ranging from 0.06–0.2 t/ha/yr.

In the semi-intensive culture type, ponds are usually a few ha to 50 ha in size and are normally tidally fed. Smaller ponds at higher elevations are sometimes pump-fed. Stocking density ranges 2–3 juveniles per square meter area. Although not systematically, liming, fertilization and feeding is practiced. About 50% of the pond water is exchanged during each spring tide or 5–7 cm of water is exchanged every alternate day. Production varies between 0.6 and 1.0 t/ha/yr. In the extensive system, 10–35 post-larvae/m^2 are stocked in smaller ponds, with sizes ranging from 0.4–5.0 ha. They are supplied mostly with pelleted feeds but they also partly subsist on natural foods. About 10–20% of water is exchanged daily by gravity drainage. Yields of 2–5 t/ha/yr. are commercially obtained. During the last 20 years, shrimp culture practices have changed from 'traditional' to 'improved traditional' and there is increasing emphasis now on semi-intensive systems. However, intensive farming system is far away to be in practice.

6.2. Other brackish water aquaculture

Despite the high potential for developing commercial coastal aquaculture industries in Bangladesh, culture of any brackish water finfish species has not been started yet. The Brackishwater Station of the Fisheries Research Institute of Bangladesh has been conducting experiments on the possibility commercial culture of some finfish species, particularly, sea bass and mullet and some crab species especially the mud crab. However, some reports suggest that at present, culture of several species of finfishes and one crab species is being carried out on a small-scale. The major species cultured are *Lates calcarifer*, *Liza cascasia*, *L. ologolepis*, *and L. tade* among the finfishes and *Scylla serrata* among the crab species (the mud crab).

In shrimp farming, a number of finfish species get entry into the ghers along with the shrimps that are introduced by trapping during watering of the ghers. These fish species are also raised with that of shrimps. At the end of the culture period, large quantities of different species of finfishes are harvested. The major species are *Mystus*, *Wallago*, *Pangasius*, *Glossogobius*, *Liza*, etc.

7. Utilization of wild and farmed products

Traditionally, the bulk of fish and shrimp caught from artisanal and industrial fisheries as well as those produced in the aquaculture units are marketed directly to the local markets and are consumed fresh. However, demand for fresh marine fishes is low among the people in Bangladesh except in some areas; at the same time, it appears difficult or impossible for the fishermen to land their catch quickly due to lack of prompt transportation system. Therefore, significant portion of the catch are processed by using simple processing techniques like drying and salting. However, during the last decades, because of improved fishing technologies in artisanal and industrial sector, landings of finfish and shellfish increased considerably with a corresponding development of processing techniques. Fish and shrimp freezing industries grew rapidly with the spread of commercial shrimp culture and in response the demand for frozen shrimps in the export markets.

The export market for processed fish and shrimps from Bangladesh increased during 1980s. Hussain [21] reported 174.7 million USD of foreign earning in 1992–1993 which was 3.06 million USD in 1972–1973. However, the export markets are dominated mainly by the frozen foods, particularly, frozen shrimps. Hussain [21] reported that frozen foods contributed 94.3% of the foreign earnings in 1992–1993 of which frozen shrimp contributed 90.1%. The other items in the export markets include dry fish, salted and dehydrated fish, shark fins, crabs, turtles and tortoises, etc. The major export markets include USA, EEC countries, Japan, Germany, ASEAN countries, and the Middle East. Export earnings from different fish and fish products and their contributions in total national export earnings from 1983 to 2001 are summarized in Table 3.

It has been reported that the processed fish and shrimps from Bangladesh has suffered from quality losses and a considerable portion of the total catch lost its taste, flavor and nutritional quality from the board to the table. Lack of proper amenities such as packaging, handling during loading and unloading, method of processing, delay in processing are some of the contributing factors that result in loss of quality [33].

8. Marketing and distribution of marine fishes

Although marine fishes are not as popular as freshwater fishes in Bangladesh and marine fishes are consumed mainly by the coastal people, considerable amounts of frozen and dried fishes are also transported to different areas of the country, particularly to Dhaka City. However, the demand for marine fishes has been in an increasing trend since the last few decades and this has led to the development of different marketing and distribution channels in different levels. Alam [58] described three different levels of fish markets; detailed descriptions are also available in Tsai and Ali [59]. A generalized marketing and distribution channel is given in Figs. 4a and b show the marketing of marine fishes in particular. Four levels of marketing systems are observed in the distribution channel of fish trade. These are the primary,

Table 3
Quantities of different fish and fish products exported in different years with corresponding foreign currency income

Year	Frozen shrimp		Frozen fish		Frozen frog leg		Dry fish		Salted and dehydrated		Crabs, turtles and tortoise		Shark fin		Total		% of total export earning
	Qnty	Value	Qnty	Value	Qnty	Value	Qnty	Value	Qnty	Value	Qnty	Value	Qnty	Value	Qnty	Value	
1983–1984	8818	155.50	2817	14.17	2495	19.25	74	0.86	283	3.12	440	2.52	43	1.30	14970	196.81	9.89
1984–1985	12682	199.45	3297	14.77	1365	10.27	47	0.55	382	3.66	425	2.43	108	2.12	18306	233.25	9.66
1985–1986	13631	269.31	5017	36.50	2463	30.07	786	10.06	422	4.95	679	4.11	50	1.25	23048	356.25	14.65
1986–1987	16275	341.75	4046	35.41	2168	30.56	402	4.90	295	3.84	461	4.10	114	3.49	23761	424.05	12.99
1987–1988	15023	361.17	4191	28.35	2708	42.42	475	6.69	372	4.81	524	6.06	130	4.62	23423	454.12	11.93
1988–1989	15386	382.05	2427	22.59	2685	43.82	567	13.89	293	4.12	293	2.65	68	2.77	21719	471.89	11.51
1989–1990	17505	414.31	3484	25.58	730	10.29	1278	23.40	161	1.44	146	0.95	35	2.80	23339	478.77	9.62
1990–1991	17985	451.22	5702	41.40	318	7.36	427	5.75	1194	13.95	405	3.22	78	3.72	26109	526.62	8.64
1991–1992	16730	455.73	2604	30.10	771	11.09	892	14.11	80	1.39	938	6.52	65	5.41	22080	524.35	6.91
1992–1993	19224	604.03	2704	38.31	—	—	1042	12.26	599	9.84	2800	21.60	238	14.25	26607	700.29	7.57
1993–1994	22054	787.73	3125	51.18	—	—	2473	41.83	50	1.06	4088	36.37	45	2.79	31835	920.96	9.12
1994–1995	26277	1045.67	9267	180.26	—	—	521	8.39	649	15.35	4760	40.67	212	16.60	41686	1306.94	9.38
1995–1996	25225	1106.39	8827	176.62	—	—	182	3.05	436	11.47	4203	39.20	56	4.21	38929	1340.94	9.38
1996–1997	25742	1188.91	8754	176.74	—	—	427	7.92	561	13.18	5952	61.48	113	8.55	41549	1457.41	7.75
1997–1998	18630	1181.48	8836	151.66	—	—	233	3.11	1106	26.43	1198	14.34	155	10.79	30158	1387.81	5.83
1998–1999	20127	1162.21	6395	153.96	—	—	137	2.23	1232	37.18	486	6.39	154	17.41	28531	1379.38	5.41
1999–2000	28514	1612.15	5227	106.95	—	—	215	3.65	809	25.96	107	1.44	262	31.17	35134	1781.32	6.28
2000–2001	29713	1885.15	5150	72.64	—	—	137	2.02	838	27.73	154	2.33	181	20.63	36173	2010.50	—

Qnty—quantity (in metric tons); value in crore *Taka* (1 crore = 10 million; 1 USD ~ 58 BDT).

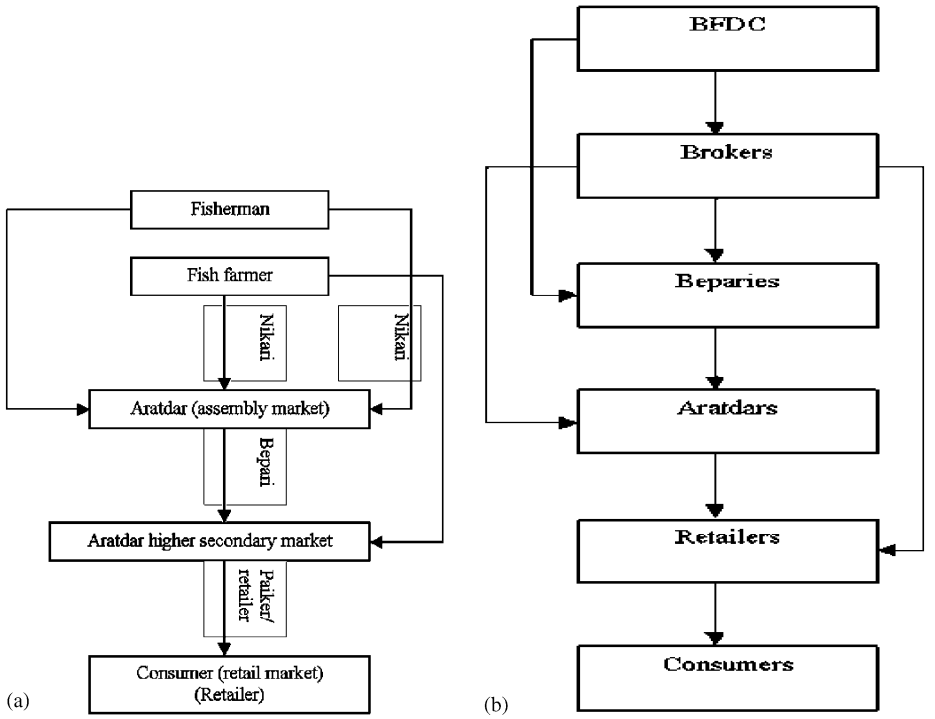

Fig. 4. (a) Generalized marketing channel for openwater fishes (A Nikari is a large wholesaler who stocks large bulk of fish from primary fishers; A Bepari is a marketing intermediary who collects products directly from producers or from primary markets for further transfer another intermediary; Paikers are small-scale wholesalers who may be involved in retailing at the same time). (b) Marketing channel for marine fishes (BFDC—Bangladesh Fisheries Development Corporation).

secondary, higher secondary and retail markets. In the course of marketing at all these levels, the collector or distributor carries out the function of handling, cleaning, sorting, icing, preservation and transportation at his cost as far as possible. As in the other fish marketing channels in Bangladesh, marine fish markets are also characterized by the presence of many intermediaries.

Fish traders generally control the fish markets and the marketing of fish, either individually or as groups by the name of Fish Traders' Associations or Fishermen's Cooperative Societies. Almost all fish markets operated by them are ill managed, unhygienic and unscientific. There is no proper handling, washing, cleaning, icing or re-icing of the fish. They care very little for post-harvest management of fishes, interested only in earning more revenue. The fish marketing and distribution system has been suffering from a general and chronic lack of well-arranged system. Due to the involvement of too many intermediaries in the marketing channel the consumers have to pay higher price but the original fishermen do not get a good price for their products; the lion shares go to the intermediaries.

9. Environmental issues

9.1. Coastal and marine pollution

At present, the marine and estuarine ecosystem of the Bay of Bengal are threatened by different types of pollutants dumped directly into the ecosystem or washed down through large number of rivers and tributaries. The major sources of marine pollution in the Bay of Bengal are industrial wastes, municipal wastes, agrochemical wastes, and oil pollution. More than 900 polluting industries, directly or indirectly, discharge their untreated liquid and solid wastes into the coastal rivers and other water areas. The Karnaphuli and the Rupsa–Bhairab rivers, which receive effluents from 309 industries in Chittagong and Khulna, are major carriers of such industrial contaminants as ammonia, chromium, mercury, phenols and DDT. The major waste producing industries include fertilizer and agrochemical industries, pulp and paper mills, dyeing, printing and packaging, textile mills, iron and still mills, sugar mills and breweries, jute industries, tanneries, cement industries, plastic and rubber industries, distilleries and refineries, etc. Reports are available of direct fish kills and the toxic effect on the mortality of post-larvae and juveniles in the nursery grounds [6].

Most of the cities and towns in Bangladesh lack domestic waste treatment facilities. As a result huge quantities of untreated municipal wastes find ways directly or indirectly into the rivers and eventually to the coastal and marine waters of the Bay of Bengal. There has been an increasing trend of the use of different types of agrochemicals, both fertilizers and pesticides with the intensification of the agrofarms and the introduction of the high yielding varieties (HYV). It has been reported that about 9000 metric tones of different pesticides and more than 2 million metric tones of fertilizers are used annually in Bangladesh [60] and at present about 1800 t/yr [6] of pesticide residues are added to the coastal waters through runoff. Huge amount of fertilizers find ways into different receiving waters through surface runoff resulting in eutrophication. As a measure of pollution control from deleterious agrochemicals, a number of chemicals have been banned by the Government of Bangladesh. However, it has been reported that some of such chemicals are still imported illegally from India through. Contamination with DDT and its toxic metabolites such as DDE has been reported [60]. DDT, a reportedly lethal and persistent chemical, is being used in fish drying plants for years to increase the shelf life of dried fish and protect invasion by insects.

The most deleteriously affected areas of localized oil pollution in Bangladesh are Chittagong and Mongla ports. Increased shipping activities in the ports, crude and refined oil transportation, oil slicking from mechanized vessels, refinery and workshop spillage and accidental oil spillage by tankers are the major sources of pollution threatening the aquatic lives in the upper Bay of Bengal. Owing to a lack of waste-reception and treatment facilities in the ports, and a lack of effective legislation and surveillance, foreign and domestic ships and trawlers discharge their oily waste in the sea. Significant discharge of crude oils and related metallic and

chemical wastes is reported from ship-breaking operations around Chittagong and Khulna.

9.2. Impacts of shrimp farming

Considerable debates and arguments occurred during the last decade on various impacts of shrimp farming on the environment, biodiversity as well as on the society [57,61,62]. In the absence of viable hatchery industry, the shrimp culture industry is mostly dependent on wild source of tiger shrimp (*Penaeus monodon*) fry for stocking. Being allured by this situation, thousands of poor landless and unemployed coastal folk engage themselves along the coastline for catching tiger shrimp fry from the nearshore waters of the Bay of Bengal. The catch includes six penaeid and one non-penaeid shrimp, four types of freshwater prawn, four types of crabs and mollusks, 50 types of finfishes and 20 types of zooplankton. The collectors or their family members sort out tiger shrimp fry from the catch and the remainder of the catch is thrown on the shore. A large number of immigrating young shrimps and fishes are destroyed before attaining a biologically sustainable size due to intensive fishing pressure. The overexploitation has been reported to result in a decreased availability of shrimp fry from year to year. Thus, it is apparent that this trend of overfishing will undoubtedly have a disastrous impact on the artisanal and commercial fishery in near future.

Large areas of natural mangroves are eradicated for construction of shrimp ponds. Construction of canals and dikes has irreversibly altered the hydrological characteristics of the areas. Conversion of mangrove areas to shrimp ponds and other forms of land uses, though initially resulting in huge profit earnings, fetched irreversible long-term impacts to the coastal communities. The Chakaria Sundarbans was completely destroyed in the name of 'improvement of shrimp culture technology'. Rapid deforestation along the Matamuhuri river basin has led to an increase in both the discharge rate and sediment load of the river. Mangrove removal is also reported to cause coastal erosion and change sedimentation patterns and shoreline configuration [57]. As a result of clearance of large areas of mangroves, natural production of fish and shrimp has been reduced to a great extent and shrimp larvae are not sufficiently available for stocking in many parts of the world, resulting in empty and abandoned farms. Because of large-scale destruction of mangroves for shrimp culture, the natural breeding grounds have been lost to a great extent (FAO/NACA, 1995). The clearing of mangroves resulted in an increased vulnerability to cyclones and tidal waves.

In ponds, constructed through mangrove cutting, highly pyritic soils are formed resulting in high acidity and high aluminium concentrations in and around the shrimp farms [57]. Potential acidity thus formed cause severe stress to cultured animals making them vulnerable to diseases and parasites. In southeast Bangladesh, several shrimp disease syndromes broke out in the form of epidemic and massive killing of farmed shrimp resulting in huge production loss, were linked to acid sulfate soils. Most of the farms are now left abandoned. Drainage of mangrove soil for agricultural purposes and the exposure of the pyritic sediments during excavation of

ponds lead to their oxidation, resulting in the formation of sulfuric acid which is released in the soil, thereby, increasing the acidity of the soil, and in such cases pH may drop below 3.0 creating a condition of severe acidity at which, solubility of aluminium, iron, and manganese increases and these may cause phytotoxicity.

Prolonged inundation of large areas for shrimp farming has led to percolation of salts in the surrounding soils resulting in altered soil chemistry. Extended inundation of lands prevents free nitrogen fixation and mineralization is halted and soil fertility reduces within a few years. Salt water intrusion in some freshwater aquifers may also be accompanied by salinization of soils. In the coastal areas of the country, loss in crop production, freshwater crisis, and loss of fodder are common consequences of salinity intrusion. The water discharged from shrimp farms contain dissolved metabolites, organic matters in the form of detritus and unused feeds, particulate organic matters, various forms of toxic and hazardous chemicals, fertilizers, feces, microbes, etc. The volume of wastes occurs at a very high amount when the ponds are dried for complete harvesting of the crop.

A wide variety of chemicals such as herbicides, pesticides, lime, fertilizers, antibiotics, preservatives in feeds, disinfectants and many other known and unknown chemicals are used in the shrimp farms throughout the culture period. The use of such chemicals has gradually been increased as a result of increased intensification and the gradual problems that arise in the management systems. It is supposed that some of such chemicals particularly the antibiotics and some persistent ones might lead to the proliferation of resistant pathogens complicating further disease treatment, due to the residual effects of the persistent chemicals, they get deposited through various food chains in different animals even in man. Huge amounts of water are used for this purpose in each cycle of culture resulting in lowering the underground water table and consequently drying wells. Severe scarcity of drinking water is common in the areas, particularly during the dry periods.

A very rich assemblage of aquatic, semi-aquatic and terrestrial plants and animals is one of the very important and common features of the mangrove areas. The pattern of plant species in the mangroves of Bangladesh has undergone a remarkable change during the past few decades. These changes have been brought about by the changing habitat condition over a long period of time because most of the mangrove species grow within a narrow range of habitat condition. In addition to the environmental hazards, direct exploitation and deforestation of mangroves, particularly at the vicinity in search of food, fuel, construction materials, and settlement, have resulted in severe degradation of mangroves. To regulate the activities within the forest and to ensure sustainable resource use from the forests, several policies have been formulated, amended, modified and improved over years and efforts have been made to orient the policies to meet current needs. Consequently, the Government formulated the National Forestry Policy-1994 for a period of 20 years. However, despite the up-to-date management policy mangrove destruction continues due to error and failure in policy implementation, weak administrative regulations and enforcement, weak institutional framework and lack of scientific management.

The composition of faunal species in the mangrove areas is far more affected by the degradation processes. A number of species important commercially and intangibly which were once present in enormous numbers are now reported to be either endangered or completely lost. The densities of many terrestrial animals have been reduced to an alarming level because of decreased habitat. The most important example is the Royal Bengal Tiger, the density of which has been reduced to a great extent because of rapid deforestation and reduction of its prey population. Unregulated human access to the forests is one of the main causes of reduction of tiger population and this reduction has subsequently resulted in increased rate of exploitation of the mangroves by man.

The biodiversity impacts of mangrove utilization are profound on the wild fish stock. It has been reported that about 12 species of fish are considered as endangered or threatened due to their gradual disappearance as a result of change or conversion of habitats [102]. Although precise information regarding the effects of import of shrimp fry from other countries on the native genetic stock are not available, there are many evidences that introduced genetic material often has a lower reproductive successes. The data on the reduction in plant and animal biodiversity and production in the coastal residential areas due to shrimp culture are very frustrating as well as alarming. It has been shown that during 1986–1989, total production of cows and buffalos have been declined by 47% and yield by 25%; mortality of chicken is very high due to higher salinity resulted from salinity intrusion; poultry production declined by 36% in shrimp culture areas [57]. Poultry farming have become difficult due to reduced natural food and degrading economy of the rural people, which does not permit them to buy feeds for the poultry. Productions of other green crops along with paddy have been reduced to a great extent. Significant reduction in the fruit trees such as coconut, mango, jackfruit, bettlenut, etc. have been reported from both Cox's Bazar and Khulna regions. Most of the fewer trees still remaining are almost fruitless even in the season.

The land use patterns, and leasing and sub-leasing systems in the coastal regions of Bangladesh have resulted in a chain of tenurial hierarchy. Repeated claims have revealed that the political leaders, relatives of powerful army officers, bureaucrats, high official bankers, business magnets, and landlords who are sufficiently powerful to handle the ownership and the tenurial processes shrimp culture ponds, have access to the necessary capitals and credits usually gain the benefits [57].

Shrimp farming activities have been reported to be less labor intensive, requiring one-fourth of that of the traditional agricultural activities. About three-quarters of the agro-based labor force have therefore been squeezed. Again, the leaseholders from outside generally do not trust the local laborers and rather hire workforce from their own localities. The unemployment problem being very acute in the coastal areas and such bias against local laborers is a source of discontent among them. In the coastal areas, the poor are becoming economically more and more vulnerable due to shrimp culture. Livestock and trees are important private resources, which save the poor in overcoming vulnerabilities. In the shrimp farming areas, common grazing grounds have been converted to shrimp and thus the grazing areas are restricted. A number of canals, earlier used by the poor fishermen for their

livelihoods have been turned into shrimp ponds. In the remaining canals, although they can be fished, virtually no fish are available due to shrimp farm effluents containing toxic chemicals and hazardous substances discharged into the canal.

10. Management issues

10.1. Management problems

The problems of the coastal and marine fisheries of Bangladesh are many and varied. The fisheries sector has been suffering from a chronic lack of well-planned management approaches [31,63–65]. The management agencies are formed on the basis of economic sectors giving major consideration on economic benefit from the resources. The complex biophysical mechanisms occurring in the ecosystems and their relations with the management are rarely considered and evaluated. Consequently, persons with sufficient knowledge on the scientific basis of fisheries management and development are ignored from the higher level of policymaking and management bodies.

Many of the fisheries development policies cannot be successfully implemented due to various reasons. Corruption at different levels of management systems, illegal fishing, use of illegal gears are some of the major constraints in successful implementation of development projects. There are frequent claims that the law enforcing agencies and the management bodies themselves are sometimes engaged with the illegal actions. If this situation prevails, virtually, no policy, rule or regulation could contribute to the development of the resources. Implementation of development policies is hindered to a great extent by shortage of manpower for official management, including monitoring, evaluation, supervision, etc. As in other Asian nations, there is a general shortage of resource management expertise in proportion to the scale and rate of development related pressures in Bangladesh. Poor management policies, weak organizational and legal efforts and, above all, the population pressure have subjected the coastal areas vulnerable for overexploitation and massive destruction. The need for a basic guideline for coastal and marine fisheries resources has been fully recognized to overcome the problems of unplanned destruction [66,67]. Due to the lack of proper handling, processing and marketing infrastructure, a large bulk of fish and other catches are damaged every year [68,69].

Various development activities have interrupted in the biological processes of the open freshwater as well as coastal and marine fisheries. River closures, barrages and sluice gates obstruct the siltation flow process, which is supposed to wash down to the Bay of Bengal, and, as a result, the rivers and estuaries are silted up. The closure of the Kumar River under the Ganges-Kobadak Project, has for example cut off the *Hilsa* migration route and, as a consequence, the *Hilsa* fishery in the Kumar river is no more evident. The *Hilsa* fishery in the Ganges has declined both in India and Bangladesh due to the Farakka Barrage.

The trawler fleet, although not permitted by rules and ordinance to fish at depths shallower than 40 m, normally fish upto 30 m and even upto 20 m depth. As their

gear is non-selective, they too harvest sizes of fish and shrimp, which fall under the post-juvenile and pre-adult categories, thereby restricting adult recruitment of a part of the population.

One of the most crucial problems in coastal and marine fisheries management of Bangladesh is characteristic tropical multi-species and multi-gear fisheries. Any single fishing operation catches a number of species at different sizes and ages. On the other hand, individuals of single population of one species belonging to a single stock are exploited by different interactive fishing gears. As a result, a large increase in artisanal fishing pressure significantly lowers the number of fish/shrimp reaching the industrial fishing resulting in lower overall catches in the industrial fleet. For these reasons, the penaeid shrimp stock is under pressure from all sides. The ESBN, pushnets and beach seine harvest the members of the same population at sizes much lower than the size at first maturity and, as a result, about 99% of the population do not get a chance to participate in the spawning process [70]. It was estimated that out of the total penaeid shrimp harvested, ESBN comprises 55.87%, the trawler fleet 29.70%, MSBN 14.30%, beach seine 0.09% and the pushnet only 0.04% by weight. The same production if converted into number shows a reversed situation i.e. the trawler fleet takes only 1%, ESBN 3.4% and the pushnetters alone take 94.6% [71]. Thus it is evident that the enhanced production in the trawl fishery largely depends not on the trawl fishery alone but on the management of the three artisanal fisheries.

Infrastructural and service facilities for fisheries development and management are inadequate. In the absence of proper landing centers, artisanal fishermen land their catches at scattered places which do not have processing, marketing and rapid transportation facilities. Some of the mechanized boats catching *Hilsa* land at a few landing centers of the BFDC. The other private landing places do not have adequate ice, freshwater supply and other facilities. Therefore, post-harvest losses are common for all types of fisheries leading to obvious loss of fish quality poor return for fishermen.

10.2. Options for better management

As a regulatory approach, a 30 mm cod-end mesh size was introduced for ESBN on the assumption that the juveniles would escape. However, increased mesh size virtually results in no catch because this gear targeted mainly the juveniles [72]. Therefore, complete withdrawal of this gear from the estuarine environment was suggested [70]. However, this option has emergence the question of how rehabilitation of about 50,000 ESBN fisherfolk would be made. Since, it would be difficult to arrange alternate employment of the big number of ESBN fisherfolk, management of existing fisheries with the direct participation of ESBN fisherfolk might be considered. Gradual reduction of fishing effort by ESBN fishery and, as a first step, closure of fishing during the peak recruitment periods, i.e. July to September and February to April in selected areas would substantially reduce the juvenile mortality [73].

After careful consideration, banning of particular fishing gear which involve few people but target big mass of fish might be useful option for management of

particular fish stocks. For example, large mesh driftnets have been operated in the Cox's Bazar region for the last two decades, targeting the Indian salmon and long jewfish. These species have been fished so much that they are nearly extinct now. So, operation of this gear needs to be stopped for possible recovery of the fish stock.

The by-catch of shrimp PL fishery and destroys large mass of other species resulting in reduced standing stock of that species year after year. To reduce the loss as by-catch, an alternate method of collection must be tried, targeting only the shrimp PL. Moreover, mortality during sorting, transporting and stocking (which accounts for about 60% of the total shrimp PL mortality after collection from Nature) should be reduced. If this mortality could be reduced substantially, 50% of the PL could be left behind in the sea to give enhanced production [70]. Fishing for PL in the months other than the peak stocking season should also be restricted. The coastal shrimp farming industries have been developed without the development of shrimp hatchery. Establishment of sufficient number of hatchery would benefit both the natural shrimp stock as well as the shrimp farming industries. In addition to the shrimp seed fishery, a huge mass of by-catch resulting from fish and shrimp trawlers and artisanal fisheries are discarded into the sea. In a country where there is a shortage of food, the nation cannot afford to discard this low-cost but high value animal protein. The large bulk of by-catch should be effectively utilized as fish meal in fish and poultry feed and can be processed into value-added products.

Some fisheries are at present biologically sustainable, but their distribution and the effort in them is limited. Expansion of these fisheries may give enhanced and sustainable production as well as create room for rehabilitation of the ESBN fisherfolk. The trammel net fishery has proved the most sustainable fishery. At present this fishery is operated in limited areas only and horizontal and vertical expansion of this fishery offers suitable opportunity in sustainable fisheries management. Another fishery that deserves expansion is the bottom long lining which has created a good employment opportunity for the fisherfolk. The fishery targets croakers and is an export oriented venture with high degree of feasibility [74].

There are waterbodies under the control and ownership of the ministries other than fisheries. Some of these waterbodies/areas are directly 'managed' by administrative units such as the Ministry of Land, Department of Forests, and MOEF. However, these are revenue oriented managements rather than scientific. But since fisheries resources are a living renewable resource requiring biological management based on research findings and scientific information irrespective of the ownership of the resources. Any development or management activity that relates the waterbodies and resources should be done only in close consultation with the MOFL/DOF to ensure no harm to the fisheries and aquatic biological resources. Establishment of integrated coastal zone management programs with direct participation of all relevant bodies would provide reasonable solution of the problem.

Immediate action should be taken to save the coastal and marine environment from pollution. The coastal industries should be critically attended and should be enforced to reduce the load of discharge. Waste treatment facilities need be established in the coastal districts and rules need be reformulated to take care of

aquatic life. Mangrove plantation programs should be undertaken jointly by the Department of Fisheries and Department of Forest to ensure recovery of the forest land and habitats for aquatic living resources. The legal aspects should be reviewed and institutional reformation should be done to formulate an easy-to-follow guideline for the fishermen and the farmers. There are gear and area conflicts between artisanal and industrial fishermen. There are reports of sea piracy and resource use conflicts. Effective measures should be taken by the appropriate authority to solve these problems.

10.3. Legal and institutional framework

In 1983, the Government of Bangladesh enacted the 'Marine Fisheries Rules, 1983', in accordance with the provisions of the 'Marine Fisheries Ordinance, 1983'. Under the provisions of the ordinance, the marine fisheries wing of the Department of Fisheries (DOF) is authorized to deal with matters relating to marine fisheries exploitation, including licensing and monitoring of fishing vessels. The Marine Fisheries Rules amended in 1993 provide for licensing and monitoring of artisanal mechanized fishing boats as well. Under the ordinance, the officers of the marine wing of the DOF have been empowered to check, seize or take appropriate action required for surveillance and enforcement of the rules of the ordinance. The Ministry of Industry is currently authorized to accord permission in consultation with the Ministry of Fisheries & Livestock (MOFL), for the acquisition of fishing trawlers. The mechanized fishing vessels are registered with the Mercantile Marine Department (MMD). To patrol the EEZ, the DOF procured two modem gunboats and placed them under the operational control of the Bangladesh Navy. Besides the MOFL, other ministries directly involved are the Ministry of Land, Ministry of Industries, and Ministry of Environment & Forest (MOEF).

Fisheries administration and management primarily remain under the control of the MOFL. The Department of Fisheries is the key organization responsible for development and management of fisheries. BFDC was established in 1964 with a view to promote the fishing industry and develop landing, preservation and processing facilities, particularly in the marine sector. The Fisheries Research Institute (FRI) was established in 1984, as an autonomous organization under the administrative control of the MOFL. Research stations and ancillary facilities of the DOF were, subsequently, transferred to the FRI. The mandate of the FRI is to plan and undertake adaptive research programs to develop suitable technology for fish farmers and fishery managers. But survey work producing information on resource monitoring and management remains with the DOF. This work is at present done by a permanent set up of the DOF, called the Marine Fishery Resources Management and Monitoring unit. Several NGOs and fishermen's cooperatives are involved in marine fisheries development activities in the country. The *Bangladesh Jatiyo Matshyajibi Samabay Samity* (Bangladesh National Fishermen Cooperative Society) was established with promising involvement and role in marine fisheries development, but is now ineffective. Among the NGOs, Codec, Caritas, and Proshika-MUK are directly involved in the development of the coastal fisherfolk community.

11. Research needs

The coastal and marine resources of Bangladesh have been exploited since very long but, unfortunately, exploitation has been done without any understanding of the basic functional ecological systems, which are very important for a sustainable resource management and to obtain the MSY. Despite the richness of the Bay of Bengal in biological genetic diversity, very little or no knowledge has so far been gathered on the biology and life history of individual species. Information on the spawning stock of individual species, spawning ecology, larval movements, larval survival and mortality in relation to environmental factors and subsequent recruitment are of particular importance for a fishery to be managed on a sustained basis. For the estuarine dependent species, an understanding of the basic ecophysiological backgrounds of breeding, feeding and nursery may provide important information on the mechanisms of their estuarine dependency that may guide the fishery managers. Unfortunately, these basic biological and ecological aspects of fish populations in the Bay of Bengal are extremely fragmentary and have long been ignored for almost all the fishes. Few research works have so far been done that include the basic biological aspects of fish biology and ecology (Table 4).

Numerous projects have so far been implemented on the coastal and marine fisheries development and much have been written on these aspects. However, almost

Table 4
List of basic fisheries experimental works on coastal and marine fish and fisheries of the Bay of Bengal

Author(s)	Year	Area of study
Alam et al. [75]	1989	Catch composition
Alam et al. [76]	1996	Maturation and spawning
Ali et al. [77]	1985	Physico-chemical aspects of estuaries
Aziz and Islam [78]	1980	Plankton study
Chowdhury and Hafizuddin [79]	1991	Description of some crabs
Gofur and Bhuiyan [80]	1983	Occurrence of fish
Haroon et al. [81]	1989	Check list of fish and prawn
Humayun et al. [82]	1989	Population dynamics
Islam and Aziz [83]	1980	Marine plankton
Khan [84]	1998	Description of new fishes
Khan [30]	1986	Age, growth and mortality
Khan et al. [85]	1985	Population dynamics
Kurita et al. [86]	1991	Ecological relations
Latifa et al. [87]	1992	Sex ratio and size distribution
Latifa et al. [88]	1986	Fecundity
Mustafa [89]	1989	Population dynamics of brown shrimp
Mustafa [90]	1996	Population dynamics of brown shrimp
Mustafa and Ali [91]	2000	Population dynamics
Rahman and Naevdal [92]	2000	Population genetics
Sarker and Rahman [93]	1991	Jew fish fishery
Sasaki [94]	1995	Description of new fish
Shafi et al. [95]	1978	Fecundity
Zafar et al. [96]	1999	Population dynamics

all efforts and reports were made on a broad aspects of management strategies giving emphasis on the management of capture fisheries to prevent overexploitation, stock assessment, determination of MSY, assessment and reduction of impacts of shrimp culture, etc. ignoring the importance of studying the biology and ecology of a particular fish in details. Although implementation is far away, some of the projects and reports pointed out important key points and suggested measures for different issues for the overall development of the sector.

Although there are numerous promising fish species for development of commercial coastal aquaculture in Bangladesh and research has been done for years, it has not yet been possible to develop coastal finfish aquaculture on a commercial basis. Most of the fish species that have proven performance and have gained momentum in coastal aquaculture and mariculture in other parts of the world are also present in the Bay of Bengal. Unfortunately, Bangladesh could not take advantage of the already established technologies elsewhere in the world to develop its own coastal aquaculture and mariculture systems.

Another important area that has immense prospects but has been completely ignored is the possibility of marine stock enhancement and sea ranching. The history of sea ranching is very old [97] and many maritime countries such as Japan, Norway, Iceland, and USA have launched successful ranching programs for marine stock enhancement. Species such as red sea bream, flounders, cod, Atlantic salmon, etc. are now proven candidates for marine stock enhancement [97–99]. The basis of the concept of stock enhancement is to utilize the full potential of the carrying capacity of the coastal and marine habitats; therefore, it requires a complete understanding of the existing stock and details biology of the species to be released. Although it appears highly technical and more advanced techniques, sea ranching is particularly applicable to restore the overexploited and depleted areas like the Bay of Bengal. Moreover, the pelagic resources such as tunas and related species, mackerels, sharks and rays, sardines, anchovies, shads offer vast potential for development of new fishery in the Bay of Bengal. Development of these resources would open a new era for the marine fisheries sector of Bangladesh.

12. General recommendations and conclusions

Although the capture fisheries production of Bangladesh has been keeping pace with the total world capture fisheries production since 1991 (Fig. 5) a large increase in fishery production from this sector is obtainable through better management and efficient resource utilizations. Also the Bay of Bengal provides a vast potential for improvement of the natural stock as well as commercial marine aquaculture and stock enhancement. However, there are many biological, social and economical constraints that must be overcome to achieve the maximum possible utilization of the resources. This needs well-arranged efforts that must include the participation of the experts, managers, organizations and stakeholders. To conserve and manage fishery resources for the benefit of the present and future generations, the resources need to be managed and exploited on a sustainable basis. This needs continuous

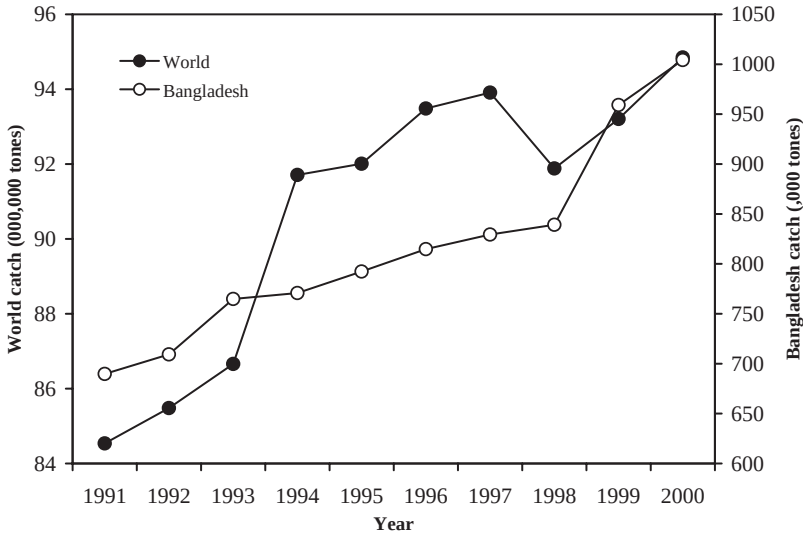

Fig. 5. Trends in capture fisheries production of Bangladesh in different years in comparison to the world production.

information-support through research [54]. Many useful suggestions and recommendations have so far been made by different authors and experts [10,33,54,58,70] that can well be considered in formulating effective management plans for sustainable development. However, peoples' awareness and perception towards sustainable development is sometimes even more important than the plan itself. Most of the fishermen are not educated enough to have a basic understanding of the long-term management goals and, therefore, it appears difficult to implement even a well-formulated plan, which necessitates extension works and awareness building programs.

Understanding the marine ecology of the area, assessment of primary and secondary productivity of EEZ of Bangladesh; marine fish stock assessment to relate with marine productivity and marine fish landing; development of improved methods for harvesting underutilized marine resources, especially pelagic fishes within the EEZ of Bangladesh; research on various methodology of monitoring the catches and fishing efforts of industrial and artisanal marine fisheries to evolve a catch monitoring system so as to assess the status and trends of resources in catch; identification of overexploited species and their management for conservation; development of methods of fry collection, identification, sorting and transport; development of controlled reproduction and hatchery production of shrimp seed; development of technique for processing by-catch and small pelagic fish for the preparation of improved quality value-added products; development of post-harvest technology to prevent deteriorative changes occurring in fish during different stages of handling, transportation, processing and preservation are some of the immediate needs for the development of the coastal and marine fisheries of Bangladesh.

A large increase in artisanal fishing pressure significantly lowers the number of shrimp reaching the industrial trawling grounds and results in lower overall catches in the industrial fleet. A situation like this preceded a temporary collapse of the shrimp stocks in the gulf [100]. As a result of the impact of the destructive fishery, about 99% of the population do not get a chance to participate in the spawning process [71]. It is evident that the enhanced production in the trawl fishery largely depends not on the trawl fishery alone but on the management of the artisanal fisheries. Therefore, the management authorities and experts should be aware of the key points in the management hierarchy. Recent ban on collecting shrimp fry from natural sources can be considered a timely step in preventing massive destruction of shrimp and other fish populations. However, such measures must take into account the socio-economic conditions and should have proper guidelines for rehabilitation of the poor fisherfolk. The government authorities should critically attend the opinions of the experts and should support the research facilities in order to get better resource exploitation to keep pace with the increasing demand for fish in the new century.

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References

[1] FAO. The state of world fisheries, aquaculture 1998. Rome, Italy: Food and Agricultural Organization; 1999. http://www.fao.org/docrep/w9900e/w9900e00.htm.
[2] BFRSS. Water area statistics of Bangladesh. Fisheries Information Bulletin, vol. 1, Bangladesh Fisheries Resources Survey System, Dhaka, Bangladesh, 1986.
[3] Chowdhury WN, Iversen SA, Khan MG, Saetre R. Preliminary results from a survey on the marine fisheries resources of Bangladesh, May. Institute of Marine Research, Bergen, 1979. 28pp.
[4] Chowdhury WN, Iversen SA, Khan MG, Saetre R. Preliminary results from a survey on the marine fisheries resources of Bangladesh. Institute of Marine Research, Bergen, 1980. 17pp.
[5] FAO. Technical cooperation program, Integrated development of Bangladesh by FAO, based on the work of HR Rabanal. Rome, FAO, FO: TCP/BGD/2309, 1984. 28pp.
[6] Mahmood N, Chowdhury NJU, Hossain MM, Haider SMB, Chowdhury SR. An environmental assessment of the Bay of Bengal region. Swedish Centre for Coastal Development & Management of Aquatic Resources (SWEDMAR). Bay of Bengal Program, BOBP/Rep/67, 1994. p. 75–129.

[7] Kausher A, Kay RC, Asaduzzaman M, Paul S. Climate change and sea-level rise: the case of the Bangladesh coast. In: Warrick RA, Ahmed QK, editors. The implications of climate change and sea level change for Bangladesh. Dordrecht: Kluwer Academic; 1996.
[8] Khan YSA, Hossain MS. Impact of shrimp culture on the coastal environment of Bangladesh. International Journal of Ecology and Environmental Sciences 1996;22(2):145–58.
[9] Alam MF, Thomson KJ. Current constraints and future possibilities for Bangladesh Fisheries. Food policy 2001;26:297–313.
[10] Hossain MS. Biological aspects of the coastal and marine environment of Bangladesh. Ocean & Coastal Management 2001;44:261–82.
[11] Wyritki K. Oceanographic atlas of the international Indian Ocean expedition. Washington, DC: National Science Foundation; 1971. 531pp.
[12] Krey J, Babenerd B. Phytoplankton production atlas of the international Indian Ocean expedition. IOC/UNESCO, 1976. 70pp.
[13] Hena MA. Physical oceanography in Bangladesh. National Seminar on Oceanography and Marine Resources, Dhaka, Bangladesh, 1980.
[14] Mridha S.The Bay of Bengal—biological oceanography and marine resources. Dhaka: Bangla Academy; 1995. 260pp. (in Bengali).
[15] Davies C, Best CJ, Collier R. Sedimentology of the Bengal shelf, Bangladesh: comparison of late Miocene sediments, Sitakund anticline, with the modern, tidally dominated shelf. Sedimentary Geology 2002;155(3–4):271–300.
[16] Alam MM, Curray JR. Sedimentary geology of the Bengal Basin, Bangladesh, in relation to the Asia- Greater India collision and the evolution of the eastern Bay of Bengal; The curtain goes up on a sedimentary basin in south-central Asia: unveiling the sedimentary geology of the Bengal Basin of Bangladesh. Sedimentary Geology 2003;155(3–4):175–8.
[17] Chaudhury AB, Naithani HB. A comprehensive survey of tropical mangrove forests of Sundarbans and Andamans. Part-I. Dehra Dun, India: International Book Distributors; 1985. 41pp.
[18] Chaffey DR, Sandom JH. Sundarbans Forest Inventory Project, Bangladesh: a glossary of vernacular plant named and a field key to the trees. Overseas Development Administration, England, 1985. 23pp.
[19] Eysink WD. Basic considerations on the morphology, land accretion potential in the estuary of the lower Meghna river. Land Reclamation Project, Bangladesh Water Development Board, LRP Technical Report 15, 1983. 39pp.
[20] Islam AKMN. Contribution to the study of marine algae of Bangladesh. Biblotheca Phycologia 1976;19:1–253.
[21] Hussain MA. Prospects, Strategies for development of sea farming in Bangladesh. A Paper Presented at the Workshop on Sustainable Development of Marine Fisheries Resources in Bangladesh, held at Cox's Bazar, August 29, 1994, organized by FRI/FAO/UNDP/BGD/89/012, 1994.
[22] Quddus MMA, Shafi M. Bangopshagorer matsya shampad (Fisheries Resources of the Bay of Bengal). Dhaka, Bangladesh: Bangla Academy; 1983 (in Bengali).
[23] Hussain Z, Archarya G. editors. Mangroves of the Sundarbans, vol. 2. IUCN: Bangladesh, Bangkok, Thailand; 1994.
[24] Rahman AKA, Khan MG, Chowdhury ZA, Hussain MM. Economically important marine fishes and shell fishes of Bangladesh. Department of Fisheries, Dhaka, 1995.
[25] BOBP. Report on the consultation on stock assessment for small-scale fisheries in the Bay of Bengal. Proceeding BOBP/Rep/10.1, vols. 1 and 2, June 16–21, Chittagong, Bangladesh, 1980.
[26] Lamboeut M. Bangladesh Demersal Resources of the continental shelf. FAO/BGD Marine Fisheries Research, Management and Development Project, FI: DP/BGD/80/025, 1987. 26pp.
[27] Khan MG, Mustafa MG, Sada MNU, Chowdhury ZA. Bangladesh offshore marine fishery resources studies with special reference to the penaeid shrimp stocks, 1988–89. Annual report. Marine Fisheries Survey, Management and Development Project, GOB, Chittagong, 1989. 213pp.
[28] Seidenstiker J, Hai MA. The Sundarbans wildlife management plan: conservation in the Bangladesh coastal zone. International Union for Conservation of Natural Resources, 1983. 120pp.

[29] Blower JH. Sundarbans forest inventory project. Bangladesh Wildlife Conservation in Sundarbans. Overseas Development Administration (ODA), England, 1985.
[30] Khan MG. Age, growth and mortality rates of the red snapper (*Lutjanus johnii* Bloch) of the Bay of Bengal, Bangladesh. Bangladesh Journal of Agriculture 1986;11(2):49–62.
[31] Quader MA. Strategies for proper management utilization of marine resource of the country. A Paper Presented at the Workshop on Sustainable Development of Marine Fisheries Resources in Bangladesh. FRI, Cox's Bazar, August 29, 1994.
[32] Sarker MN. Marine fishery resources of Bangladesh. In: Bangla Academy Science Newsletter. Baisaak-Assnin (1400 B.Y.). 1993. p. 113–157 (in Bangla).
[33] Kamal M. Assistance to Fisheries Research Institute—A Report Prepared for the "Assistance to Fisheries Research Institute". In: Acamey B, Dhaka, editors. Consultancy Report on Marine Fisheries Resource Management, BGD/89/012, FRI-GOB/UNDP/FAO, 2000.
[34] Ahmed ATA. Studies on the identity, abundance of molluscan fauna of the Bay of Bengal. Final report, BARC Contract Research Project, Department of Zoology, University of Dhaka, 1990.
[35] Sarker MN, Alam F. Prospects of culture of commercially important marine bivalves in Bangladesh. In: Compilation of reports on the marine fishery survey and research. Department of Fisheries, Bangladesh, 1988. p. 357.
[36] Pagcatipunan RN. A report of the development of shellfish resources in Bangladesh. FAO/UNDP Fishery Advisory Services Project (BGD/81/034) and Fishery Resources Survey System(BGD/79/015), 1982. 82pp.
[37] Alam F, Sarker MN. Study on the culture of blood clam (*Anadara* spp.) in relation to some ecological parameters. In: Compilation of reports on the marine fishery survey and research. Bangladesh: Department of Fisheries, Bangladesh; 1986. 357pp.
[38] Islam AKMN, Aziz A. Addition to the list of marine algae of St. Martins Island, Bangladesh II. Brown, red and blue green algae. Nova Hedwigia (34) 1982.
[39] Sarker MN. Studies on the red sea weeds in Bangladesh. A Paper Presented at the Regional Workshop on the Taxonomy, Ecology and Processing of Commercially Important Red Sea Weeds, 21–28th April, 1992, held at Kasetsart University in Bangkok, Thailand, Organized by FAO/NACA and France Govt., 1992.
[40] Penn JW. An assessment of potential yields from the offshoredemersalshrimp,fish stocks in Bangladesh water (including comments on the trawl fishery 1981–92). FAO field document FI;DP/BGD/81/034, Rome, 1983. 22pp.
[41] White TF, Khan MG. Marine Fishery Resources Survey: Demersal Trawling. Survey cruise report BO, 1 FAO/BGD/80/025/CRI, Chittagong, 1985. 67pp.
[42] Mustafa MG, Humayun M, Paul SC. Report on the result from the FAO 15th cruise of R.V. Anusandhani (Special shrimp cruise Sept.–Oct. 1985). Marine Fisheries Research Management and Development Project, DOF, Bangladesh, 1985. 50pp.
[43] West WQB. Fishery resources of the upper Bay of Bengal, IQFC/DEV/73, 1973. p. 28–44.
[44] Saetre R. Surveys on the marine fish resources of Bangladesh Nov–Dec 1979 and May 1980. Report on Surveys with the R.V. Dr. Fridtjof Nansen. Institute of Marine research, Bergen, 1981. 67pp.
[45] Khan MG. Results of the 13th Cruise (July, 1983) with the R.V. Anusandhani of the demersal fish and shrimp ground of the Bay of Bengal, Bangladesh. Marine Fisheries Survey, Management and Development Project, GOB, Chittagong, 1983.
[46] Rahman AK, Khan MG. Sustainable fisheries development and the environment in Bangladesh. Country Status Paper Presented at the Eight Session of the Committee for the Development and Management of Fisheries in the Bay of Bengal (IQFC), April 3–5, Dhaka, Bangladesh, 1993.
[47] Rashid MH. Mitsui-Tayo Shrimp Survey, 1976–77 by survey research vessel. Fish Bulletin No. 2. Marine Fish Department, Chittagong, Bangladesh, 1983.
[48] Shahidullah M. Marine fisheries resource management in Bangladesh, current status of exploitation. Marine Fisheries Bulletin. No. 2, 1986. 23pp.
[49] Shimura T. Catch statistics of Bangladesh. September 1983–August 1984. Fisheries Resource Survey System, Department of Fisheries, Bangladesh. Shrimp fry collection. BOBP/WP/89, 1984. p. 5–17.

[50] White TF, Khan MG. The marine fishery resources of Bangladesh and their potential for commercial development. Key note Paper Presented at the National Seminar on Fisheries Development in Bangladesh, Dhaka, January, Souvenir, 1985. p. 1–4.
[51] DOF. Fish Catch Statistics, various issues, 1994–1998. Department of Fisheries, Government of the People's Republic of Bangladesh, 1998.
[52] Islam MS, Khan MG, Quayum SA, Sada MNU, Chowdhury ZA. The estuarine set bag net fishery. In: Studies of interactive Marine Fisheries of Bangladesh. Bay of Bengal Program, Madras, India, BOBP/WP/89, 1993. p. 19–50.
[53] BOBP. Shrimp seed collection in Bangladesh. A seminar on estuarine set bagnet fisheries of Bangladesh, held at Cox's Bazar from January 12–15, 1992, organized by BOBP/FAO/DOF, 1992.
[54] Mazid MA, Gupta MV. Research and information needs for fisheries development and management. In: BOBP (1997). Report of the National Workshop on Fisheries Resources Development and Management in Bangladesh. The Bay of Bengal Program, India, 1997.
[55] BOBP. The by-catch from Indian shrimp trawlers in the Bay of Bengal. The potential for its improved utilization. BOBP/WP/68, 1991.
[56] Karim M, Aftabuzzaman A. Brackish and marine water aquaculture: potential, constraints and management needs for sustainable development. In: Report of the National workshop on fisheries resources development and management in Bangladesh. BOBP/REP/74. Bay of Bengal Program, Chennai, India, 1995.
[57] Deb AK. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. Ocean & Coastal Management 1998;41:63–88.
[58] Alam S. Production, accessibility and consumption patterns of aquaculture products in Bangladesh. In: FAO, 2001. Production, accessibility, marketing and consumption patterns of freshwater aquaculture products in Asia: a cross-country comparison. Rome: Food and Agriculture Organization of the United Nations; 2001.
[59] Tsai C-F, Ali MY. Open-water fisheries of Bangladesh. Dhaka: University Press; 1997. 212pp.
[60] Matin MA. Environmental pollution and its control in Bangladesh. Trends in analytical chemistry 1995;14(10):468–73.
[61] Mahmood N. On fishery significance of the mangroves of Bangladesh. Paper Presented at the Workshop on "Coastal Aquaculture and Environmental Management" held during 25–28 April 1995 at Cox's Bazar, organized and sponsored by Institute of Marine Science, Chittagong University (IMS, CU), 1985.
[62] Mahmood N. Effect of shrimp farming, other impacts on mangroves of Bangladesh. Paper Presented at the 3rd Session of the IPFC working party of experts on inland Fisheries, Bangkok, Thailand, June 19–27, 1986.
[63] Rahman AKA. Coastal fisheries management in Bangladesh. Paper Presented at the Expert Consultation on the Development of Community Based Coastal Fishery System for the Asia and Pacific. Kobe, Japan, June 9–12, 1992.
[64] Ahmed M, Capistrano AD, Hossain M. Co-management of Bangladesh fisheries. Fisheries Management and Ecology 1997;4(3):233–48.
[65] Rahman MM. Bangladesh-er upakulia abong samudrik matsha samphad unnayan o babastapana (Development and Management of the coastal and Marine Resources of Bangladesh) Department of Fisheries, The People's Republic of Bangladesh, 1997. 56pp. (in Bengali).
[66] BARC. Strategic plan for the National Agricultural Research System to the Year 2010 and Beyond. Mimeo. Bangladesh Agricultural Research Council, Dhaka, March 1995.
[67] Amin NM. Matshyasampad Babosthaponai Prathisthanik Samonnoyer Guruttya (Importance of Institutional Co-ordination in Managing Fisheries Resources. Sankalan: Matsya Sampad Unnayan, Fish Week 98. Directorate of Fisheries and Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh, Dhaka, 1998 (in Bengali).
[68] Coulter JP, Disney JG. The handling, processing and marketing of fish in Bangladesh. ODNRI Bulletin No. l, 1987. 49pp.

[69] Mazid MA. Research support for sustainable marine fisheries development. In: Mazid MA, Sinha VRP, Kamal M, editors. Sustainable development of marine fisheries resources in Bangladesh. Bangladesh: Bangladesh Fisheries Research Institute; 1994, p. 41–45.
[70] Khan MG, Latif MA. Potentials, constraints and strategies for conservation and management of open brackishwater and marine fishery resources. In: BOBP (1997). Report of the National Workshop on Fisheries Resources Development and Management in Bangladesh. The Bay of Bengal Program, India, 1997.
[71] Khan MG. Present status and future plan for sustainable marine resource development. In: Mazid MA, Sinha VRP, Kamal M, editors. Sustainable development of marine fisheries resources in Bangladesh. Bangladesh: Bangladesh Fisheries Research Institute; 1994, p. 30–37.
[72] Hansen UJ, Mustafa MG. Survey to study the design, behavior and performance of the set bagnet operated in the estuaries of Bangladesh. DIFTA, Danish Institute for Fisheries Technology & Aquaculture. For FAO, Bay of Bengal Program, 1992. 28pp.
[73] Khan MG, Islam MS, Mustafa MG, Sada MNU, Chowdhury ZA. Bio-socioeconomics assessment of the effect of the estuarine setbagnet on the marine fishes of Bangladesh. Bay of Bengal Program, Madras, India, BOBP/WP/94, 1994. 28pp.
[74] Huq QM, Khan MG, Chowdhury ZA, Sarker MN. Bottom longline fishery for croaker (Sciaenidae). In: Studies of interactive marine fisheries of Bangladesh. Bay of Bengal Program, BOBP/WP/, 1993. p. 107–14.
[75] Alam S, Das NG, Islam MA, Roy B. The fish composition in the "Behundi" net catch of Chittagong Coast, Bangladesh. Chittagong University Studies Part II: Science 1989;13(1):71–6.
[76] Alam MJ, Kamal D, Kader MA. A preliminary study of the maturation and spawning of *Setipinna phasa* (Ham.) from the Bay of Bengal. Bangladesh Journal of Zoology 1996;24(1):65–71.
[77] Ali S, Shaha S, Mahmud N. Studies on the physico-chemical aspects of Maheshkhali channel, Bay of Bengal. Dhaka University Studies, Part II: Science 1985;33(1):43–50.
[78] Aziz A, Islam AKMN. Marine dinoflagellates from the Bay of Bengal, Bangladesh. Journal of Bangladesh Academy of Science 1980;3(1–2):41–50.
[79] Chowdhury SH, Hafizuddin AKM. Crab fauna of Bangladesh: Part I. Some marine crabs from the Bay of Bengal. Chittagong University Studies Part II: Science 1991;15(2):65–77.
[80] Gofur MA, Bhuiyan AL. Successional occurrence of the fish fauna of the Karnaphuli river estuary (Bangladesh) in response to salinity. Chittagong University Studies Part II: Science 1983;7(2):69–78.
[81] Haroon AKY, Khan AA, Halder GC, Rainboth WJ. A check-list of the fish fauna of the Muhuri Irrigation Project land surrounding region (Bangladesh). Bangladesh Journal of Zoology 1989;17(1):19–28.
[82] Humayun M, Khan MGU, Mustafa MG. Some aspects of population dynamics of the threadfin bream (*Nemipteros japonicus*) of the Bay of Bengal, Bangladesh. Bangladesh Journal of Agriculture 1989;14(1):73–80.
[83] Islam AKMN, Aziz A. Marine diatoms from the Bay of Bengal. Bangladesh Journal of Botany 1980;9(1):29–35.
[84] Khan MAR. New record of six marine fishes from St. Martin's Coral Island, Bay of Bengal in Bangladesh. Journal of the Bombay Natural History Society 1998;95(2):228–33.
[85] Khan MG, Humayun M, Zamal H. Some aspects of population dynamics of white grunter (*Pomadasys hasta* Bloch) of the Bay of Bengal, Bangladesh, as estimated from length-frequency data. Chittagong University Studies Part II: Science 1985;9(2):33–44.
[86] Kurita Y, Saotome Y, Kasuga I, Hayasi T. Relation between tuna catches and oceanic condition in Bengal Bay. Bulletin of the Japanese Society of Oceanography 1991;5(1):18–24.
[87] Latifa GA, Ali S, Bala N. Sex ratio and size frequency distribution of silver jew, *Johnius argentatus* (Houttuyn 1782) from the Bay of Bengal. Bangladesh Journal of Zoology 1992;20(2):325–32.
[88] Latifa GA, Ali S, Bala N. Observation on the fecundity of silver jew, *Johnius argentatus* from the Bay of Bengal (Bangladesh). Bangladesh Journal of Zoology 1986;14(1):1–8.
[89] Mustafa MG. Population dynamics of penaeid brown shrimp, *Metapenaeus monoceros* Fabricius from the Bay of Bengal. Bangladesh Journal of Zoology 1989;17(2):149–58.

[90] Mustafa MG. Population dynamics and management of the brown shrimp, *Metapenaeus monoceros* (Fab.) from the Bay of Bengal. Bangladesh Journal of Zoology 1996;24(1):45–51.
[91] Mustafa MG, Ali MS. Population dynamics and management of the hardtail scad *Megalaspis cordyla* from the Bay of Bengal. Pakistan Journal of Scientific and Industrial Research 2000;43(5):304–10.
[92] Rahman M, Naevdal G. Population genetic studies of hilsa shad, *Tenualosa ilisha* (Hamilton) in Bangladesh waters: evidence for the existence of separate gene pools. Fisheries Management and Ecology, 2000;7(5):401–11.
[93] Sarker MN, Rahman AKA. Jew fish (Sciaenidae: Perciformes) fishery in the Bay of Bengal. Bangladesh Journal of Zoology 1991;19(2):161–6.
[94] Sasaki K. Two new species of Atrobucca (Sciaenidae) from the Bay of Bengal. Japanese Journal of Ichthyology 1995;42(3–4):269–75.
[95] Shafi. Fecundity of the Indian halibut, *Psettodes erumei* (Psettodidae: Pleuronectiformes) from the bay of bengal. Bangladesh Journal of Zoology 1978;6(2):113–20.
[96] Zafar M, Matin AKMA, Mustafa MG, Amin SN. Population dynamics of *Coilia dussumieri* from the Kutubdia channel of Bangladesh coastal water. Pakistan Journal of Scientific and Industrial Research 1999;42(6):320–4.
[97] Moksness E, Stole R. Larvae culture of marine fish for sea ranching purpose: is it profitable? Aquaculture 1997;155:341–53.
[98] Jonasson J, Gjedrem T. Genetic correlation for body weight of Atlantic salmon grilse between fish in a sea ranching and land-based farming. Aquaculture 1997;157:205–14.
[99] Tanaka M, Seikai T, Yamamoto E, Furuta S. Significance of larval and juvenile echophysiology for stock enhancement of the Japanese flounder, *Paralychthys olevaceus*. Bulletin of Marine Science 1998;62(2):551–71.
[100] Vanzalinge NP. The Bangladesh shrimp resources, management issues and data requirement. FAO/UNDP Marine Fisheries Research Management, Development Project, BGD/80/025, Chittagong, 1986. 19pp.
[101] Froese R, Pauly D, editors. Fishbase. World Wide Web electronic publication. www.fishbase.org, version 14; August 2003.
[102] Machintosh DJ, Phillips MJ, Lewis III R, Clough B. Thematic Review on Coastal Wetland Habitats and Shrimp Aquaculture. Report Prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium, 2002. Available online at http://www.enaca.org/Shrimp/Consortium.htm