Background paper for preparation of
the 7th Five Year Plan

OPPORTUNITIES AND STRATEGIES FOR OCEAN AND RIVER RESOURCES MANAGEMENT

Prepared by

Professor Dr. M Shahadat Hossain[1]
Professor Sayedur Rahman Chowdhury[1]
Professor Dr. Umme Kulsum Navera[2]
Professor Dr. Mostafa Ali Reza Hossain[3]
Professor Dr. Badrul Imam[4]
Dr. S M Sharifuzzaman[1]

[1] Institute of Marine Sciences and Fisheries, University of Chittagong
[2] Department of Water Resources Engineering, Bangladesh University of Engineering and Technology
[3] Department of Fish Biology and Genetics, Bangladesh Agricultural University
[4] Department of Geology, University of Dhaka

Submitted to

Food and Agriculture Organization of the United Nations
Bangladesh Country Office, Dhaka, Bangladesh

December 2014

TABLE OF CONTENT

List of tables

List of Figures

ACRONYMS

BADC	Bangladesh Agricultural Development Corporation
BBL	Billion Barrels
BBS	Bangladesh Bureau of Statistics
BCF	Billion Cubic Feet
BIDS	Bangladesh Institute f Development Studies
BoB	Bay of Bengal
BOBLME	Bay of Bengal Large Marine Ecosystem Project
CBD	Convention on Biological Diversity
CCC	Convention on Climate Change
CPUE	Catch per unit effort
CZ	Coastal Zone
CZPo	Coastal Zone Policy 2005
DOE	Department of Environment
DoF	Department of Fisheries
ECA	Ecologically Critical Area
EEZ	Exclusive Economic Zone
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GoB	Government of Bangladesh
IHO	International Hydrographic Office
IO	Indian Ocean
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modeling
MAF	Mean annual flow
MoA	Ministry of Agriculture
MoF	Ministry of Fisheries
MoFA	Ministry of Foreign Affairs
MoWR	Ministry of Water Resources
MPA	Marine Protected Area
NWMP	National Water Management Plan
SWERA	Solar and Wind Energy Resource Assessment
TAC	Total allowable catch
TCF	Trillion Cubic Feet
UNCED	United Nations Conference on Environment and Development (a.k.a. Rio 92)
UNCLOS	United Nations Convention on the Law of the Sea
UNCSD	United Nations Conference on Sustainable Development (a.k.a. Rio+20)
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
WB	World Bank
WCED	World Commission for Environment and Development
WSSV	White spot syndrome virus

DEFINITIONS

Bay	with first letter capitalized, Bay (usually, the Bay) would mean the Bay of Bengal.
bay	would mean any semi-enclosed arm of the *world ocean* generally defined as *bay*.
sea	would mean the salt-water reservoir generally known as *sea*; usage examples: *sea-fairer, sea-food, sea-level, wealth from the sea,* etc.
marine	of or pertaining to the *sea or oceans*; usage examples: *marine resources, marine management, marine fish,* etc.
maritime	nearly the same as *marine* and often used interchangeably; of or pertaining to objects, phenomena and actions related to the *sea*; usage examples: *maritime boundary, maritime trade, maritime climate,* etc.
ocean	any part of the *world ocean*, which inherits major features of an ocean basin, such as depth greater than thousands of meters. Deeper parts of the Bay of Bengal, therefore, can be and should be referred to as *ocean*, and its characteristics and possessions as *oceanic*. Usage examples: *ocean currents, oceanic deposits, ocean governance*, etc. (On the contrary, for example, Gulf of Thailand, Persian Gulf, etc. are not *oceanic*.)
world ocean	is the salt-water body of the Earth as a whole, all named and unnamed oceans, seas, bays, gulfs, straits, etc. combined.

Chapter 1
OCEAN AND RIVERS OF BANGLADESH: A BACKGROUND

1.1 Characterizing Bangladesh's marine system in the Bay of Bengal: implications for fisheries, mineral resources, and resource economics

The Bay of Bengal (BoB) is the north-eastern extension of the Indian Ocean which lies north of 6°N latitude and west of about 95°E longitude, the Andaman Sea and Andaman Islands excluded (IHO 1953). Being an extension, BoB shares many oceanic characteristics of the Indian Ocean including cyclones and southwest monsoon, and has active connections to the Andaman Sea, Malacca Strait, Palk Strait, etc. The BoB is characterized by some unique features, notably:

1) it is a shallow oceanic arm, 1.0-1.8 kilometer shallower than open ocean basins, comparable in depth to the Mediterranean Sea, the Red Sea, and the South China Sea, theoretically making any potential sea-bottom activity relatively easier and less expensive than doing it on deeper ocean floor;

2) it sits on the thickest sediment deposits of the world, 21-22 km at its thickest (Allen and Allen 2005; Curray 1991), with an average of about 16.5 km (Wasson 2003), and hosts the world's largest so-called *fluvio-deltaic slope complex* (Blakeley 2010) named the *Bengal Fan*, making it a good candidate for large fossil fuel reserves trapped in the sediment; for which there are too little data for reliable estimates of hydrocarbon potential;

3) it receives one of the greatest freshwater discharges of all large river systems, 1.6 trillion cubic meters per year (Madhupratap *et al.* 2003; Subramanian 1993), making it

4) one of the freshest seas in the world, salinity ranging from almost 'zero' near the coast (Chowdhury *et al.* 2002; Mahmood *et al.* 1997;Mahmood *et al.* 2002a,b) to below 30 ppt (Benshilla *et al.* 2014; Lagerloef 2012), compared with 35 ppt and above for the world average (Svedrup *et al.* 1942); which means

   4.1) fresher and lighter water sitting on top of saltier and heavier water makes it harder for the nutrient rich deeper water to turn over and reach the surface in a process called 'upwelling', which is necessary for enhancing primary biological productivity at sea, and

   4.2) at the same time rendering coastal salt-extraction processes less efficient than for other seas (Hossain *et al.* 2006);

5) enormous amount of river discharge associated with the rapid denudation of the world's steepest and the youngest mountain range, the Himalayas, means this Bay also receives one of the world's largest volumes of sediment, or about 665 million tons per year as a historical average (Wasson 2003),

   5.1) making it an ideal place for land reclamation by judicious use and engineering intervention of the incoming sediment,

5.2) at the same time rendering it one of the most turbid seas (a) favored by some species of fishes (*e.g., Hilsa*), which also means (b) lesser sunlight penetration due to turbidity in concert with intense cloud cover during the monsoons (Gomes *et al*. 2000) that hinders photosynthesis and makes the sea biologically less productive, and (c) greater turbidity makes its coasts visually less appealing/attractive to tourists;

6) one of the world's most active volcanic chains and earthquake epicenters, that of Java-Sumatra trench near Indonesia, sits on the southern rim of the BoB, making it susceptible to rapid-moving tsunamis;

7) it is one of the tropical cyclone hotspots of the world, as 7% of world's cyclones occur here (Gray 1968); unlike other oceans, the BoB has two cyclone seasons each year (Li *et al.* 2013); 25 of world's 35 deadliest and killer cyclones originated in the BoB (WU, undated); furthermore, cyclones and tropical depressions appear to be becoming more frequent (Chowdhury *et al.* 2012);

8) unlike other oceans and seas, the BoB exhibits a distinctly unique reversal of ocean currents (Schott *et al.* 2009), clockwise in the summer monsoon and anti-clockwise in the winter season, under the influence of south-westerly and north-easterly winds in these seasons respectively, having profound impacts on seasonal climate and many other aspects of the oceanography, mandating different seasonal approaches of managing and administering marine resources and assets;

9) The northern BoB is a semidiurnal 'macrotidal' environment, that means tide elevation rises and falls more than 4 meters (>13ft), up to 6m (>19ft) in some places, twice daily, resulting in strong tidal currents creating enormous potential for tapping this dynamic force for mechanical work and power generation; seasonal sea-level in this region rises by about 1m (>3ft) during the south-west monsoon (August) season compared to the cool winter (February) level (Chowdhury1993) giving rise to a unique seasonal shift of sea-level (found only here and in the Arabic Gulf) and hence generating shoreline variations having practical implications for natural ecosystems and human activities;

10) almost all of the BoB's shallowest 100-200m of water is well-oxygenated whereas the water below this depth is seriously in short of oxygen supply, a condition referred to as 'hypoxia' (Hellya and Levin 2004) or 'oxygen minimum zones' (Diaz and Rosenberg 2008), in which animals find it hard to survive; this suggests a mid-to-deep water unable to support large fishery at these depths;

11) biological productivity in the BoB is much lesser than in the Arabian Sea particularly in the entire summer monsoon season (Kumar et al. 2002; Gauns *et al.* 2005) which means the BoB can only support a smaller oceanic fish population; and

12) the BoB, being located in the tropics, means it is low in productivity, but rich in biodiversity.

Figure 1.1 illustrates some of the important characteristics of the Bay.

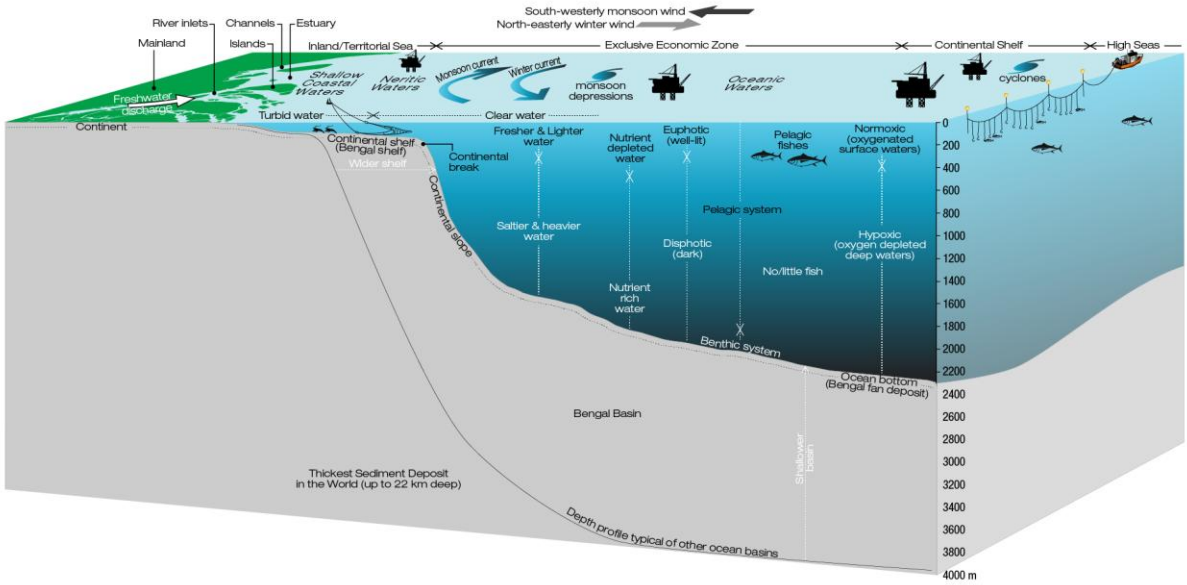

Figure 1.1. Schematic diagram showing salient characteristics of the marine system of Bangladesh using actual depth profile of the Bay of Bengal (vertically exaggerated), other elements not to scale

By virtue of this unique melange of characteristics, the BoB also has some uniqueness in its fisheries and mineral resources, and economic prospects and challenges. Strategizing and planning for exploration, management and exploitation of the economic potential from the BoB does, therefore, require unique approaches from other large Bays.

1.1.1 Maritime area of Bangladesh

At the end of the final settlement of maritime border disputes with neighboring states Myanmar and India in 2012 and 2014 respectively, Bangladesh has received entitlement to 118,813 sq. km in the BoB comprising her territorial sea and Exclusive Economic Zone (EEZ) (MoFA, 2014). Taking into account major river inlets and estuaries, which are together very much a part of the marine ecosystem, the total marine waters of Bangladesh stands at 121,110 sq. km of which coastal waters and the shallow shelf sea constitute about 20% and 35% respectively, the rest (45%) lying in deeper waters (Chowdhury 2014a). Almost all of Bangladesh's marine fishing is carried out in shallow and shelf waters, beyond which no fishing is being currently done due to lack of vessel capacity and appropriate fishing technologies.

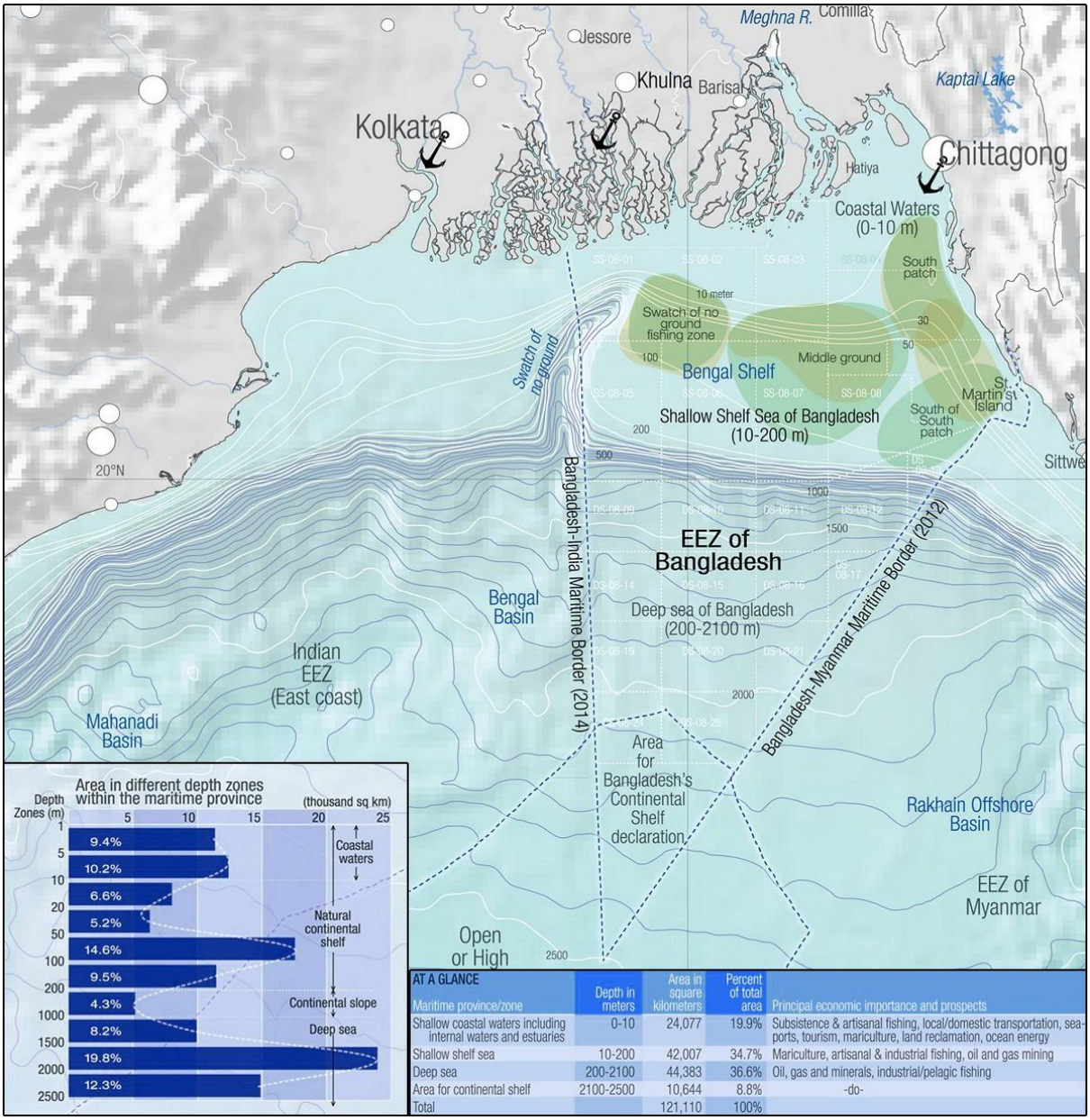

Figure 1.2. Maritime area of Bangladesh (from Chowdhury 2014a)

Within the BoB, Bangladesh has the widest shallow shelf region extending more than 100 nautical miles (185 km), 3-4 times wider than those of Myanmar, the eastern coast of India and the global average (65 km), providing a greater shallow bottom fishing area per unit length of coastline than its neighbors. Being located in the largest delta of the world means the coast of Bangladesh is in a continuous process of reshaping itself that will continue for millennia in the future, which translates on the ground into coastal erosion and accretion taking place all the time for centuries. This dynamic of the coast raised both havoc and opportunities.

1.2 River System: Characteristics of the river network of Bangladesh, hydrology and drainage basin

Bangladesh, having a small territory, is rich in diversity and complexity especially in the water sector. The flood plain in Bangladesh lies in the Indian subcontinent between 20°25' and 38°40'N latitudes and 88°01' and 92°40'E longitudes (BBS 2007). The longest reaches of the major rivers that flow through Bangladesh and predominately give rise to flooding lie outside of Bangladesh. The

combined river system of Ganges-Brahmaputra-Meghna(GBM) forms the biggest delta in the world and brings in three times the volume of water from that part of their catchments beyond the Bangladesh, from India, Nepal, Bhutan and China (1.72 million square meters) compared to that generated within Bangladesh. The river system carrying water from GBM basin is considered as the lifeline of Bangladesh, of which only 8% of their length actually lies within Bangladesh. This water comes mostly in the monsoon season and creates flooding, a process which carries fertile silt to this land. In contrast, the low flow in the winter in these rivers is critical for drinking, irrigation as well as supporting aquatic flora and fauna.

The watersheds of these rivers are adjacent to each other, covering the central, north and northeastern parts of South Asia and the Great Himalayan highlands. These basins together are around 665,000 square miles (1.7 million sq. kilometers) in area. The Ganges River originates from the southern slopes of the Himalayas, whereas its tributaries originate from both the Himalayas and the central highlands of India. The Brahmaputra River originates from the northern slopes of the Himalayas, in Tibet of China. Its tributaries originate from the Kailash Range, the Tibetian Plateau, the Himalayan range, the Lushai Hills and the Garo and Jaintia Hills. The Meghna River originates from the Lushai Hills. Its tributaries originate from the Lushai Hills and the Garo and Jaintia Hills. The Bengal Basin has some independent rivers to the west originating from the Choto Nagpur Highlands and to east originating from the Lushai Hills.

The country is criss-crossed with many rivers, but only 405 of them are recognized in Nod Nodi (BWDB 2012). Most of the rivers are either tributaries or distributaries of the Ganges, the Brahmaputra or the Meghna River. The National Water Management Plan (NWMP) divides Bangladesh into 8 hydrological regions, but for river systems it is divided into 6 regions: (i) North-Western region (Atrai, Ichamoti, Ghagot, Teesta, Dharala, Brahmaputra-Jamuna) (ii) North-Central region (Arial Kha, Kaliganga, Buriganga, Turag, Shitalakkha etc.), (iii) North-Eastern region (Kalni, Khowai, Surma, Monu, Someshawri etc.), (iv) Eastern-Hilly region (Ichamoti, Karnafuli, Halda, Sangu etc.), (v) South-Eastern region (Gumti, Titas, Meghna, Dakatia etc.) and (vi) South-Western region (Kobadak, Gorai, Chitra, Nabaganga, Rupsa, Posur etc.). 57 transboundary rivers originate outside the boundary of Bangladesh.

The Brahmaputra-Jamuna River has several right bank tributaries: the Teesta, the Dharla, the Dudhkumaretc and two left bank distributaries - the Old Brahmaputra and the Dhaleswary Rivers. It is a wandering braided river with an average bankful width of about 11km. The channel has been widening, increasing from an average of 6.2km in 1,834 to 10.6km in 1992 (FAP16 1995). The river has an average annual discharge of 19,600 m^3/s. The Ganges River draining the south slope of Himalayas is a wide meandering river with a bankful width about 5km. In the Bangladesh reach (length about 220km), a left bank tributary named the Mahananda joins the river upstream of the Hardinge Bridge and a right bank distributary the Gorai carries a part of the high stage Ganges flow to the south western region. The average annual discharge of the river is around 11,600 m^3/s. The discharge varies from a minimum of 1000 m^3/s to a maximum of 70,000 m^3/s with a dominant discharge of about 38,000 m^3/s. It is observed that the dry period discharge is often much lower than 650 m^3/s. The Upper Meghna River originates in the Shillong Plateau and foothills and is a canaliform type of meandering river and locally has anabranches (streams splitting from the sides that later re-join main stream). It is relatively a small river bankful width of about 1km. The river has a catchment area of about 77,000 km^2 and a length of about 900km. The average annual discharge of the river is about 4,800m^3/s and dominant discharge is about 9,500 m^3/s.

The source of surface water in Bangladesh is the rainfall in this country and the stream flow coming in from outside this country. The total water resource generated in this country is about 1,094 MAF or 1,350 Billion Cubic Meters annually.

1.3 Differences in approaches to manage ocean and river resources

Owing to the widely varying characteristics, geographic extent, ecosystem characteristics, biotic communities, ecosystem goods and services, trade and other economic potentials, the river system and the marine system mandate different approaches of management, exploration and exploitation, and perhaps quite different institutional frameworks for dealing with inherent complexities of these systems

Chapter 2
MARINE AND RIVER RESOURCES: PROSPECTS FOR ECONOMIC PROSPERITY

2.1 Marine Resources of Bangladesh

Marine resources of Bangladesh can be described variously as i) "finite", "infinite" and "renewable" based on the volume of stock and regeneration, ii) "living" and "non-living" based on their status/state of life, iii) "capital/stock" and "potential" based on their immediate availability and readiness for harvest/utilization, and iv) "carbon positive", "carbon negative" and "carbon neutral" based on their greenhouse carbon-dioxide emission signatures when used. Hossain *et al.* (2014a) suggested a list of available and potential marine resources of Bangladesh (Table 2.1) which can be tapped to enhance economic focuses for the country. The authors have considered "maritime human resources" as an important resource, because judicious utilization and management of theseresources depend on a large highly trained workforce. Marine resources can be further divided into other divisions on the bases of various other scientific and socio-economic perspectives, for example, "small-scale/artisanal" vs. "industrial", "high input-output ratio" vs. "low or medium input-output ratio", "rapid return" vs. "long term return", "single" vs. "multiple/competing/conflicting" use, "environment friendly (green)" vs. "environmentally damaging (red, orange)", "self reliant development" vs. "aided development", "public sector" vs. "private sector/foreign investment", and other economic feasibility indices, socio-demographic indices.

Table 2.1. An overview of marine resources of Bangladesh (after Hossain *et al.* 2014a)

Marine Resources of Bangladesh at a glance		
Stock Resources	Living resources	Fisheries resources:
		Marine fishes:
		Demersal (bottom dwelling) fishes, riverine & estuarine fishes, pelagic (free swimming) fishes.
		Shrimps, crabs, lobsters, mussels, etc.
		Other living resources:
		Marine algae, various marine plants & animals as raw materials for pharmaceutical and cosmetics industries.
	Non-living	Salt and brine, potable water by desalination.
		Fuel: Oil and gas.
		Other valuable minerals.
Potential resources	Recreational utilization of -ocean:	
	Coastal and marine tourism: cruise-ship, yacht, floating hotel and restaurant	
	Marine sports: Surfing, diving, snorkeling, boating, sport fishing, etc.	
	Use of ocean in maritime trade and transportation:	
	Trade expansion, fleet expansion, port development, transit and transshipment.	
	Land reclamation and development:	
	Acceleration of char and island formation by engineering interventions.	
	Forest resources development (mangrove forests):	
	Fisheries resources development:	
	Coastal aquaculture: fish, shrimp, crab, oyster and pearl cultivation.	
	Mariculture: Fish and algae cultivation in cages and other enclosures.	
	Energy development:	
	Power generation from current, tide, wave and maritime wind; bio-gas and bio-fuel from marine alage.	

Table 2.1. continued

Human Resource	Scientists:	
		Marine scientist, marine biologist/ecologist, marine fisheries biologist, maritime meteorologist, climatologist, marine geologist, petroleum geologist, etc.
	Engineers and technologists:	
		Offshore engineer, naval architect, marine engineer, coastal engineer, mining engineer, marine energy engineer, aquaculture technologist, biotechnologist and hatchery technologist, seismologist, remote sensing & optical/acoustic technologist, geomorphologist/sedimentologist, etc.
	Maritime professionals:	
		Coastal zone planner & manager, coastal forest manager, marine fisheries manager, tourism manager, maritime lawyer, merchant marine, port manager, maritime trade analyst, shipping liner & entrepreneur, marine pollution & environment expert, marine conservationist, hydrographer, surveyor, etc.
	Skilled workers:	
		For ship building & scrapping, shipping & port operations, fishing & fish cultivation, post-harvest fish handling & processing, coastal & offshore structure, etc.

2.1.1 Fisheries resources

The fisheries resources play a significant role in fulfilling the demand of animal protein and socio-economic development of the country. For example, more than sixteen million people (about 11% of total population) of Bangladesh directly or indirectly depend on the fisheries sector for their livelihood. The BoB of Bangladesh is blessed with rich coastal and marine ecosystems, hosting a wide range of biodiversity, such as fishes, shrimps, molluscs, crabs,mammals, seaweeds, etc. (Table 2.2). A number of surveys examined the status of marine fisheries resources between 1970s and 1980s (Table 2.3), but no recent and comprehensive knowledge is available on the fisheries stocks, systematics, biological and ecological aspects of the coastal and marine fisheries of Bangladesh. The important fish families are Sciaenidae, Ariidae, Nemipteridae, Carangidae, Mullidae, Synodontidae, Trichiuridae, Leiognathedae, Pomadasyidae and Clupeidae (Table 2.4), and these ten families make up about 47% of the total biomass (Lamboeuf 1987), Croakers (Sciaenidae-12.8%) and catfishes (Ariidae-11.99%)being the dominant groups.

Table 2.2. Coastal and marine fisheries resources of Bangladesh

Category	Number of species (reviewed by)		
	Hossain 2001	Islam 2003	Ahamed *et al.* 2012
Bony fish	475	475	442
Cartilaginous (soft-boned) fish	50	–	–
Shrimp	25	24	56[a]
Crab	15	50	16
Lobster	5	–	3
Mollusc (Oyster)	301 (6)	301 (3)	336
Algae/Seaweed	56[b]	20-22[c]	168
Coral	13	–	66
Starfish/Echinoderms	3	–	4
Whale/Dolphin	11	–	–
Squids (Cuttlefish)	–	7 (2)	–

[a]Shrimp/Prawn; [b]Algae; [c]Seaweed

Table 2.3. Standing stock (in tons) of demersal fish, pelagic fish and shrimp of the Bay of Bengal during the1970s and 1980s.

Demersal fish	Pelagic fish	Shrimp	Reference
264,000-373,000	---	9,000	West (1973)
160,000	90,000-160,000	---	Saetre (1981)
200,000-250,000	160,000-200,000	4,000-6,000	Penn (1983)

Table 2.4. Estimated biomass of marine fish of Bangladesh (Hussain and Rahman 2010)

	Fish family/ group	Common name(s)	Biomass (tons)	Relative abundance (%)
1	Sciaenidae	Croakers	20,670	12.8
2	Ariidae	Catfishes	18,729	11.6
3	Nemipteridae	Threadfin breams	7117	4.4
4	Carangidae	Jacks, Scads	5039	3.2
5	Mullidae	Goat fishes	4,811	3.0
6	Synodontidae	Lizard fishes	4,663	2.9
7	Trichiuridae	Hairtail/Ribbon fishes	4,043	2.5
8	Leiognathidae	Pony fishes	3,998	2.5
9	Pomadasyidae	Grunters	3,415	2.1
10	Clupeidae	Sardines, Shads	3,109	1.9
11	Scombridae	Mackerels, Tunas	1,836	1.1
12	Priacanthidae	Bullseyes	1,433	0.9
13	Stromateidae	Pomfrets	1,348	0.8
14	Cephalopods	Squid, Cuttle fishes	1,296	0.8
15	Engraulidae	Anchovies	1,082	0.7
16	Gerridae	Silver-biddies	959	0.6
17	Harpodontidae	Bombay duck	783	0.5
18	Lutjanidae	Snappers	356	0.2
19	Rajidae	Skates, Rays	6,714	4.2
20	Others	---	69,679	43.3
	Total		161,080	100%

The harvest of marine capture fisheries was 379,497 tons during 2000-2001 that ramped up to 588,988 tons in 2012-2013 (DoF 2014)and sold as frozen (transported to large cities and overseas) or fresh in local markets. A considerable amount of fish are salted and dried, mainly for human consumption. Incidentally, the use of dried fish as a source of fishmeal is gradually increasing due to intensification of fish and poultry farming. Hilsa shad (*Tenualosa ilisha*)is the larget and single most valuablespecies with annual catch of 340,000 MT, and generates employment and income for 2.5 million people valued at $US 1.3 billion per year (BOBLME 2012, Hossain *et al.* 2014). At present 50-60% of global hilsa catch takes place in the coastal and marine waters of Bangladesh, 20-25% in Myanmar, 15-20% in India and the remaining 5-10% in other countries. A total of 46,568 MT tiger shrimp (*Penaeus monodon*) was caught from BoB during 2012-2013 (DoF 2014), most of which directly go to the processing plant and end up in the markets of USA, EU and Japan. Over the last 10-15 years, live giant mud crab (*Scylla serrata*) and estuarine eel (*Muraenesox bagio*) have been exported to East Asian countries. Less than 20% exported live crab come from crab fattening by the marginal farmers of Satkhira, Bagerhat and Cox's Bazar coasts. Moreover, the harvest of young and undersized sharks and rays are dried, while the large sharks are dumped overboard after removing their fins and some other body parts. The majority of phaisa (*Setipinna phasa*) caught in the coast are used to make fermented fish product.

2.1.2 Oil and gas

World energy consumption has more than doubled over the past four decades, mostly driven by the developing economies. Increased economic activities demand more energy and nearly 62% is currently supplied from oil and gas, with about one third of this is shared by offshore production (Douglas-Westwood 2005). Depletion of reserves in shallow waters (<500 m water depth) is causing the oil majors to move into deep water regions, such as in Africa, Brazil and Gulf of Mexico, but major fields are still to be found. This move to deep waters has resulted in the growing utilization of floating production systems and subsea production technology at the expense of fixed platforms. In addition, the oil and gas industry is using new technology such as hydraulic fracturing (fracking) to produce oil from previously non-producing deposits.

Bangladesh is yet to assess the true potential of its offshore oil and gas prospects (Imam 2013). While an impressive gas success ratio of 3:1 (3 exploration wells drillings result 1 discovery) was observed in the onshore area, the success ratio in the offshore is less impressive, i.e. 9:1. Some 26 Tcf (trillion cubic feet) gas reserve has so far been discovered in Bangladesh, of which only about 1 Tcf is located in the offshore areas. Until 2014, there were drilled 19 exploratory wells in BoB, resulting in

only two gas discoveries, i.e. the Sangu and the Kutubdia, with small reserves. The Sangu reserves of 0.8 Tcf have already depleted, whereas the Kutubdia reserves 0.04 Tcf are yet to be developed. Moreover, the drilling of the Magnama (3.5 Tcf) and Hatia (1.0 Tcf) in late 2007/early 2008 were disappointing due to non-commercial volumes of hydrocarbons (Blakeley 2010). Figure 2.1 shows the settled maritime boundaries between Bangladesh-Myanmar and Bangladesh-India and the exploration blocks defined by Bangladesh in the shallow sea (SS, up to 200m depth) and the deep-sea (DS, >200 to 2500m).

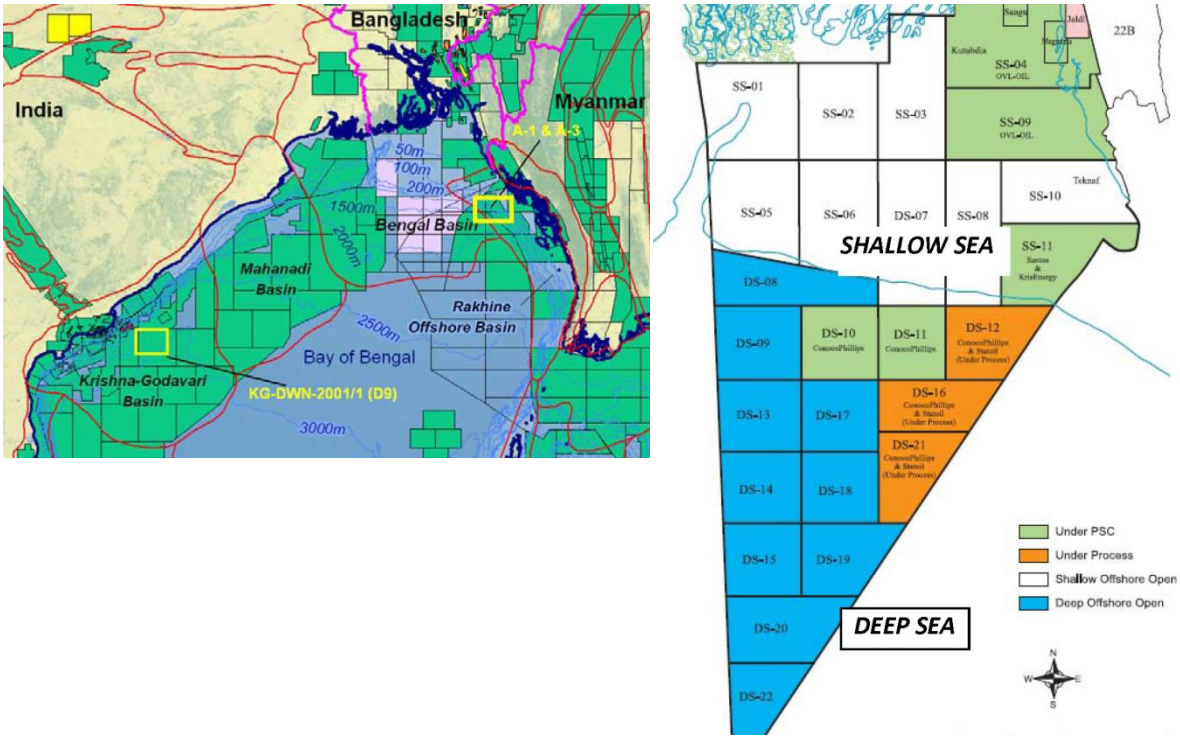

Figure 2.1. Geological basins in the Bay of Bengal (left); and oil/gas exploration blocks in the shallow sea and deep-sea in Bangladesh EEZ (right)

The shallow offshore blocks of Bangladesh adjacent to the Myanmar blocks are considered an area of particular interest because of the recent discoveries of several large gas fields (Shwe, Shwe phu, Mia) in the Arakan offshore of Myanmar. Due to close proximity to the discovered gas fields of Myanmar, these Bangladeshi blocks are likely to have comparable geological structures and gas/oil prospects. Moreover, the speedy exploration schedule is now being pursued further in the Myanmar blocks adjacent to the Bangladeshi block testifies that this area (i.e. Arakan offshore of Myanmar) has been seriously taken up for gas/oil exploration by the Myanmar Government. Therefore, Bangladesh should give most preference to explore the bordering blocks with Myanmar, such as the shallow water blocks SS10, SS11 and deep water blocks DS-12, DS-16 and DS-21. However, a logical plan is necessary to through survey (using state of art technology) the BoB in order to identify potential oil and gas fields, and their reserves. According to a report (Lerche 1992), the onshore (shallow) reserves in North America, Arabian Gulf and Eastern Europe is greater than their offshore reserves, while the offshore (deep) reserves of the rest of the world is nearly four times as greater as the onshore reserves. A delay in the exploration may offset the opportunity of harnessing the oil and gas resources, especially those (if any) located on either side of the borders (India and Myanmar), because whoever drills last is likely to lose their fair share of gas and oil reserves.

Bidders and oil companies are most likely to drill on the shallow shelf sea first due to relative easiness and cost-effectiveness, but drilling in this area without extensive and overall environmental, socio-economic and fisheries impacts analysis may prove to be suicidal as pollution from drilling activities on the Bengal Shelf may affect the ecosystem and biological resources (e.g., shrimp fishery). Moreover, any potential oil spill near the coast, of which there is no guaranteed preventive

technology yet even in the most advanced and high-tech oil industry, will have a far reaching impact on fishery (Upton 2011), fishing grounds, fish breeding and nursery heavens, salt-marsh ecosystems, coral reef, mangrove ecosystems, coastal tourism, salt industry, peoples' livelihood and health, which reduce the benefits of the exploitation of fossil fuels.

Considering the high environmental risks/stakes including associated greenhouse gas emissions, potential risks of spills, habitat destruction, and also the finiteness and non-renewable nature, the exploitation of oil and gas should be carried out in the most professional and cautious manner. These oil and gas resources are also limited and, therefore, are very critical for the energy security in the short run.

2.1.3 Mangroves

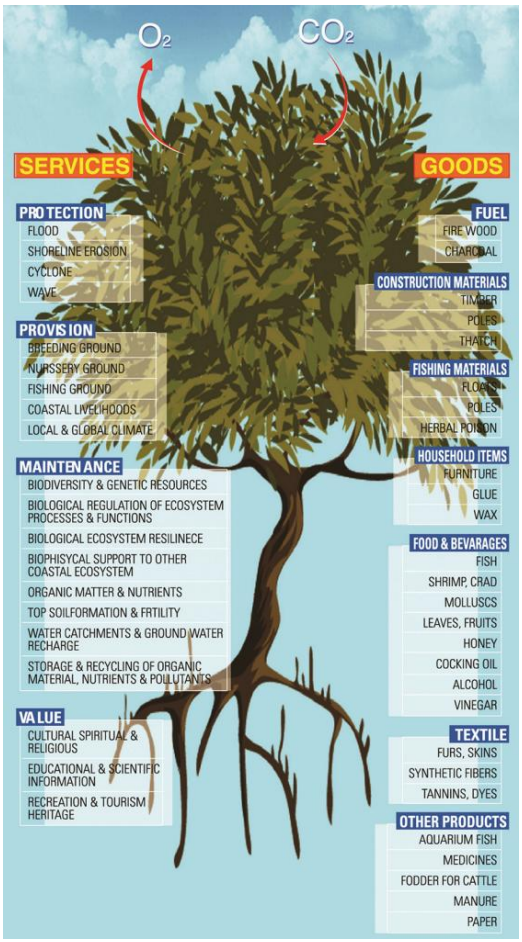

Figure 2.2. Productive and protective role of mangrove forest as goods and services in the Ganges Basin, Bangladesh (Hossain 2013a)

The Bangladesh coast supports 441,455ha of mangroves, including the world's largest single tract of natural mangroves, i.e. the Sundarbans (Hasan *et al.* 2013). Mangroves play an essential role in maintaining a healthy coastal environment by providing protection for a myriad of juvenile aquatic species, functioning as a habitat for a variety of terrestrial fauna, improving coastal protection and acting as a processor of nutrients that sustains many complex food chains (Kovacs 1999). However, these vital tropical ecosystems in the coastal intertidal zones, covering about 170,000 km^2 (Rollet 1984; Khan and Hossain 1996), continue to be under immense threat from a variety of human activities. During the past 20 years, approximately 35% of the world's mangrove forest area has been lost (Valiela *et al.* 2001). One of the greatest limitations to their protection is the lack of proper inventory and monitoring. To this end, Hossain (2013a) analyzed Landsat satellite imagery and assessed spatial distribution of 27014 ha of existing mangrove forest and 60000 ha of an accretion area for future mangrove planting in the Ganges basin, Bangladesh.

Important goods and services of mangroves upon which the coastal community can ensure their daily demand are shown in Figure 2.2. Fishing, shrimping and crabbing in the mangrove forest and adjacent area are important sources of income and livelihoods in the islands of the Ganges basin. Some elderly fishers reported that the structure of the mangrove trees enables them to withstand wave impacts and help to dissipate wave action from severe storms (Hossain 2013a).

The protective benefits of mangrove forest against tropical cyclone and wave action are important and well-recognized (Hossain *et al.* 2008; Barbier *et al.* 2008). The importance of mangroves as nursery grounds for the larval and juvenile stages of fin fishes, shrimps, crabs, and cockles has been highlighted by many researchers around the world (Khan and Hossain 1996; Glaser 2003; Lee 2004; Hossain *et al.* 2009). The annual economic value of mangroves, using the cost of the products and services they provide, has been estimated $200,000-900,000/ha (Wells 2006). In Bangladesh, this value would translate to between about $90 billion and $400 billion. To maintain a balance between social and economic aspects, an integrated resource management approach, for example mangrove-nursery-livestock or mangrove-livestock-pond-agriculture, shouldbe examined (Hossain and Das 2010).

2.1.4 Mineral resources

The Indian Ocean (IO) is known to be largely devoid of 'ferromanganese nodules' which are rich sources of manganese, nickel, iron and some 'rare earth elements'. Though there are some reports on their occurrence in other parts of IO (Cronan and Tooms 1967, 1968, 1969), the BoB lacks such 'hydrogenous mineral formations', understandably because the sedimentation rate in the BoB outperforms the growth rate of any such deposits. Whether there are any other potential mineral resources besides oil and gas in the BoB is yet to be investigated in full, but the high sedimentation rate in the coastal areas may affect this potential.

The new millennium has brought accelerating utilization of marine minerals, while knowledge of new types of marine mineral resources is expanding with significant present and potential scientific and economic benefits (Rona 2002). The utilization of marine minerals is driven by growing societal and industrial needs, which may be met by turning to the ocean for materials that are in short supply, strategically vulnerable, environmentally sensitive to recover on land, or can be recovered more economically from the seafloor.

Beach material commonly known as sandvaries in colour ranging from dark-brown, gray, black, light brown, golden to silvery white. Several investigations have been carried out in the coastal region to find heavy materials in the sandy beaches of Bangladesh. Sands containing valuable heavy minerals are found intermittently over the length of a 250 km coastal beltfrom Patenga to Teknaf. The entire coastal belt has been explored with the discovery of 17 deposits of potentially valuable minerals such as zircon, rutile, ilmenite, leucoxene, kyanite, garnet, magnetite and monazite (Alam 2004). The reserve of heavy minerals and their mineralogical compositions (% by weight) in different areas of Teknaf has shown in Table 2.5. Proper extraction and commercialization of minerals from beach sand may enhance the growth of different industries such as welding electrodes, paper, glass, chemical and ceramic sectors in the country. So, by installing mineral extracting industries in the Teknaf region, it may bepossible to create huge employment opportunities for the local community.

Table 2.5. Reserve of important economic heavy minerals and their composition (metric tons) in different areas of Teknaf (modified from Alam 2004).

	Name of sites		
Valuable components (MT)	Badarmokam	Subrang	Teknaf
Crude sand	1,765,000	347,558	1,393,580
Heavy minerals	411,000	68,582	442,291
Zircon	4,932	4,184	28,306
Rutile	3,288	1,372	13,230
Ilmenite	94,530	19,614	163,170
Leocoxene	18,002	3,470	20,124
Kyanite	--	727	14,728
Monazite	4,932	206	3,045
Magnetite	10,275	1,001	7,209
Garnet	--	3,018	22,424

2.1.5 Renewable energy

Renewable energy sources may be helpful in tackling the challenges of energy security and global climate change. The renewable energy sources include hydropower, solar, wind, ocean, and geothermal energy. In contrast with the more established oil and gas sector, the wind, wave and tidal energies are embryonic sectors and barely register economically because of the low level of activity (Table 2.6). However, most suitable onshore locations for wind turbines need to be identified and the best (windiest) offshore sites have to be connected to the main transmission grid. Moreover, the possibility of installing mini- and micro-level hydroelectric power plants in the hilly areas of Bangladesh must be explored. A wind generator with a capacity of 2 MW has already been installed in the coastal area of Kutubdia, Bangladesh, but remains inactive. Moreover, solar energy in remote areas of Bangladesh is becoming popular and it is much necessary to promote this sector with efficient technology, equipment and investment. Presently there are about 264,000 solar panels installed throughout the country (http://www.emrd.gov.bd).

Table 2.6. Electricity generation costs from different energy sources in the UK (see Douglas-Westwood 2005)

Energy type	Euro Cent/kWh
Onshore wind	5.3
Offshore wind	7.9
Wave/tidal	9.5
Nuclear fission	3.3
Coal	3.6-4.6
Gas	3.2-4.5

2.1.6 Marine resource use decisions: an example

Figure 2.3 shows an example of multi-criteria attribution of resources which can be employed forcorrect resource use and development planning. In this example only four broad criteria have been used, but in practice, more scientific and socio-economic criteria should be taken into account, appropriate weights assigned to them to figure out which resources are to be used first, given more priority, create lesser environmental impacts and provide most economic thrust, etc. A detailed multi-criteria assessment of that kind is beyond the scope of this paper.

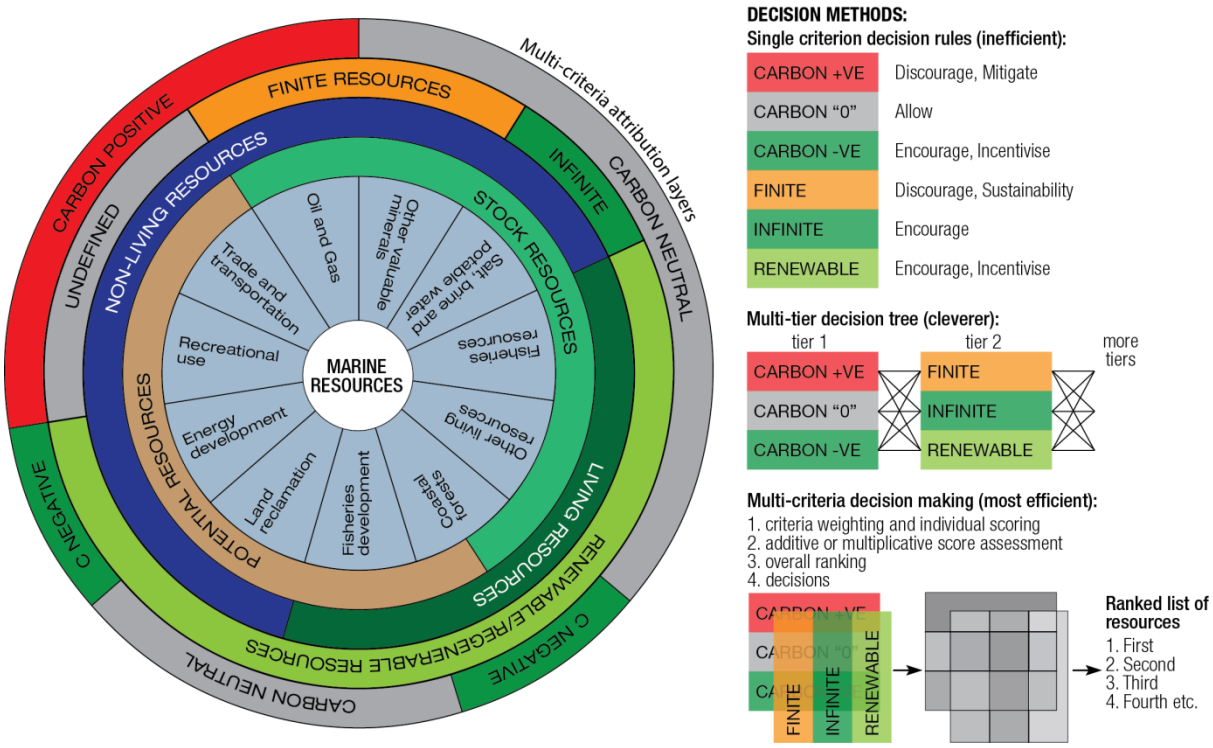

Figure 2.3. Example of multi-criteria attribution of marine resources for right decision making and planning

2.2 River resources of Bangladesh

The rivers of Bangladesh mark both the physiography of the nation and the life of the people. About 405 in number covering 939,073ha in area, these rivers generally flow southwards (Hasan 2013). The larger rivers serve as the main source of water for cultivation and as the principal arteries of commercial transportation. Rivers also provide fish, an important source of protein. Flooding of the rivers during the monsoon season causes enormous hardship and hinders development, but fresh deposits of rich silt replenish the fertile but overworked soil. The rivers also drain excess monsoon rainfall into the BoB. Thus, the great river system is at the same time the country's most important resource and is also itsgreatest hazard.

During the annual monsoon period, the rivers of Bangladesh flow at about 140,000 m^3/s (cubic meters per second), but during the dry period they diminish to 7,000 m^3/s. Because water is so vital to agriculture, more than 60 percent of the net arable land, some 8.8 million hectares (Hasan 2013), is cultivated in the rainy season despite the possibility of severe flooding, and nearly 40 percent of the land is cultivated during the dry winter months. Water resource development has responded to this "dual water regime" by providing flood protection, drainage to prevent over flooding and water

saturation, and irrigation facilities for the expansion of winter cultivation. Major water control projects have been developed by the national government to provide irrigation, flood control, drainage facilities, aids to river navigation and road construction, and hydroelectric power. In addition, thousands of groundwater wells and electric pumps are used for local irrigation. Despite severe resource constraints, the government has made a policy to cover additional areas under irrigation while avoiding concomitant salinity intrusion.

Given this fact, Bangladesh should accumulate the highest knowledge about river behavior and play a pioneering role in hydrology, river control and river training, and optimum use of river resources. However, the country has not conducted surveys of river resources and river routes on a continuous and frequent basis. It only means that our authorities are either ignorant of or completely indifferent to harvesting the benefit from rivers that nature has bestowed upon us in course of its development. Proper knowledge of river resources through regular surveys would be of immense benefit for the country, its economy and environment. It would guide us in proper use of the advantages. Rivers, which offer great potential benefits, have in many ways turned into banes for us. The time for converting bane into boon by reclaiming the rivers is still with us - provided that authorities really recognize the necessity.

2.2.1 Inland aquatic biodiversity

In addition to 939,073 ha of rivers, tributaries and canals, there are 250,727 ha of beel-haor and water saturated areas, 8,800,000 ha of agriculture land (partially flooded during the rainy season) and 51,739 ha of lake areas which all are important aquatic habitat having a rich biodiversity (Table 2.7). Freshwater fishes of Bangladesh are the third richest in biodiversity in the world, following those of China and India (Hossain 2013c). Total fish production in 2012-2013 was 2,821,266 MT, contributing about 83% of total fisheries production. This accounts for 4.37% of GDP while providing more than 2% of export earnings, and provides employment for more than2 million people (DoF 2014). Although there is steady growth in inland fish production (both in capture and culture activities) in the last three decades (i.e. from 7.5 lakh metric tonnes to 35 lakh metric tonnes), fish represent only 56% of the total animal protein consumption in Bangladesh (FAO 2014). To this end, the fish production needs to be maximized by implementing an ecosystem approach to fisheries or aquaculture, establishing protected areas, reducing levels of pollution, and also through habitat restoration.

Table 2.7 The diversity of freshwater fauna of Bangladesh

Group	Species no.
Finfish	267
Prawn	20
Mollusc	36
Crab	4
Frog	10
Turtle & Tortoise	24
Crocodile	2
Snake	18
Otter	3
Dolphin	1
Total	385

Chapter 3
PAST DEVELOPMENTS AND FUTURE DIRECTIONS IN MARINE AFFAIRS

Being a coastal state, Bangladesh and segments of its people, particularly those living near the coast, have always relied on the wealth from the BoB. Formal and informal mechanisms to exploit the resources from the sea gradually evolved with (i) growing number of people relying on the sea for livelihood, (ii) greater understanding in communities and state levels of the marine resources, (iii) enhanced technological support and technical knowledge, and (iv) increasing state interventions, regulations and incentives. Most of the small scale coastal operations were driven by peoples' needs at community levels, whereas large scale maritime operations, *e.g.*, shipping, coastal protection, afforestation, tourism, etc. were state-controlled at the beginning, with some gradually being opened up for private sector and foreign investors (*e.g.*, commercial fishing, mining, aquaculture, etc.). While the maritime economic activities have substantially grown in size and diversity, their management has barely been founded on holistic principles. Notwithstanding the disconnects among various marine activities, most major marine sectors have progressed on their own in terms of developing the 'rules of the game', however fragmentary and incomplete.

In this chapter, we examine various national approaches towards marine resource and activity management in different sectors in light of the recent thrust in the international arena in dealing with the ocean affairs on state and broader scales.

3.1 Legal and institutional framework

3.1.1 International and Regional Conventions and obligations

[A] United Nations Convention on the Law of the Sea (UNCLOS):

UNCLOS III, adopted in 1982 after decades of scrutiny and modifications to earlier versions, and finally coming to effect in 1994, is rightly called the "constitution for the seas" (WOR-1, 2010), because it laid out the framework and rules of engagement with the oceans for the first time in several centuries of its exploitation by humankind leading to all kinds of degradations, problems and conflicts. This framework makes all coastal states collectively responsible for the sustainable use of the oceans, and holds individual states accountable within respective maritime jurisdictions. It is considered a primary instrument of ocean governance, and is one of the most comprehensive international treaties.

[B] FAO Code of Conduct for Responsible Fisheries, 1995 and Compliance Agreement of 1993

The FAO Code of Conduct for Responsible Fisheries which was adopted at an international conference in 1995, addresses nearly every aspect of fisheries. It encourages countries to develop and implement their national fisheries policies based on a prescribed standard stipulated therein. This code of conduct is non-binding, but FAO strives to get the work done by commissioning a special committee, the FAO Committee of Fisheries (CoFi), which oversees the implementation of its standard in member countries. Two year prior to the Code of Conduct, FAO negotiated a legally binding agreement called the Agreement to Promote Compliance with International Conservation and

Management Measures by Fishing Vessels on the High Seas, which mandates that fishing vessels accomodate certain obligations.

[C] UN Fish Stock Agreement, 1995

In another UN-convened conference in 1995, the UN Straddling Fish Stock Agreement was adopted, which came into effect in 2001. This legally binding agreement provides the framework for long-term conservation and sustainable management of straddling and highly migratory fishes in the sea. This agreement is seen as a groundbreaker to global rule of fisheries management. Bangladesh is a signatory to this treaty.

[D] Ramsar Convention, 1971

Convention on Wetlands of International Importance, especially as Waterfowl Habitat popularly known as Ramsar Convention is an international treaty adopted with the aims of conservation and sustainable use of world's wetlands as places having immense ecological, economic, socio-cultural, scientific and recreational importance. Bangladesh is a signatory to this treaty and is the host of three Ramsar recognized site, namely, Hakaluki Haor, Tanguar Haor and a part of the Sundarbans.

[E] Convention on Biological Diversity, 1992

The Convention on Biological Diversity (CBD), often touted as Biodiversity Convention, was agreed upon in the conference of world leaders in Rio de Jenerio, Brazil in 1992 also known as Earth Summit. It has three goals, namely (a) conservation of biological diversity, (b) sustainable use, and (c) fair and equitable sharing of benefits arising from biological resources. Bangladesh has ratified to the convention and therefore mandated to act on the principles and issues of this convention.

[F] UNEP Regional Seas Conventions

Regional Seas Conventions framework by the UN Environment Program (UNEP) provides the legal framework for regional action plans for tackling environmental problem in the marine regime. Several conventions and protocols in different maritime regions of the world have already been adopted under this framework. However, the northern Bay of Bengal is still lacking a regional convention and protocol, a matter which may be taken up with the neighboring states for greater environmental benefits in the region.

3.1.2 National Policies, Acts, Rules and Plans

[A] Maritime Zone and coastal-oceanic realm

The Territorial Waters and Maritime Zones Act, 1974 is the first and the only instrument to provide for declaration of zones and bringing areas in the BoB within the country's territorial jurisdiction according to provisions of international agreements and laws. Drawing on what was already agreed upon in UNCLOS-I (1958) and UNCLOS-II (1960), this law provides the country with the legal means of establishing its sovereign and other rights on respective zones in the sea. This law could be seen as the cornerstone of what to follow in future decades in marine management for the ocean-based economy.

What could be the next most important legal basis for a concerted development and management strategy of the maritime areas is the combination of the Coastal Zone Policy, 2005 (CZPo) and the Coastal Development Strategy, 2006. Despite all good intents, however, the CZPo fell short of recognizing the sea itself as an important constituent of the coastal-marine zone, except for a few mere mentions of the EEZ. It doesn't even show maps of the maritime areas in its background and technical papers illustrating a highly land-centric mindset in formulating the policy, which affected how the other details were laid out later. The national CZ management initiative has seemingly died off after 2005-2006, and has failed to show any great promise. No substantial document, knowledge product, and/or action is visible after that time. Almost no "will be"s in the CZPo turned into "has been"; after a decade of adoption of the policy most targets still remain in the to-do-list. That is an indication of a failing instrument. It is failing ostensibly due to (i) failure to incorporate professionals qualified in Coastal Zone Management, and Coastal and Ocean Policy in its formulation stage in the first place, resulting in (ii) an overly/unreasonably land-centric view of the coastal zone, the highly

important oceanic regime being virtually ignored, (iii) selecting an arguably inappropriate lead ministry and a lead agency, (iv) failure to assemble a regular workforce in the lead agency having sufficient disciplinary diversity required to deal with the complexity and multidimensionality of the CZ, and (v) conceivably, lack of will in general. What could have been the visionary instrument for blue economic development, is itself suffering from what appears to be 'blue blindness'.

[B] Fisheries

B1. Early fisheries laws

Among the earliest fisheries laws that came into effect on this land were The Private Fisheries Protection Act, 1889 and The Indian Fisheries Act, 1897. The former provided for the safeguarding of fish keeping and fish growing operations in privately owned water bodies, and the latter laid out the foundation for more comprehensive fisheries protection laws and rules that were enacted subsequently. The 1897 law brings the coastal waters up to a certain limit in its jurisdiction for the purposes of fish protection. The East Bengal Conservation and Protection of Fish Act, 1950, with the enactment of which the earlier law was repealed, expanded on the 1897's law and provided for state control on various activities like using guns, arrows, poisons, erecting dams, etc. detrimental to inland fisheries; however this law omits the coastal waters from its jurisdiction. Subsequent amendments in1963 and1970 provided for control of nets and inclusion of scientific studies to their respective programs of protection of fish. The first law enacted in independent Bangladesh was The Protection and Conservation of Fish (Amendment) Ordinance, 1982 which essentially replaced certain terms and names in the existing laws in order to reflect the changes that came with independence. The Protection and Conservation of Fish (Amendment) Rules come in every 2 to 3 years, which reflects the necessity and actions taken to adjust and modify the regulatory mechanisms in order to enforce the provision of the Law. It also illustrates the weakness of the scientific understanding on many aspects of our fishery resources resulting in adoption of *ad-hoc* measures and subsequent shifting of policies, laws and regulations.

B2. Recent developments

In 1983, The Marine Fisheries Ordinance was enacted which was the first comprehensive legal instrument to provide for the exploitation, conservation and management of the marine living resources including but not restricted to fishes. It defines the "Bangladesh Fisheries Waters" in the BoB. It lays out important provisions for protection and conservation of fishery resources therein, *e.g.*, bans and moratoriums, protected areas, regulation of type, class and number of fishing vessels, regulation of nets and fishing methods, etc. It also guides the protection of the rights and livelihood of small fishing communities by laying out provisions of designated exclusive fishing zones for them. One year later, The Fisheries Research Institute Ordinance, 1984 enabled the formation of the institute to "coordinate fisheries research" and to develop more efficient and economic methods of production, management, processing and marketing of fish.

The next most important document that came into being is the National Fisheries Policy, 1998. It guides that the exploitation, conservation and management of marine fisheries be achieved through comprehensive stock assessments, fishery education, research, and joint-venture initiatives with foreign and offshore entrepreneurs. It also advocated declaration of shrimp aquaculture as an industry and extension of state patronizations to the industry, and creation of mechanisms to boost export of fishery commodities. It continues to recognize the fishing rights and exclusive zones for small fishing communities.

Only recently, the National Shrimp Policy, 2014came into existence, which is broadly based on many principles of the Fish Policy '98, while recognizing shrimps as valuable fishery resources. Besides laying out targets and principles of exploitation, conservation and management of marine shrimps, it also guides the regulation of shrimp brooder (mother shrimps) collection from the sea, technology development to mitigate impacts of climate change, job creation and poverty easing in the shrimp sector, improved cultivation and enhancement of shrimp production, protection of natural breeding and nursing grounds of shrimps, etc. Furthermore, it guides various actions including zoning of coastal land for shrimp farming, export promotion, education, research, credits, insurance, database creation, etc. Two preceding instruments (namely, theFish Hatchery Act, 2010 and the Fish Hatchery

Rules, 2012) lay out provisions and rules for the establishment, licensing, and operation of fish and shrimp hatcheries, regulation of brood collection zones, and adherence to environmental requirements.

Despite the expectations, targets and ambitions set forth in various policies and acts, there is still no act or policy or regulation in place for developing and regulating coastal aquaculture and mariculture in the BoB, which appears to be a justified requirement.

[C] Energy and mineral resources

Two early laws in the energy and mineral resources from the pre-independence periods are the Petroleum Act, 1934 and The Regulation of Mines and Oil Fields and Mineral Development (Government Control) Act, 1948.

Two more recent documents that govern the petroleum sector of the country are The Bangladesh Petroleum Act, 1974 and National Energy Policy, 2004. The former replaces (by annulment) the two earlier laws, namely The Petroleum Ordinance, 1974(which in turn replaced The Petroleum Act, 1934 and The Regulation of Mines and Oil Fields and Mineral Development (Government Control) Act, 1948). Both this Law and the National Energy Policy identify the need for planning, implementation and organizing exploration, exploitation, development and production of petroleum wealth from the sea - the territorial waters, continental shelf and the EEZ. The Law bestows all such wealth to state ownership and allows contracts called "petroleum agreements" with other parties for accomplishing the aforementioned jobs on behalf of the state. It also provides for survey, research and experiments in the petroleum sector.

The National Energy Policy, on the other hand, covers a wider energy mix including petroleum resources. It recognizes that sustainable economic growth and socio-economic development of the country heavily rely on secured supplies of energy. It guides the state in using energy from various sources, including fossil fuels (imported oil, gas, coal), and renewable energy from tidal power, ocean wave, solar radiation, and wind power. It also emphasizes meeting the demands from indigenous sources as much as feasible. It stipulates engagement of public and private sectors to this end.

There is, however, no comprehensive guide or law with regard to other minerals that can be extracted from the marine systems.

[D] Environmental protection

a) Bangladesh Environment Conservation Act, 1995
b) Bangladesh Environment Conservation Rules, 1997, and subsequent amendments in 2000 and 2001,
c) Bangladesh Environment Conservation (Amendment) Act, 2000
d) Bangladesh Environment Conservation (Amendment) Act, 2002
e) National River Protection Commission Act, 2013
f) National Action Plan for Adaptation (NAPA) to Climate Change
g) Bangladesh National Conservation Strategy 2005

[E] Shipping, trade & commerce

An early laws=, namely The Ports Act, 1908, lays out various provisions for overall port operations and the control that may be needed for such operations. Any such port that is not governed by a law specifically crafted for that port, or a navigable reach of a river or channel, can be designated as a port and governed by this law. Ports are critically important installations of the country, The Protection of Ports (Special Measures) Act, 1948 provides for the safety and protection of these installations. Two of country's currently operational sea-ports, *i.e.*, Chittagong and Mongla ports, are governed by their respective laws - The Chittagong Port Authority (Amendment) Act, 1995 which amends The Chittagong Port Authority Ordinance, 1976, and The Mongla Port Authority (Amendment) Act, 1995 which amends The Mongla Port Authority Ordinance, 1976. Recent passage of a similar law, the Paira Port Authority Act, 2013, lays the foundation for future operations of the third sea-port of the country.

The Bangladesh Shipping Corporation Order, 1972 provides for the establishment of the Bangladesh Shipping Corporation for "ensuring better operation and development of shipping and ocean transport services". The Bangladesh Merchant Shipping Ordinance, 1983 is a comprehensive

law determining and controlling various operational aspects of the maritime shipping sector, and provides for the establishment of the Department of Shipping to this end. The Inland Water Transport Authority Ordinance, 1958 provides for the establishment of such a public authority for the "development, maintenance and control of inland water transport" andThe Inland Shipping Ordinance, 1976 lays out operational details of shipping and vessels in these waterways. These four laws together founded the backbone of the shipping and water transport sector of the country. However these laws don't embody the cross-sectoral aspects of shipping.

International trade and commerce are regulated by The Imports and Exports (Control) Act, 1950 and subsequent orders released under the purview of this Law. e.g., Import Policy Orders, 2012-2015. Together these instruments have the potentials of creating a thriving trade and business sector and thereby supporting the shipping sector as well.

[F] Tourism

The Bangladesh Parjatan (Tourism) Corporation Order, 1972 is the first legal instrument in the tourism sector which allows the establishment of the Bangladesh Parjatan Corporation, a state owned entity, for "promotion, better operation and development of tourism" in the country. The National Tourism Policy, 2009 is a pragmatic, promising and more comprehensive approach to the development of tourism industry in the country, targeted to increase foreign currency earnings, improve livelihood and reduce poverty. It stipulates attracting tourists to places of interest including environmentally and archaeologically sensitive sites, at the same time calling for appropriate responses for their conservation. Sports and alternative tourism practices are encouraged in this policy. It also guides regional, subregional, interminsterial and interagency coordination for fulfilling its goals. The Bangladesh Tourism Board Act, 2010 passed next year allowed the establishment of this supervisory organization, which would frame necessary rules and regulations, and advise the concerned agencies and the government for the development of this sector. The Bangladesh Tourism Protected Areas and Special Tourism Zone Act, 2010andThe Bangladesh Tourism Protected Areas and Special Tourism Zone Rules, 2011 provide for declaring and managing potential areas exclusively for tourism and putting an end to any other activities in these areas.

[G] Water resources sector

a) National Water Policy, 1999
b) National Water Management Plan, 2001
c) Bangladesh Water Act, 2013

[H] Scientific research

As mentioned earlier in [B2] above, The Fisheries Research Institute Ordinance, 1984 allowed the establishment of a research institute to coordinate fisheries research in the country. The achievements and practical outcomes from this institute in 30 years of its founding may be brought into question and critically evaluated, but the necessity of an organization of its kind cannot be undermined.

Only recently, a national oceanic research organization has been founded for spearheading all kinds of oceanographic research including biological, physical, chemical and geological nature. This would be the lead ocean research body of the country. A law by the name of The National Oceanographic Research Institute Act is currently awaiting passage in the Parliament. Details of this law are not publicly available yet.

[I] Defense and Law enforcement

Safeguarding the territorial integrity of the maritime zones is of utmost importance for any economic activity to be carried out in this area. The naval wing of the Armed Forces Division is entrusted with maintaining sovereignty and territorial integrity of our oceanic realm, which is formed and empowered to do so by The Navy Ordinance, 1961, and by its amendments, e.g., The Navy (Amendment) Ordinance, 1977.

A non-military force named the Bangladesh Coast Guard has been recently formed under the provisions of The Coast Guard Act, 1994, which will join hands with the Navy in times of war in defending the territory, but will patrol the seas as a regular duty to uphold any interest of the state

inside the maritime boundary. Important relevant duties of this force include protecting the sea from polluters, protecting key maritime installations, enforcing law and order in the sea, providing basic security to personnel at sea, deterring trespassing and trafficking, and preventing illegal fishing. It also helps enforce any law of the state that applies to the maritime area. The Bangladesh Navy under special provisions also plays some of these roles.

3.2 Development initiatives

Some development initiatives have recently been taken and some are in the process of being initiated in different sectors, namely shipping, fisheries, environment, research, etc. to either boost economic growth or to manage the capital resources more sustainably. Among notable developments in the shipping sector, besides modernization of existing ports, is a new sea-port Paira being constructed in Patuakhali district. In addition, an Inland Container Terminal (ICT) has been constructed near Dhaka and container transport by ships to and from Chittagong Port is being carried out.

Exciting developments in the marine fisheries sector particularly with respect to conservation and sustainable exploitation are going on. A calculated proportion of the bottom trawls have already been converted to mid-water trawls in order to lessen pressure on the demersal fish stocks, to reduce destruction of sea-bottom habitats, and to exploit the mid-water fish stocks. A temporary ban on fishing in a certain period of the year has been imposed for several years now to allow breeding and recruitment of important fishes, specifically Hilsa. Several Marine Protected Areas (MPA) are in the process of being declared to maintain marine biodiversity and fish stocks at sustainable levels (although there is no national policy on MPA development needs or priorities). Destructive fishing methods and gear (*e.g.*, set bag net) have been completely banned from operation. Vessel Tracking and Monitoring System (VTMS) with satellite communication links are going to be installed soon in fishing vessels in phases, in order to monitor and control their maneuver at sea for various management purposes.

In the environment sector, several Ecologically Critical Areas (ECA) have been enforced in various coastal ecosystems to maintain critical habitats, biodiversity, marine turtle breeding and conservation, and mangrove restoration and growth. Mangrove afforestation in newly accreted intertidal areas has been going on for decades now.

Recently the National Oceanographic Research Institute (NORI) has been founded for coastal and oceanic research of all kinds. Recently an initiative has also been taken to establish a Chief Hydrographer's Officer at the Armed Forces Division of the Prime Minister's Office to coordinate and lead hydrographic surveys and other related research activities in the BoB.

3.3 Issues remaining to be addressed

An institutional framework can be broadly divided into its 'institutions' - the set of rules which defines practices, assigns roles, and guides the interactions among the occupants of the roles (Young 1994); and 'organizations' - the material entities which take part in actions or assume roles. As far as the organizations are concerned, Bangladesh seems to have a nearly adequate number and type of bodies, from supervisory entities to implementing agencies, in various sectors of ocean affairs. From the review and discussions of the existing legal documents, it becomes also apparent that there have been quite a lot of policies, laws, orders and rules which are used to manage various sectors and organizations related to marine management, development and economy. What seems lacking in the institutional backbone is the mechanism of 'interaction' and the ability to see the marine-coastal system as a highly integrated entity, which would require a top order vision and policy backed by multi-sector strategies translated into highly organized and closely coordinated actions. Monitoring and assessment is a weakness in Bangladesh, so there is inadequate reporting on the progress of various marine initiatives (such as Integrated Coastal Zone Management).

Moreover, the older laws in general are lacking the embodiment of the recent paradigm of good governance which would ideally provide for explicit mechanisms to ensure equity, public participation, accountability, transparency and other democratic principles.

A serious weakness in Bangladesh is public participation, at a variety of levels (regional and community levels, certain classes of stakeholders, private sector, etc. (see BOBLME, 2012). Such

lack of public participation threatens inclusionary politics that are required for true democratic institutions to be viewed positively by the populace.

3.4 Challenges and constraints of advancement

In trying to find an answer to why the desired progress has not been made in developing ocean economy despite having adequate legal instruments and organizations, the following bottlenecks have been identified:

a) Weaknesses in policy: for example, CZPo 2005, as described in 3.1.2[A].
b) Lack of coordination and integration: as described in 3.3.
c) Lack of knowledge or scientific understanding: graduate universities which could have been the leaders of knowledge creation are poorly funded for research.
d) Inadequate human resources: for example, (i) in shipping business, hatchery operation, etc. there are large number of foreign nationals working as experts, (ii) Marine Fisheries Department is run by only a handful of people, the scope of the work is way beyond their human capacity. In general, marine-related departments seem to be inadequately staffed by knowledgeable, educated specialists.
e) Lack of investment: for example, in the mining and petroleum industry.
f) Improper allocation of roles and designation of focal points: for example, (i) WARPO with an inbreed of civil and water engineers are entrusted with the complex and multidisciplinary task of CZ management, (ii) Bay of Bengal Large Marine Ecosystem (BOBLME) project is represented by Fisheries Research Institute, (iii) International Hydrographic Office (IHO) is represented by BIWTA not having any presence in the sea; (iv) Intergovernmental Oceanographic Commission (IOC) is represented by the Ministry of Education, not by the Ministry of Science and Technology according to the mandate given in the Rules of Business of the GoB.
g) Lack of will: at least partially, ocean development remained stagnant due to lack of political will of the governments.
h) Weak intersectoral interaction, particularly on marine policy issues.
i) Inadequate public participation and stakeholder inclusion (tourism, provincial and state governments, communities, private sector, fishermen, etc.).
j) Last but acutely critical is the lack of integration and coordination among laws, agencies, and field level operations.

3.5 Ocean governance framework: a way forward

Considering the legal provisions available for fostering various maritime economic activities, and also the lacking therein particularly in cross-sectoral integration and coordination, it seems only logical to craft an Ocean Governance Framework (OGF) utilizing existing and new instruments for the much anticipated economic growth and sustainable development of the country.

3.5.1 Compound nature of marine/ocean affairs

The seemingly quiet and unpopulated ocean, on a closer and objective look, reveals the true nature of interactions with humans which makes it no lesser occupied than its land counterpart. A plethora of natural capital resources, enormous ecosystem services and climate benefits, and a vibrant commercial and service sector; use by a wide range of stakeholders from sectors and communities; a large array of local, state, regional and global actors and agencies shaping and reshaping the rules; and all of these constituents interacting with each other - are making the task of ocean management extremely complicated and challenging (Figure 3.1). Despite enormous opportunities and provisions, ocean-based economic development is often thwarted by a number of challenges, which must be surmounted through a wisely crafted ocean governance mechanism to deal with the compound nature of the system. Only with strong intersectoral coordination and buy-in will ocean governance work.

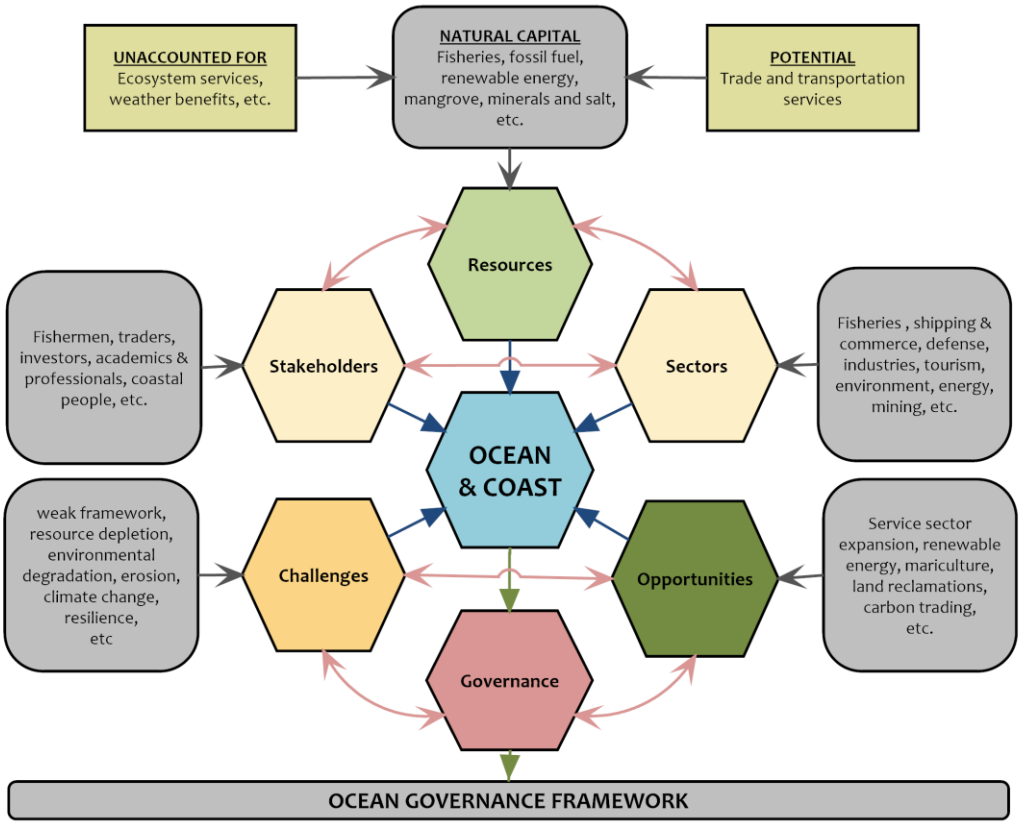

Figure 3.1. Complex interactions of resource base, users, actors, challenges and opportunities of ocean management leading to the logical response of governance

3.5.2 Integration mechanisms

Integration means to unify, to put parts into a whole, i.e., constituent elements are brought together. Cicin-Sain (1994) addressed the meaning of "Integrated Management" in the context of oceans and coasts. Integrated fisheries management is an initiative aimed at addressing the issue of how fisheries resources can be best shared between competing users within the broad context of "ecologically sustainable development". The process of bringing together separate components is a functional whole that involves coordination of interventions. This integration may take place at three different levels viz. system, functional and policy (Hossain et al., 2007). Systems integration refers to the physical, social and economic linkages of land and water uses and ensures that all relevant interactions and issues are considered. Functional integration ensures that programs and projects are consistent with fisheries management goals and objectives; and policy integration ensures that management actions are consistent with other development and policy initiates. Vertical integration refers to integration between the local level and state or national or international activities and policies. Horizontal integration refers to integration between different sectors (such as fisheries and forestry) (Figure 3.2).

Integration can be seen as one of the tools or methodologies for realizing the goal of Holism - ideally meaning that all aspects of an issue or consequences of a decision are considered (natural sciences, economic, socio-cultural, legal, institutional questions, etc.). There is a need for at least five different dimensions of integration:

a) among sectors
b) among levels of government
c) between land-water interface
d) among disciplines
e) between nations (especially when nations share an enclosed or semi-enclosed water body)

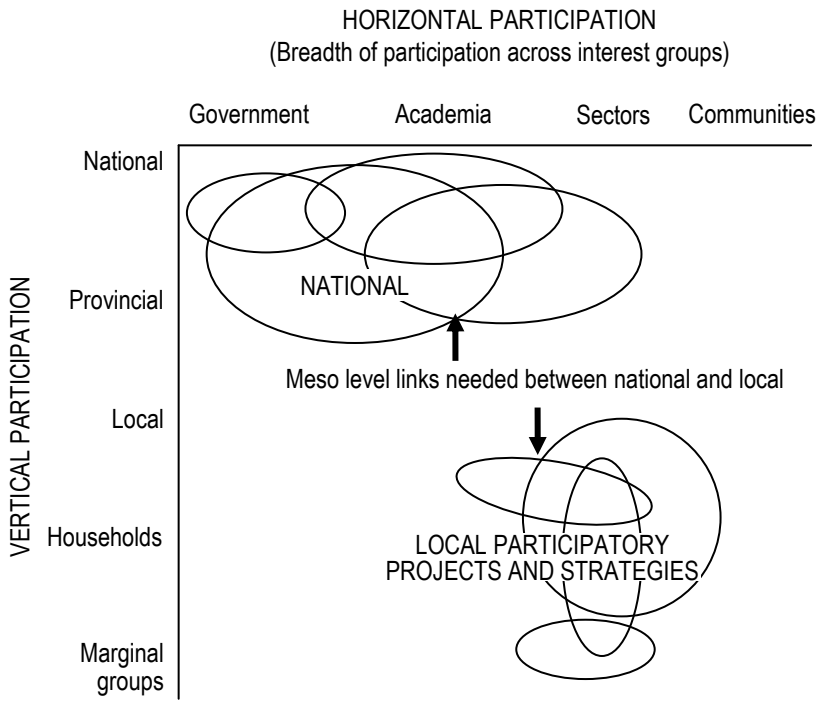

Figure 3.2. National and local participation experience showing horizontal and vertical integration (source: Bass et al. 1995; Hossain et al. 2007).

The knowledge base needs to incorporate three main sources of information: resource users, managers and scientists. To integrate user and manager practical knowledge with scientific knowledge, management-related information must be collected, organized and communicated effectively. For example, user and manager practical knowledge can be organized in a systematic way and distinctions made between observation and inference (Usher 2000). Moreover, the process of collecting and organizing practical information must also include techniques of validation (e.g. data triangulation). Particular attention may be given to practical information directly relevant to conflicts among user-groups, since user statements may be politicized. Both practical information provided by users and managers and scientific data must be considered during decision-making.

3.5.3 Elements of good governance

There is no universal set of rules to lay out the guiding principles of good governance, after careful examinations and consulting literature the following broad elements seem appropriate for application in designing an ocean governance scheme for Bangladesh:

- equitable allocation of resources and opportunities
- justice
- sustainability
- precautionary approach/principle
- cross-sector integration and coordination
- public and stakeholder participation
- transparency
- accountability

3.5.4 A proposed framework for good ocean governance

We therefore propose an Ocean Governance Framework (OGF) for coastal and marine affairs of Bangladesh, a barebones structure which is shown in Figure 3.3. At the top of the scheme should be an Integrated Coast and Ocean Management Policy (ICOMP) driven by obligations and aspirations leading to an Integrated Coast and Ocean Management Plan, at the heart of which should be Marine Spatial Planning, which we describe in greater detail in chapter 5. Existing legal framework of the

country will be useful as is, or with necessary modifications to guide strategic planning in different sectors. There should be a strong mechanisms to integrate and coordinate the implementation of plans in different sectors at various levels (horizontal and vertical interplay among agencies and other actors). This framework can be further extended to include cross-border and regional collaborations particularly in the fields of environmental management, conservation, scientific research, etc.

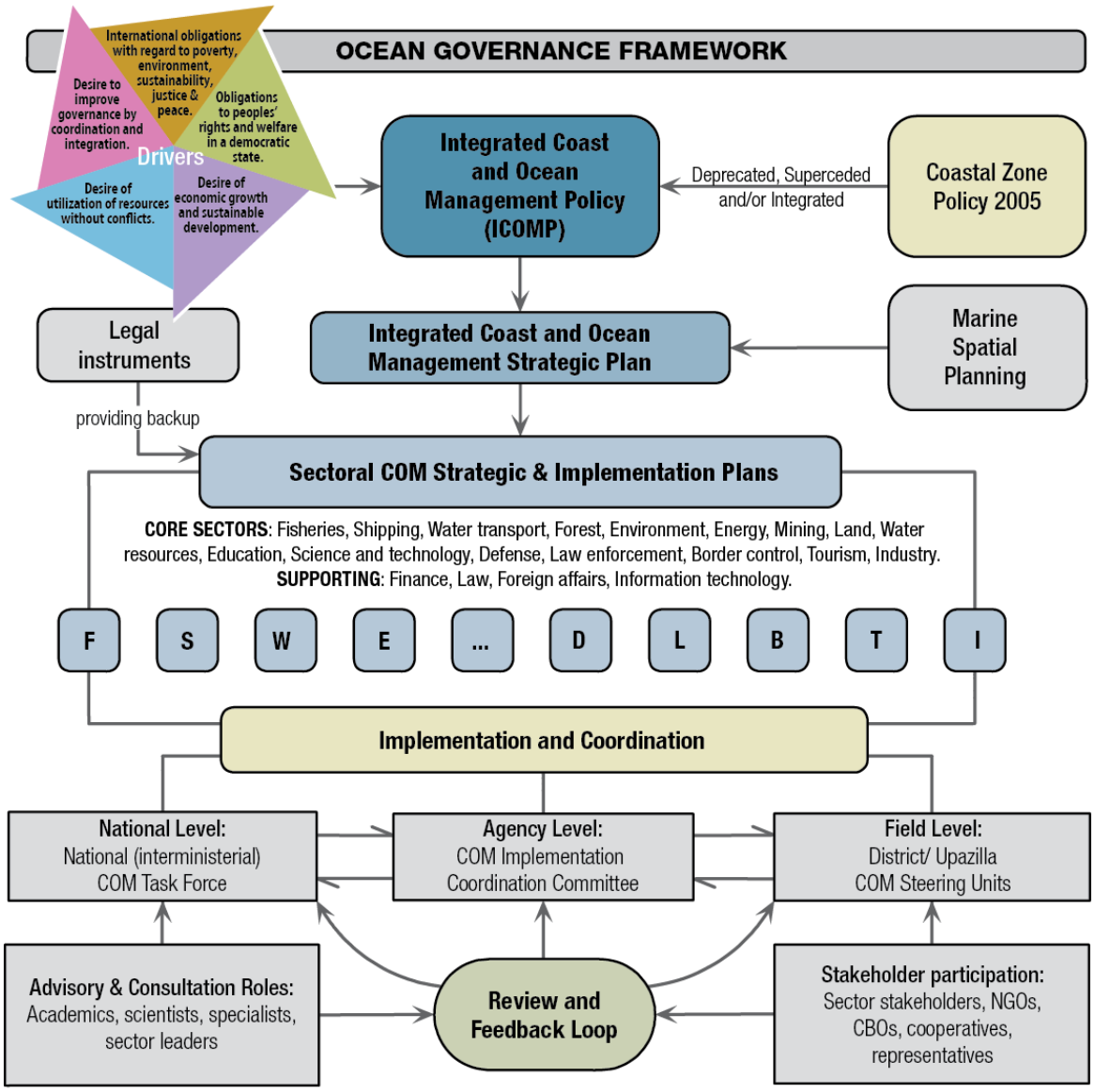

Figure 3.3. A proposed framework of Ocean Governance for Bangladesh

Chapter 4
OCEAN AND RIVER RESOURCES MANAGMENT ISSUES

4.1 Need for "blue growth" and means

Ocean resources are extremely important to our society and national economy. About 30 million people (one fifth of the population) are directly dependent on the marine sector for activities like fisheries, aquaculture, tourism, shipping, shipbuilding and ship decommissioning, and offshore oil and gas production. Recent settlements of the maritime border disputes with neighboring states have opened up opportunities for ocean-based economic growth and development for the Bangladesh: the blue growth potential. Using smart solutions and innovations, the blue growth (blue economy) concept fosters the idea of exploiting untapped potentials of our marine environment for increasing food security, improving nutrition and health, alleviating poverty, creating jobs, lifting trade and industrial profiles while protecting ecosystem health and biodiversity, and improving regional security and peace. In order for these to be achieved, we must understand the complexities of the marine systems and learn how to maximize its use for the intended growth, create institutions for good governance, mitigate environmental consequences, and prepare ourselves for the changing climate in a changing world. Regular monitoring and assessment, with its communication, are essential components of this framework (components that are now essentially missing).

4.1.1 Economic growth by ocean activities

The ocean (Bay of Bengal) and coasts are the most valuable resources and strongest economic drivers of Bangladesh. The maritime economic activities such as shipping, marine construction, energy development, commercial fishing, coastal aquaculture, and tourism have contributed to the national economy and supported jobs. Businesses, communities, and governments that rely on ocean resources need high-quality scientific information and data. Greater access to high-quality data and information are required but not sufficient, for maritime industries, resource managers, and decision makers at all levels of government to make responsible and effective decisions. Government needs to take the following actions that strengthen the national economy through enhanced accessibility to data and information and robust, sustained observing systems, all encompassed by a transparent, well-reported, and effective monitoring and assessment framework.

i) Advance mapping and charting capabilities: Improved mapping, charting, and associated products will enhance the efficiency of maritime commerce through safer navigation and better

accident-avoidance, and updated hydrographic charts and seafloor maps will support marine industries such as offshore energy. Survey of the oceans for civilian purposes has a number of distinct sectors including hydrographic survey for the production of navigation charts, exploration and development of oil & gas reserves, port & harbours, submarine cable routes, wind farms installations, etc. Such charting will also permit expansion of digital marine charting to be incorporated into Vessel Tracking and Monitoring systems, for fisheries, marine transport, etc.

ii) Accessibility to data and information: Agencies need to facilitate the availability of relevant ocean data to provide easier access to information for research, planning, and decision support. Moreover, using public input, local and traditional knowledge, and scientific information can help to identify and communicate the economic value of ecosystem services, such as healthy and productive wetlands that support spawning, breeding, and feeding of commercially important fish species. This information can help decision makers consider the value of these services when evaluating actions that may affect the economy. Expansion and openness of internet resources throughout the country are required, with attention paid to devolving computer knowledge and use to the smallest community and stakeholder entity possible.

iii) Develop observing systems for the economic benefit: Government agencies, academics and research organizations can jointly support the development and maintenance of ocean observing systems. Real-time information on waterway conditions from ocean observing systems such as the Oceanographic Real-Time System (physical, chemical and biological) directly supports the daily operations and efficiency of maritime commerce, fishing fleet operation and other activities that rely on the marine environment. Continued development of ocean observing programs will stimulate private sector ocean technology development and provide a rigorous test-bed for further innovations. Such real-time systems can be made available (at a fee or not) to shipping interests to help assure safe, effective navigation and transit.

iv) Increase efficiencies in decision-making: A key goal of the policy is to improve efficiency across government agencies, including permitting, planning, and approval processes to save time and money for ocean-based industries. Interagency work includes land/water use zoning for site-specific activities such as ports and harbor operation, ship building and ship recycling, fishing and aquaculture, oil and gas well, renewable energy plant, etc. to support marine commercial sectors as well as ensure appropriate environmental and other required safeguards.

v) Protecting and restoring marine and coastal systems: Restoration activities provide direct economic opportunities, and healthy natural systems support jobs in industries such as tourism, recreation, fishing and farming. Agencies will coordinate to protect, restore, and enhance wetlands, mangroves, sea grass beds, coral reefs, and other high-priority ocean, estuary and coastal habitats. With the rapid build-out of the Bangladesh coast due to river sedimentation processes, Bangladesh has an unparalleled opportunity to expand its mangrove resources, thereby expanding the varied economic benefits (not least of which is combatting effects of climate change).

vi) Prevent environmental degradation: River-borne pollutants, municipal wastes, industrial effluents, agro-chemical residues, ship and tanker discharges have significant adverse economic, public health-related, and ecological consequences. High nutrient discharges from rivers could intensify large-scale hypoxia. Government agencies will take steps to prevent and reverse widespread economic impacts caused by environmental degradation. They will take action to strengthen the monitoring, science, data access, modeling, and forecasting of the nature of pollutants and the damage they cause to marine ecosystem and resources to provide decision makers with the necessary information to minimize and mitigate harmful impacts on ocean economies.

vii) Develop human capacity and skilled workforce: Academic institutions will coordinate to ensure that educational programs include diverse student groups and that a highly competent workforce is developed. Academic institutions action will result in more students at the undergraduate and graduate level, pursuing academic fields related to ocean and coastal science and management. This will support the Nation's leadership in ocean research and development and the application of best management practices. For example, universities and research organizations will use existing education and training resources to provide scholarship, fellowship, and internship opportunities in ocean research, marine laboratories, and natural sciences to provide opportunities for education and training. Moreover, arranging periodic ocean-focused academic competitions for high school and college students will create a positive impact on ocean-related career paths.

viii) Tourism: Marine and coastal tourism has enormous potential for Bangladesh, where the largest compact mangrove forest and the longest sandy beach is located. Marine cruise tourism can be developed linking destinations like Chennai, Colombo, Andaman-Nicober islands, Palk Strait and Indian Ocean trip using luxury cruise ships. At present, marine tourism is only a weak link in marine policy discussions in Bangladesh.

4.1.2 Maximizing/optimizing output

[A] Enhancing potential of coastal aquaculture:

Black tiger shrimp *(Penaeus monodon)*, locally known as *bagda*, is the only brackish water (coastal) aquaculture species predominantly cultivated in the coastal districts of Satkhira, Khulna, Bagerhat and Cox's Bazar. Shrimp farming expanded rapidly between 1970 and 1990, to about 183,221 hectares (Belton *et al.* 2011), mostly in *ghers* (piece of land protected from the sea by polders) under extensive production systems. This farming practice is significant to our national economy, earning the second largest foreign exchange for the country, about US$478 million (EPB 2012). Despite the immense potential for further growth, shrimp cultivation is facing multiple challenges related to disease outbreaks, technological barriers, poor compliance with quality standards, sourcing of seed, etc. By selectively overcoming these bottlenecks, shrimp cultivation can be intensified and the production improved considerably.

i) Production intensification (from extensive to semi-intensive system): Most of the shrimp farms in Bangladesh use traditional or extensive cultivation methods characterized by low-stocking density and zero to minimum inputs, with low yields(60-230 kg/ha (Table 4.1)), hence making suboptimal use of the land-water resources. These outdated modes of production need to be upgraded to semi-intensive methods with the introduction of healthy seed, quality feed and good husbandry practices, reaching a plausible boost in production up to 6,000 kg/ha (Paul and Vogl 2011). Intensification comes with its own risks and challenges, but at some point in growing demands and diminishing supplies measures must be taken to meet such challenges, and techniques must be learnt to reduce and avert the risks. Cautious intensification of farming should now be undertaken at pilot scales in carefully selected areas, taking full advantage of the collective knowledge of the international community (Mexico, China, Ecuador, etc.).

Table 4.1. Shrimp farming systems and their level of production in Bangladesh (after Belton *et al.* 2011).

Production system	Characteristics			
	Management	Stocking (PL/m^2)	Yield (kg/ha)	Remarks
Extensive	Natural feeding, little or no management	0.2–1.5	60–230	Followed by majority of farms (>90%)
Improved extensive	Supplemental feeding, little management	1–2.5	350–500	Followed by some farms only
Semi-intensive	Artificial feeding, aeration, waste control	5–10	Avg. 2,000	Investment intensive and remains very rare

ii) Disease control: Diseases such as WSSV (white spot syndrome virus) and luminous bacteria (*Vibrio harveyi*) are the bottlenecks to economic and production sustainability of shrimp larviculture (hatchery) systems. Chemical disinfectants and antibiotics are commonly used to control diseases, despite their serious consequences for human health, for example, the immergence of antibiotic-resistant pathogens (Heuer *et al.* 2009). As an alternative, application of probiotics (beneficial microorganisms) and with improved husbandry techniques, hygiene and bio-security practices should be embraced to promote health management and eco-friendly shrimp aquaculture in Bangladesh (Sharifuzzaman and Adhikari 2013).

[B] Develop sea salt extraction:

The oceans are the most prolific source of sodium chloride accounting for over 50% of the world production. The reserves in the seas are estimated at 50 million billion tonnes (Mannar 1982). The production of common salt is one of the most ancient and widely distributed industries in the world. Nearly 120 countries have salt producing facilities ranging from primitive solar evaporation to advanced, multi-stage evaporation in salt refineries. The requirements of Europe and North America

are met mostly by mining while in Asia, Africa, Australia and South America, solar evaporation is the main source.

Sea salt has been produced traditionally along the Cox's Bazar coast of Bangladesh for generations. The sea salt production by evaporation is mainly dry season dependent. In a longer dry season, the salt farmers can get about 20 tons/ha production. The annual salt production in the Cox's Bazar coastal segment of Bangladesh is 22MT, where the Samut Sakhon of Thailand produces 43MT (Table 4.2). Most of the salt farms are small-scale, using manually operated local equipment and lease the land from landowners, or sometimes from the government on a yearly basis (Hossain *et al.* 2006). Community-focused land leasing systems, sufficient credit facilities, use of mechanical equipment (water pump, leveler, etc.) and reliable weather forecasting can enhance salt production. Moreover, formation of salt farmer's cooperatives can ensure bargaining power and maximize economic return (i.e., salt price) for their standard of living.

Table 4.2. Salt cultivation area and production rate in Bangladesh and Thailand (Hossain *et al.* 2006)

Coastal Zone	Name of sub-district	Area (ha)	Production (MT)	Production rate (MT/ha)
Cox's Bazar coast, Bangladesh	Cox's Bazar Sadar	2588	58445	23
	Chakaria	5565	116585	21
	Moheshkhali	6748	130618	20
	Kutubdia	2085	39125	28
	Teknaf	317	13227	42
	Banskhali	2328	44999	20
	BSCIC Experimental Plot	40	961	25
	Total	19671	403960	22
Samut Sakhon coast, Thailand	Nakhok	1077	45234	42
	Kalong	1445	69360	48
	Bang Tholat	1010	40400	40
	Bang Bo	410	15990	39
	Bang Krachao	335	14740	44
	Bang Ya Phrack	463	20835	45
	Krok Krak	85	3570	42
	Khok Kham	358	14320	40
	Pan Tile Norasingh	358	13604	38
	Total	5541	238053	43

[C] Develop marine and coastal eco-tourism:

Marine Tourism is one of the world's largest marine markets and is likely to show high growth in future years. It is estimated that more than half of the world population lives 60 km or closer to the coast, with this proportion likely to increase, further boosting domestic tourism and leisure activities. The growth of tourism in general is due to more leisure time, increased spending power and improved communication and transportation technologies. Improved communication will give tourists better information on destinations and activities. Improved transportation systems will enable quicker and more direct travel to previously inaccessible areas. Within the tourism sector generally, consumers are becoming more widely travelled and are demanding higher quality and more varied leisure experiences. 'Special interest tourism' within the marine context could be an area with considerable development potential.

As particular coastal destinations become more popular with tourists, overuse can lead to problems of pollution and over development, leading to an eventual decline in tourism. Sustainable tourism is of particular relevance within the marine tourism sector, as it depends upon the quality of the marine environment and sustainable tourism probably represents a significant business opportunity.

[D] Human resources development

Behind the production of every product or service there is human mind, effort and working hours, no product or service can be produced without help of human being. Human being is the fundamental resource for making or constructing anything. Today many experts claim that machines and technology are replacing human resource and minimizing their role or effort. But even machines

and technology have been built by the human aid and besides companies have been continuously in search for talented, skilled and qualified professionals to further develop latest machines and technology, which again have to be controlled or used by humans to bring out products.

Well-trained, skilled and educated human resources are the driving force of the development of an economy, who can participate in the globalization of business and the accompanying technological revolution. Dynamic and sustainable development is not possible without skilled work force. Having assessed the need of world market and local industry, appropriate courses on science and trade are essential to introduce at tertiary education system. Moreover, to turn youths into productive and skilled work force, technical and vocational courses need to expand. Women are also need to encourage in ocean and river related education and jobs. Academic innovation and research funds need to provide to universities to generate knowledge and upgrade research capability. Student and expert exchange among regional and global institutions at graduate and post-graduate levels will strengthen the linkages for further development.

4.1.3 Marine biotechnology

Interest in marine biotechnology has been gaining momentum across the globe and the activity is expected to generate 10-12% annual growth in the coming years. This is largely for meeting the growing demands of bioproducts and biomaterials that cannot be guaranteed from terrestrial sources alone. Marine biotechnology (or blue-biotechnology) is a young subset of biotechnology and simply refers as the science and technology that uses marine bioresources such as fish, algae, bacteria and invertebrates, or their parts, to bring desirable products and other benefits for humans. Although, many institutes (BARI, BLRI, BJRI, BRRI, BTRI, NIB), research centres (BCSIR, ICDDR,B), universities and private organization of the country are involved in conventional (land-based) biotechnology works with mentionable progress and success (i.e., whole genome sequencing of jute, high-yielding varieties of rice, pest/ salt/ drought resistant crops, biofertilizers, vaccines, etc.), surprisingly there is no national marine biotechnology R&D institute and programmes. The promising pharmaceutical and coastal aquaculture sectors as well as livelihoods of poor people of the country would benefit if marine organisms can be used as a source of new materials/ products especially for applications in health (antibiotics, anti-cancer, bioactives compounds, nutritional supplements, etc.) and food (marine fish, shrimp, molluscs, seaweed farming). To date, coastal/ marine aquaculture of the country is centred on only tiger shrimp (*P. monodon*) farming, but it is also a disease prone industry and economically less attractive. In order to enhance aquaculture productivity, domestication of new species such as grey mullet (*Mugil cephalus*), seabass (*Lates calcarifer*), white shrimp (*P. indicus*), mud crab (*Scylla serrata*) and their larviculture technology, and selective breeding schemes to develop disease-resistant shrimp stocks can be the suitable alternatives involving biotechnological approaches. Nevertheless, numerous untapped novel microorganisms and under exploited fisheries resources of BoB offers huge development potential of marine-based biotech to shape the creation and production of new processes, products and services to market, as mentioned in Table 4.3.

Table 4.3. Areas where marine biotechnology offers scope to develop industrial economic activity.

Area	Scope
Health care	Therapeutics, pharmaceuticals, nutraceuticals, medical devices, drug delivery systems, wound dressings, cell therapy, prosthetics
Mariculture	Development of coastal and marine aquaculture, feeds, genetics, domestication of new species and larviculture technology
Food	Ingredients that modify physical properties of food, i.e. gelling agents, colourants, textures and flavours, nutritional components, functional foods (i.e. foods that confer health benefits over and above basic nutrition)
Industry	Input to various manufacturing units, from textiles to chemicals, to biomaterials including adhesives, filters, films as well as industrial processes using enzymes such as equipment cleaning and waste remediation
Energy	Biofuel from microalgae as alternative source of energy
Agriculture	Animal feeds, fertilizers, herbi-/fungi-/pesticides
Environment	Biosensors, bioremediation (removing hydrocarbons)
Cosmetics	Cosmeceuticals including thalassotherapy products, personal care products

Source: adapted from Marine Institute, Ireland (www.marine.ie)

4.1.4 Diversification of resource utilization

Humans directly harm ocean ecosystems in several ways; among these overexploitation of resources is well known. Marine overexploitation is the harvesting of fish, invertebrates and plants beyond sustainable yields and is largely related to livelihood activities, increasing population pressure and associated rising demands for seafood. An estimate suggests that many commercially important marine resources are by now overexploited or depleted, and the greatest impact of which is being felt within fisheries. This sort of scenario is also common in our context, and fisheries (mainly fish and shrimp species), mangroves and coral reefs of BoB are seriously threatened due to various reasons.

Every year, for a few months, many coastal poor people including women used to engage catching of wild prawn postlarvae along the coastline. This is an important livelihood activity contributing 40% of total annual income for households living near the lower Pasur River of southwest Bangladesh (Ahmed *et al.* 2010). But, the quantity of by-catch (i.e. larvae/ juvenile of non-target fish/ shellfish species) is high in prawn larvae fishing, posing significant negative impacts on the production and biodiversity of coastal ecosystems. Moreover, the only coral reefs at St. Martin's Island having one of the highest levels of productivity and biodiversity is currently in a vulnerable position due to coral mining, destructive and unmanaged resource harvesting.

Whereas coastal and marine waters of BoB are rich in fisheries diversity with over 400 fish species, as well as various species of crustaceans (shrimp, lobster, crabs), molluscs (clams, oysters, mussels) and cephalopods (squid, cuttlefish, octopus), only a few species such as hilsa, Bombay duck, Indian salmon, pomfrets, jewfish, catfishes etc. are harvested commercially in high volume year after year. This way of fishing would eventually lead certain fish stocks to be overfished. In addition, the once flourishing Chakaria Sundarbans has been destroyed mainly due to expansion of shrimp farming and to a certain extent for extracting firewood, housing and building materials by the settlers residing near the coastline (Hossain *et al.* 2001). These facts suggest that any harvesting and associated activities must be rational in order to protect renewable and nonrenewable resources in the marine biome. The diversification option (Table 4.4) is of primary importance to use resources sustainably as long as this adaptive strategy supports the intended activities to survive economically.

Table 4.4. Possible diversification options within the areas of fisheries and aquaculture.

Area	The ways and means
Fisheries resources	i) Use of non-traditional fishery items, i.e. marine finfish (flatfish), molluscs (oysters, mussels), cephalopods (squid, cuttlefish), elasmobranchii (sharks, rays and skates), macroalgae (seaweeds) as food. ii) Use by-catch/ non-target species as alternative food species, export items, value added products (such as fish protein concentrate, fish silage, fish body oil & liver oil, fish canned products, chitin & chitosan), fish meal, etc.
Coastal aquaculture and mariculture	i) Integrated farming techniques, such as integrated multi-trophic mariculture (finfish+shellfish+seaweed), silvo-aquaculture or integrated mangrove-shrimp systems. ii) Farming fish in offshore marine cages. iii) Diversification of farmed species, such as start farming of grey mullet (*Mugil cephalus*), seabass (*Lates calcarifer*), white shrimp (*P. indicus*), etc.
Capture fisheries	i) Diversify fishing areas, such as start fishing at deeper parts of the ocean to avert risks associated with overfishing of certain fish stocks. ii) Initiate pelagic fishing, longline fishing, etc. to enable harvesting of unexploited fish communities.

4.1.5 Role in socio-economic development

Coastal communities have depended for generations on ocean and coastal resources for their lives and livelihoods. Over time, they have developed ecosystem-related knowledge and skills, and have evolved institutions that regulate their interactions with each other, with the resource base and with the outside world (Hossain 2013b). There are local, district, national, regional and global efforts to support and grow marine economies, protect and conserve the environment that supports quality of life, and sustain unique social and cultural identities (Figure 4.1). Different stakeholders share aninterest in growing their economies and providing jobs that support strong communities, which they address through a diverse and often unique array of marine uses. For example, their interests range

from conventional boating to shipping, they have different subsistent and commercial fisheries, and they offer distinct tourism and recreational activities. They also have different priorities for environmental protection and the use of ocean resources. In the Saint Martin's Island, coral reef ecosystem conservation is a focus area, whereas in the Moheshkhali and Kutubdia Islands, addressing living shoreline with shellfish reef development is suitable for coastal defense and food production; and mangrove afforestation in the Meghna deltaic regions is a top priority. In the marine and coastal ecosystems, fish habitat suitability modeling efforts (Hossain *et al.* 2014) are essential to enhance natural recruitment through habitat-specific marine protected area establishment.

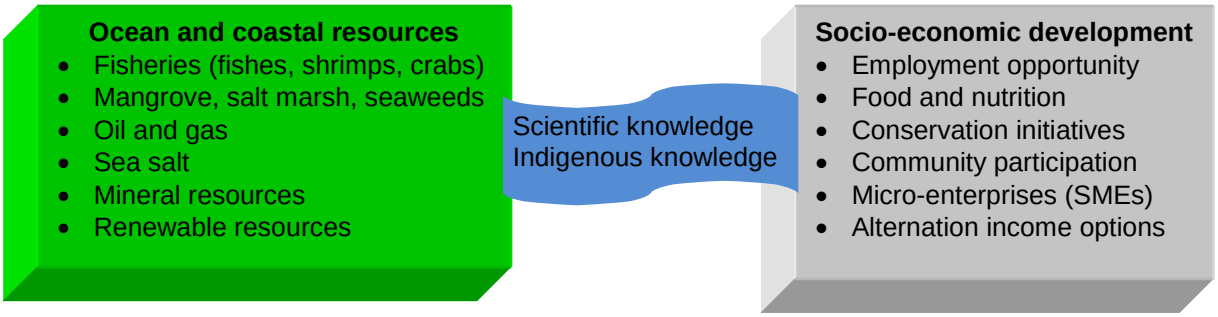

Figure 4.1. Ocean and coastal resources link socio-economic development

Hossain and Lin (2001) found that the major activities of the people at Cox's Bazar coast are fishing, shrimp farming, crop farmer, salt production and tourist operator, both as daily labour and owners of businesses. No integration was reported among the coastal professionals, managers, extension workers and researchers for ocean and coastal resources management (Hossain 2013b). Fishing zone selection, fixing fish price, cooperative fishing and formation of fishing-processing-selling group can enhance resource management sustainability as well as livelihood security.

4.1.6 Investment needs

Water is so central to the lives of people in Bangladesh that affects the resources as well as livelihoods. Bangladesh is a country where agriculture and fisheries production is the mainstay of the rural communities' livelihood system, and therefore livelihood strategies are inextricably linked to the nation's water resources management. Indeed, the river system, most of which emanate from outside the country, have shaped much of the history, economy and culture of the people. Investments from the Government, development partners and private entrepreneurs are needed to prioritize in ocean and river resources management sectors, particularly silt management and navigability of the river-ways, water resource assessment and utilization (fisheries, oil & gas, minerals), and ocean-based industry development (oil & gas, wind/tidal/wave energy, mariculture, marine biotechnology, tourism).

Within the parameters of a competitive investment, potential sectors are evaluated to determine if they advance global competitiveness, create jobs, leverage public and private resources, can demonstrate readiness and ability to use funds quickly and effectively, and link to specific and measureable outcomes. In connection to this, the following investment priorities are important:

a) Collaborative innovation: Initiatives must engage stakeholders; facilitate collaboration among urban and rural areas; provide stability for economic development through long-term intergovernmental and public-private collaboration; and support the growth of existing and emerging industries.
b) Public-private partnerships: Investments that use both public-private resources and leverage complementary investments by other government/public entities and/or nonprofits.
c) National strategic priorities: Initiatives that encourage job growth and business expansion related to advanced manufacturing; information technology infrastructure; job-driven skills development; natural disaster mitigation and resiliency; access to capital for small-medium sized enterprises; and innovations in science and health care.
d) Global competitiveness: Initiatives that support high-growth businesses and innovation-based entrepreneurs to expand and compete in global markets, especially encourage foreign direct investment.

e) Environmentally sustainable development: Investments that promote job creation and economic prosperity through projects that enhance environmental quality and develop and implement green products, processes, places, and buildings as part of the green economy. This includes support for energy-efficient green technologies.

4.2 Water governance

The role of water cannot be isolated and defined independently from other factors of socio-economic development. Water governance is defined by the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water service delivery at different levels of society. Importantly, the water sector is a part of broader social, political and economic developments and is thus affected by decisions outside of the water sector (Figure 4.2).

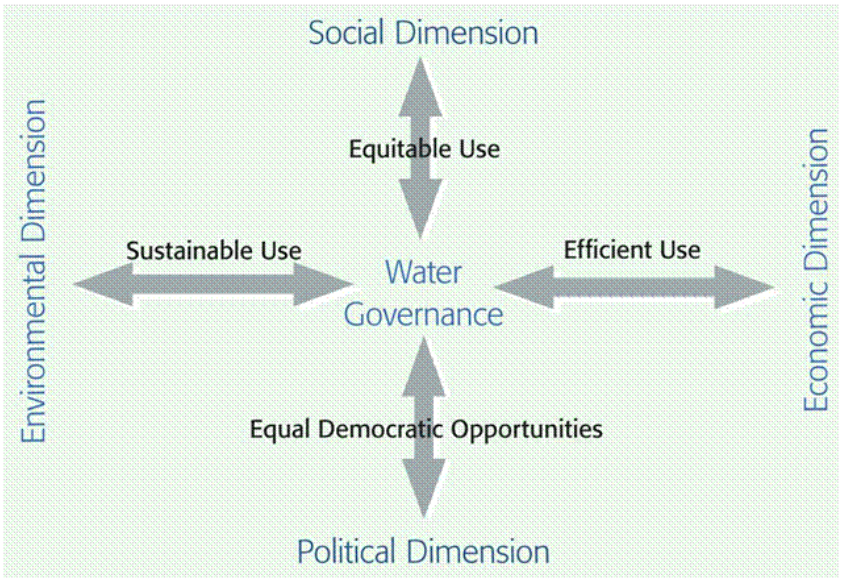

Figure 4.2. Dimensions of water governance (http://www.watergovernance.org/)

The social dimension points to equitable use of water resources. Apart from being unevenly distributed in time and space, water is also unevenly distributed among various socio-economic strata of society in both rural and urban settlements. The economic dimension draws attention to the efficient use of water resources and the role of water in overall economic growth. Aggressive poverty reduction and economic growth depend highly on water and other natural resources. The political empowerment dimension points at granting water stakeholders and citizens at large equal democratic opportunities to influence and monitor political processes and outcomes. At both the national and international levels, marginalized citizens, such as indigenous people, women, slum dwellers, etc., are rarely recognized as legitimate stakeholders in water-related decision making, and typically lack voices, institutions and capacities for promoting their water interests. The environmental sustainability dimension shows that improved governance allows for enhanced sustainable use of water resources and ecosystem integrity.

Most international development agencies and water managers, such as UN-Water, Global Water Partnership and World Water Council, now agree that better governance of water resources, rather than availability, is the key to resolving the growing water crisis. This involves putting in place the political, social, economic and administrative systems needed to develop and manage water resources, and to ensure equitable delivery of water-related services.

The most fundamental role of water in socio-economic development is its use for domestic purposes. Use for drinking, personal hygiene, and other domestic purposes constitutes a primary component of welfare that is inadequately provided in much of the developing world. Availability of a greater quantity of water can improve health by allowing improved personal hygiene and general sanitation. Health is a function of numerous environmental and cultural factors such as nutrition, human waste disposal, and personal hygiene.

The role of water as an input to productive processes has a variety of dimensions since most productive activities involve water use. At a fundamental level, water contributes in fisheries production (capture and culture), agriculture production, industrial processes (raw materials, processing and cooling), hydroelectric power generation, waterborne transportation and waste disposal.

Water occurs and moves through the hydrologic cycle with potential negative roles to socio-economic development in several ways. Significant constraints arise from natural fluctuations in water availability such as, water shortage can disrupt water-using activities, excessive water (i.e. torrential rain, flooding, saline water intrusion) may damage properties, water logging (low lying land with poor drainage facility) can hindrance land productivity, and disease transmission diminishes human welfare and can prevent settlement of certain geographic regions.

a) Agriculture and fisheries account for about 80 per cent of water use; an increased focus on this sector is needed to address the water crisis.
b) Integration of scientific knowledge with indigenous knowledge and practices needs to be recognized as a strong basis for water governance.
c) Building trust in communities and among partners is an essential part of capacity development, so that they can act collectively for mutual benefits.

4.2.1 River-based flood management

River-based flood management system is an important planning tool for the water sector. Bangladesh has to transit runoff froman area which is 12 times larger than its size. Annually, 1,360,000 million m^3 of discharge originate outside Bangladesh. About 85 per cent of this discharge is generated between June-October. The amounts of water which transits the country can fill a pool the size of Bangladesh to a depth of about 9meters (FRPPB 2014). Besides water, the rivers also carry high loads of silt from the steep and denuded upstream – an estimated 1.2 to 2.4 billion tons of sediments are carried annually to the Bay of Bengal.

Bangladesh is a low-lying country, with 70% of its land area being less than 1m above sea level and 80% of it being floodplain. The causes of flooding in Bangladesh are mainly due to:

a) Bangladesh receives large amounts of water passing through it with two major rivers (the Ganges and Brahmaputra) converging and forming a huge delta formed from silt deposited by the river as it enters the sea.
b) Both rivers have large volumes of water flowing through them to the sea as they have large drainage basins which increases the flood risk;
c) The main cause is the above average and long period of heavy rain which caused all 3 rivers (including the Meghna) to have their peak flow at the same time.
d) Bangladesh has a monsoon climate and the annual torrential rains which result often result in the rivers exceeding their capacity and flooding;
e) In the spring, melting snow from the Himalayas further increases the flood risks as torrents of melt water enter the rivers at their source.
f) Most of the country consists of a huge flood plain and delta.
g) 10% of the land area is made up of Lakes and Rivers.
h) Tropical storms bring heavy rains and coastal flooding.
i) Increasing population pressure in the foothills of the Himalayas where the rain contributes to the source of the River Ganges and Brahmaputra has resulted in intense deforestation. It is believed that this reduction in interception has resulted in more water entering the rivers.
j) Deforestation in the headwaters is also believed to be responsible for the increased soil erosion.
k) Increasing population pressure in Bangladesh may result in the sinking of many new wells resulting in the lowering of the water table and the subsequent subsidence of land making it even more prone to flooding.
l) Urbanization and human habitation of the flood plain has increased magnitude and frequency of floods.
m) Global warming is blamed for sea-level rise, increased snowmelt and increased rainfall in the region.

n) The building of dams in trans-boundary Rivers of upper riparian countries has increased the problem of sedimentation in Bangladesh.
o) The prevalent and intense tropical cyclones in the Bay of Bengal present a flooding threat from the marine side, which effects are felt up to Dhaka on occasion.

For effective river-based flood management system, the following needs to be implemented:
a) Enhancing Flood Forecasting and Early Warning;
b) Strengthening Monitoring networks;
c) Efficient Data collection through Satellite Imagery, Real Time Data Management, and Flood Forecast Modeling;
d) Effective Dissemination of Flood Early Warning message;
e) Analysis of flood hazard and population at risk in Bangladesh
f) Analysis of existing vulnerabilities of the population of Bangladesh
g) Planning Assumptions (A large proportion of the flood affected population livesunder the national poverty line. The baseline socio-economic status including access to health, education and other services isquitelow.)
h) Projection of priority humanitarian needs (Development of plausible scenarios with future flooding patternsunder conditions ofclimate change).
i) Flood Response Preparedness to undertake effort in reducing damage of properties and lives
j) Process of developing the Flood Response Preparedness Plan
k) GOB Standard Operating Procedures (SOP) for Emergency Response
l) Need assessment: tools and approach
m) Local level Preparedness
n) Pre-positioning of Relief Items
o) Emergency food, health and communication fund
p) Resource Mobilization Strategy
q) Strengthening of Organizations engaged on Flood Management (WARPO, BWDB, LGED, BMD, JRC, DMB, NGOs).
r) Increase the lead time of flood forecasts

Flood Management in Bangladesh will be based on:
a) Flood Forecasting Schemes in Bangladesh
b) River maintenance and erosion control:
c) Flood control and drainage project:
d) Floods from Cyclones: Indigenous Flood-Proofing Techniques
e) Raised Roads leading to selected schools and protected to become multi-purpose flood evacuation shelters.
f) Raised Community facilities to ensure safe evacuation.
g) Drains constructed to remove excess water in raised areas.
h) Culverts built to allow excess water to drain.
i) Public Latrines and shower places to be built on raised homesteads to improve sanitation facilities during flood season.
j) Public tube wells to be installed on raised homesteads to reduce contamination of drinking water.
k) Raised Traditional Homestead community clusters to demonstrate the effectiveness of indigenous mud raising techniques for flood proofing.
l) Flood proofing

4.2.2 River navigability

Inland navigation is of substantial economic importance to Bangladesh because its numerous watercourses provide the cheapest means of transportation. The total length of waterway of Bangladesh is approximately 24,000 km and covers 9,778 km^2 (7% of the country). Siltation, however, has disrupted river communications in many water channels (CCIND, 2014). The main challenges for navigation are de-silting of these channels not only to restore their navigational capability but also to assist surface drainage. Policies of the Government are:

a) Water development projects should cause minimal disruption to navigation and, where necessary, adequate mitigation measures should be taken.
b) Minimum stream-flows in designated rivers and streams will be maintained for navigation after diversion of water for drinking and municipal purposes.
c) Dredging and other suitable measures would be undertaken, wherever needed, to maintain navigational capability of designated waterways.
d) Take necessary steps to remove all existing unauthorized encroachments on rivers and watercourses and to check further encroachments that cause obstructions to water flows and create environmental hazards.
e) To stop unplanned construction on riverbanks and indiscriminate clearance of vegetation on newly accreted land.
f) Dredging technique and dredging method should be determined wherein raising of river banks with dredge spoils be considered
g) River training for the purpose of navigation and the programs for different scales of training should be undertaken where it is feasible.
h) Present deeper draft, long vessels should be replaced by flat bottom shallow draft vessels.
i) For navigability, the water depth in a river should be sufficient to ply passenger and cargo vessels.

There are mainly four types of rivers in Bangladesh: they are (i) the main rivers (Ganga-Jamuna-Meghna), (ii) the primary tributaries (Titas, Gumti, Teesta, Dhaleswari etc.), (iii) the distributaries (Mathabhanga, Gorai, Tetulia, etc.) and (iv) independent rivers (Karnafuli, Sangu, etc.). The navigable rivers can be of three types (Haque, 2008) (i) navigable year-round, (ii) navigable during monsoon and floods, and (iii) navigable but need transshipment at some key spots. The main problem arises during winter time when the river flows are reduced to base flow. Also withdrawal of water in the upstream sectors dries up the river flow downstream. Some navigation khals were excavated for drainage and navigation purposes but the majority of them are not operational now.

The major navigation routes in Bangladesh are centered at some important river ports such as Dhaka, Narayanganj, Chadpur, Bhairab, Barisal, Chittagong and Khulna. The connectivity of these ports especially in waterways is important for the economy. So the maintenance of the navigability of the rivers of the country should take a priority importance which will generate jobs, and is less expensive than road links.

4.2.3 Silt management

The only way for land to counter the effects of a rising sea is for sediment to accumulate at a rate that is sufficient to keep pace with the rate of sea level rise. Limited data show that the average sediment accumulation rate for the last few hundred years in the coastal areas of Bangladesh is 5-6 mm/year, which is not enough to keep pace with the rising sea level (Khalequzzaman, 1989). As a result, net land elevations must have been decreasing over time, resulting in more flood inundations. Sediments on a delta plain are rich in decomposed organic matter, and are subject to compaction due to dewatering and the weight of the overburden. Most deltas subside due to the weight of the thick sediment layer. Subsidence along with compaction reduces land development.

The sediments which underlie Bangladesh's floodplains mainly come from geological formations from outside the country (Brammer 2012).

a) 18 physiographic regions (Brammer 2012) are important to understand the hydrology, soil and land use and also the sediment transport character of the delta.
b) The geological history of the Ganges-Brahmaputra-Meghna delta is important both to understand groundwater hydrology in the flood plain area and the river network system, as well as to understand the behavior of the river system during monsoon and dry season (BADC 1992).
c) Many factors contribute to different sediment and sedimentation rates in different areas in Bangladesh.
d) The rates of sediment accretion varyacross the delta because of ongoing tectonic subsidence of the Bengal Basin (Alam *et al.* 2003).

e) Four main types of flood plain are recognized in Bangladesh, (i) river, (ii) piedmont, (iii) tidal and (iv) estuarine.
f) Each of the main floodplain types has characteristic relief, hydrological and sedimentation patterns.
g) The water brings down about 1.2 to 2 billion tons of silt annually to deposit over the flood plains and in the Bay of Bengal.

This huge amount of sediment can be used in well managed manner to reclaim land in the coastal area. The sediment management can also have a significant input in river bank protection works. It is necessary to monitor sediments in the major rivers of the country.

4.2.4 Integrated Water Resources Management (IWRM)

An efficient Integrated Water Resources Management (IWRM) is of utmost importance for a country like Bangladesh, which is formed by alluvial deposits and criss-crossed by 405 rivers including 57 transboundary rivers. To ensure the availability of water from rain, surface and ground water sources to the consumers without jeopardizing the interest of anyone, it must adopt measures for implementing an optimum IWRM. Water sectors in Bangladesh face huge problems in many cases: e.g., flood and water scarcity during the wet and dry season respectively, frequent sedimentation of rivers and bank erosion on a massive scale, salinity intrusion, degradation of ground water sources, deterioration of surface water and ground water quality and so on (CEGIS 2003). To tackle the ever-expanding water needs for the growing population of our country, it is felt an urgency on national level to promote efficient national policies for the optimization of our limited water resources under certain severe constraints like lack of control on upstream flows of rivers originated outside borders of our country, hindrance to deltaic plain management and inefficient land use management for the construction of water structures (Figure 4.8).

IWRM, which will ensure development of water resources and rational utilization for the benefits of the people must be promoted with some specific objectives (Gupta *et al.* 2005). The objectives are:

a) To ensure the efficient management and wise use of limited water resources of our country.
b) To ensure the improvement of people's quality of life by increasing the availability of clean water in timely manner and sufficient quantities for the usage of different purposes.
c) To ensure the water availability to all sectors of the society including the poor and underprivileged group with special consideration to women and children on the basis of equity and efficient management.
d) Conservation of aquatic and water dependent ecosystems and resources of fisheries.
e) To develop the public as well as private water delivery systems with suitable administrative and financial measures and initiatives
f) To ensure the sound environment for the decentralization of water resources management through proper administrative measures.

The policy of the Government of Bangladesh to develop and promote an effective and optimal IWRM through co-operation among the national as well as the international users have to take the following steps:

a) To develop a system of mutual communication among the neighboring countries for sharing necessary data, information and knowledge based on hydrology, morphology, water pollution, ecology, changing watershed characteristics, cyclone, drought, flood forecasting etc. for the optimum allocation of water resources among the users.
b) To develop a system of joint assessment of the transboundary rivers with the neighboring countries to understand the actual condition of the river systems within the basin.
c) To promote an organized efforts among the neighboring countries for efficient catchment management by ensuring the preservation of forests and erosion control and preventing land degradation as much as possible.
d) The Government will exercise its water allocation power by giving priority for allocating water during critical periods to the water shortage zones.
e) Involvement of public and private organizations for the arrangement of necessary training programmes among the local people to make them to use water resources efficiently.

f) All the necessary relevant technical procedures (e.g. physical modeling, mathematical modeling and hydraulics computation, integrated environmental analysis, EIA and SIA) would be performed and updated on a regular basis as a part of intelligent IWRM.
g) To introduce rainwater harvesting techniques and conservation to facilitate availability of safe and affordable drinking water supplies among the users.
h) To ensure the recharge of underground aquifers and rainwater management by preserving natural depressions and water bodies in major urban areas.
i) In case of construction of new industrial areas, zoning regulations to be established strictly in consideration of fresh and safe water availability and effluent discharge possibilities.
j) Economically feasible as well as environmentally safe hydropower schemes and recreational activities will be allowed at or around the water bodies.
k) To preserve the natural flow of the water bodies and to check further encroachments all existing unauthorized encroachments on rivers and watercourses to be removed.
l) To maintain aquatic environment and facilitate drainage natural water bodies such as beels, haors, and baors to be preserved for the national interest.
m) To formulate a central database and Management Information System (MIS) compiling information from various agencies of research and data collection on the existing hydrological systems, water resources, water quality and ecosystem.

Figure 4.8. Integrated Water Resources Management framework for sustainable use of water resources in Bangladesh

To be committed to exploring, developing and using the national water resources it is incumbent on GoB to formulate and implement the IWRM strategy effectively as well as efficiently to ensure the benefits to all community of users. An intelligent execution of IWRM strategy in Bangladesh will certainly pave the way to ensuring the limited water resources optimization to a great extent.

4.3 Resource depletion and environmental degradation

Depletion of resources including drying-out of the only gas well in the Sangu gas field, and more importantly the fisheries resources is a major concern for the country. Although the total annual marine fisheries production (catch) shows year-to-year increase, it is frequently being reported by fishing companies, trawl owners, fishing boat operators and coastal fishermen communities that the catch-per-unit-effort (e.g. per trawler, per hour, per net, per boat, per person indicators) is alarmingly in decline, even more so against the growing demand of fish resulting in the skyrocketing of price, which in turn is a proxy indicator of scarcity. Another important indicator of fish stock decline is the introduction of low value and non-conventional fishes in the consumption chain. These indicators have not been systematically investigated; however, there are limited indications of many species of fish going nearly extinct or rare from Bangladesh marine waters and river estuaries during the next three decades.

Pollution, waste disposal and other forms of environmental degradation are other major concerns for the marine ecosystems of Bangladesh. Despite environmental regulation acts and rules, toxic industrial effluents are discharged untreated in many cases causing serious damage to the ecosystems and fisheries. A new form of thin polythene shopping bags known as PP, has plagued the solid waste management scenario of the country. Thousands of tons of them are introduced to the waterways, and those eventually get carried to the sea and deposited at the bottom making the habitat inhabitable for shrimps and bottom-dwelling (demersal) fishes. Oil, pesticides and nutrient pollution also impact the marine waters of Bangladesh (Mahmood *et al.* 1994a,b).

4.4 Knowledge gap/Resource assessment

4.4.1 Fisheries stock assessment

Fish stocks for more than three decades are being assessed based on fragmented and less reliable catch data from commercial vessels, which poses a serious risk on the stocks of being miscalculated and possibly being caught out-of-balance, risk of unwary overexploitation included. Recent declining trends of the catch-per-unit-effort (CPUE) by commercial trawlers indicate an alarmingly dwindling stock, despite the total production (catch) seems to be increasing in the short term possibly due to increased number of vessels in operation and employment of modern underwater fish finder technologies. Notably, indiscriminate and uncontrolled use of fish detection technologies can be proven destructive to fish stocks already under stress.

4.4.2 Oil and Gas exploration/survey

Bangladesh Petroleum Exploration & Production Company Limited (BAPEX) represents the national entity in building up a national work force, which can carry out oil and gas exploration and production. Oil and gas discovery in Mahanadi and Krishna Godavari (KG) Basins of India and Rakhine Basin of Myanmar confirm hydrocarbon resources availability in the Bay of Bengal. Bangladesh drilled twenty wells in the offshore of the Bay of Bengal but yielded only two discoveries. The Sangu was the single commercial discovery and has already been depleted, whereas the Kutubdia not yet been commercialized due to small reserve.

To meet challenges and minimize energy crisis, Bangladesh need to explore and exploit oil and gas in the maritime territory of the Bay of Bengal. In fact, the country requires massive exploration and drilling activities to increase its overall gas output. There is no alternative but to offer more contracts to the international oil companies to accelerate offshore exploration and drilling activities to ensure the country's future energy security. Apart from, technology transfer, adequate training, equipment and capacity building for BAPEX in offshore exploration are necessary.

In the past, the oil and gas sector has not been an active participant in marine policy formation. In the future, oil and gas exploration and exploitation must be accomplished with full participation by the participants of such exploration and exploitation in policy, legal, and regulatory development and

implementation. Partnerships should be established between public and private sectors to share data and information, monitoring, and best practices, as well as monitoring and assessment protocols and results.

4.4.3 Assessment of renewable energy potentials

The increase of power consumption reduces the source of fossil fuel day-by-day. Most power plants are dependent on natural gas in Bangladesh, resulting in the quick depletion of natural gas reserves, which will reduce to zero within a short time. Thus, it is necessary to reduce the dependency on fossil fuel by the utilization of renewable energy as much as possible. Solar radiation, wind, wave and tide are the sources of renewable energy, which can be utilized by various technologies with having commercial viability. In this connection, suitable sites, technology transfer and training on renewable energy sources need to be explored to mitigate the increasing energy demand and a contribution to reduce global warming.

4.4.4 Assessment of land reclamation

Ecologists and engineers must work together to create structures that are beneficial to ecosystem enhancement as well as shoreline stabilization. Localized impacts on the coastal geomorphology are possible, for example, changes to waves and currents and displacement and changes to biological communities. Living Shorelines are thought to have many positive attributes, such as erosion control, increase accretion, improve water quality, support natural vegetation, accelerate plantation zones, resilience to sea level rise and salinity intrusion, and the potential for reclamation of coastal land. Demonstration sites are needed to increase familiarity and authenticate the effectiveness and long-term durability of this method of shoreline stabilization.

4.4.5 Environmental flow (E-flow) assessment of major rivers

E-flow is the amount of water needed in a watercourse to maintain healthy ecosystems. The term is used in the context of rivers which have been dammed, with most or all of the flow trapped by the dam — the failure to provide an E-flow can have serious ecological consequences (Akter, 2009). According to the Global Environmental Flows Network (GEFM), E-flow refers to water provided within a river, wetland or coastal zone to maintain ecosystems and the benefits they provide to people. E-flow is that flow that is essential within a stream to maintain its natural resources and dynamics at desired or specified level.

E-flow management provides:

a) The water flows needed to sustain freshwater and estuarine ecosystems in coexistence with agriculture, industry and cities.
b) An estimation E-flow needs everywhere immediately and to integrate E-flow management into every aspect of land and water management.
c) The increased uses of water especially through diversion and storage by the upper riparian country have created significant impact on the natural flow regime of the lower riparian country. The flow regime has been impacted through morphological, hydrological and environmental changes. These changes in the flow regime have in turn caused changes in the dynamics of the aquatic system with adverse impact in the ecological and environmental conditions.

E-flow assessment is required for

a) Balancing the use (or development) of water from aquatic ecosystems for various purposes whilst protecting (or managing) the aquatic ecosystems so that it can continue to be used by present and future generations.
b) E-flow requirements area must in planning for new projects related to water resources development and management, evaluating the operation and management of existing projects.
c) E-flow means that water in rivers is managed in such a way that downstream users and ecosystems receive enough water for their sustainability.
d) It entails negotiations between water users, based on an understanding that their water use has no effects on others, and on their common natural environment.

e) In E-flow assessment, the river environment means not just the river channel, but it includes the connected flood plains and wetlands.

For the ecology of a watercourse, there may be a need to recommend E-flow requirements for other purposes like:

a) maintenance of the channel diversity
b) sustenance of fisheries
c) navigation
d) prevention of saline intrusion
e) dilution of effluent
f) maintenance of the flood carrying capacity of the channel
g) protection of the rights of other abstractors
h) cultural and social reasons and
i) prevention of invasive plant species

It has become essential to assess the E-flow for the sustainability of the rivers in Bangladesh specially the major rivers as many lives and livelihood as well as the environment depended on these rivers. The E-flow assessment is required to preserve the river and its associated functions for sustainable development. The E-flow assessment for Ganges, Gorai, Jamuna, Teesta, Old Brahmaputra, Surma-Kushiara system, Meghna, Buriganga and Halda River needs to be done onan urgent basis.

4.4.6 Future water demand

Bangladesh has every water challenge imaginable, and all in large measures (CSIRO 2014). The challenges, furthermore, look set to magnify in future. Some of them are:

a) The population of Bangladesh will increase from the current 160 million to about 214 million by 2050 (BIDS 2014a) and the economy will grow.
b) This will increase water demand for drinking, industrial, fisheries and irrigation in the dry as well as monsoon season.
c) The projected increase in temperatures due to climate change will also increase the demand for irrigation water and other water uses.
d) Climate change is also expected to increase the challenges and coping with the challenges: today is not easy, and the future will be more difficult.
e) Declining flows are most significant in the dry season and are due to upstream diversions. So the water demand assessment for the dry season is the most important challenge which needs to be taken care of.
f) The growing wealth will lead to a greater per capita demand for urban and industrial water, and this will be multiplied by alarger population.
g) These factors will also lead to a demand for more food and for a different pattern of food consumption, probably with more animal protein in the diet and a lesser dependence on staples such as rice.
h) Future water use in Bangladesh will be tied to the dominant water user: dry season Boro rice with the over use of groundwater.
i) The agriculture sector is by far the largest consumer of water in Bangladesh (Chowdhury 2010).
j) National Water Policy (MoWR 1999) sets the following order for priority for water uses: domestic and municipal uses, non-consumptive uses (e.g. navigation, fisheries, and wildlife), sustenance of the river regime, and other consumptive and non-consumptive uses such as irrigation, industry, environment, salinity management, and recreation.
k) Industrial demand is also increasing; many industries use water as a direct input to production.
l) Annual domestic water demand is expected to increase by 200% by2050 while industrial demand is expected to increase by 440%.
m) Transportation accounts for 6% of GDP and water transportation accounts for 15% of the transportation sector's share of GDP.

n) Forest currently covers 12% area of Bangladesh; forest water demand has been estimated to be 2.9 km^3 (CEGIS 2014).
o) Annual water demand for the fisheries sector in Bangladesh has been estimated 5.2 km^3 (open water capture fisheries 3.1 km^3 and closed water culture fisheries 2.1 km^3).

The ability to design and implement effective policies, and to coordinate their implementation in order to strengthen the water management issues and water security is a permanent challenge. The design of robust planning and operations should increasingly be formulated with strong involvement of national stakeholders in order to increase national ownership. From an economic standpoint, first and foremost, water is linked with major productions. Agriculture remains the single most important source of employment in rural areas, with two-thirds of the labor force is either directly or indirectly involved in agriculture, and hence agriculture is critical in alleviating poverty.

4.5 Climate change challenges

4.5.1 Ocean acidification and loss of biodiversity

Emissions of carbon dioxide (CO_2) are the driving force of climate change and ocean acidification. The ocean reservoir of carbon is much greater than both of the terrestrial and atmospheric systems and provides an important net sink for carbon through exchange of CO_2 across the air-sea. Over the past 200 years, atmospheric CO_2 has increased from 280 ppm to a global average of nearly 390 ppm due to burning of fossil fuels, cement production and land-use changes (Hilmi *et al.* 2012).Atmospheric CO_2 concentrations are expected to reach 467-555 ppm by Year 2050 that would cause surface ocean pH to decline, on average, to 7.8 in Year 2050 (Cooley *et al.*, 2009).Over the past two decades, there have been measurable decreases in the weight of calcium carbonate ($CaCO_3$) shells of pteropods (marine snail) (Roberts *et al.*, 2008) and foraminifera (unicellular protists) (Moy *et al.*, 2009) in the Southern Ocean, and corals of the Great Barrier Reef, suggesting a recent decline in calcification, a process in which body tissue is harden by calcium salts or deposits (Cooper *et al.*, 2008). Hossain *et al.* (2013) analyzed the trends of water pH of the Bay of Bengal for the thirty years (1970-1999) (Figure 4.4) and reportedmaximum pH 8.52 during 1971 and Minimum 7.0 during 1979 with an average 8.15. Trend analysis showed that, pH is decreasing over the period with an increased trends at higher latitude.

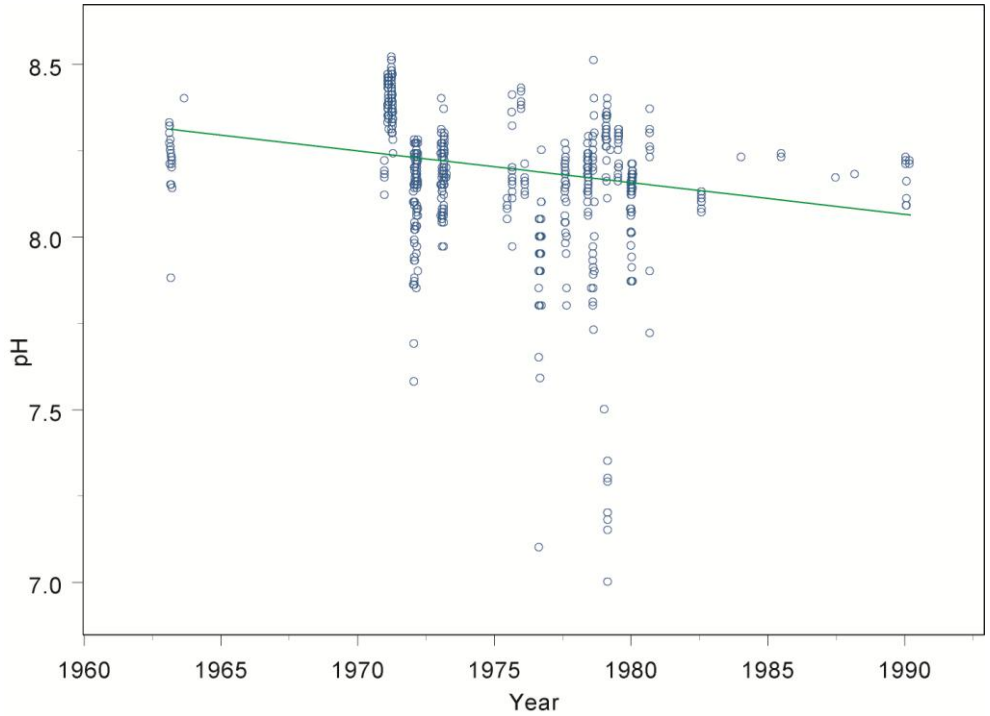

Figure 4.4. Showing the long-term water pH variation in the Bay of Bengal, presented with longitude and yearly trends (source: Hossain et al. 2013)

Problem-tree analysis for ocean acidification indicates relationships of fossil fuel combustion, water pH, ocean ecosystem and people livelihood (Figure 4.5).

Funding is necessary to build networks of ocean acidificationmonitoring stationsaround the state territorial water in the Bay of Bengal to generate real-time monitoring of changing conditions throughout the most sensitive coastal areas (i.e. Saint Martin's Island coral reefs, Cox's Bazar beach, Chittagong port, Meghna deltaic gateway, Sunderbans mangrove forest, and Swatch of No Ground fishing zone).Establish research collaboration with developed country academic institutions to undertake need-based action research.

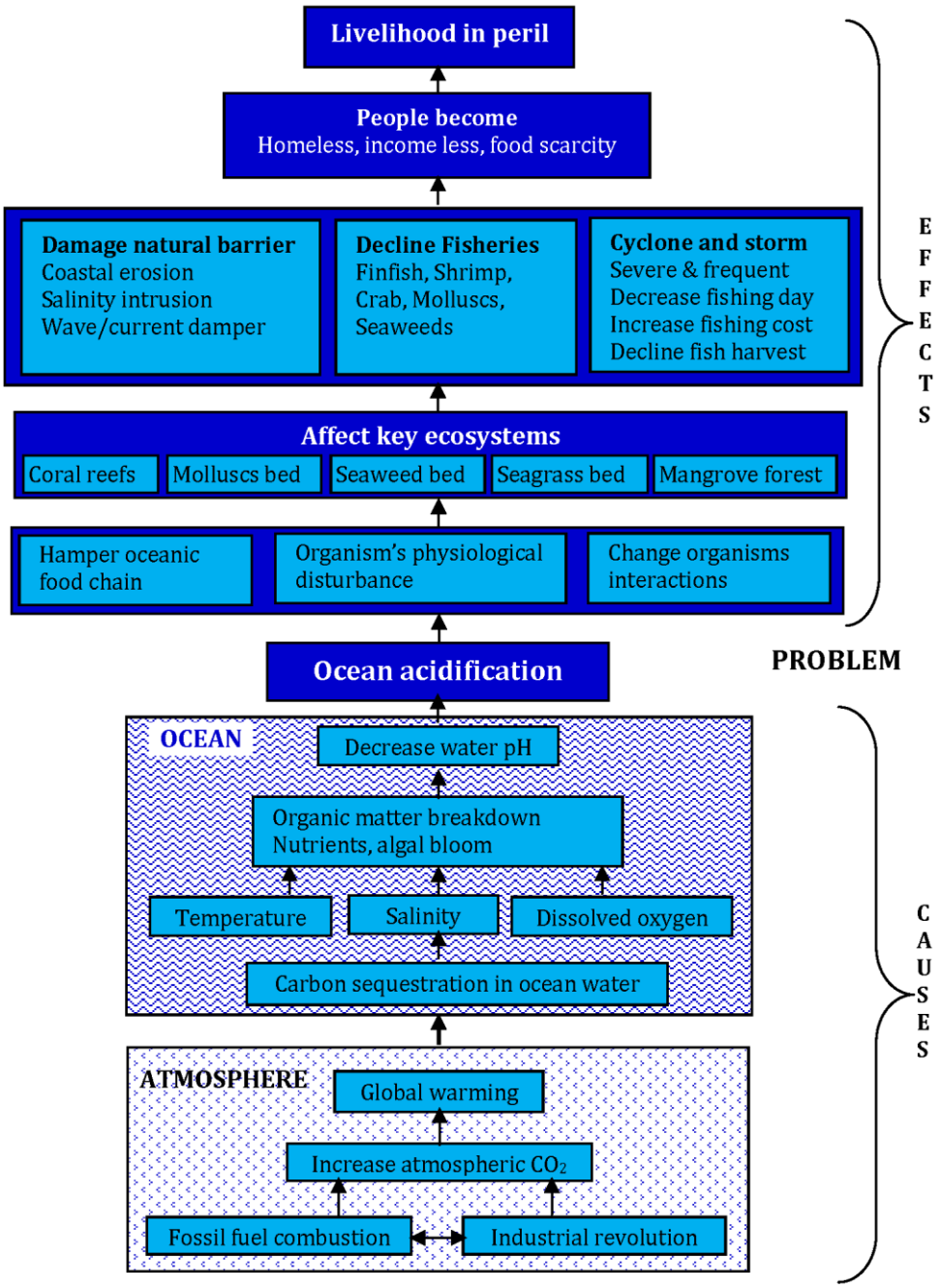

Figure 4.5. Problem tree analysis shows the causes and effects for ocean acidification in the Bay of Bengal (source: Hossain et al. 2013)

4.5.2 Intensification of cyclones and depressions

Bangladesh is one of the most disaster prone countries of the world and here climatic events are considered an integral part of the social fabric. The heat statusof the Ocean in the form of Sea Surface

Temperature (SST) is one of the most important variables used in climate change monitoring programs and is often related to other variables such as sea level change and hurricane intensity (Vinogradova 2009). The Bay of Bengal is a potentially energetic region for the development of cyclonic storms; about 7% of the global cyclonic storms are formed in this region (Gray 1968). Chowdhury (2012) reported that night SST has increased by 0.30-0.48°C during 1985-2009 at rates between 0.0126° and 0.0203° per year. Results indicate that at the low and mid-latitude zones early summer temperature is dropping while the late summer temperature is rising more quickly. In other months and at other latitude zones SST is consistently rising at a rate of about 0.02°C per year. The cyclone seasons in the Bay of Bengal are likely to widen further as the cooler months too become warmer. Moreover, as the usually cooler high latitude zones get warmer, cyclones will get larger replenishment area for gaining heat energy, thus increasing the risk of cyclones at the coast. An increasing number of cyclones and probable linkage of increased SST with livelihood of coastal fisher's communities is shown schematically in Figure 4.6.

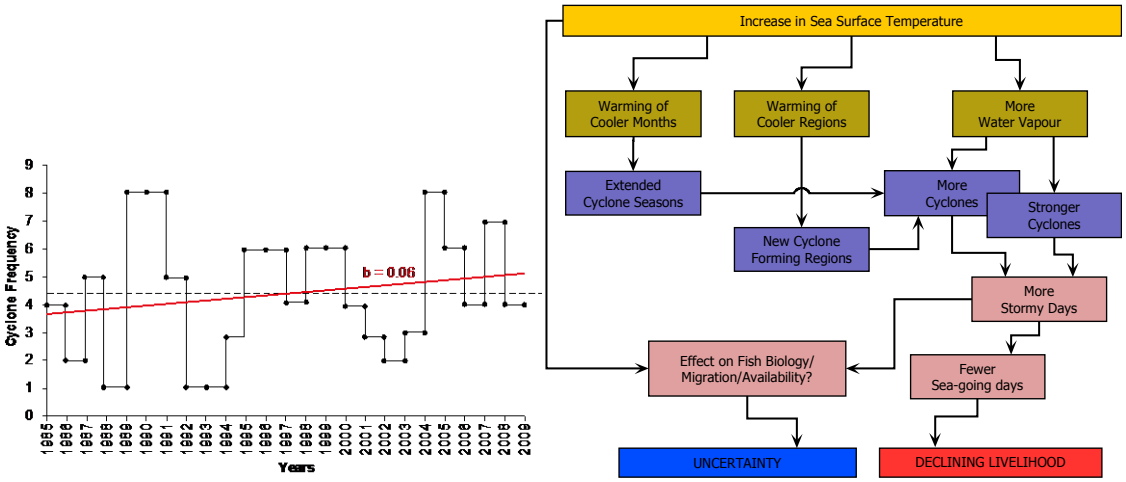

Figure 4.6.Iincreasing trend of tropical cyclones (left);and probable linkage of increased SST with livelihood of coastal fisher's communities(right) in Bangladesh (Chowdhury et al. 2012)

4.5.3 Sea-level rise and coastal flooding

Since mid 1980s and early 1990s Bangladesh has been widely talked about for its vulnerability to future Sea-Level Rise (SLR) due to global warming (Broadus *et al.* 1986; Milliman *et al.* 1989; Titus 1990; Broadus 1993; Milliman and Huq 1996). Confirmations of the Relative SLR (RSLR) in Bangladesh started coming soon thereafter (Mahmood *et al.* 1992; Kabir 1992). Indication of its intensification (more than 5mm per year increase) in recent years has also been found (Rana 2013).

The reference to RSLR is made since the level of the sea relative to the land is not only due to the movement of the sea (global sea level rise), but also local physico-chemical processes (giving rise to seasonal changes) and tectonic processes such as subsidence and compaction/ consolidation of the Ganges-Bramaputra-Meghna River deltas in the BoB.

Despite the process being slow and gradual, the consequences of RSLR for Bangladesh are reckoned to be grave, especially given the low-lying nature of the country as a whole. Not only the coastal ecosystems are likely experience drastic and irreparable damages, inundation of coastal low lying lands will lead to loss of mangrove forests, loss of agricultural land, damage to properties, and displacement of coastal populations and mass exodus, to name just a few. Chowdhury (2014b) has shown how coastal towns and cities and their periurban service areas will be affected at various levels of inundations (Figure 4.7), including complete loss of the country's current salt production and flooding of most of the coastal aquaculture areas.

Figure 4.7. Extent of coastal flooding due to anticipated Sea-level Rise of 1m (left), 2m (middle) and 3m (right) (Source: Chowdhury 2014b)

4.6 Sustainability issues

The concept of sustainability came into prominence with the publication of the World Commission on Environment and Development (WCED) report called Our Common Future (WCED 1987). The message was "it is possible to achieve a path of economic development for the global economy which meets the needs of the present generation without compromising the chances of future generations to meet their own needs".A central precept of Sustainability, to quote Pearce et al. (1989), is that sustainable development leaves 'future generations a wealth inheritance - a stock of knowledge and understanding, a stock of technology, a stock of man-made capital, and a stock of environmental assets - no less than that inherited by the current generation'. Young (1992) recognizes a number of themes underlying the sustainability concept, summarized by his 'three Es' such as environmental integrity, economic efficiency, and equity between present and future generations.

Sustainability becomes a 'way of thinking', helping to modify the context to which it is applied. Thus, sustainability principles can 'highlight unsustainable systems and resource management practices (Turner 1991). The tests of sustainability having been applied and unsustainable practices revealed, the way opens for new, sustainable management approaches to coastal area management to be devised and adopted (Figure 5.2). The mixture of equity, environmental and economic concepts recognizes the quality of human life of both present and future generations.

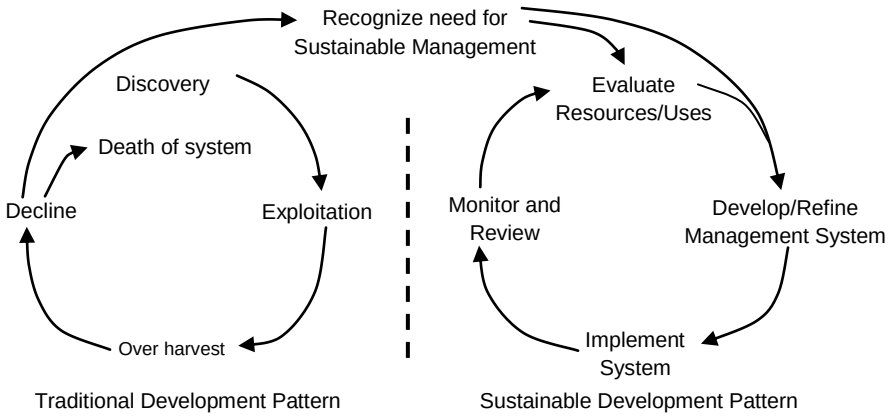

Figure 4.8. Sustainable and unsustainable approaches to coastal resource use (Dutton and Hotta 1994).

Chapter 5
ESSENTIAL TOOLS IN COASTAL AND OCEAN MANAGEMENT

5.1 Marine Spatial Planning (MSP)

Marine Spatial Planning, often known as Coastal and Marine Spatial Planning (CMSP), is a science-based tool for addressing specific ocean management challenges and advancing the goals of economic development and conservation. It is a process designed for planners and policy makers allowing them to make better and more informed decisions about the use and management of the seas. A recent publication issued by the Intergovernmental Oceanographic Commission of UNESCO (Nov. 2014) discusses this subject in detail.

5.1.1 What MSP is

IOC/UNESCO defined MSP as "... a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that usually have been specified through a political process (IOC, 2014)".

MSP provides decision makers with information about the geography, environment, natural phenomena, current and future uses, etc. for better planning of existing and future utilization of resources and space. The current practice of fragmented 'sector-by-sector' or 'use-by-use' planning governed by discrete laws and regulations, and implemented by disconnected agencies and bodies results in multiple uses often leading to competition or conflict with each other. MSP brings all these spaces, resources, agencies, uses, and times together in one analytical framework to resolve and/or reduce conflicts. In essence, if used correctly, MSP/CMSP will help us manage our oceans facing growing demands as smoothly as achievable. In other words, MSP helps us finding a balance between nature conservation objectives and resource use goals in a more sustainable way (BALANCE, 2008).

5.1.2 What MSP is not

Many people tend to perceive MSP as a map of the ocean; however, it is imperative for the policy makers to understand that it is in fact an analytical process involving spatial (*i.e.*,geographic) information often resulting in maps created as and when required for visualizing objects or processes in space and time.Another common misperception of MSP is that it deals only with spatial objects (in geographic space), in reality MSP quite often deals with elements in the temporal space (*e.g.*, seasons, years, decades) and agent space (*e.g.*, human users, natural forces, biological agents, etc.) as well, and their interactions with each other. This is why MSP is so effective in guiding planners as to which course to take for reaching a particular quantifiable target.

MSP is sometimes thought of being synonymous to Marine Zoning (MZ), which is the oceanic counterpart of land-use zoning or urban zoning. In practical terms, zoning is just one of many activities of MSP.

5.1.3 How would we do MSP?

Besides a set of people capable of designing and running the MSP framework and analyses, we would require current information on various oceanic phenomena, marine resources, their uses and users, managers and agencies, their interactions and responses to different patterns of uses, seasonality, etc. We would certainly require approximate projections of future uses of these resources, potential users, anticipated change in any management practices, etc. We may also require some past information; for example, which resources went extinct, and under what circumstances, etc. in order

to understand and model those mechanisms and pathways. For designing and running an effective MSP for the BoB, a range of data variables and information would be necessary (Table 5.1), which may be collected by different government agencies, NGOs, universities, research centres and also spread across scientific literature. Much of this information may be already known, some may have to be generated, whereas some may never be economically or technically feasible to investigate. Lack of some information will introduce some levels of uncertainties in MSP outputs, but use of available information would certainly make the planning process better than doing it without any scientific analysis.

Table 5.1. Example of a list of data variables useful for designing and running an MSP

Sector	Probable sources of information	Data variables
Shipping	Department of shipping and Port Authorities	Shipping routes, shipping density, port locations, port limits, anchorages, channel depth, wreckage, navigability
Trade	Ministry of Commerce, EPB, NBR, Investment Board	Cargo volume, cargo density, container volume
Fisheries and aquaculture	Department of Fisheries, Fisheries research Institute	Fish habitats, fish migration routes, life cycle of estuarine fishes and shrimps, mother shrimp collection sites, aquaculture farming areas, mariculture sites, fishing areas, vessels density, effort density, catch density, catch composition, fishing gears and methods, protected areas, moratoriums, breeding seasons (dates),
Energy and Mining	Department of Energy, PetroBangla, research articles	Leasing blocks, gas fields, oil & gas wells, offshore platforms, liquification plants, pipelines, salt farming areas, potential tidal power plant locations, potential offshore wind farm locations
Communication		Submarine cables, landing stations and distribution
Environment and conservation	Department of Environment	Marine Protected Areas, sanctuaries, Ecologically Critical Areas, pollutants entry points/pathways and dispersal pattern, waste disposal, shipbreaking, blue-carbon sequestration
Forest	Department of Forest	Mangrove forests, afforestation sites
Geomorphology	Water Resources	Erosion and accretion areas, river discharge, sediment input, sediment transport, sediment texture, potential land reclamation sites, coastal defense
Oceanography	NORI, Universities, research literature	Oceanic current, tidal regimes, wave characteristics, upwelling and eddies, biological productivity, salinity, sea surface temperature, research sites and transects, sites of moored platforms, bottom mounted instruments, rover and robotic instruments
Hydrography	Navy, BIWTA	Bathymetry, wreckage
Meteorology	DoMeteorology, SPARRSO, Universities, research literature	Tropical cyclones and depressions, monsoon onset and development, weather variables, wind speed and direction, moisture and cloud cover, sunshine, radar coverage, drone flying zones
Climatology and Climate Change	Universities, research literature	Rates of Sea-level change, ocean acidification,
Hazards and disasters	MoDM, SPARRSO, DoM, research literature	Historical cyclone trajectories, landfall locations, storm surge height, coastal elevation and inundation models, tsunami prone areas, cliff erosion
Tourism	DoT	Marine cruise routes, coastal tourism zones, marine sports and recreation sites,
Military	Navy and Coast Guard	Bases, exercise zones, petrol

Here we present, as example, an *ad-hoc* scenario (Figure 5.1) of the different uses of BoB within Bangladesh's EEZ indicating competing and understandably conflicting uses of space in the sea, a scenario like which may acts as an entry point for initiating MSP for BoB.

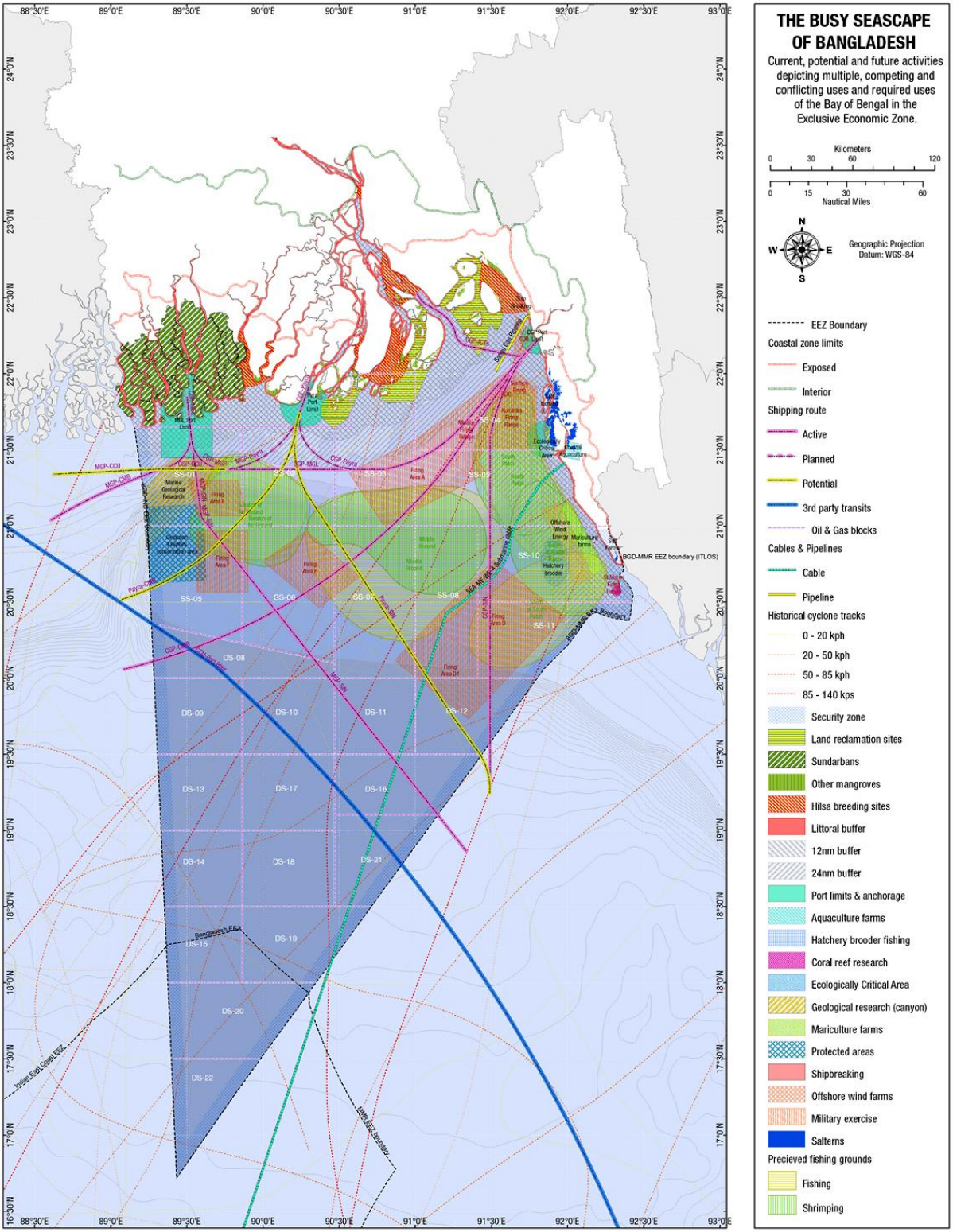

Figure 5.1. The Busy Seascape of Bangladesh: a precursor for developing the MSP framework

[This figure MUST not be reused/reproduced in documents other than those related to the 7th 5-year plan of Bangladesh without the explicit consent of the authors]

5.2 Ecosystem Approach to Fisheries Management (EAFM)

FAO Code of Conduct, 1995 laid out broad principles and approaches for effective and responsible fisheries management, which embody the concept of EAF (FAO 2003). At the core of EAF concept is that fishes of a single species (*e.g.*, hilsa, or tiger shrimp) is not an isolated animal resource, rather is an integral part of the ecosystem that it lives in, and it interacts in many ways with

the ecosystem itself and all other living and non-living elements of the ecosystem in very delicate and intricate ways. The concept of sustainable development for attaining social goals, enhanced scientific understanding of ecosystem structures and function, and poor performance of conventional single-species fisheries management - all motivated this paradigm shift. Table 5.2 shows the FAO suggested elements for EAFM.

Table 5.2. Suggested Elements for an Ecosystem Approach to Fisheries Management

TITLE
BACKGROUND
Social and institutional aspects
Area of operation of the fishery, jurisdiction and ecosystem "boundaries"
History of fishing and management
Social and economic benefits, both now and in the future
Description of stakeholders and their interests
Description of other uses/users of the ecosystem, especially activities that could have major impacts and arrangements for coordination and consultation processes
Consultation process leading to the plan
Ongoing consultative arrangements
Details of decision-making process, including recognized participants
Descriptions of fishing activity, resources and the ecosystem
Description of resource (target species and by-product)
Description of the aquatic ecosystem in which the fishery occurs
Description of fleet types or fishing categories
Ecological issues and challenges
Details of critical environments, particularly sensitive areas
Details of bycatch concerns including threatened/protected species
Details of other environmental concerns, including biodiversity and trophic changes
OBJECTIVES
Objectives, reference points and performance measures for the fishery • Resource • Environment (including bycatch, habitats, prey protection, biodiversity, etc.) • Social • Economic
MANAGEMENT MEASURES
Agreed measures for the regulation of fishing to meet all objectives within agreed time frame, including by-catch, habitat protection, prey protection, etc.
DECISION RULES
Pre-agreed rules for applying management measures
ACCESS RIGHTS
Nature of rights granted in the fishery and details of those holding the rights

Source: FAO 2003

5.3 Conservation (Marine Protected) Areas

Life originated in the oceans, and thrived well there for millions of years. It is naturally the home of hundreds of thousands of animals and plants. From the dawn of the history until very recently oceans were perceived to be bountiful and endless in its resources, and to be enjoying an indemnity from any damage by human - be it exploitation or dumping of wastes. Scientific findings have proved these perceptions wrong, but the human attitude in most part has not changed (Agardy 1997). Oceanic biodiversity, including fishes and other ones on which the very existence of billions of people depends, are threatened by various human activities including overfishing, pollution, modifications & destruction of habitats, industrial and shipping operations, etc.

The concept of Marine Protected Areas (MPA) as a means of protection of ecosystems and conservation of biological diversity from all kinds of degradations and loss came through The World Congress on National Parks (1962). The concept has been expanded to cover marine ecosystems and marine biodiversity was advanced in another congress on parks in 1982 (IUCN 1987). In subsequent years the international community has further advanced the idea to a point of reaching binding agreements. By agreeing to International agreements Bangladesh also has to allocate about 10% of its maritime area for such protection and conservation of marine habitat and ecosystem.

Declaring and managing MPAs remains not only an international legal obligation, it is also very much needed for giving the degrading and declining fish stocks and other species an opportunity to recover. MPAs include but are not necessarily "complete prohibition" or "no-go/no-take" areas, experts have developed several kinds of MPA implementations (Gubbay 1995), such as:

a) Strict protection (*i.e.* Strict Nature Reserve/Wilderness Area)
b) Ecosystem conservation and recreation (i.e. National Park)
c) Conservation of natural features (i.e. Natural Monument)
d) Conservation through active management (i.e. Habitat/Species Management Area)
e) Landscape/seascape conservation and recreation (i.e. Protected Landscape/Seascape)
f) Sustainable use of natural ecosystems (i.e. Managed Resource Protected Area).

Although Bangladesh has proposed certain MPAs, it still lacks a strategy or mechanism for identifying and prioritizing MPAs for future establishment.

It becomes now clear that MPAs in fact become part of ecosystem and resource management strategy, at the same time providing the protection ecosystems and its inhabitants very much need to thrive and strive. MPAs Also have social and economic roles, they are selected based on, among other things, the following criteria:

Table 5.3 Summary of Social and Economic Criteria Used to Select Marine Protected Area and Reserve Locations (Source: Houde et al. 2001).

Value Type	Criteria
Economic	Number of fishers dependent on the area
	Value for tourism
	Potential contribution of protection to enhance or maintain economic value
Social	Ease of access
	Maintenance of traditional fishing methods
	Presence of cultural artifacts or wrecks
	Heritage value
	Recreational value
	Educational value
	Aesthetic appeal
Scientific	Amount of previous scientific work
	Regularity of survey or monitoring work
	Presence of current research projects
	Educational value
Feasibility or Practicality	Social and political acceptability
	Accessibility for education and tourism
	Compatibility with existing uses
	Ease of management
	Enforceability

5.4 Habitat and Range Modeling

Habitat and range modeling is an extremely important set of analytical processes and tools to determine the habitats and migration ranges of valuable and critically important fishes and other marine species. This process involves determining habitats of these species in different stages of their life cycle (from egg to adult and mother). For example, hilsa is of critical importance for our fisheries economy, as well as cultural heritage and community livelihood. It is a migratory fish, which migrates to inland rivers, estuaries and fresher & turbid waters for laying eggs, and return to the sea. Juveniles also return to the sea after a certain size/age is reached. Knowing the habitats and migration path of this fish is extremely important for the management and conservation of its stock and catch. Figure 5.2 shows, as example, a recent confirmation of breeding grounds of hilsa in Bangladesh fisheries waters using sophisticated geospatial and oceanographic modeling processes. The model can be and should be further extended to discover its migration routes, and interannual and decadal varibility of abundance in particular areas of the sea.

Similar applications of these tools should be applied to all other valuable and ecologically important species (e.g. shrimps, tuna, dolphins, turtles, etc.) in order to establish single-species

conservation-management objectives and carry these forward toward a more comprehensive ecosystem approach, the EAFM. Furthermore, results of such modeling will serve as valuable input parameters to the MSP/CMSP process.

Figure 5.2. Breeding areas of hilsa in the coastal waters and inland channels (Source: Hossain et al. 2014)

5.5 Building with Nature

Building with Nature, also often referred to as Living Shoreline Approach (LSA) is a novel Ecosystem Engineering approach of protecting coastal areas and communities from erosion, and enhancing the natural defense of the coast using living organisms, at the same time providing various ecosystem services and products to people. One method of LSA is known for decades, i.e. 'green-belt' or coastal mangroves, however, newer methods are emerging, for example, protecting the coast and enhancing accretion by building oyster reef. An oyster reef protects shorelines quite in a different way than the mangrove does. It helps dampen the wave and current which are the most prominent causes of erosion in coastal areas. Living oyster reefs grow with time and self-repair any damage, therefore they require almost no maintenance. Furthermore, oyster reefs provide shelter for many marine organisms like a coral reef does, delivering similar biodiversity and protection benefits, in addition, providing food (e.g. crab, fish, oyster, mussels, etc.) to local communities.

The LSA possibilities are not just limited to mangrove or oyster reefs, other viable living organisms and a variety of their combinations can be used to protect coasts, enhance accretion,

conserve biodiversity and provide livelihood for communities. Figure 5.3 shows an experimental oyster reef at Kutubdia Island and its effect on enhancing accretion.

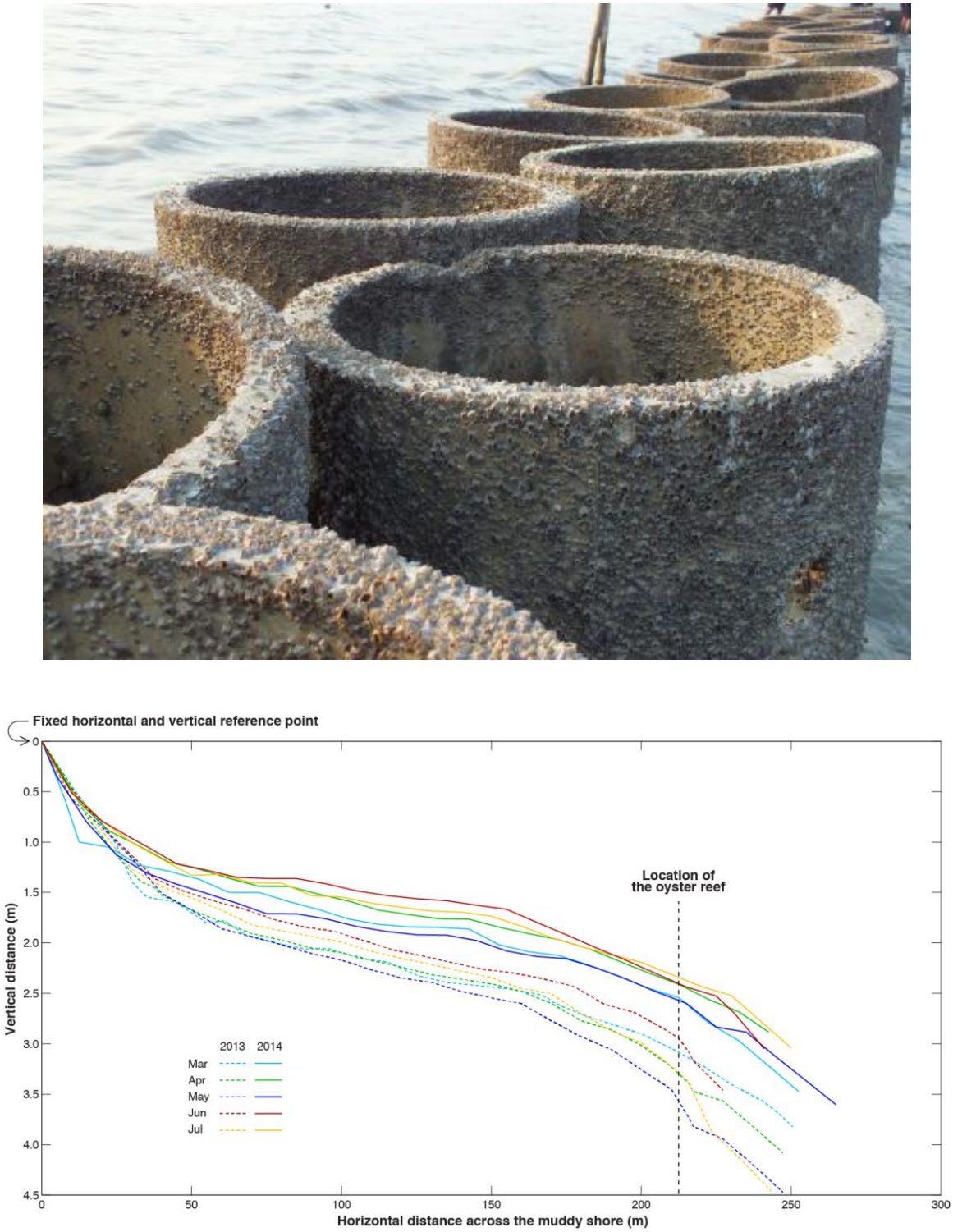

Figure 5.3. A living shoreline being built for oyster reef at Kutubdia Island (top), lifting of shore elevation in the first year of the experiment, 2013-2014 (bottom) (Source: Hossain 2014d)

Chapter 6
CONCLUSION AND RECOMENDATIONS

After having reviewed substantial literature, background documents and position papers, the so-called 'blue economic development' or the economic development utilizing ocean resources and potentials appears promising for Bangladesh. Nonetheless, sustaining any economic growth or progress is seriously contingent on maintaining good health of the ocean, its ecosystem and biodiversity, and on the success of acting on precautionary and sustainability principles. On the other hand, considering the global ratio of economic contributions of maritime services and manufacturing sectors (US$1,130 billion) to that from capital resource exploitation (US$432 billion) (Our Ocean Wealth, 2012), Bangladesh should not expect to achieve a dramatically different outcome, particularly when the oil and gas reserves in the BoB seem less promising (Blackeley 2010) and conventional fisheries are already showing signs of decline and degradation (Haroon 2014). There is certainly some reserves of gas in the Bengal Basin, but there are several indications that it does not carry tremendous potential, and the potential for oil is even bleaker. Therefore, Bangladesh should focus broadly on (i) protecting and managing the fisheries for the present and the future generations, (ii) developing a strong renewable energy sector using ocean and atmospheric forces, (iii), maintaining existing (*e.g.*, ship building) and developing new maritime industries; (iv) extending fishing areas using new technologies and methods even beyond EEZ in the international waters, (v) developing a strong human resource base for domestic utilization, and export to foreign job markets, (vi) substantially increasing fisheries production and export earnings through improved aquaculture and introduction of mariculture, (vii) creating a competitive tourism industry, including ecotourism and marine cruises, (viii) further increasing revenue from shipping and commerce by the expansion of domestic fleet and destinations, transhipment and transit provisions, linking neighboring states to the sea-ports, etc. (ix) give special priority to anticipated Climate Change impacts on all relevant matters, and adjust policies and plans, (x) maintain the inland river systems and ecosystems for fishery, sediment transport, and inland shipping; and (xi) building a solid science, research and education base. Above all, for maintaining seamless and coordinated planning and actions (xii) an integrated Coastal and Ocean Management Policy should be put in place.

In view of the above mentioned priority areas, we discuss some relevant actions/programs that Bangladesh can undertake to create and maintain a prosperous and sustainable ocean economic base.

6.1 Sustainable fisheries production and management

(A) Highest priority should be given to sustainable fisheries resource management considering the importance of this resource for sustaining livelihood of millions of poor people, as a source of protein and export earnings, and its potential to replenish itself (sustainability) if properly taken care of. To this end, stock and maximum sustainable yield/total allowable catch (quota) must be determined by thorough assessments on a regular basis. Therefore, capacity building and proper actions in the marine fisheries sector should be brought to immediate focus.

(B) Conservation of fish biodiversity and healthy stock will remain keys to the success in this sector in the long run. Suitable areas in the EEZ and coastal waters should be declared as Marine Protected Areas (MPA) of appropriate kind to facilitate conservation and protection of fish diversity, and also protection of breeding, nursing, growth, migration, habitats, etc.

(C) Land based pollution consisting primarily of solid wastes (e.g. plastics, polythene, toxic substances) and untreated industrial effluents must be banned from entering into the sea, and be enforced with rigor and determination, if the habitats and the lives of fishes are to be protected. Shore-based and ship-borne pollution should also receive due importance.

(D) No industrial practices should be allowed on the continental shelf and onshore areas which may cause destruction and degradation of fish habitats, and decline of fish stocks. Such activity may include irresponsible and destructive means of oil and gas explorations/exploitation. All hydrocarbon exploration on the shelf and coastal waters should be carried out using internationally accepted practices. Any subsequent drilling and rig operations must be regulated so as not to cause any harm to the ecosystems and the living resources, and operators should be firmly held responsible for taking appropriate mitigation measures. Compensation after damage should also be in place for the inevitable, but not to be considered an alternative to mitigation. Oil and gas as well as other mineral resource exploration and exploitation should include active involvement by operators and owners in marine policy, legal and regulatory debates, and should be active partners in effective monitoring and preservation of living marine resources.

6.2 Renewable ocean energy

Grid connected renewable energy from tide and onshore & offshore wind is a promising possibility. The true potential should be assessed and technical feasibility be studied as soon as possible, and projects should be undertaken to supply considerable 'green' electricity from these sources. Such initiatives will not only ensure energy security, but also bring useful credits (such as carbon credit), and perhaps funding as well, from international/intergovernmental green development initiatives.

6.3 Maintaining existing and creating new maritime industrial fronts

(A) Ship building has already been proven as a highly effective industry for the economy of Bangladesh. It should be promoted and nurtured in all possible ways, including its horizontally and vertically linked businesses, and given opportunities and incentives for growth and expansion. Other similar manufacturing and engineering fronts should also be seriously explored.

(B) Marine biotechnology and industries based on biotechnology research are now overdue. Universities and research institutions should be encouraged and given funding & logistics for opening up this promising field for future industrial growth.

6.4 Extending marine fishing horizon

Bangladesh's marine fishing is effectively limited to the continental shelf only, i.e. up to a depth limit of 200m, and most fishing boats and vessels operate even closer to the shore - within 40-50m depth. This limitation in fishing area is primarily due to smaller tonnage of the vessels, but also due to fishing gear preference of the operators. The implications of this limited fishing zone are threefold, firstly, fishing effort is intense on a smaller space and volume of water putting excess pressure on the stock therein; secondly, some open ocean high value fishes (for example, species of pelagic tuna/Scombridae, mackerel, Indian salmon/Polynemidae, etc.) only rarely appear in Bangladeshi fish catch despite their availability in deeper areas; and finally, the large area within the EEZ and beyond has tremendous untapped potential. It is, therefore, imperative for Bangladesh to create the necessary environment to encourage fishing operators to venture into deeper and open ocean areas with high-tonnage vessels, using alternate gear, such as tuna long-lines and hooks, and expanding the fishing horizon not only on the geographic front, but also on economic and nutritional fronts.

6.5 Development of maritime human resource

A large eligible population places Bangladesh in a suitable position to produce skilled human resources in almost any sector imaginable. A thrust in blue economic growth may come from a large army of skilled coastal and offshore engineers, navigators, merchant mariners, fisheries technologists, biotechnologists, etc. and in a variety of other professions (Table 2.1 in chapter 2). Targets to produce skilled human resource for domestic and international job markets, and its export should be given special attention in strategic planning.

6.6 Enhancing fisheries production by improved cultivation

(A) National Shrimp Policy 2014 recognizes that the country's export earnings can be gradually increased and also poverty can be reduced by increasing shrimp production. Currently traditional shrimp aquaculture farms in Bangladesh produce only 60-230 kg per hectare, whereas in southeast Asia production per hectare is as high as 6,000 kg. Rapid production intensification of up to thousands of kilograms might not be the right way due to risks associated with super-intensification (e.g. diseases outbreaks and other environmental negative consequences); nevertheless with the help of improved cultivation methods current production may safely be doubled or tripled (i.e. 200-600 kg/ha) resulting in enormous economic benefits and optimal use of land-water resources, at the same time maintaining environmental integrity.

(B) Some species of fishes, for example, sea bass (*Koral*), can be cultivated within temporary enclosures (e.g. cage) in open sea. Introduction of such mariculture or marine farming techniques can add additional income generation for people and the country. Moreover, new fish and shellfish species should be brought into the process of domestication in order to diversify coastal aquaculture practices for improved productivity. As an example, China produces nearly half of its fish and aquatic foods from aquaculture and mariculture.

6.7 Redesigning tourism industry

The tourism industry, despite its huge potential and recent developments, still remains locked in a 'go-see-dine-sleep' model of the past years. In spite of growing appetites, 'action tourism' (e.g. tracking, climbing, surfing, diving, boating, sport fishing, etc.) is virtually non-existent. Coastal and marine tourism has great potentials for expansion not only in terms of activities, but also of destinations, modes of travel and accommodations, amenities, target demographics, and overall philosophy. This sector should undergo an overhaul - in planning and operation, to include, for example, luxury marine cruises to distant destinations. The tourism sector also should be a major face in the development of marine policy, laws and regulation.

6.8 Expanding shipping and commerce

The shipping industry in general, and the ports in particular, are already contributing a large proportion to the country's economy and growth. However, the true potential is far from being tapped yet. Bangladesh's flag bearing cargo fleet carries only a small portion of import and export commodities. Expansion of the fleet in terms of its size and capacity, and of destinations will substantially lift the economic face of the country in a short time. Serious planning and actions are required to increase maritime shipping and trade activities and earnings. Inland water transport should also be brought to focus, and issues about inland ports/terminals and river navigability should be addressed in a systematic manner.

6.9 Climate Change mitigation and adaptation planning

(A) Climate Change and associated phenomena including Sea-level rise, weather and climatic shift, changing rainfall patterns, intensification of tropical cyclones, ocean acidification, etc. in Bangladesh are now generally visible and established through scientific investigations. All new policies and strategic action plans should therefore made to include and existing policies and plans updated to include where necessary mitigation and adaptation to climate change.

(B) Coastal erosion is an age-old issue for the deltaic coast which is likely to worsen with rising sea-level and increasing storm activities. Land reclamation from sea by engineering interventions of

naturally transported sediment is a prospect for the central coastal area, and should be considered in the delta plan. Protection of coastal zones and islands by mangrove afforestation should continue and be backed up by 'build with nature' (living shoreline, oyster reef, etc.) approaches.

6.10 Maintaining river system and ecosystem health

River systems and inland water resources should be maintained and managed in a way to support fish populations, navigability and sediment transport to the coastal areas. Freshwater fishes should be given natural corridors by maintaining links among water bodies and/or periodic controlled flooding of suitable areas, which would also be beneficial for soil fertility. Dams and barrages are extremely damaging to river ecosystems, sediment movement and navigation, and also detrimental to downstream coastal ecosystems and remains a dominant cause of coastal erosion. Blocking of stream flow of any kind should not dominate the irrigation agenda. Ecosystem management should be a goal of both integrated water resources management and marine and coastal zone management.

6.11 Science and research

No policy or strategy can succeed without an intricate knowledge of the system under consideration, and all management decisions should be based on the underlying science and the scientific understanding of the processes involved. Therefore, study of the science of the oceans and the coastal zone and associated research should be given high priority. Universities involved in the study of marine sciences, marine fisheries, coastal zone management, oceanography, etc. should be given research funding and facilities; science based knowledge acquired at these institutions should be incorporated in policy and planning processes. The National Oceanographic Research Institute (NORI) should be made operational as soon as possible, and joint research projects with universities should be launched based on our national marine science priorities. A national marine science data infrastructure should be developed.

6.12 Integrated policy and strategy, interagency coordination and marine spatial planning

(A) An integrated coastal and ocean management policy and framework should be developed and run by a special task force at the highest level of the government (e.g. under the Prime Minister's Office) to ensure proper coordination and integration among different ministries and line agencies. Considering the highly multidimensional nature of coastal and ocean affairs, no specialized ministry/agency should be designated as the lead agency for coastal and ocean management. More details may be seen in chapter 3.

(B) The current practice of fragmented 'sector-by-sector' or 'use-by-use' planning, managed by discrete laws and regulations, and implemented by disconnected agencies and bodies, is causing competition or conflict among multiple users of the ocean. Marine Spatial Planning (MSP) is required for addressing specific ocean management challenges and advancing the goals of economic development and conservation. Considering the busy seascape of Bangladesh, the development of an MSP framework is highly relevant for balancing ecological, economic, and social goals toward sustainable development. The MSP should be integrated and multi-objective, strategic and future oriented, and continuous and adaptive. More details may be seen in chapter 5.

6.13 Improved Ocean Governance

(A) Multisectoral cooperation and coordination in marine affairs

(B) Broad stakeholder inclusion, including private sector and public-private partnerships

(C) Establishing a rigorous marine-oriented monitoring and assessment facility, to gauge national activities and implementation, and to assess their effectiveness at meeting goals. Communicate such results widely, in a timely fashion.

Chapter 7
REFERENCES

Agardy TS (1997). *Marine Protected Areas and Ocean Conservation*. Academic Press, California, USA. 244pp.

Ahmed N, Troell M, Allison EH, Muir JF (2010). Prawn postlarvae fishing in coastal Bangladesh: Challenges for sustainable livelihoods. *Marine Policy* 34:218-227.

Akter J (2010). *Environmental Flow Assessment of Ganges River*, M.Sc Thesis, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000.

Alam MK (2004). Bangladesh's maritime challenges in the 21st century. Dhaka: Pathak Shamabesh Book.

Alam MM, Curry JR, Chowdhury MLR and Gani MR (2003). An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin fill history, *Sedimentary Geology* V 155:179-208.

Allen PA and Allen JR (2005). *Basin analysis: Principles and Applications.* Wiley-Blackwell, 560pp.

Anon (2013). Sustainable Oceans: Reconciling Economic Use and Protection. EU-US Conference Series. 130pp.

BADC (1992). *Final Report of the Deep Tubewell II Project*, vol. 2.1.Natural Resources. Preparedby Mott McDonald International in association with Hunting Technical Services for the Bangladesh Agricultural Development Corporation.

Bass S, Dalal-Clayton DB and Pretty J (1995). Participation in strategies for sustained development, Environmental Planning Issues No 7, International institute of Environment and Development, London.

BALANCE (2008). Towards Marine Spatial Planning in the Baltic Sea, BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) Technical Summary Report 4/4, Copenhagen, Denmark. 133pp.

BWDB (Bangladesh Water Development Board), 2012. Bangladesher Nod Nodi (Rivers of Bangladesh). Bangladesh Water Development Board, Vol. 1-6, Dhaka, Bangladesh.

BBS (2007). *Statistical Year Book of Bangladesh*, Bangladesh Bureau of Statistic, Ministry of Planning, Dhaka, Bangladesh

Belton B, Karim M, Thilsted S, Murshed-E-Jahan K, Collis W and Phillips M (2011). Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center. November 2011.

Benshila R, Durand F, Masson S, Bourdallé-Badie R, Montégut CB, Papa P and Madec G (2014). The upper Bay of Bengal salinity structure in a high-resolution model, *Ocean Modelling* 74:36-52. DOI: 10.1016/j.ocemod.2013.12.001

Blakeley I (2010). Frontier Exploration: Bay of Bengal - Many Possibilities and Challenges Ahead. *GeoExpro* 7(1):30-34.

BOBLME (2012). *Management advisory for the Bay of Bengal Hilsa fishery*. Bay of Bengal Large Marine Ecosystem, 6pp.

Brammer H (2012). *The Physical Geography of Bangladesh*, The University Press Limited, Dhaka, Bangladesh.547pp.

Broadus JM (1993). Possible impacts of, and adjustments to, sea level rise: the cases of Bangladesh and Egypt. *Climate and sea level change: observations, projections, and implications*, *5*:263.

Broadus J, Milliman J D, Edwards SF, Aubrey DG and Gable F (1986). Rising sea level and damming of rivers: possible effects in Egypt and Bangladesh. *Effects of changes in stratospheric ozone and global climate*, *4*:165-189.

CEGIS (2003). Analytical Framework for The Planning of Integrated Water Resources Management, December 2003, Version 2.0, Center for Environmental and Geographic Information Services (CEGIS) for Government of The People's Republic of Bangladesh.

Charlier RH and Finkl CW (2009). *Ocean Energy: Tide and Tidal Power*, Springer, Berlin. 262pp.

Chowdhury MSN, Hossain MS, Mitra A and Barua P (2011). Environmental functions of the Teknaf Peninsula mangroves of Bangladesh to communicate the values of goods and services. *Mesopotamia Journal of Marine Science* 26(1):79-97.

Chowdhury SR (1993). *Study of the tidal behavior along the coast of Bangladesh with special emphasis on the seasonal variations*. MSc Thesis, Institute of Marine Sciences, University of Chittagong. Feb 1993.

Chowdhury SR (2014a). *Maritime Province of Bangladesh (map)*. University of Chittagong.

Chowdhury SR (2014b). Urbanization: Threat to Coastal Towns from Sea-level Rise. Keynote presented at seminar on Coastal Towns, Chittagong Press club. Nowzuan. July 5.

Chowdhury SR, Mahmood N, Sharif ASM, Uddin MM and Ullah MS (2002). Material flux through the Karnaphuli River, in Proceedings, Assessment of material fluxes to the coastal zone in South Asia and their impacts, *APN/SASCOM/LOICZ Workshop*, 08-11 December, Negombo, Sri Lanka. pp.27-30.

Chowdhury SR, Hossain MS, Shamsuddoha M and Khan MMH (2012). *Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh*. CPRD, Dhaka, Bangladesh. 54pp.

Chowdhury SR, Hossain MS and Sharifuzzaman SM (2014). *Cook the Ocean Bangladesh Style: An Illustrated Seafood Guide and Cookbook.*University of Chittagong-WageningenUR-Royal HaskoningDHV, 21pp.

Cronan DS and Tooms JS (1967). Geochemistry of manganese nodules from the N.W. Indian Ocean. *Deep Sea Research and Oceanographic Abstracts* 14(2):239-248. DOI: 10.1016/0011-7471(67)90009-5

Cronan DS and Tooms JS (1968). A microscopic and electron probe investigation of manganese nodules from the northwest Indian Ocean. *Deep Sea Research and Oceanographic Abstracts* 15(2):215-218. DOI: 10.1016/0011-7471(68)90042-9

Cronan DS and Tooms JS (1969). The geochemistry of manganese nodules and associated pelagic deposits from the Pacific and Indian Oceans. *Deep Sea Research and Oceanographic Abstracts* 16(4):335-359. DOI: 10.1016/0011-7471(69)90003-5

CSIRO (2014). An integrated water resources assessment: final report, report prepared by CSIRO, WARPO, BWDB, IWM, BIDS and CEGIS for the department of foreign affairs Australia aid-CSIRO research for develop alliance.

Curray JR (1991). Possible greenschist metamorphism at the base of a 22-km sedimentary section, Bay of Bengal. *Geology*, 19:1097-1100. DOI: 10.1130/0091-7613(1991)019<1097:pgmatb>2.3.co;2

Diaz RJ and Rosenberg R (2008). Spreading Dead Zones and Consequences for Marine Ecosystems, *Science* 321:926-929.

DoF (2014). *National Fish Week 2014 Compendium* (In Bengali). Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh, 144p.

Douglas-Westwood Limited, 2005. World marine markets. A report to WTSH by Douglas-Westwood Limited, report number 328-05, Canterbury, UK, 94 pp. www.dw-1.com

ECOBAS (2012). *Eco-engineered Coastal Defense and Food Production*. Institute of Marine Sciences and Fisheries,University of Chittagong. 11pp.

EPB (2012). Export statistics (2010–2011). Export Promotion Bureau, Dhaka, Bangladesh.

FAO (2003). *Fisheries Management: The Ecosystem approach of Fisheries*, Food and Agriculture Organization of the UN, FAO Technical Guideline for Responsible Fisheries 4. Rome, 112pp.

FAO (2012). *The State of World Fisheries and Aquaculture*, Food and Agricultural Organization of the UN, Rome. url: http://www.fao.org/docrep/016/i2727e/i2727e00.htm (as on Oct 01, 2014).

FAO. 2014. The state of world fisheries and aquaculture 2014. FAO, Rome. (In press).

FAP 16 (1995). Completion Report, Bangladesh Flood Action Plan 16, Flood Plan Coordination Organization, Ministry of Water Resources.

Flournoy AC (2011). Three Meta-Lessons Government and Industry Should Learn from the BP Deepwater Horizon Disaster and Why They Will Not, 38 B.C. *Environmental Affairs Law Review* 38(2):281-303.

FRPPB (2014). *Flood Response Preparedness Plan of Bangladesh*, June 2014, Department of Disaster Management, Ministry of Disaster Management And Relief.

Gauns M, Madhupratap M, Ramaiah N, Jyothibabu R, Fernandes V, Paul JT and Kumar SP (2005). Comparative accounts of biological productivity characteristics and estimates of carbon fluxes in the Arabian Sea and the Bay of Bengal, *Deep Sea Research, Part II* 52(14-15):2003-2017. DOI: 10.1016/j.dsr2.2005.05.009

Glaser M (2003). Interrelations between mangrove ecosystem, local economy and social sustainability in Caeta Estuary, North Brazil. *Wetlands Ecology and Management* 11:265-272.

Gomes HR, Goes JI and Saino T (2000). Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal. *Continetal Shelf Research* 20(3):313-330. DOI: 10.1016/S0278-4343(99)00072-2

Gray WM (1968). Global view of the origin of Tropical Disturbances and Storms. *Atm. Sc. Paper* 114. Colorado State University. 105pp. DOI: 10.1175/1520-0493(1968)096<0669:GVOTOO>2.0.CO;2

Gubbay S (Ed) (1995). *Marine Protected Areas: Principles and Techniques for management*. Springer, UK. 232pp.

Gupta AD, Babel MS, Albert X and Mark O (2005). Water Sector of Bangladesh in the Context of Integrated Water Resources Management: A Review. *Water Resources Development* 21(2):385-398.

Haroon MI (2014). Marine fisheries potentials, trends and development. Paper presented in the seminar of World Oceans Day 2014, Institute of Marine Sciences and Fisheries, University of Chittagong, Bangladesh, 08 July 2014.

Hasan MN, Hossain MS, Bari MA and Islam MR (2013). Agricultural land availability in Bangladesh. SRDI, Dhaka, Bangladesh, 42 pp.

Hellya JJ and Levin LA (2004). Global distribution of naturally occurring marine hypoxia on continental margins, *Deep-Sea Research, Part I* 51:1159-1168. DOI: 10.1016/j.dsr.2004.03.009

Heuer OE, Kruse H, Grave K, Collignon P, Karunasagar I, Angulo FJ (2009). Human health consequences of use of antimicrobial agents in aquaculture. *Clinical Infectious Diseases* 49, 1248–1253.

Hossain MS (2001). Biological aspects of the coastal and marine environment of Bangladesh. *Ocean & Coastal Management*, 44(3-4): 261-282.

Hossain MS (2013a). Conserving Mangrove Ecosystem for Climate Change Adaptation in the Ganges Basin. In: Moksness E, Dahl E and Stottup J (eds.), Global challenges in integrated coastal zone Management. Wiley-Blackwell, UK, p.85-100.

Hossain MS (2013b). Short Study on the Ecosystems and Fishing Communities of Cox's Bazar Sadar and Moheshkhali, Cox's Bazar. COAST Trust, Dhaka, Bangladesh, 49pp.

Hossain MS (2013c). An Illustrated Guide to Fishes of Noakhali. Centre for Coast, Climate and Community (Tetra-C), Bangladesh, 308pp.

Hossain MS and Lin CK (2001). Land Use Zoning for Integrated Coastal Zone Management: Remote Sensing, GIS and RRA Approach in Cox's Bazar Coast, Bangladesh. *ITCZM Publication Series*, No.3, Integrated Tropical Coastal Zone Management, Asian Institute of Technology, Bangkok, Thailand, 25pp.

Hossain MS, Lin CK, Hussain MZ (2001). Goodbye Chakaria Sunderban: The Oldest Mangrove Forest. *WetlandScience and Practice* 18(3):19-22.

Hossain MS, Hossain MZ and Chowdhury SR (2006). An Analysis of Economic and Environmental Issues Associated with Sea Salt Production in Bangladesh and Thailand Coast. *International Journal of Ecology and Environmental Sciences* 32:159-172.

Hossain MS, Das NG and Chowdhury MSN (2007). Fisheries Management of the Naaf River. Coastal and Ocean Research Group of Bangladesh, 268 pp.

Hossain MS, Wong S, Chowdhury MZR, Shamsuddoha M (2009). Remote Sensing and GIS Application to Mangrove Forest Mapping in the Meghna Deltaic Islands of Bangladesh. *Bangladesh Journal of Marine Sciences and Fisheries* 1(1):81-96.

Hossain MS and Das NG (2010). GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (*Macrobrachium rosenbergii*) farming in Companigonj Upazila of Noakhali, Bangladesh. *Computers and Electronics in Agriculture* 70:172-186.

Hossain MS, Das NG, Sarker S and Rahaman MZ (2012). Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. *Egyptian Journal of Aquatic Research* 38: 213-226.

Hossain MS, Chowdhury SR, Sharifuzzaman SM and Sarker S (2013). Ocean Acidification Vulnerabilities in Bangladesh. IUCN Bangladesh Country Office, Dhaka, 92 pp.

Hossain MS, Chowdhury SR and Sharfuzzaman SM (2014a). *Reflections on the opinions of marine scientists on the roles and responsibilities of the state in utilizing and managing marine resources of Bangladesh*. Submitted to H.E. the Prime Minister of GoB, August 20, 2014. (In Bangla, original title: evsjv‡`‡ki mgy`ª m¤ú‡`i e¨envi I e¨e¯'vcbvq iv‡óªi KiYxq wel‡q mgy`ªweÁvbx‡`i Awfg‡Zi cÖwZdjb)

Hossain MS, Sarker S, Sharifuzzaman SM and Chowdhury SR (2014b). Habitat Modelling of Juvenile Hilsa *Tenualosa ilisha* (Clupeiformes) in the Coastal Ecosystem of the Northern Bay of Bengal, Bangladesh, *Journal of Ichthyology* 54(2):203–213.

Hossain MS, Sarker S, Chowdhury SR and Sharifuzzaman SM (2014c). Discovering spawning ground of Hilsa shad (*Tenualosa ilisha*) in the coastal waters of Bangladesh, *Ecological Modelling* 282:59-68. DOI: 10.1016/j.ecolmodel.2014.03.001

Hossain MS, Rothuis A, Chowdhury SR, Smaal A, Ysebaert T, Sharifuzzaman SM, Dankers P, Tangelder M, Duijn A, Talukder A and Islam MR (2014d). Oyster reefs for coastal defense and food production: experience from Bangladesh. Paper presented in the *International Conference on Deltas in Times of Climate Change II*, Rotterdam, the Netherlands, 24-26 September 2014.

Houde E et 12 (2001). *Marine Protected Areas: Tools for sustaining ocean ecosystems*, National Academy Press, Washington DC, USA. 272pp.

Hussain MM (1971). The commercial fishes of the Bay of Bengal. Survey for Development of Fisheries in East Pakistan. 60pp.

Hussain MG and MJ Rahman (2010). Marine fisheries resources of Bangladesh: Stock status and management issues. pp 37-51. In: Hussain MG and Hoq ME (eds.), Sustainable Management of Fisheries Resources of the Bay of Bengal. Support to BOBLME Project, Bangladesh Fisheries Research Institute, Bangladesh. 122 p.

IHO (1953). *Limits of Oceans and Seas* (Special Publication No. 23). 3rd Edition. International Hydrographic Organization, Mote Carlo. 38pp.

IOC/UNESCO (2014). Marine spatial Planning Initiative. url: http://www.unesco-ioc-marinesp.be/marine_spatial_planning_msp (as on October 19, 2014).

Imam B (2013) Energy Resources of Bangladesh. 2nd edition, Bangladesh University Grants Commission, Agargaon, Dhaka. 324 p.

Islam MS, Khan MG, Quayam SA, Sada MN and Chowdhury ZA (1993). The Estuarine Set Bag Net (ESBN) fishery. In: Studies of Interactive Marine Fisheries of Bangladesh. Bay of Bengal Programme, Madras, India, pp.21–50.

Islam MS (2003). Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. *Ocean & Coastal Management* 46(8):763–796.

IUCN (1987). *The Bali Action Plan*, Commission on National Parks and Protected Area, International Union on Conservation of Nature, Ottwa, Canada. 29pp.

Kabir MH (1992). *Variation in Mean Sea-Level along the coast of Bangladesh*. MSc Thesis, Institute of Marine Sciences, University of Chittagong.

Khadem SK, Ullah SM, Aditya SK, Ghosh HR, Mariam L, Mazumder RK., Bhowmik NC and Hussain M (2007). Country Report of Solar and Wind Energy Resource Assessment (SWERA) - Bangladesh, Renewable Energy Research Center, University of Dhaka, Bangladesh

Khan YSA and Hossain MS (1996). Impact of shrimp culture on the coastal environment of Bangladesh. *International Journal of Ecology and Environmental Sciences* 22(2):145-158.

Kovacs JM (1999). Assessing mangrove use at the local scale. *Landscape and Urban Planning* 43:201-208.

Kumar SP, Muraleedharan PM, Prasad TG, Gauns M, Ramaiah N, de Souza SN, Sardesai S and Madhupratap M (2002). Why is the Bay of Bengal less productive during summer monsoon compared to the Arabian Sea? *Geophysical Research Letter* 29(24):88,1-4. DOI: 10.1029/2002GL016013

Lagerloef G (2012). Satellite Mission Monitors Ocean Surface Salinity, *EOS, Transactions, American Geophysical Union* 93(25):233-234. DOI: 10.1029/2012EO250001

Lamboeuf M (1987). Bangladesh demersal fish resources of the continental shelf,. R.V. Anusandhani trawling survey results (Sep. 1984 - June, 1986) Rep. Prep. for the FAO/UNDP project strengthening of the national programfor Marine Fish Resources Management Research and Development. FAO, Rome, 1987, FI: DP/BGD/80/025, Field document 1: 26 p.

Lee SY (2004). Relationship between mangrove abundance and tropical prawn production: a re-evaluation. *Marine Biology* 145(5):943-949.

Lerche I (1992). *Oil exploration: Basin Analysis and Economics*. Academic Press, Inc. 177pp.

Li Z, Yu W, Li T, Murty VSN and Tangang F (2013). Bimodal Character of Cyclone Climatology in the Bay of Bengal Modulated by Monsoon Seasonal Cycle, *Journal of Climate* 26(3)1033-1046. doi: 10.1175/JCLI-D-11-00627.1

Madhupratap M, Gauns M, Ramaiah N, Kumar SP, Muraleedharan PM, de Sousa SN, Sardessai S and Muraleedharana U (2003). Biogeochemistry of the Bay of Bengal: Physical, chemical and primary productivity characteristics of the central and western Bay of Bengal during summer monsoon 2001. *Deep Sea Research, Part II* 50(5):881-896. DOI: 10.1016/S0967-0645(02)00611-2

Mahmood N, Chowdhury MJU and Chowdhury SR (1992). Sea Level Rise situation in Bangladesh: Problem identification, policy implications and Research needs. In, *Proceedings of the Workshop on Coastal Zone Management of Bangladesh*. UNESCO/BNCU, 27-31 Dec 1992. 10pp.

Mahmood N, Chowdhury MJU, Hossain MM, Haider SMB and Chowdhury SR (1994a). *State of the Environment relating to marine fisheries of Bangladesh*, Institute of Marine Sciences, University of Chittagong, Bangladesh. 154pp.

Mahmood N, Chowdhury MJU, Hossain MM, Haider SMB and Chowdhury SR (1994b). Bangladesh, In *An Environmental Assessment of the Bay of Bengal Region* (Ed. Holmgren S). BOBP/REP/67, SWEDMAR. 76-119pp.

Mahmood N, Chowdhury SR and Saikat SK (1997). *Oceanography of estuaries and the shelf sea of Bangladesh: an overview of Oceanographic studies in estuaries and offshore waters of Bangladesh*, Institute of Marine Sciences, University of Chittagong, Bangladesh.

Mahmood N, Chowdhury SR, Sharif ASM, Uddin MM, Ullah MS and Islam MH (2002a). *A review of research works on water quality of the Lotic, Estuarine and Marine environment in Bangladesh* (Review Monograph). Institute of Marine Sciences, University of Chittagong. 24pp.

Mahmood N, Chowdhury SR, Uddin MM, Sharif ASM and Ullah MS (2002b). Water, nutrient and sediment flux study through the lower Meghna River estuary. In, Assessment of material fluxes to the coastal zone in South Asia and their impacts *Proceedings of the joint APN/SASCOM/LOICZ Workshop*, 08-11 December 2002, Negombo, Sri Lanka. pp.21-25.

Mannar MGV (1982). Guidelines for the establishment of solar salt facilities from seawater. underground brines and salted lakes. Industrial and Technological Information Bank (INTIB), Industrial Information Section, United Nations Industrial Development Organization (UNIDO), UNIDO Technology Program. 149pp.

Marine Institute (2005). *Marine industries global market analysis*. Douglas-Westwood Limited, Marine Foresight Series No.1. Marine Institute, Galway, Ireland, 132 pp, http://www.marine.ie

Milliman JD, Broadus JM and Gable F (1989). Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples. *Ambio*, 340-345.

Milliman JD and Haq BU (Eds.) (1996). *Sea-level rise and coastal subsidence: causes, consequences, and strategies* (Vol. 2). Springer.

MoFA (2014). Press Release: Press statement of the Hon'ble Foreign Minister on the verdict of the Arbitral Tribunal/PCA. Dhaka, 08 July 2014. (Ministry of Foreign Affairs) url: http://www.mofa.gov.bd/PressRelease/PRDetails.php?txtUserId=&PRid=854 (as on Sep 23, 2014).

Our Ocean Wealth (2012). *Harnessing our Ocean Wealth: An Integrated Marine Plan for Ireland*, Marine Coordination Group Bureau, Ministry of Agriculture, Food & the Marine, Ireland. 74pp.

Paul BG and Vogl CR (2011). Impacts of shrimp farming in Bangladesh: challenges and alternatives. *Ocean & Coastal Management* 54, 201–211.

Pearce DW, Markandya A and Barbier EB (1989). *Blueprint for a Green Economy*. Earthscan, London.

Penn JW (1983). An assessment of potential yield from the offshore demersal shrimp and fish stock in Bangladesh water (including comments on the trawl fishery 1981-1982). FE:DP/BGD/81/034, Field Doc. 22 p. Fishery Advisory Service (Phase II) Project, FAO, Rome, Italy.

Rana Y (2013). *Investigation of Relative Sea-Level Change in the Eastern and Western coast of Bangladesh from tidal record*, MSc Thesis, Institute of Marine Sciences and Fisheries, University of Chittagong.

Ray GC and Ray JM (2014). Marien Conservation: Science, Policy and Management. Wiley-Blackwell, 370pp.

Rollet B (1984). La ecologia de los manglares con referen cia especial a la base biologica para la ordencion sostenida, forestal Y pesca. Food and Agriculture Organization of the United Nations, Rome.

Rona PA (2002). Marine Minerals for the 21st century, *Episodes*, 25(1):2-12.

Saetre R (1981). Survey of the marine fish resources of Bangladesh Nov.-Dec. 1979 and May 1980. Report on surveys in the R.V. Dr. Fridtjof Nansen. Institute of Marine Research, Bergen. 67p.

Schott FA, Xie SP and McCreary JP, Jr (2009). Indian Ocean Circulation and Climate Variability, *Review of Geophysics* 47, RG1002, 46pp. doi: 10.1029/2007RG000245

Sharifuzzaman SM and Adhikari S (2013). An assessment of biosecurity and hazard management practices in the larviculture of shrimp (*Penaeus monodon*), Bangladesh. *Communications in agricultural and applied biological sciences* 78(4):417-20.

Subramanian V (1993). Sediment load of Indian rivers. *Current Science* 64, 928-930.

Sverdrup HU, Johnson MW and Fleming RH (1942). *The Oceans: Their Physics, Chemistry, and General Biology*, Prentice-Hall, NY. 1087pp.

Titus JG (1990). Greenhouse effect, sea level rise and land use. *Land Use Policy*, 7(2):138-153.

UNCLOS (1982). *United Nations Convention on the Law of the Sea*. 208pp. Available online on http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm

Upton HF (2011). The Deepwater Horizon Oil Spill and the Gulf of Mexico Fishing Industry. Congressional Research Service, US Gov. 14pp.

Valiela I, Bowen JL and York JK (2001). Mangrove forests: One of the Worlds threatened major tropical environments. *BioScience* 51(10):807-815.

Wasson RJ (2003). A sediment budget for the Ganga–Brahmaputra catchment. *Current Science* 84(8):1041-1048.

WCED (1987). *Our Common Future*. World Commission on Environment and Development. Oxford University Press.

Wells S (2006). *In the front line: Shoreline protection and other ecosystem services from mangroves and coral reefs*. UNEP-WCMC.

West WQB (1973). *Fishery Resources of the upper Bay of Bengal*. Indian Ocean Programme, Indian Ocean Fisheries Commission, Rome, FAO, IOFC/DEV/73/28. 28pp.

WOR-1 (2010). *World Ocean Review 2010: Living with the Oceans*, Maribus, Germany. 232pp.

WU (Weather Underground) (undated). The 35 deadliest tropical cyclones in world history. url: http://www.wunderground.com/hurricane/deadlyworld.asp (as on Sep 23, 2014).

Young MD (1992). Sustainable investment and resource use: equity, environmental integrity and economic efficiency. Man and the Biosphere Series (UNESCO), Vol. 9, 192 pp.

Young OR (1994). *International Governance: Protecting the Environment in a Stateless Society*, Cornell University Press, Ithaca.