Vulnerability of the Bay of Bengal to Ocean Acidification.

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Vulnerability of the Bay of Bengal to Ocean Acidification

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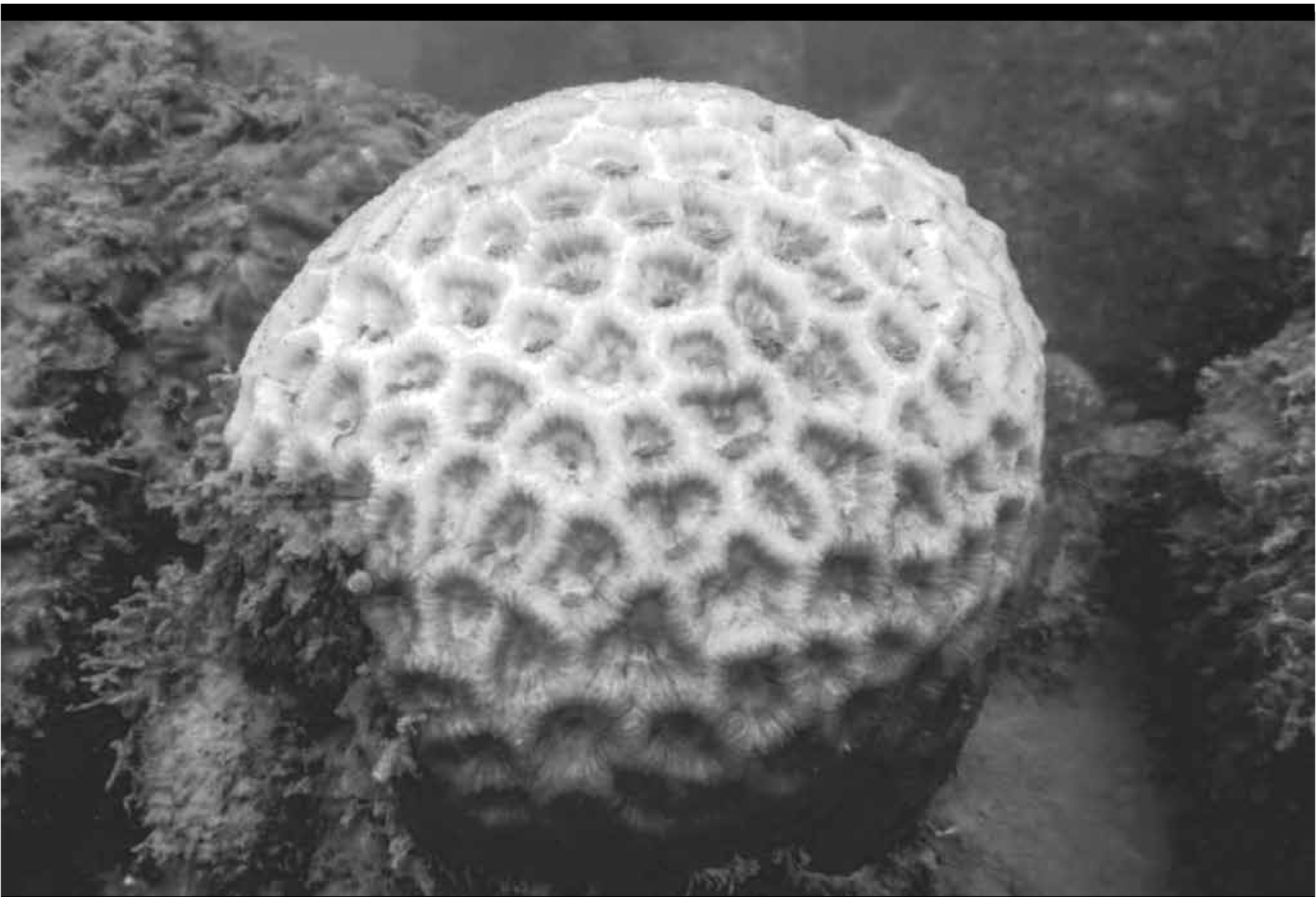

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Executive Summary

Fossil-fuel combustion releases carbon dioxide to the atmosphere, leading to a warmer climate. Increasing atmospheric CO_2 is changing the global ocean's chemistry, as one-fourth of the anthropogenic CO_2 is absorbed by the ocean. In addition, ocean absorbs CO_2 from the respiration and breakdown of dead organic matter. When CO_2 dissolves in seawater, it forms carbonic acid, decreasing both ocean pH and the concentration of the carbonate ion.

The historical trends analysis showed an increasing water temperature with a decreasing pH levels over the period which may lead substantial effect on the biodiversity of the Bay of Bengal. The Institute of Marine Sciences and Fisheries (IMSF) in Chittagong University have been contributed in research and data generation from the coastal and marine ecosystems of Bangladesh. In addition, Bangladesh Navy, Bangladesh Inland Water Transport Authority and Coast Guard have been significantly contributed in hydrographical data collection and monitoring of the shelf water of Bangladesh in the Bay of Bengal.

Ocean acidification could affect marine food chain and substantially change the marine biota which is huge threat to global protein supply and food security for millions of people, including the multi-billion dollar fishing industry. Acidification can affect marine organisms, especially to those that build their shells and skeletons materials from calcium carbonate, such as species of corals, oysters, clams, mussels, and snails. The molluscs and crustaceans support valuable commercial and recreational fisheries, where the coral reef ecosystems support a variety of subsistence, recreational, and commercial fisheries worldwide.

Due to the effect of ocean acidification, an estimated 19% of the world's coral reefs have been damaged and a further 35% are seriously threatened. As a result, one-third of all reef-building corals are at risk of extinction. The Saint Martin's Island is the only coral bearing island of Bangladesh located in the Bay of Bengal. Among the 66 coral species in 1997, only 40 species were recorded in 2008 and the remaining 26 coral species may be lost in the next 11 years, posing serious threat to the coral biodiversity in Bangladesh. The ocean acidification refers to the process of lowering the oceans' pH levels which results coral bleaching, slow growth and decrease coral species diversity. Moreover, feeding and spawning areas of reef inhabiting aquatic species may be reduced which ultimately lead to dramatic loss of fisheries biodiversity. The global economic value of these reef services has been estimated to be $30 billion per year based on a value of $100,000 per square kilometer per year. Projections of the lost coral reef area in year 2100 due to acidification are 16-27% that translates to economic losses of as much as $870 billion in year 2100.

The impacts of ocean acidification may be either direct, through alteration of different physiological processes of organisms (such as survival, reproduction and development, growth, metabolism, thermal tolerance, immune response, and behavioural responses), or indirect, through biophysicochemical interactions (such as predator-prey abundance, nutrient recycling or habitat changes). The global marine capture fisheries and aquaculture industries have provided 110 million metric tons of human food in 2006 with a commercial value of $170 billion. Changes in fishery industries due to acidification are likely to disproportionately affect the developing nations that often rely very much on marine-related economic activities than developed nations.

An increased CO_2 causes reduction in water pH which also reducing soil pH and responsible for the damage of mangrove vegetations. The low soil pH may harm breathing roots of mangroves and causes mangrove mortality. Acidification can also cause physical damage and alter topography and hydrology. Declining of mangrove ecosystem will not only cause colossal loss of coastal habitat, aquatic resources and biodiversity, but also will increase soil erosion, changes in sedimentation pattern and shoreline configuration, vulnerability to cyclonic storms, tidal bore and lead to the loss of feeding, breeding and nursery ground for various marine, estuarine and fresh water fishery resources.

Coastal people inherit skill and knowledge on fishing, shrimping, crabbing, agriculture, livestock rising, trading and other occupations. But, their livelihoods from fisheries, farming and forestry are at risk in many regions of the world vulnerable to ocean acidification. Thus, impacts on food yields and livelihoods will therefore also affect mental health and health-related behaviours. If acidification damages marine habitats or reduces harvests, the resulting decline in revenues could mount job losses and additional indirect economic costs.

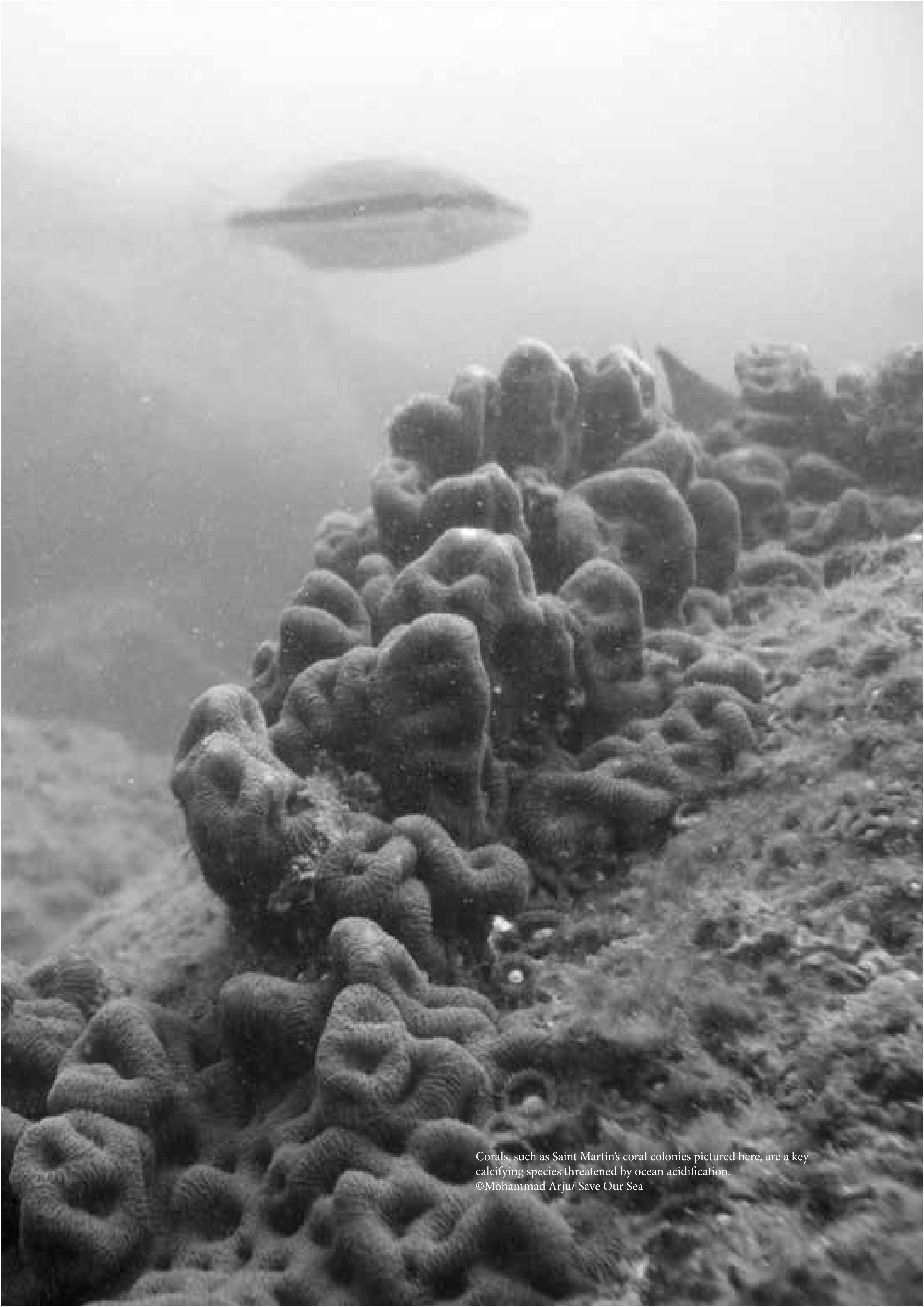
In Bangladesh, the Ministry of Environment and Forests and its agencies in collaboration with some other Ministries/Departments are responsible to develop the policy documents addressing climate change challenges, including ocean acidification. Each of the Ministry or Department has specific

roles and responsibilities on mitigation and adaptation practices to enhance resilience of the community in the face of extreme natural events. Moreover, these wings are involved in advocacy, governance and negotiation in home and abroad. In addition, academic and research institutions work on climate change challenges, ocean acidification, carbon sequential, and aquatic food production issues to develop knowledgeable and skilled human recourses. Given the economic and social importance of the oceans to human societies, government at the local, national, and international levels must begin to assess and implement adaptive approaches to acidification.

The UNFCCC agreed for National Adaptation Plans (NAPs) that can endow developing countries with a strong climate-smart strategic planning process and policy dialogue, embracing and integrating sector-wide and programmatic approaches as part of a coherent institutional, policy and regulatory framework. In addition, UNFCCC focused substantial further definition on loss and damage in the UNFCCC context. Bangladesh has prepared National Adaptation Programme of Action (NAPA, 2005) with 15 priority activities to combat climate change impacts, including awareness rising, technical capacity building, and implementation of projects in vulnerable regions with a special focus on agriculture and water resources. Bangladesh Climate Change Strategy and Action Plan (BCCSAP, 2009) was outlined to build capacity and resilience within the country to meet climate change challenges over the next 20 – 25 years.

The development of adaptation capacity with resilient infrastructures (such as houses, roads, schools, health centres, community places) and income generating options are essential. As a potential initiative, coastal plantation, coral and oyster reefs development (i.e. introduction of living shoreline concept), high yielding varieties of rice/ fish farming, raising livestock (for meat and milk) and poultry (for egg and meat) hold great promise. Thus, global and regional supports in the form of fund, technology, equipment and human resource development to promote adaptation capacity with resilient infrastructure are the prime requirements.

Moreover, funding is necessary to install in situ high-precision sensors around the territorial waters in the Bay of Bengal of Bangladesh to generate real-time monitoring of changing water conditions in sensitive areas. In this way, researchers will able to analyse and integrate data for developing models to determine the current and future costs of ocean acidification. However, reductions in CO_2 emissions should be large enough to avoid the worst consequences of ocean acidification and climate change and at the same time it is important to introduce global economy-wide emissions policies and international agreements. Also, communicating of problems from ocean acidification to stakeholders (i.e. policy makers, donors, media and public) is utmost important.



Corals, such as Saint Martin's coral colonies pictured here, are a key calcifying species threatened by ocean acidification.

1. Introduction

1.1. Background

Human emissions of too much carbon dioxide (CO_2) are driving force of acidification of the ocean as well as global climate change. While research on various aspects of climate change has been widely studied, the problem of ocean acidification (OA) has only been recognized recently. Since the acidification of ocean water is primarily driven by the well-known law of chemical equilibrium between CO_2 and water, the initial impact of ocean acidification is relatively clear (Caldeira and Wickett, 2005). However, the eventual impact depends on the complex interaction of many other variables.

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). But, carbon uptake by the ocean has slowed down the atmospheric increase and its associated consequences for the Earth's climate, and without such an uptake, it is estimated that the atmospheric CO_2 would now be around 450 ppm (Sabine et al. 2004; Que´re´ et al. 2009).

An increasing rate of addition of CO_2 to seawater by air-sea gas exchange due to increasing anthropogenic CO_2 is leading to increased hydrogen ion concentrations, and hence a fall in pH. Dissolved CO_2, carbonic acid and bicarbonate are also increasing; however, the concentration of carbonate ions is decreasing because of a reaction between CO_2 and carbonate, further increasing the bicarbonate levels (Raven et al. 2005). The relative changes in bicarbonate, carbonate and hydrogen ion concentrations in the surface ocean arising from doubling, tripling and quadrupling of atmospheric CO_2 (compared with pre-industrial values). Uptake of this additional CO_2 has already increased the average acidity of the global ocean by ~30% (i.e. decreasing pH from 8.2 to 8.1, or by 0.1 units) since the beginning of the industrial revolution, and the increase in acidity is expected to be three fold (i.e. yielding a decrease in pH to 7.8) by the end of this century, if global CO_2 emissions continue to rise at the current rates (Hilmi et al. 2012). Therefore, absorption of CO_2 by the oceans at a rate of 25 million tons of CO_2 per day may contribute to the mitigation of global warming, but evidently this will alter marine carbonate chemistry and cause ocean acidification.

Ocean Acidification – a simple primer

When CO_2 dissolves in seawater it forms carbonic acid (H_2CO_3), which dissociates to form equilibrium with hydrogen ions (H^+), bicarbonate ions (HCO_3^-) and carbonate (CO_3^{2-}):

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow 2H^+ + CO_3^{2-}$$

This equilibrium is dominated by bicarbonate, (CO_2 = 1%, CO_3^{2-} = 8% and HCO_3^- = 91%, of total dissolved inorganic carbon.

With continued uptake of CO_2 by the ocean drivers, this equilibrium shift toward the centre, increasing the concentration of Hydrogen ions, and thereby reducing pH. This pH shift changes the equilibrium between bicarbonate and carbonate, driving that equilibrium also toward the centre, thereby depleting the available carbonate pool. This increases the solubility of $CaCO_3$.

Since the onset of the industrial revolution, an increasing partial pressure of atmospheric CO_2 (pCO_2) has already caused a ~30% increase in ocean acidity (= pH declines by 0.1 units). Therefore, a 'business-as-usual' type scenario will continue to raise atmospheric CO_2 levels for the remainder of this century, leading to increased dissolution of CO_2 in the oceans and further reduction in pH – this refers to 'ocean acidification'.

Source: Havenhand 2012

1.2. Significance of ocean acidification in the context of climate change

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. 2009c). Models of future CO_2 emissions and ocean uptake suggest that the atmospheric level of CO_2 would peak shortly after the highest rate of fossil fuel combustion and then subside as the oceans absorb the CO_2, resulting an increase in ocean acidity (Ruttimann 2006).

Past emissions of CO_2 in the atmosphere will continue the acidification process, even it is reduced substantially

The general characteristics of future chemical changes in the ocean from increasing atmospheric CO_2 are highly predictable. Across the range of scenarios used by the Intergovernmental Panel on Climate Change (IPCC), the surface ocean pH is projected to decrease about 0.4 ± 0.1 units by 2100 as compared to pre-industrial conditions (Meehl et al. 2007). Time series records of ocean carbon chemistry over the past 25 years also show clear trends of increasing ocean carbon and decreasing pH in lockstep with increasing atmospheric CO_2 (Bates, 2007; Dore 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). However, more research is needed to confirm whether these issues are due to the effects of ocean acidification alone.

For several reasons, ocean acidification has serious implications for the type of policy interventions required to control climate change. First, since ocean acidification is exclusively driven by CO_2, as opposed to climate change which is also caused by other greenhouse gases (such as methane, water vapor, nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride), the additional cost associated with CO_2 emissions due to ocean acidification changes the trade-offs between the reductions of greenhouse gases. Second, the absorption of CO_2 by the oceans and the impact of ocean acidification occur over a short time scale, whereas the warming of the atmosphere substantially lags behind the build-up of greenhouse gases in the atmosphere. This changes the dynamics of optimal emission control. Third, the consideration of ocean acidification also has implications for the choice of policy instrument for the control of climate change. Climate change may be countered by geo-engineering, but ocean acidification would continue unabated and may even accelerate if sun-blocking sulphur dioxide particles are used to cool the planet.

1.3. Global state of ocean acidification

A continued global CO_2 emissions in line with current trends estimate atmospheric CO_2 levels of over 800 ppm by Year 2100 which may lead to ocean 150% more acidic than it was before industrialization (Makarow et al. 2009). Incidentally, with an emissions peak in 2100, the surface pH of the ocean would not begin to stabilize until 2750 (Ruttimann 2006). The pH level a kilometer below the ocean surface, in this scenario, is projected to continue to fall until 3000 (Ruttimann 2006). A general circulation model, simulating an atmospheric CO_2 concentration of 1,900 ppm in 2300, projects a maximum reduction of surface pH by 0.77 units (Caldeira and Wickett 2003).

Although the geological record shows that episodes of acidification occurred in the past and that the marine organisms adapted to an increased acidity, examples of acidification occurred before tens of thousands of years ago (Erba et al. 2010). Isotope studies of sediments indicate that the current observed and projected rates of acidification are as much as 100 times faster than what occurred in the earlier period (Ruttimann 2006). Furthermore, reviews of the geological record have found that over the past 300 million years, ocean pH was not more than 0.6 units lower than today (Caldeira and Wickett 2003). Thus under future projected levels, a continued acidification will present huge challenge to marine organisms adapted to current oceanic conditions.

2. Assessment of Ocean Acidification

2.1. Review of methods

Historical records and nearly real-time ocean observation and analysis systems indicate that the oceans of the world are changing (Bindoff et al. 2007; Roemich et al. 2012) with an increase in temperature and acidity, and changes in salinity in all ocean basins (Durack et al. 2012; Durack and Wijffels 2010). These changes are 'over and above' the seasonal, inter-annual, decadal and longer temporal-scale variability caused by climate oscillations such as the El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Indian Ocean Dipole (IOD), North Atlantic Oscillation (NAO) and the Southern Annular Mode (SAM).

Multi-model projections, based on IPCC Special Report on Emissions SRES scenarios, indicated that a reduction of pH values between 0.14 and 0.35 units are likely to occur (IPCC 2007; Hobday and Lough 2011; Stock et al. 2011; Brown et al. 2013; Ganachaud et al. 2013). Although there is uncertainty in the exact nature of these expected changes due to the limitations of the existing global climate models, climate change is likely to impact on the world's oceans by (1) increasing stratification (i.e. layering of water masses), causing reductions in the availability of nutrients to the photic zone; (2) affecting the strength of major ocean currents, causing changes in upwelling, mixing and transport of nutrients; (3) reducing dissolved oxygen levels and (4) causing sea levels to rise (Ganachaud et al. 2011, 2013). In turn, these changes are expected to reduce overall primary productivity (Polovina et al 2011; Howell et al. 2013) and alter the biomass and composition of lower trophic levels (Richardson 2008), leading to changes in the structure of food webs that support marine fisheries (Polovina 2005; Le Borgne et al. 2011). Studies of ocean acidification impacts on marine organisms from different climatological latitudes are shown in Table 1.

2.2 Parameters/indicators

Ocean acidification is the change in ocean chemistry driven by the oceanic uptake of chemical inputs

Table 1. Impacts of ocean acidification on marine organisms

Parameters	Species	References
pH, CO_3, pCO_2 and sea surface temperature (SST)	Over-wintering pteropods in the Arctic	Lischka and Riebesell 2012
Atm. CO_2 and pH	Cellular and physiological impacts on coral	Kaniewska et al. 2012
SST, pH, Chl-a, $NO_{2/3}$ and PO_4	Effect on cyanobacteria	Lomas et al. 2012
pCO_2, CO_2 and pH	Development of sea-urchin larvae	Brennand et al. 2010
pH and CO_2	Impact on marine fauna and ecosystem	Fabry et al. 2008
pCO_2 and CO_2	Calcification in oyster larvae	Miller et al. 2009
SST, pH, PCO_2, Ω calcite, Ω aragonite, CO_3, Alkalinity and Salinity	Growth and survival of larval shell-fish	Talmage and Gobler 2010
pCO_2	Early life stages of Atlantic herring	Franke and Clemmesen 2011
CO_2 and pH	Tropical marine fish	Munday et al. 2009
CO_2	Death of coral reefs	Brander et al. 2009
CO_2	Coral reef fishes	Ferrari et al. 2012
Temperature, salinity, DIN, POC, DIP, silicate, Chl-a, $\delta^{13} C_{POM}$, C:N and Zea/Fuco	Phytoplankton	Biswas et al. 2011
CO_2 and pH	Dogfish	Hayashi et al. 2004
CO_2 and pH	Feed intake of seabass	Cecchini et al. 2001
CO_2	Larval survivability of red sea-bream	Ishimatsu et al. 2005
pCO_2 and pH	Shell dissolution and calcification rates of mussel	Gazeau et al. 2007
pCO_2	Oyster calcification rate	Michaelidis et al. 2005
Ωarag (the saturation state of aragonite)	Clam shell dissolution and mortality	Green et al. 2004
pH	Occurrence of Jelly fish	Attrill et al. 2007

from the atmosphere, including carbon, nitrogen, and sulfur compounds. The oceans currently absorb approximately half of the CO_2 produced by burning fossil fuel; put simply, climate change would be far worse if it were not for the oceans. When partial pressure of oceanic CO_2 is less than atmospheres, uptake is occur which reduce water pH and decrease alkalinity. Overall fate of atmospheric CO_2 in oceanic ecosystem is shown in Figure 1.

To a first-order approximation, annual changes in tropical surface ocean chemistry in response to ocean acidification can be estimated from the assumption that surface water CO_2 exists in equilibrium with atmospheric concentrations (Orr et al. 2005; Bates 2007). However, short-term and local variations in both temperature and salinity dramatically affect Ωarag on shorter temporal and

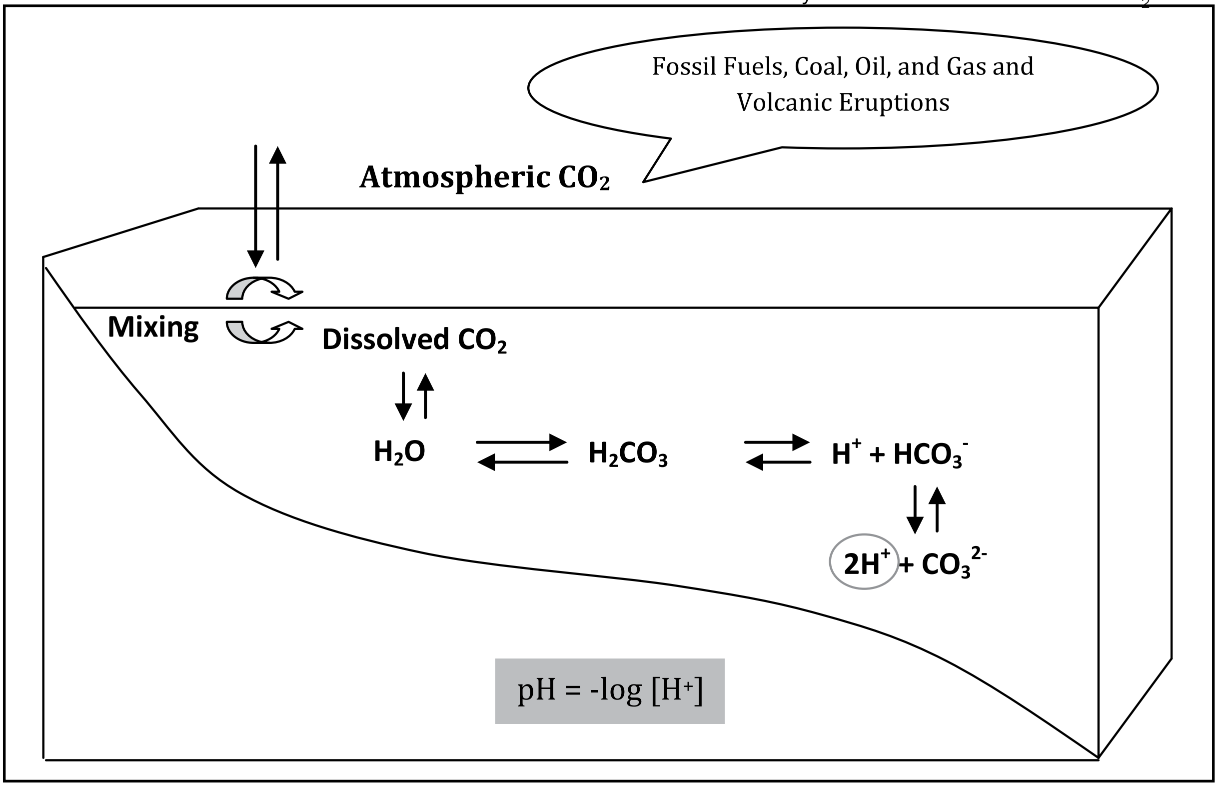


Figure 1. The fate of atmospheric CO_2 in marine ecosystem

spatial scales. For example, increasing temperature (or decreasing salinity) will increase the carbonate ion concentration due to the temperature (and salinity) dependencies of the equilibrium constants governing the reactions shown in the following equation.

$$CO_2(atm) \Leftrightarrow CO_2(aq) + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + CO^{2-}_3$$

Direct measurements of ocean chemistry through ship surveys, long-term time-series stations, and a growing number of autonomous moored and underway platforms will provide the most accurate means of tracking ocean acidification for the foreseeable future. However, these in situ measurements are inherently limited in space (time series, moored stations) and/or time (ship surveys). Although current satellite observations do not directly measure changes in ocean carbonate chemistry, they can provide synoptic observations of a range of physical and optical parameters that allow us to model changes in the distribution of carbonate chemistry within the surface ocean where no in situ observations are available. A host of satellite-derived products are becoming available that can offer important information regarding surface ocean thermodynamics, gas exchange, biological modification, and deepwater mixing process.

pCO_2: pCO_2 is the partial pressure of CO_2 in the atmosphere and the ocean. In the ocean, the pCO_2 is determined by the amount of dissolved CO_2 and H_2CO_3. It varies with alkalinity, latitude, depth, and temperature. Biological processes in the ocean also exert an influence on the pCO_2 in the ocean. As the atmospheric CO_2 concentration increases, the difference in partial pressure between the atmosphere and the seawater results in absorption of anthropogenic CO_2 into the surface layer of the ocean (i.e. Henry's Law). The increase of pCO_2 in the surface ocean profoundly affects the seawater carbonate system. It lowers the pH, decreases the availability of carbonate (CO_3^{2-}) ions and lowers the saturation state of the major shell-forming carbonate minerals.

pH: When CO_2 dissolves in seawater, carbonic acid is produced via the reaction. This carbonic acid dissociates in the water, releasing hydrogen ions and bicarbonate. The increase in the hydrogen ion concentration causes an increase in acidity, since acidity is defined by the pH scale, where pH = -log [H^+] (so, as hydrogen increases, the pH decreases). This log scale means that for every unit decrease on the pH scale (Figure 2), the hydrogen ion concentration has increased 10-fold. Monthly water pH variation in different rivers and estuaries of coastal Bangladesh are shown in Appendix-A.

'saturation horizons' in the oceans, which represent the transition depth between waters that are either under-saturated or over-saturated. Monthly temperature variation in different rivers and estuaries of coastal Bangladesh are shown in Appendix-B.

Salinity: Although seawater is naturally salty, but little variations in Sea Surface Salinity (SSS) can have dramatic effects on the water cycle and ocean circulation. SSS tells us about the concentration of dissolved salts in the ocean surface water (i.e. upper few centimetres). Throughout Earth's history, certain processes have served to make the ocean salty. The weathering of rocks delivers minerals, including salt, into the ocean. Evaporation of ocean water and formation of sea ice both increase the salinity of the ocean. However these 'salinity rising' factors are continually counterbalanced by processes that decrease salinity such as the continuous input of fresh water from rivers, precipitation of rain and snow, and melting of ice.

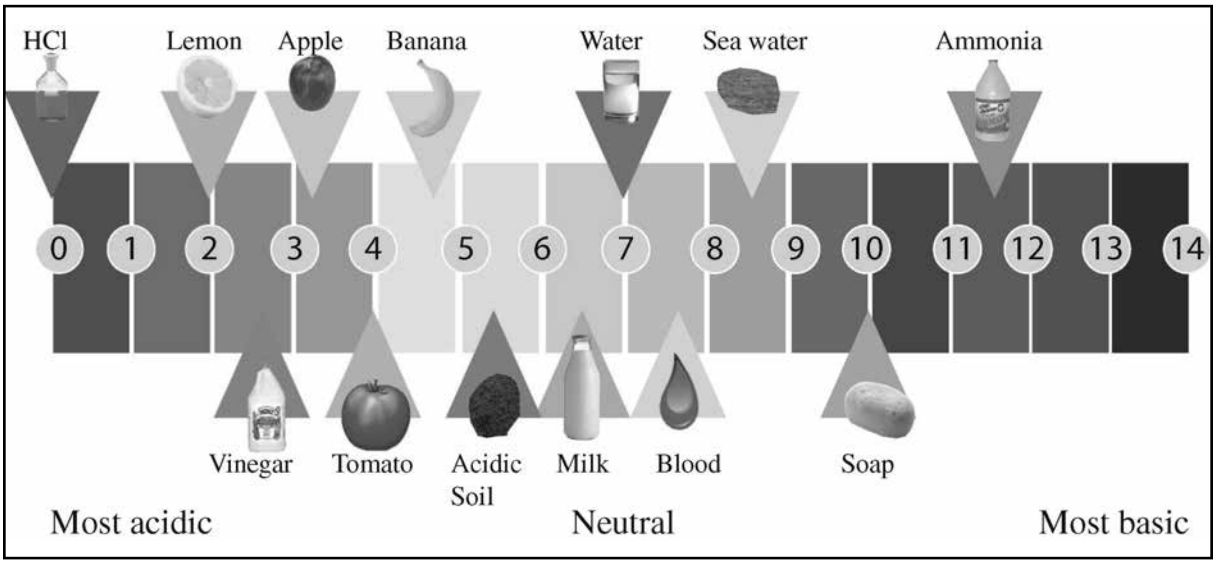


Figure 2. The pH scale with values of some common ingredients (modified from http://asset.emsofl.com/)

Alkalinity: Alkalinity of sea water measures the ability of water to neutralize acids to the equivalence point of carbonate or bicarbonate. The ability of the ocean to absorb atmospheric CO_2 over century and longer timescales will depend on the amount of calcium carbonate ($CaCO_3$) dissolution in the water column or sediments. Oceanographers define a quantity called the alkalinity [Alk] in terms of the concentrations of carbonate ion and bicarbonate ion as shown below:

$$[Alk] = [HCO^-_3 (aq)] + 2 \times [CO_3^{2-} (aq)]$$

The alkalinity is a measure of the ability of seawater to neutralize acidity (protons). Each bicarbonate can neutralize one proton and each carbonate can neutralize two protons.

Temperature: The impacts of changes in seawater chemistry are complicated by ocean temperature. The solubility of both calcite and aragonite (which are different forms of calcium carbonate used by marine organisms) is affected by the amount of CO_2 in seawater, which is partially determined by temperature, for example colder waters naturally hold more CO_2 and are more acidic than warmer waters. The sum of these differences leads to

Since 86% of global evaporation and 78% of global precipitation occur over the ocean, SSS is the key variable for understanding how fresh water input and output affects ocean dynamics. By tracking SSS we can directly monitor variations in the water cycle, including land runoff into the ocean, sea ice freezing and melting, and evaporation and precipitation over the oceans. Monthly salinity variation in different rivers and estuaries of coastal Bangladesh are shown in Appendix-C.

Dissolved oxygen: The concentration of dissolved oxygen is an important indicator of the health of aquatic ecosystem. Persistently low dissolved oxygen will harm most aquatic life because there will not be enough oxygen for them to use. In some circumstances, water can contain too much oxygen and is said to be supersaturated with oxygen, which is also dangerous for fish. Supersaturated conditions occur in highly turbulent waters because of aeration, and also on sunny days in waters experiencing algal blooms or with many aquatic plants, because of photosynthesis. The air is one source of dissolved oxygen and aquatic plants are another. The speed at which oxygen from the air enters and mixes through a water depends on the amount of agitation at the water surface, the depth of the water and the rate at which it mixes itself. As water temperature rises, oxygen diffuses out of the water into the atmosphere. Warm or saline water holds less dissolved oxygen than cold water or freshwater. Monthly dissolved oxygen variation in different rivers and estuaries of coastal Bangladesh are shown in Appendix-D.

2.3. Data sources and analysis

Present initiative aims to give an overview on the acidification of the Bay of Bengal with an emphasis on the territorial waters of Bangladesh. Data on ocean acidification in Bangladesh are still scarce. The long term yearly average data on sea surface temperature (SST) and pH were collected from the National Oceanographic Data Center (NODC) to develop a scenario of ocean acidification in the Bay of Bengal of Bangladesh.

The NODC provides scientific and public stewardship for national and international marine environmental and ecosystem data. Moreover, the National Coastal Data Development Center (NCDDC) and NOAA Central Library, with its regional branches, are providing access to the world's most comprehensive sources of oceanographic data in an integrated way. The NODC maintains and updates a national ocean archive with environmental data acquired from domestic and foreign activities and produces research data which help monitor global environmental changes. These data include physical, biological and chemical measurements derived from *in situ* oceanographic observations, satellite remote sensing of the oceans, and ocean model simulations. The NODC manages and operates the World Data Center (WDC) for Oceanography. Also, the NODC represents NOAA/NESDIS to the general public,

Table 2. Oceanic environmental data of the Bay of Bengal from NODC, NOAA

Type	Parameters	Archive	Temporal resolution	Spatial resolution	Format
In situ	SST, pH	WOD09	1963-1990	5^0-25^0N, 80^0-95^0E	OSD

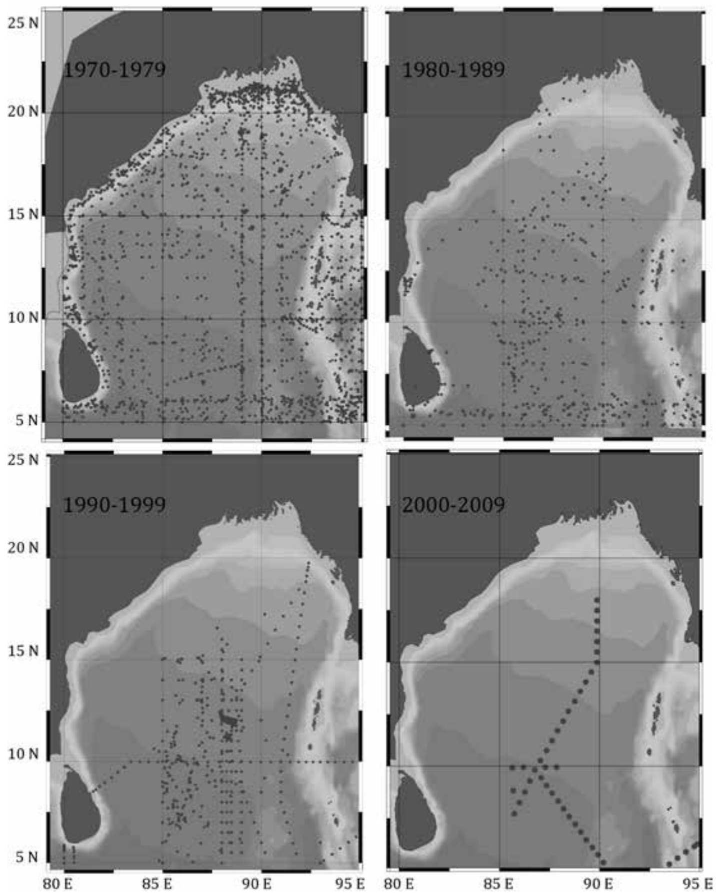


Figure 3. The geographical distribution of data points sampled in the Bay of Bengal between 1970-2009 (source: WOD09; http://www.nodc.noaa.gov/OC5/ WOA09/)

government agencies, private institutions, foreign governments, international organizations and the private sector on matters involving oceanographic data (http://www.nodc.noaa.gov/OC5/ WOA09/).

The SST and pH for the year 1963-1990 were derived from NODC as OSD format (Table 2) which is then visualized in Ocean Data View (ODV, version 4) software. After visualization, data were exported to spreadsheet file with their temporal (Figure 3) and spatial distribution, and subsequently used in ArcGIS for further analysis.

chemical measurements are needed over decadal time scales which are only available at a very limited number of stations confined mostly to the southern tropics of the Bay of Bengal.

There is also a critical need for well-developed spatial and temporal models that give accurate present-day and future estimates of aragonite and calcite saturation states in the coastal zones. The shallow continental shelves are the most biologically productive areas in the Bay of Bengal and are home to the majority of the marine fisheries, but accurate

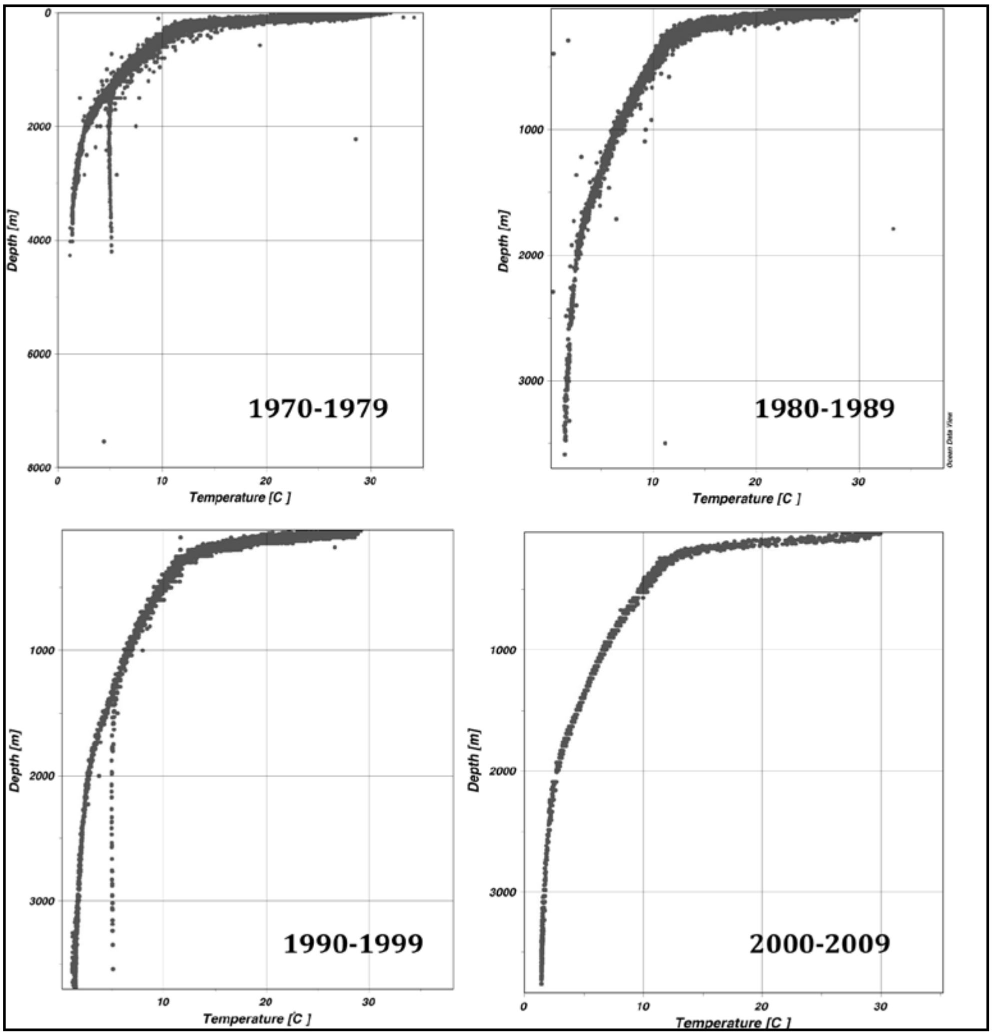


Figure 4. The vertical distribution of temperature in the Bay of Bengal during 1970-2009.

saturation state data are not available for analysis and prediction. Future initiative should focus more on measured variability, including oscillations on short-term biologically relevant to decadal time scales, to characterize driving mechanisms and to better evaluate models that are used to make future projections (Hofmann et al. 2011; Shaw et al. 2012; Doney et al. 2009). Time-series stations are complemented by large-scale sections in the Bay of Bengal.

2.4. Trends analysis

Ongoing changes in surface pH, pCO_2 and temperature saturation states are measurable at time-series stations, which tell us about trends as well as daily, seasonal, inter-annual and decadal variability. The measured surface ocean trends agree with what is expected from the measured atmospheric increase in carbon dioxide, assuming the air-sea CO_2 in equilibrium. Yet the high-precision

Vertical distribution of SST (Figure 4) showed that, temperature varies both with depth and time.

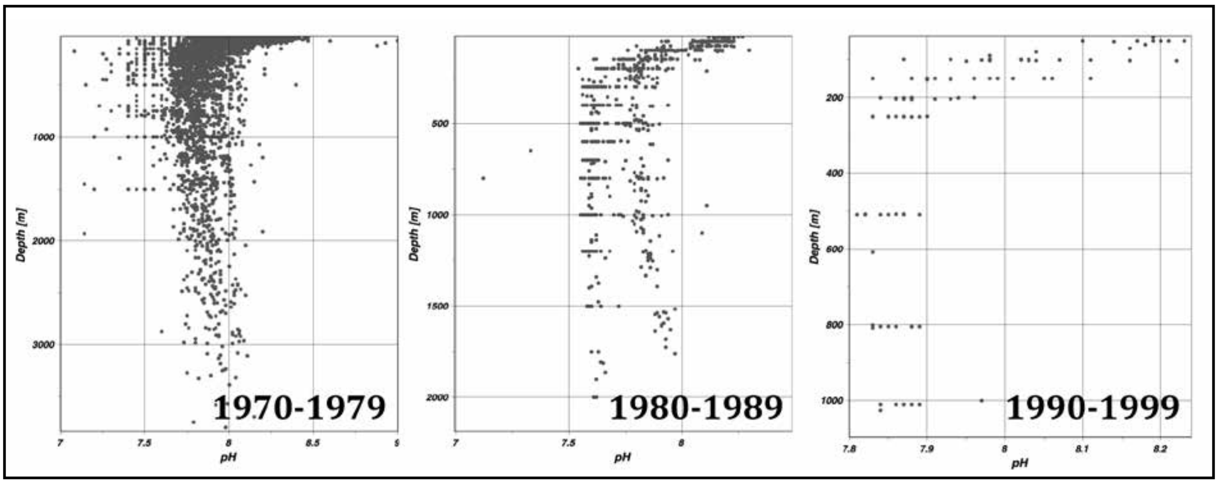


Figure 5. The vertical distribution of pH in the Bay of Bengal during 1970-1999

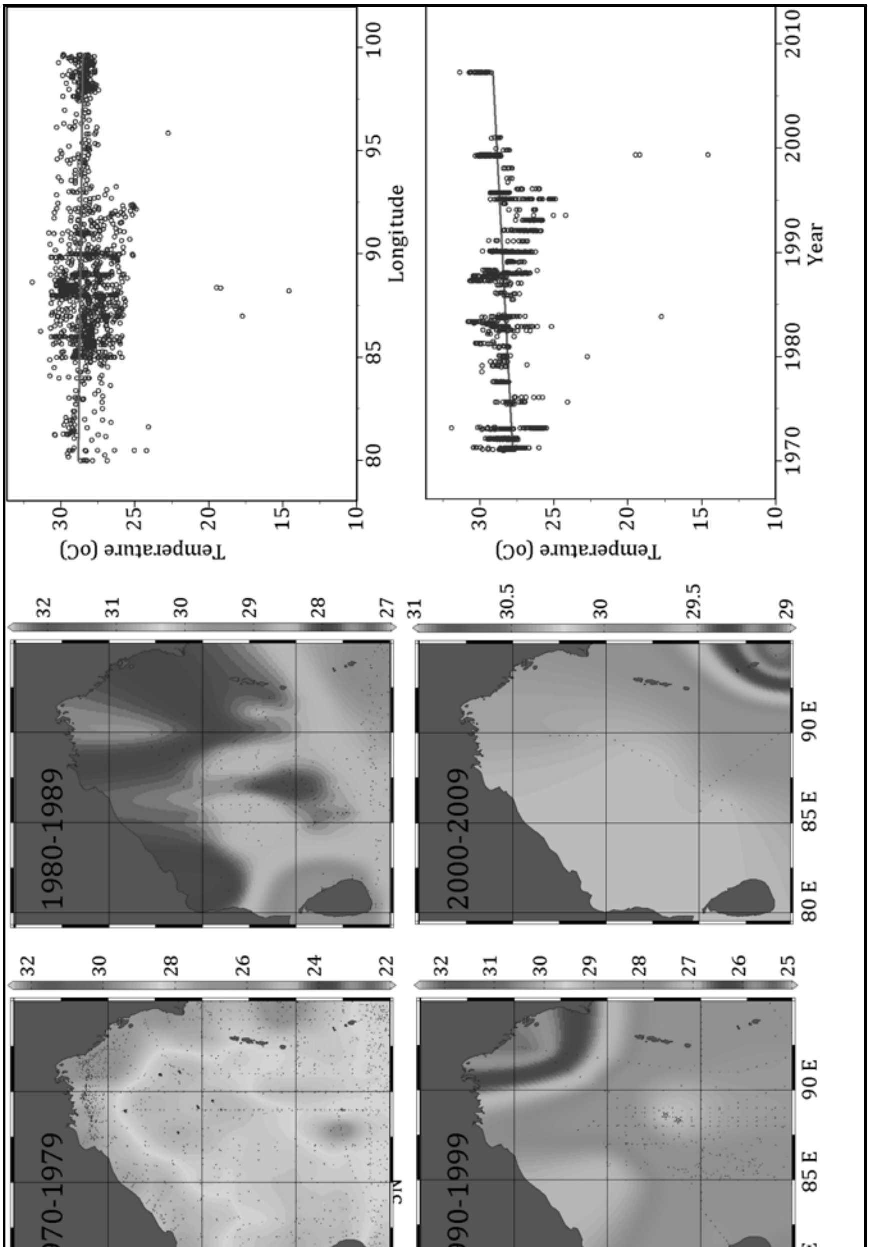


Figure 6. Showing the long-term sea surface temperature (SST) variation in the Bay of Bengal, presented with longitude and yearly trends

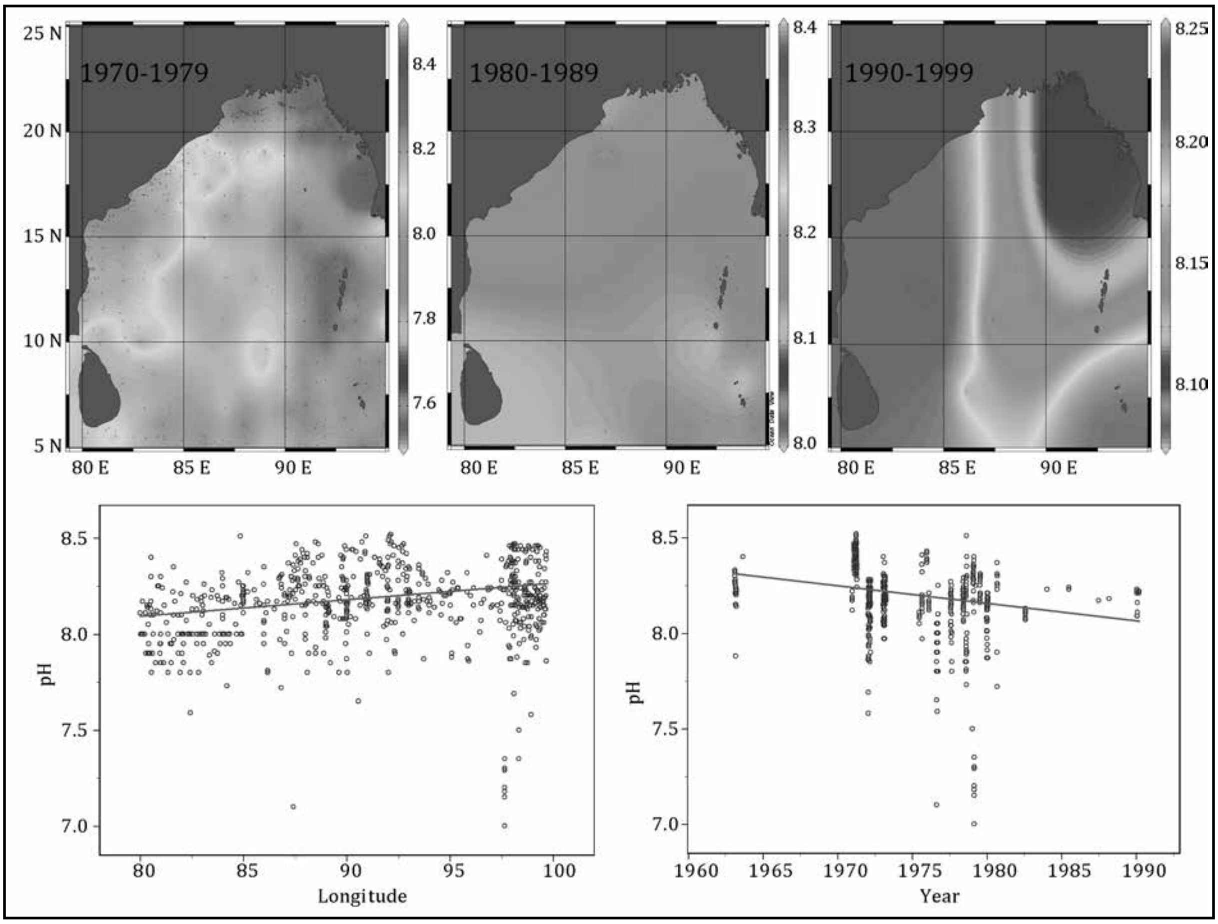


Figure 7. Showing the long-term water pH variation in the Bay of Bengal, presented with longitude and yearly trends

Average temperature was found 28.39^{0}C, 28.86^{0}C, 29.31^{0}C and 29.39^{0}C during 1970-1979, 1980-1989, 1990-1999 and 2000-2010, respectively. The vertical distribution of pH is shown in Figure 5, and the average pH was found 7.8, 7.6 and 7.3 during 1970-1979, 1980-1989 and 1990-1999, respectively.

The trends of forty years (1970-2010) of SST are shown in Figure 6. The maximum sea surface temperature was 31.91^{0}C during 1973 (April) and Minimum 14.35^{0}C during 1999 (December) with an average 28.39^{0}C. Trends analysis showed that, SST is increasing over the period. There is also an increased trend found at higher latitude.

The trends of pH for the thirty years (1970-1999) are shown in Figure 7. The maximum pH was found 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.

2.5. Facilities for measuring future ocean acidification in bangladesh

The Institute of Marine Sciences and Fisheries (IMSF) of Chittagong University is engaged in analyzing water, sediment and biological samples from the river, estuarine and near shore ecosystems of the Bay of Bengal for academic and research purposes. The IMSF has covered several important coastal and marine environments such as the Saint Martin's Island, Naaf River, Moheshkhali Channel, Bakhkhali River, Kutubdia Channel, Karnafully River, Sandwip Channel, Meghna estuary and Sunderban mangrove ecosystems. Moreover, the laboratory facilities and qualified researchers of IMSF are active in primary data generation for the government organizations, donors and private entrepreneurs. Moreover, the Bangladesh Navy (BN), Bangladesh Inland Water Transport Authority (BIWTA), Bangladesh Coast Guard and Chittagong Port Authority are playing important role in collection and monitoring of oceanographic data from the shelf water of Bangladesh in the Bay of Bengal (Figure 8). Besides, the role of Space Research and Remote Sensing Organization (SPARRSO), Geological Survey of Bangladesh, Survey of Bangladesh and Meteorological Department are significant in this discipline. The Department of Fisheries and Marine Science at Noakhali Science and Technology University, Fisheries and Marine Resource Technology Discipline at Khulna University and Marine Fisheries Academy at Chittagong are the emerging organizations in ocean research. Geo-spatial distribution of water salinity and dissolved oxygen in 10 m depth coastal water of Bangladesh have developed using IMSF research data (Figure 9).

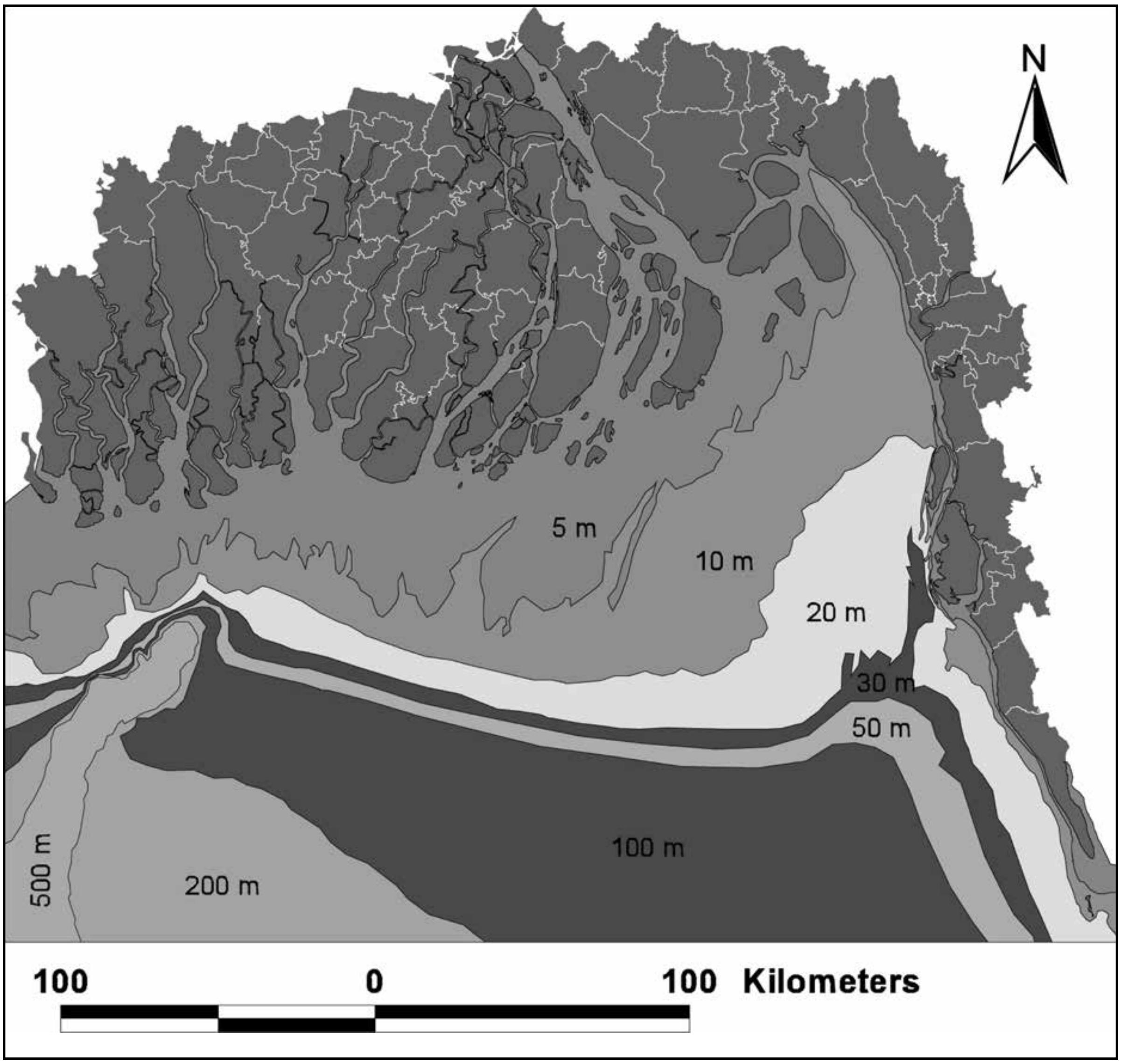


Figure 8. Coastal zone of Bangladesh with shelf water in the Bay of Bengal

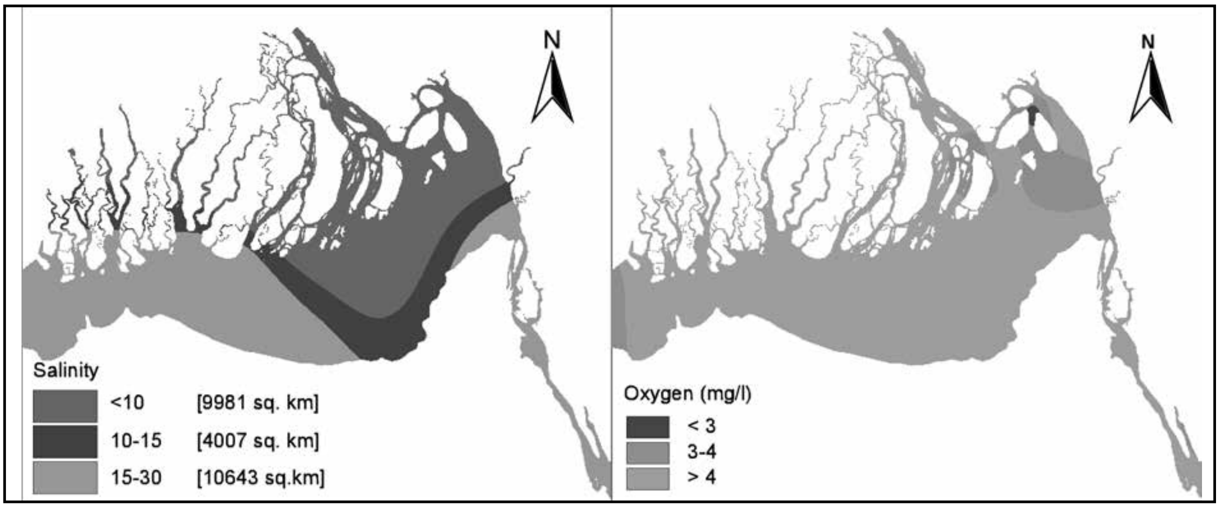


Figure 9. Distribution of water salinity and dissolved oxygen in 10 m depth coastal water of Bangladesh

3. Effects of Ocean Acidification on Marine Environment

3.1. Effects on biodiversity and food chain

Ocean acidification could affect marine food chain and lead to substantial changes in oceanic biodiversity which may threaten protein supply and food security for millions of people as well as the multi-billion dollar fishing industry. Phytoplankton are the base of marine food chain and unlike land plants, most marine phytoplankton are thought to have mechanisms to actively concentrate CO_2 which will impact phytoplankton species diversity in the natural environment and primary production, food web structure and marine biogeochemical cycles. Islam (1981) found 107 species of phytoplankton in the Karnafully estuary. Sayedullah (2003) identified 55 genera of phytoplankton from the Meghna estuary, of which 23 genera belongs to 13 family of Bacillariophyta, 19 genera belongs to 8 family of Chlorophyta and the remaining 13 genera belongs to 5 family of Cynophyta. Incidentally, the jellyfish blooms have increased over the last several decades (Purcell et al. 2007). Attrill et al. (2007) reported a significant correlation of jellyfish occurrence in the North Sea from 1971 to 1995 with a decreased pH (from 8.3 to 8.1) of surface waters. The jellyfish are both predators and potential competitors of fish and may substantially affect pelagic and coastal ecosystems. Therefore, substantial changes to species diversity and abundances, food-web dynamics, and other fundamental ecological processes could occur in the marine environment.

Ocean acidification may directly affect some marine species that supply many services to humans. For instance, molluscs and crustaceans support valuable commercial and recreational fisheries (Cooley and Doney, 2009a), and coral reef ecosystems support a variety of subsistence, recreational, and commercial fisheries worldwide (Bryant et al. 1998). Calcifiers are also provide pearls, shells, and coral pieces that are using for jewellery making. However, the declining populations of small calcifiers, like planktonic pteropods, and molluscs and corals larvae may increase competition among aquatic predators and at the same time may decrease the abundance/diversity of many commercial species. If reduced calcification decreases the fitness or survivorship of calcifying organisms, then some planktonic calcareous species may undergo shifts in their distributions as the inorganic carbon chemistry of seawater changes. The calcifying species are CO_2 sensitive and could potentially be replaced by non-calcifying species and/or by those species not sensitive to elevated pCO_2. Acidification can affect many other marine organisms, but especially impacts those that build their shells and skeletons from calcium carbonate, such as corals, oysters, clams, mussels, snails, and the phytoplankton and zooplankton which form the base of the marine food web.

The effects of ocean acidification in Bangladesh are analyzed in this report by using the data of Islam (2005), Kamal (2000), Chowdhury et al. (2009), Samsuzzaman (2009), Talukder (2010), Nabi et al. (2011) and Hossain et al. (2013). Historical trends analysis of water temperature and pH (Figure 10) showed that, water temperature has an increasing trend, whereas water pH has a decreasing trend, although these changes are not statistically significant. The effects of historical changes in water temperature and pH on fisheries biodiversity is shown in Figure 11. A reduction of pH value has negative effects, and a positive higher pH value has positive effects on fisheries biodiversity. Whereas positive temperature implies increase in water temperature which has negative impact and a negative value indicate reverse effect on fisheries biodiversity. Hussain (1971) reported 475 finfish species from the coastal and marine waters of the Bay of Bengal, but Islam et al. (1993) reported 185 species of finfish and shellfish. Chwdhury et al. (2011) recorded 98 finfish, 23 species of shrimps and prawns, 13 crabs, 11 species of molluscs, 3 echinoderms and 4 other crustaceans from the Naaf River Estuary. Hossain et al. (2013) identified 53 finfish species from the Meghna River estuary.

A bleached Gorgonian sea fan in the Bay of Bengal.
©Mohammad Arju/ Save Our Sea

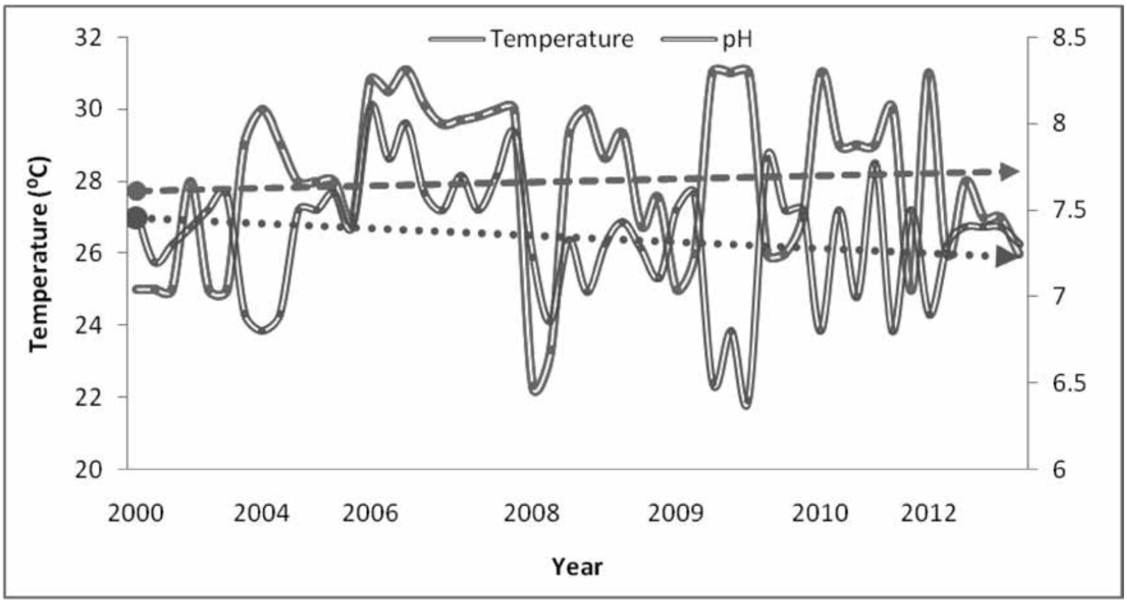


Figure 10. The historical trends of water temperature and pH in the coastal waters of Bangladesh

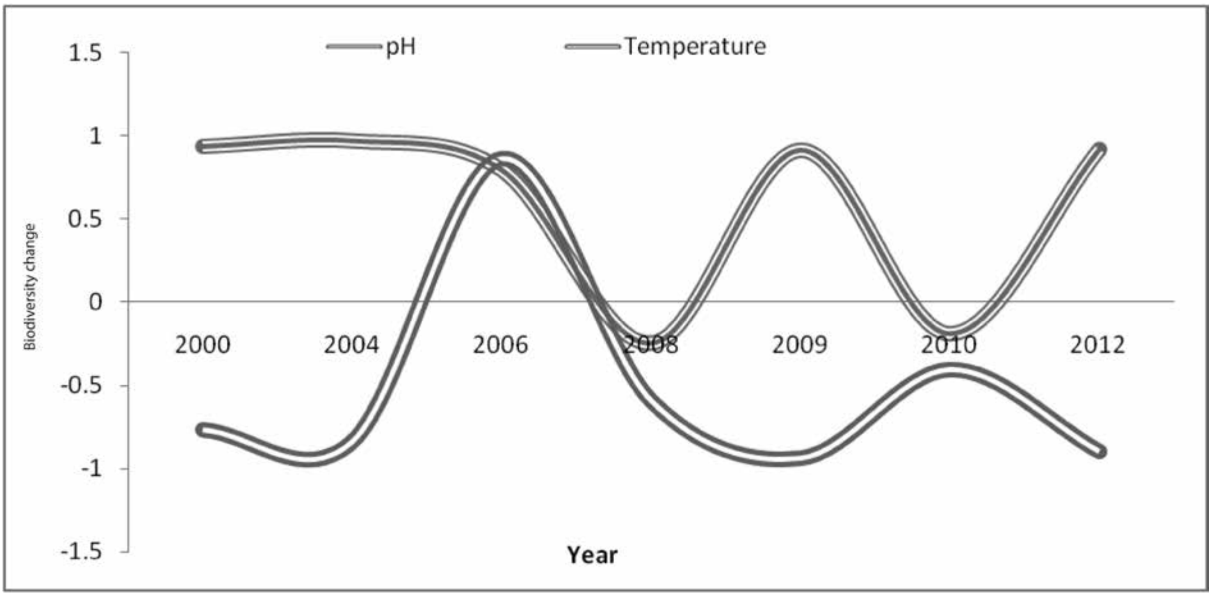


Figure 11. The effects of water temperature and pH on the fisheries biodiversity

3.2. Effects on coral reefs

Although coral reefs occupy only 0.2% area of the marine environment, they are the most productive and biologically diverse marine ecosystems (Reaka-Kudla 2001) and are thought to provide important habitat, feeding grounds and nursery supports for many deep-water organisms, including several commercially important fish species (Mortensen 2000; Fossa et al. 2002; Husebø et al. 2002; Roberts et al. 2006). In the coming decades, the net effect of ocean acidification on coral reef ecosystems will probably be negative as many reef-building marine calcifiers will be heavily impacted by the combined effects of increasing sea-surface temperatures (i.e. coral bleaching) and decreasing carbonate saturation states of surface waters (Guinotte et al. 2003; Buddemeier et al. 2004). Already an estimated 19% of the world's coral reefs have been lost and a further 35% are seriously threatened (Wilkinson 2008). As a result, one-third of all reef-building corals are considered to be at risk of extinction (Carpenter et al. 2008). A small increases in sea temperature (i.e. 1-2^{0}C) will breakdown the relationship between host corals and their symbiotic dinoflagellate algae (such as zooxanthellae), on which they rely for energy and growth (Muscatine 1973; Trench 1979). The vulnerability of different taxa to acidification depends on the form of carbonate that they secrete. The coralline algae, which are essential for cementing coral rubble into solid reef, forms a critical habitat for the early life stages of many organisms, including corals, and secrete high magnesium calcite and thus are particularly vulnerable to acidification (Kuffner et al. 2007). Mass bleaching of corals (i.e. bleaching of multiple species on an ecologically significant scale) was first observed in the late 1970s and was correlated with abnormally high sea temperatures, especially induced by *El Niño* events recurring every 4-7 years (Glynn, 1991) superimposed on generally elevated sea temperatures due to global warming (Hoegh-Guldberg, 1999).

The Saint Martin's Island is the only coral bearing island of Bangladesh in the Bay of Bengal with a total area of about 7.5 km^2. Haider (1992) recorded four coral species of the genus Acropora (*A. pulchra, A. horrida, A. humilis* and *A. variabilis*) from neritic waters of the island. The reef is subject to greater scouring and supports rich stands of macro algae, sometime seasonally, as well as some well-developed coral communities. The hard substrates and reef are important for artisanal fisheries and they can act as important foci for commercially important species. The island is an important nesting area for marine turtles, and a wintering area for migratory shore birds (Hossain 2001). Ocean acidification due increased CO_2 level will decrease pH, which will results coral bleaching, and down growth and decrease coral species diversity. Moreover, when CO_2 levels go up, the calcification of coralline algae will probably be completely inhibited. The feeding and spawning areas of reef inhabiting fishes will be reduced which ultimately lead to dramatic loss of fisheries biodiversity.

Table 3. The records of coral species at Saint Martin's Island, Bangladesh

Year	Coral species	Temperature (^{0}C)	pH	Reference
1997	66	28-29	-	Tomasik 1997
2008	40	27.5-29.5	7.5-7.8	Sultana et al. 2008

Tomasik (1997) recorded 66 coral species from the Saint Martin's Island and found the water temperature between 28 and 29^{0}C. Sultana et al. (2008) found only 40 coral species in the region, and the water temperature was 27.5-29.5^{0}C with pH values of 7.5-7.8. These two comparisons indicate declination of corals by 26 species in 11 years which is alarming for the coral biodiversity in Bangladesh (Table 3). The specific effect of water temperature and pH changes on coral associated fishes is shown in Figure 12. The water temperature and pH data were reproduced from Sultana et al. (2008). All data were tested for normality and effects were calculated at 95% confidence intervals. The dashed line shows the regression line, whereas the shaded lines represent the 95% confidence intervals. Findings show that, with an increase in pH, the coral associated fish species number is increasing, alternatively a decrease in pH will inversely affect the fish diversity (Figure 12A). Also, an increase water temperature decrease the number of fish species (Figure 12B).

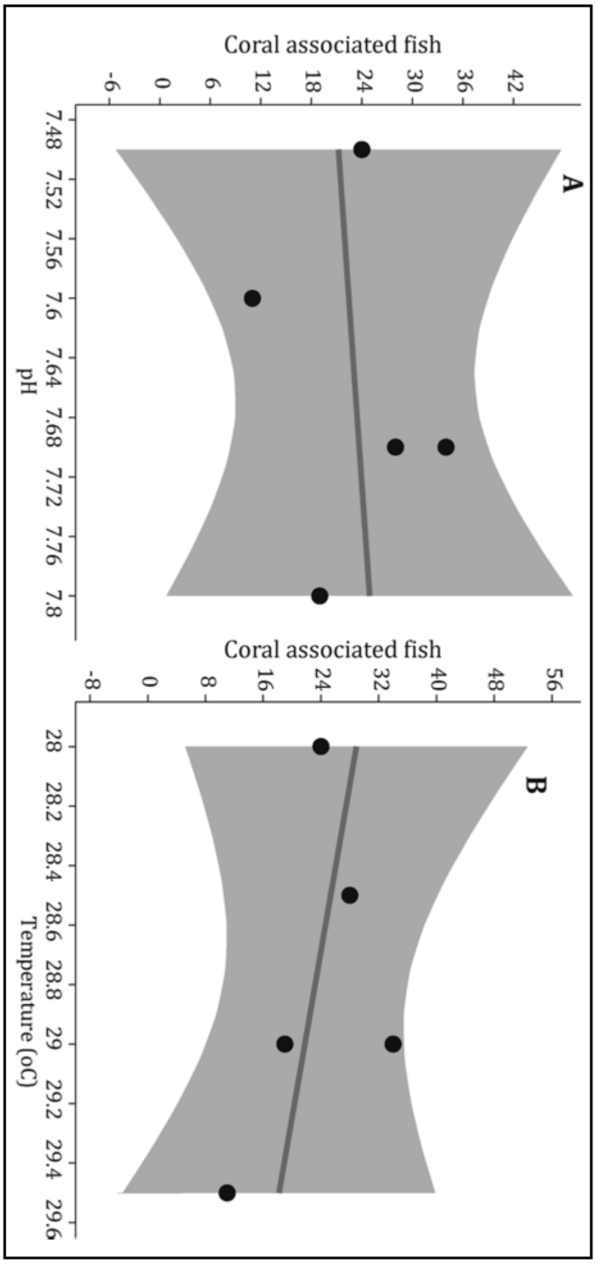


Figure 12. The effects of water pH and temperature on coral associated fish diversity in the Saint Martin's Island, Bangladesh

The northeaster part of the Saint Martin's Island is a sandy beach extending for about 5 km in a single stretch and averaging about 100 m in width at high tide. During low tide the rocky zone extend 0.8-1.0 km in the south-western coast, while 2.0-2.5 km in the south-eastern coast with 200-500 m width. Most of the sessile mollusc species, particularly the oysters, green mussels and barnacles are abundant in the rocky zone. The living corals are present in the rock pools that remain submerged during high tide.

Large coral fauna were observed in the rock pools of about 0.5-2.0 m depth surrounding the island (Hossain et al. 2007). Dense coral populations were observed in the east coast of Galachipa, southeast coast of Daskhinpara, rocky area of Siradia and southwest coast of Daskhinpara (Figure 13). Macro algae are produced naturally in the intertidal and subtidal zone surrounding the island. Huge quantity of uprooted and torn parts of algae used to be on the beach of east, west and south coast of the island due to tide, current and wave action of the Bay of Bengal.

Coral reefs function as habitat for commercial fish stocks, natural barriers protecting coastlines, and catalysts for recreation and tourism (Makarow et al. 2009). The value of coral reefs include direct use values such as coral mining and recreational opportunities, as well as indirect use values including coastal protection, and habitat and nursery functions for commercial and recreational fisheries (Brander et al. 2009). In addition, there is welfare value of preserving a unique diverse natural ecosystem (Brander et al. 2009). The global economic value of these reef services has been estimated to be $30 billion per year based on a value of $100,000 per km^2 per year (Cooley et al. 2009). Given their open access nature and role as a public good, reefs are usually undervalued in decisions that relate to their use and conservation (Brander et al. 2009).

The global economic value for only the shoreline protection provided by coral reefs is estimated to be $9 billion per year (Cesar et al. 2003) (Table 4). If reefs are compromised by acidification, the ecosystem services of coastline protection and shoreline

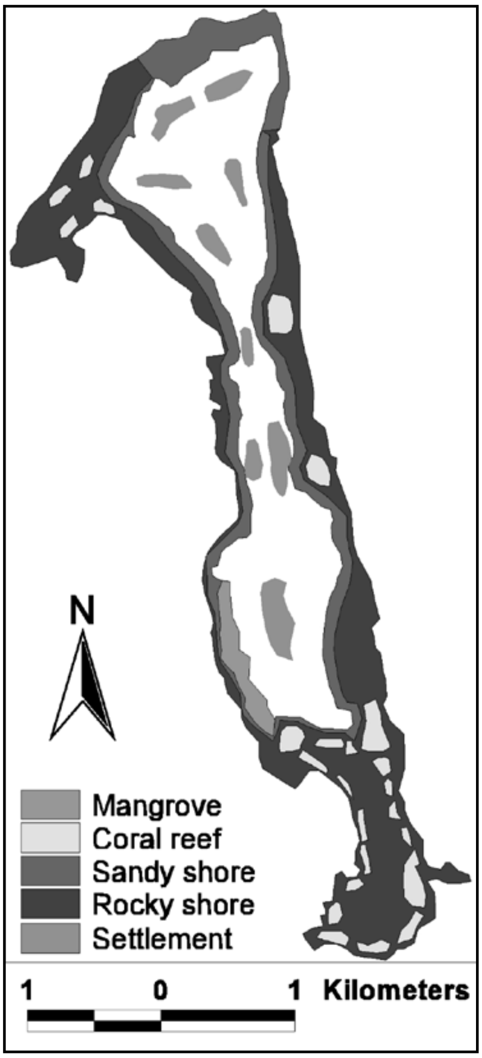


Figure 13. Extent and distribution of rocky shore, sandy shore and coral reef in the saint Martin's Island (Source: Hossain et al. 2008)

Table 4. Examples of ecosystem services provided by coral reefs (source: Cooley et al. 2009)

Nation	Year	Value (US $)	Source
Shoreline protection by coral reefs			
St. Lucia	2006	$28–50 million	Burke et al. 2008
Tobago	2006	$18–33 million	Burke et al. 2008
Belize	2007	$120–180 million	Cooper et al. 2008
Shoreline protection by mangroves			
Belize	2007	$120–180 million	Cooper et al. 2008
Direct economic impacts of coral reef tourism			
Tobago	2006	$43.5 million (15% of GDP)	Burke et al. 2008
St. Lucia	2006	$91.6 million (11% of GDP)	Burke et al. 2008
Indirect economic impacts of coral reef tourism			
Trinidad & Tobago	2006	$58–86 million	Burke et al. 2008
St. Lucia	2006	$68–102 million	Burke et al. 2008
Belize	Annually	$26–69 million	Cooper et al. 2008
Reef tourism direct and indirect impacts			
Belize	2007	$150–196 million	Cooper et al. 2008

stabilization would be lost (Cooley et al. 2009). This would result in greater economic losses from storms and require greater investment in seawalls and other fortifications to protect property and human lives (Cooley et al. 2009). Recent estimates found that projected damage to coral reefs due to acidification would result in a 0.18% loss in global gross domestic production in Year 2100 (Makarow et al. 2009). In 2000, the total area of coral reefs was 307,000 km^2, globally (Brander et al. 2009). Projections of lost coral reef area in Year 2100 due to acidification only, excluding degradation due to warming, sea level rise, and other pollution, range from 16% (30,000 km^2) to 27% (65,000 km^2) (Brander et al. 2009). These projected losses in coral reef area translate to economic losses of as much as $870 billion in Year 2100 (Brander et al. 2009).

3.3. Effects on shellfish

Increased acidity in ocean water is affecting the size and weight of shells and skeletons, and similar sort of problem is widespread across marine species. Different species-specific responses among molluscs have been observed, but majority of mollusc due to ocean acidification ate neutral to negative (Cooley et al. 2012). By examining four different types of marine animals, i.e. clams, sea snails, lamp shells and sea urchins, scientist found that as the availability of calcium carbonate decreases due to increased ocean acidification, thus skeletons get lighter and account for a smaller part of the animal's weight. The effect occurs consistently among the mentioned species suggesting that the effect is widespread across marine organisms, and that increasing ocean acidification will progressively reduce the availability of calcium carbonate.

Gazeau et al. 2007; Miller et al. 2009 also found decrease shell thickness and rate of calcification in shellfish as a resultant of ocean acidification. The rise in acidity makes seawater corrosive to many marine organisms, especially those that require calcium in their 'formative' growth stages, such as shellfish larvae. The shellfish industry, therefore, is the first to bear the burden of the chemical changes taking place in the oceans' pH levels, as they require calcium carbonate for external shell formation. Molluscs are important aquaculture species, and provide a small but significant protein source for the humans (Turley and Boot 2010). Recently, molluscs production has experienced a sharp drop due decrease in ocean pH values (Berge et al. 2006). Physiological impacts induced by lowered pH have the potential to affect a shellfish at any stage in its life cycle; however, adults tend to have more protection as well as better mechanisms to deal with a fluctuating environment with early life stages tending to be more vulnerable. In nature, large numbers of larvae are often produced by the organisms which have high rates of larval mortality, for example, coastal estuarine bivalves experience more than 98% mortality during settlement (Turley et al. 2006). The oyster (Ridgwell and Schmidat 2010), echinoderm (Fabry et al. 2008) and fish larvae (Guittuso and Hansson 2011) as well as barnacle, tube worm and copepod eggs have all been found to either be increasingly malformed or have slower rates of development at higher CO_2. Moreover, barnacle settlement has also been affected due to elevated CO_2 (Hendriks et al.

Table 5. The effects of ocean acidification on different mollusc species, negative effects (decreasing trend) are denoted by minus sign

Species	Experimental organ/stage	References
Mercenaria mercenaria		Green et al. 2004
Pinctada fucada	Shell (-)	Knutzen 1981
Tivela stultorum	Fertilization rate (-)	Alvarado-Alvarez et al. 1996
Placopecten magellanicus	Fertilization (-), Embryo (-)	Desrosiers et al. 1996
Mytilus galloprovincialis	Metabolism (-)	Michaelidis et al. 2005
Mytilus edulis	Calcification (-)	Lindinger et al. 1984
Haliotis laevigata		Harris et al. 1999
Crassostrea virginica	Calcification (-)	Miller et al. 2009
Mercenaria mercenaria		Talmage and Gobler 2009
Crassostrea virginica	Calcification (-), Metabolism (-)	Ries et al. 2009
Mercenaria mercenaria	Calcification (-)	Beesley et al. 2008
Mya arenaria	Calcification (-)	Gazeau et al. 2007
Mytilus galloprovincialis	Shell (-)	Michaelidis et al. 2005
Saccostrea glomerata		Parker et al. 2010
Strombus alatus	Calcification (-)	Ries et al. 2009

2010). Finally, nutrition and income that come from shellfish is going towards a vulnerable state due to ocean acidification. The effect of ocean acidification on mollusc species is shown in Table 5.

The effects of water pH and temperature on the settlement and growth of oyster spats were assessed by linear regression analysis from two different temporal spectrum (2004 and 2012) but in same temporal scale in the Cox's Bazar coast, Bangladesh (Figure 14). The water temperature and pH data were used from Hossain et al. (2004) and ECOBAS (2012). All data were tested for normality and the effects were calculated at 95% confidence intervals. Data points are value of spat density and pH and spat size and pH for 2004 and 2012. The dashed line shows the regression line, whereas the shaded lines represent the 95% confidence intervals. Findings show that, with increase of pH, spat settlement and growth is decreasing which indicate decrease in pH will inversely effect the spat settlement and growth rate at Cox's Bazar coast, Bangladesh (Figure 15).

ECOBAS (2012) is the integrated efforts of the IMARES Wageningen UR, Royal Haskoning, LEI and Chittagong University addressing the "Building and Farming with Nature" can easily be embedded in the multi-annual strategic plan for the Dutch-Bangladesh future bilateral cooperation as it is being developed in the context of the CIWK (Information Chain for Water, Food and Climate Services). Some shellfish species in the coastal waters of Bangladesh such as oyster (*Crassostrea madrasensis*), green mussel (*Perna viridis*) and clam (*Meretrix meretrix*) can be potentially used as ecosystem engineers and grown naturally to adapt ecosystem-based solutions for coastal defence. These organisms are capable of forming conspicuous habitats that influence tidal flow, wave action and sediment dynamics in the coastal ecosystem and, in doing so, reduce hydrodynamic stress and modify the patterns of local sediment transport, deposition, consolidation, and stabilization processes (Figure 16). Besides, the bivalve reefs also support habitat for numerous species of fish, crustaceans and shellfish, can provide food/protein security, and contribute to a healthier ecosystem with multiple benefits and functions.

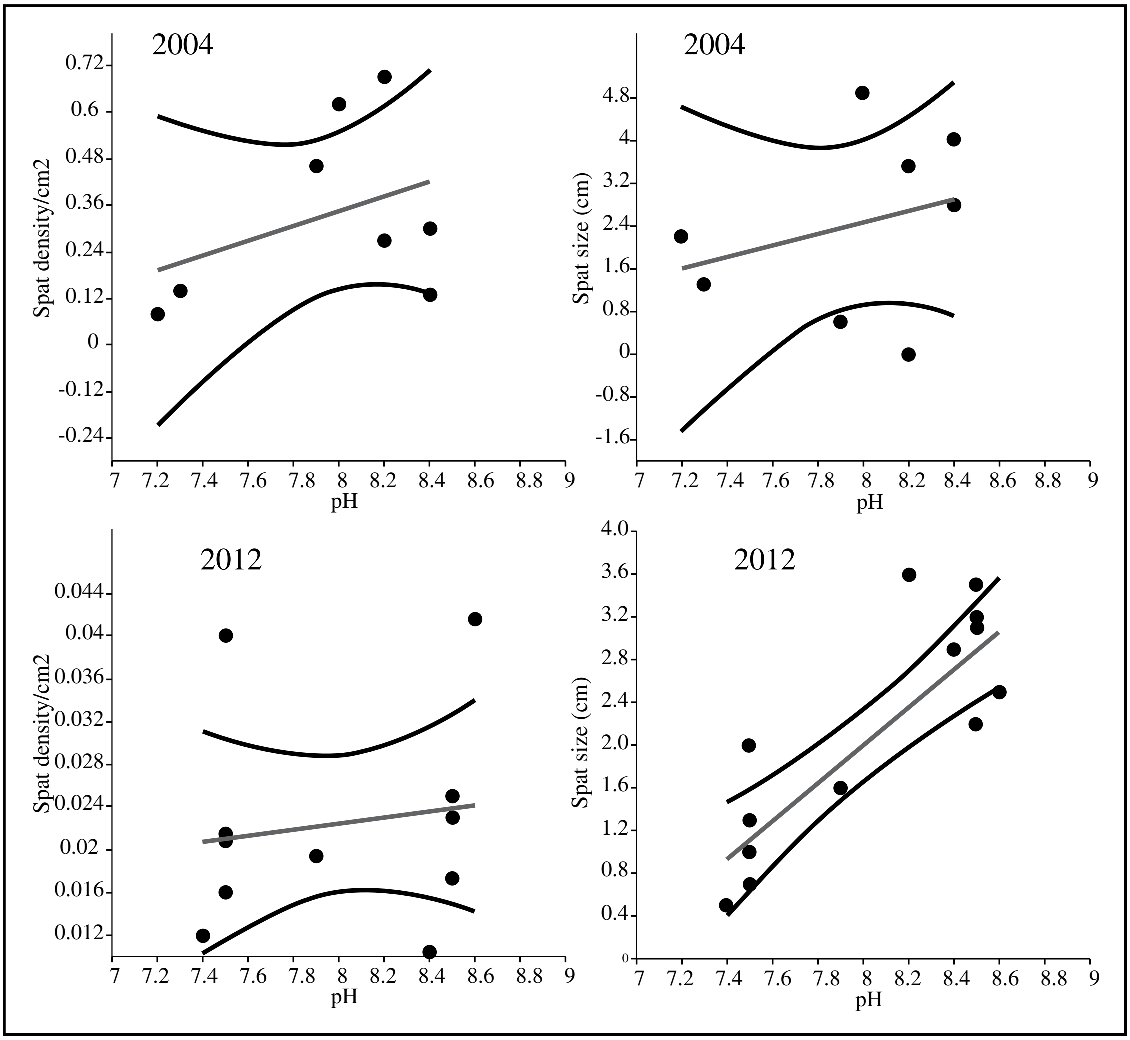


Figure 14. Effect of pH and temperature on oyster spat density and growth at Cox's Bazar coast, Bangladesh (Hossain et al 2004; ECOBAS 2012)

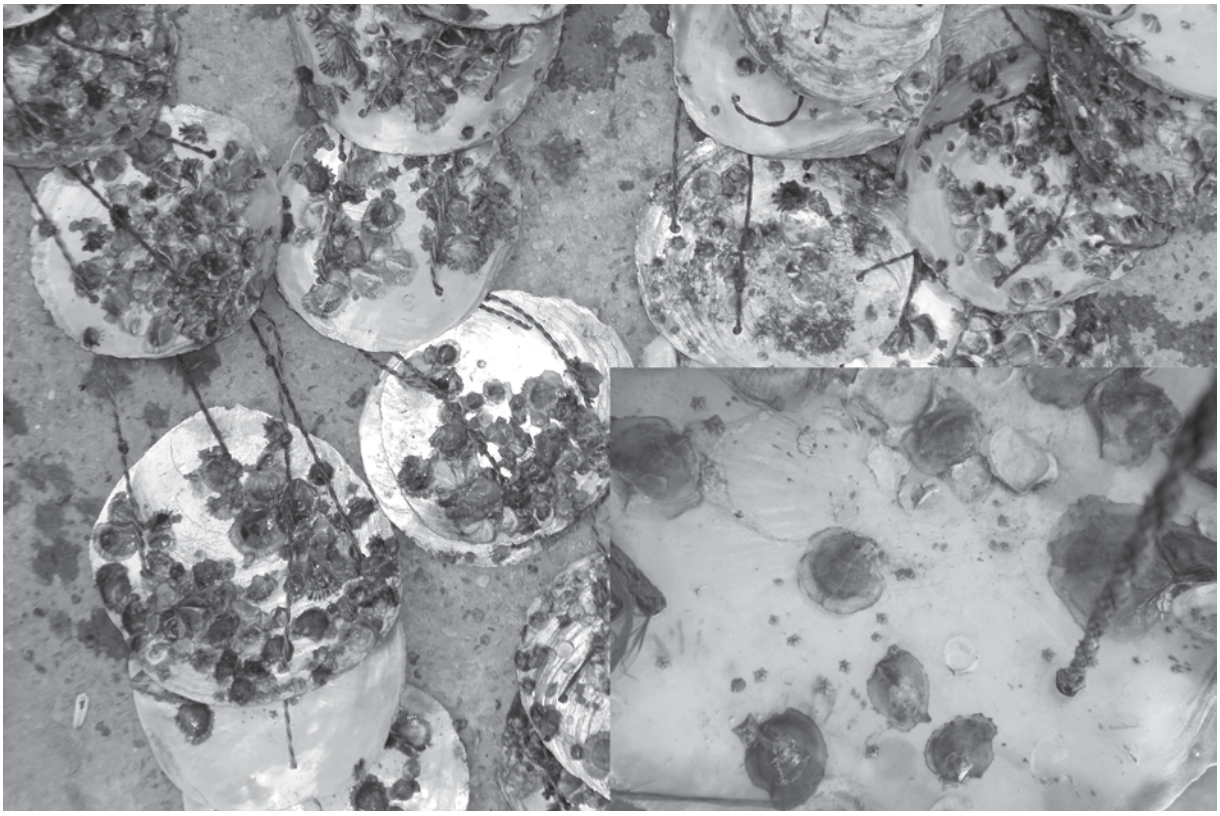


Figure 15. Settled oyster spats on the windowpane shell in the Cox's Bazar coast, Bangladesh (ECOBAS 2012)

Figure 16. The green mussel population in the Moheshkhali Island, Cox's Bazar (ECOBAS 2012)

3.4. Effects on commercial fisheries

Oceanic ecosystem supports rich and diverse fisheries that form an integral component of the ecosystem and are associated with economic and other societal benefits. The acidity of the oceans is one important parameter that influences fisheries production; others include ocean temperature, availability of nutrients and other factors affecting primary productivity, and the state of fish stocks. The state of fish stocks is determined by 'natural' factors influencing recruitment and mortality, and also, importantly by fishing pressure, which in turn is determined by fisheries management. Adult marine fish are generally tolerant of high CO_2 conditions (Melzner et al. 2009) and juvenile stages are most sensitive to changes in acidity, coupled with changes in seawater temperature. As these stages are also those affected most by over fishing of mature animals, it is particularly important that we understand the potential additional stress that ocean acidification may induce on these organisms and those that support them. Responses by juveniles and larvae to ocean acidification include diminished olfactory and auditory ability that affecting predator detection and homing ability in coral reef fish (Munday et al. 2010), reduced aerobic scope (Munday et al. 2009) and enhanced otolith growth in seabass (Checkley et al. 2009), however, the relative insensitivity of crustaceans to acidification (Ries et al. 2009) has been ascribed to well-developed ion transport regulation and high protein content of their exoskeletons (Krocker et al. 2010). Nevertheless, spider crabs show a narrowing of their range of thermal tolerance by approximately 2^0C under high CO_2 conditions (Walther et al. 2009). Mortality occurred in fish species only at very high CO_2 levels (50,000 ppmv), although mortality due to anthropogenic CO_2 is never expected in marine environments (Hayashi et al. 2004). The hatchling stages of some species appeared fairly sensitive to pH decreases on the order of 0.5 or greater, but high CO_2 tolerance developed within a few days of hatching (Ishimatsu et al. 2004) and also causes depress metabolism in some species (Hand 1991; Pörtner and Reipschläger 1996; Guppy and Withers 1999). The effects of ocean acidification on some fish species are summarized in Table 6. Examples of the response of marine fauna to ocean acidification are shown in Appendix-E.

Table 6. The effects of ocean acidification on different mollusc species, negative effects are denoted by minus sign, positive effects plus sign and no effect 0

Species	Growth	Survival	Others	References
Amphiprion percula	0	0	Embryonic duration (0)	Munday et al. 2009
Rainbow trout	+		Energy conversion efficiency (+)	Dockray et al. 1998
Sillago japonica		-		Kikkawa et al. 2006
Pagrus major		-		Ishimatsu et al. 2005
Euthynnus affinis		-		Kikkawa et al. 2003
Paralichthys olivaceus		-		Hayashi et al. 2004
Clupea harengus	-		Metabolism (-)	Franke and Clemmesen 2011
Scyliorhinus canicula			Embryogenesis (-)	Davenport 1987
Gadus morhua		-		Frommel et al. 2011
Anarhichas minor	-		Metabolism (-)	Foss et al. 2003
Sparus aurata	-		Metabolism (-)	Michaelidis et al. 2007
Acanthochromis polyacanthus			Sagittal otoliths (-)	Munday et al. 2011
Oncorhynchus mykiss			Sagittal and lapillar otoliths (-)	Payan et al. 1999
Psetta maxima			Sagittal and lapillar otoliths (-)	Payan et al. 1999
Dicentrarchus labrax			Feeding (-)	Small et al. 2010
S. canicula		-		Small et al. 2010
Gadus morhua			Stock (-)	Toresen and Østvedt 2000
Pomacentrus amboinensis			Sensory organ (-)	Ferrari et al. 2012
Sparus aurata			Metabolic capacity (-)	Michaelidis et al. 2007
Seriola quinqueradiata		-	Cardiac output (-)	Ishimatsu et al. 2004

In acidic seas, it is required to domesticate resistant species for successful aquaculture operations

Marine fishes are playing the central role in meeting the demand of animal protein supply in Bangladesh. The total production of fisheries from 1950-2009 is shown in Table 7. Data are discussed at 10 years intervals emphasizing capture fisheries, culture fisheries and total fisheries production. Marine capture fisheries contributed 5.5% of the total capture during 1950-1959 which increased to 28.8% in 2000-2009. Similarly, coastal culture fisheries contributed 5.9% during 1950-1959 which increased to 32.1% in 2009-2009. Trade and export of fisheries commodity is also showing an increasing trend (Figure 17).

Table 7. Annual average catch of marine fisheries in Bangladesh from 1950-2009 (FAO, 2012)

Year	Marine capture fisheries	% total capture	Marine culture fisheries	% of total culture	Total marine fisheries	% of total
1950-1959	335000	5.5	2426103	5.9	2761103	5.9
1960-1969	511600	8.4	4952471	12.1	5464071	11.6
1970-1979	701209	11.6	6369497	15.6	7070706	15.1
1980-1989	980811	16.2	6192072	15.1	7172883	15.3
1990-1999	1784722	29.5	7823183	19.1	9607905	20.5
2000-2009	1744897	28.8	13148945	32.1	14893842	31.7
Total	6058239	100	40912271	100	46970510	100

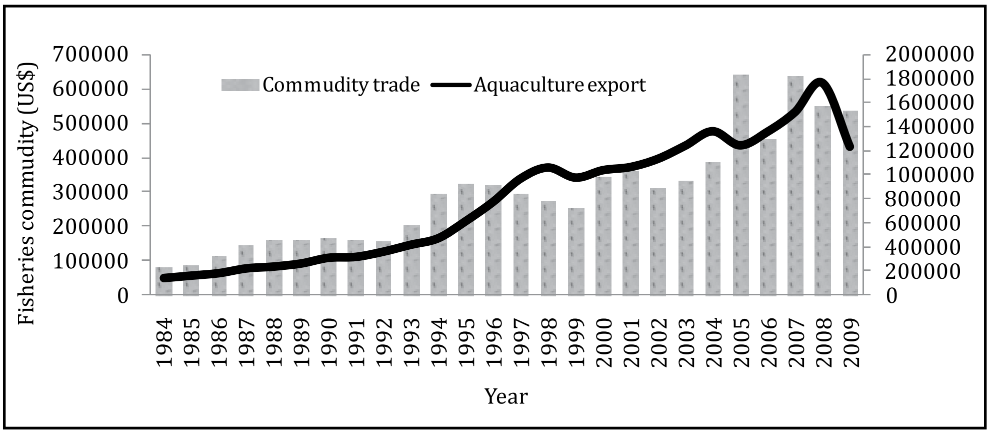
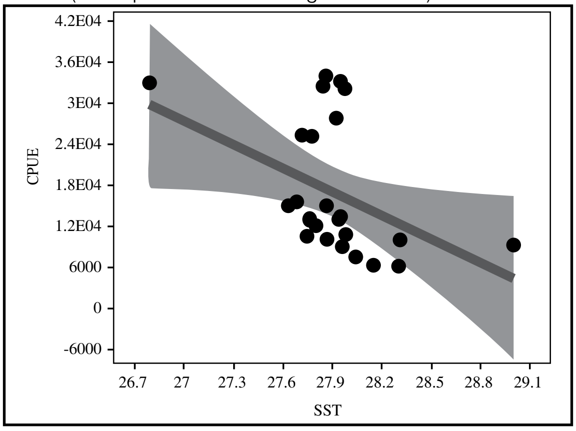


Figure 17. The trends in international fish trade of Bangladesh from 1984-2009 (FAO 2012)

The effects of SST on catch per unit effort (CPUE) were assessed by linear regression analysis (Figure 18). CPUE data were calculated from total yearly catch data of 1986-2010 and SST data were derived from WOD09 for the same time period. All data were tested for normality and the effects were calculated at 95% confidence intervals. Data points are value of SST and CPUE from the 1986-2010 time periods. The dashed line shows the regression line, whereas the shaded lines represent the 95% confidence intervals. Findings show that, with increase of SST, CPUE is decreasing ($R^2 = 0.79$) which is indicating a lower production of marine capture fisheries.

Figure 18. The effects of increasing SST on marine capture fisheries (catch per unit effort during 1986-2010)



Though the total fisheries commodity trade and aquaculture product export increased over the period (Figure 17), the CPUE is decreasing (Figure 18). Negative value in figure 19 shows a decline in CPUE from the previous year and positive value indicate increase in CPUE from the previous year. Accumulating the decline and increased rate of CPUE for each year form 1986-2010 time period, a declining trend is observed for the net CPUE.

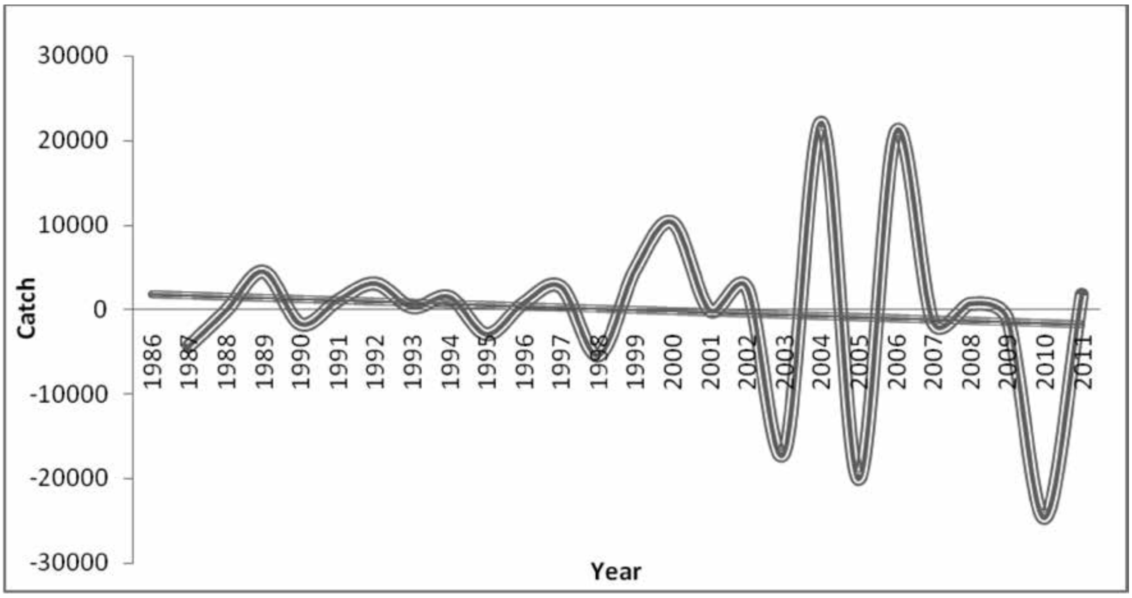


Figure 19. The changes in CPUE from 1986-2010 in the Bay of Bengal

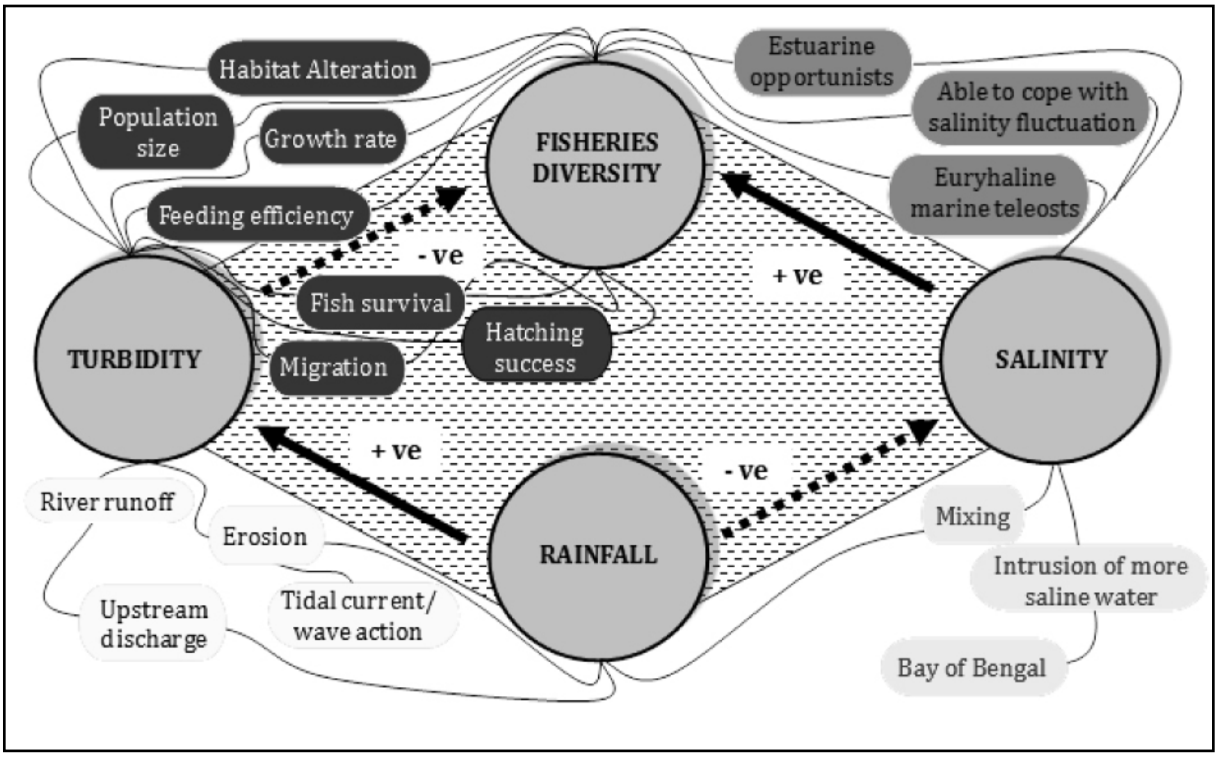


Figure 20. Interactions among the major environmental variables and their effects on the fisheries diversity of Naaf River, Cox's Bazar (Chowdhury et al. 2011)

Chowdhury et al. (2011) reported the major environmental variables and their effects on fisheries diversity at the Naaf River estuary (Figure 20). The Naaf River is a highly diverse fisheries ecosystem with favourable water quality than that of many other river/estuarine systems in Bangladesh.

The environmental aspects i.e. hydrological and meteorological parameters are act as a driving force for fisheries distribution at the Meghna river estuary. Regarding spatial and temporal fish assemblage structure, two major groups were indicated by cluster analysis in the Meghna river estuary (Hossain et al. 2013). Group 1 comprises the sample of the February, March and April of 2003. On the other hand Group 2 is formed by November, December and January of 2003 and showed 32% similarity with Group 1 (Figure 21). Water pH was the most important hydrological factors followed by dissolved oxygen, transparency and water temperature on species distribution at the Meghna river estuary (Figure 22).

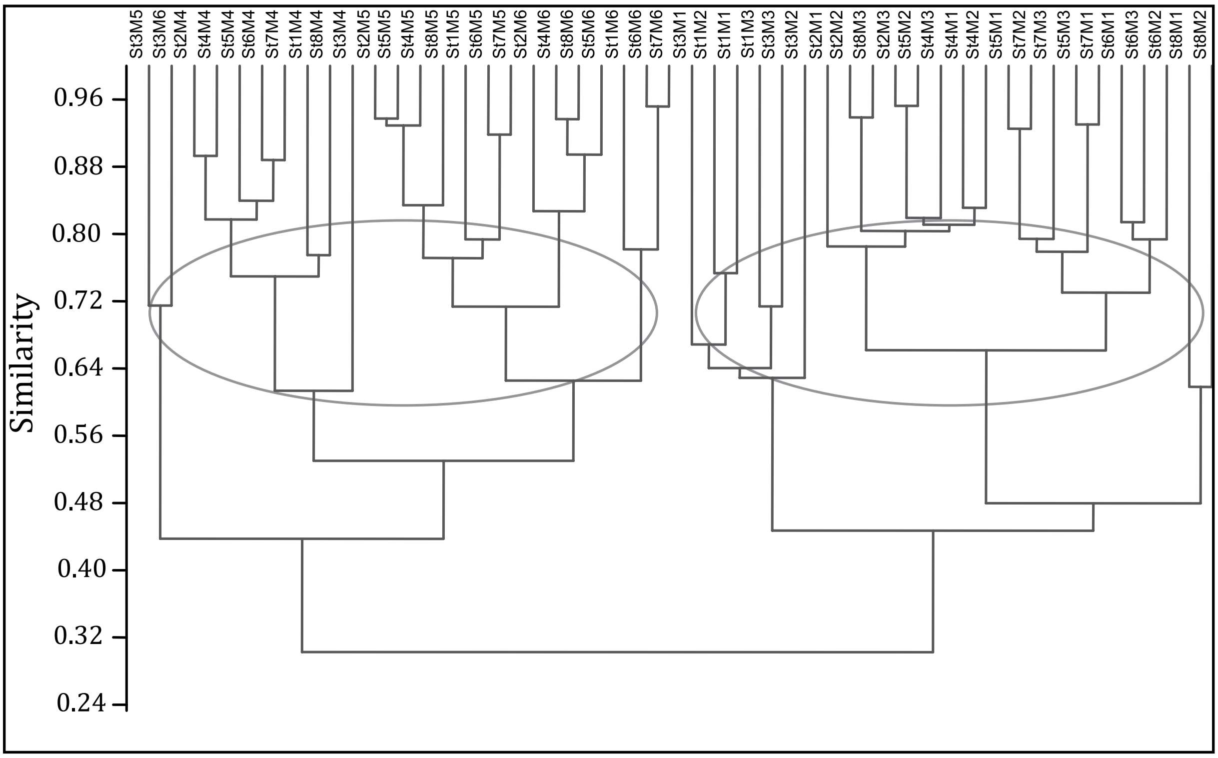


Figure 21. The spatial and temporal cluster of fish assemblage (a Bray-Curtis similarity matrix) in the Meghna estuary (Hossain et al. 2013)

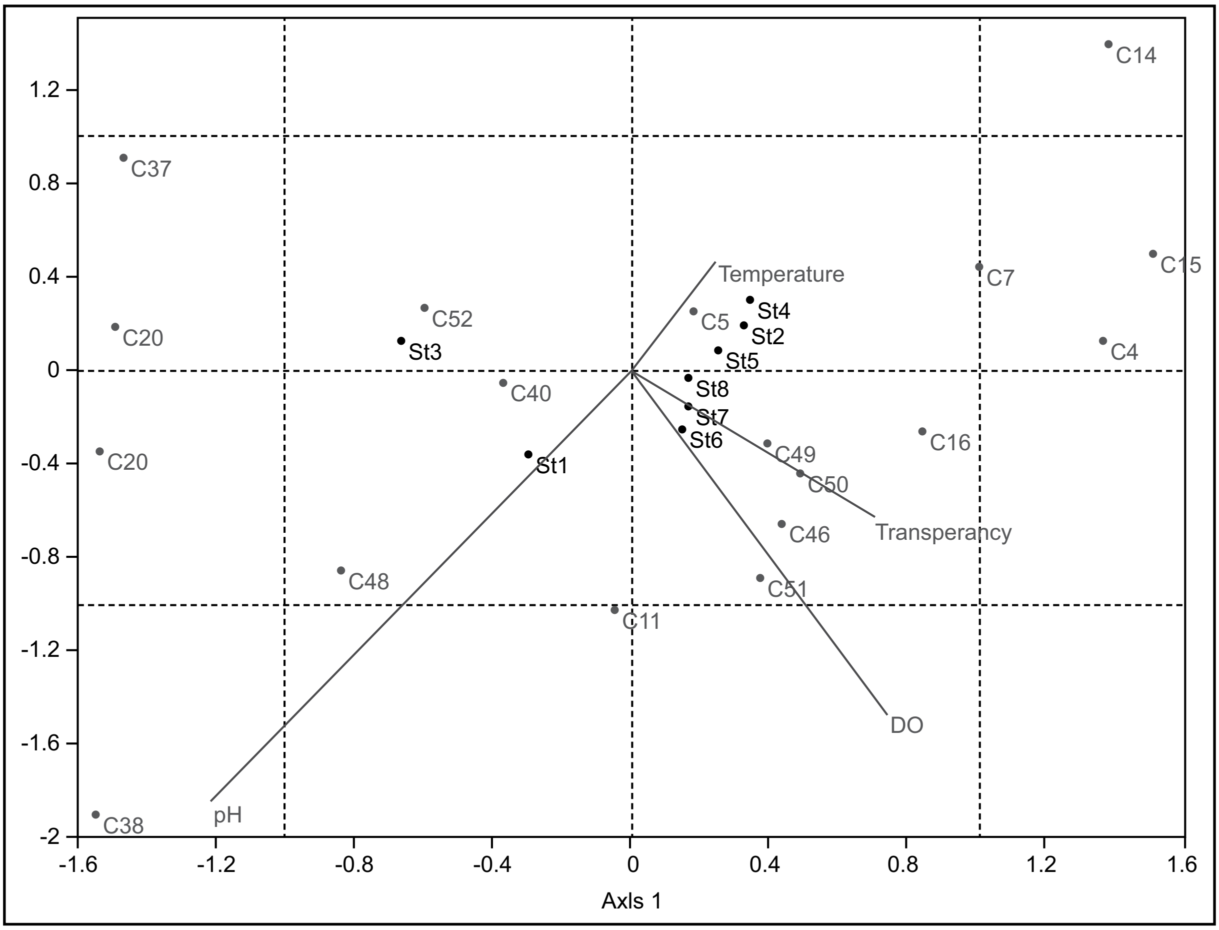


Figure 22. Canonical correspondence analysis of fish species abundance with hydrological parameters in the Meghna estuary (Hossain et al. 2013)

3.5. Effects on mangrove forest

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, operating in improving coastal protection and acting as a source of nutrients that sustain many complex food chains (Kovacs 1999; Hossain 2013). The protective benefits of mangrove forest against tropical cyclone and wave action is important and well-recognized (Hossain et al. 2003; Barbier et al. 2008). The importance of mangroves as nursery grounds of larval and juvenile stages of finfishes, shrimps, crabs, and cockles has highlighted by many researchers around the world (Mahmood et al. 1985; Khan and Hossain 1996; Hossain 2001; Glaser 2003; Lee 2004; Hossain et al. 2009) (Appendix-F). The annual economic value of mangroves, estimated by the cost of the products and services they provide, is about US$ 200,000-900,000 per ha (Wells 2006). Important goods and services of mangroves upon which local community can ensure their daily demand are shown in Figure 23. Fishing, shrimping and crabbing in the mangrove forest and adjacent areas is an important source of income and livelihood option in the islands of Ganges basin (Hossain 2013).

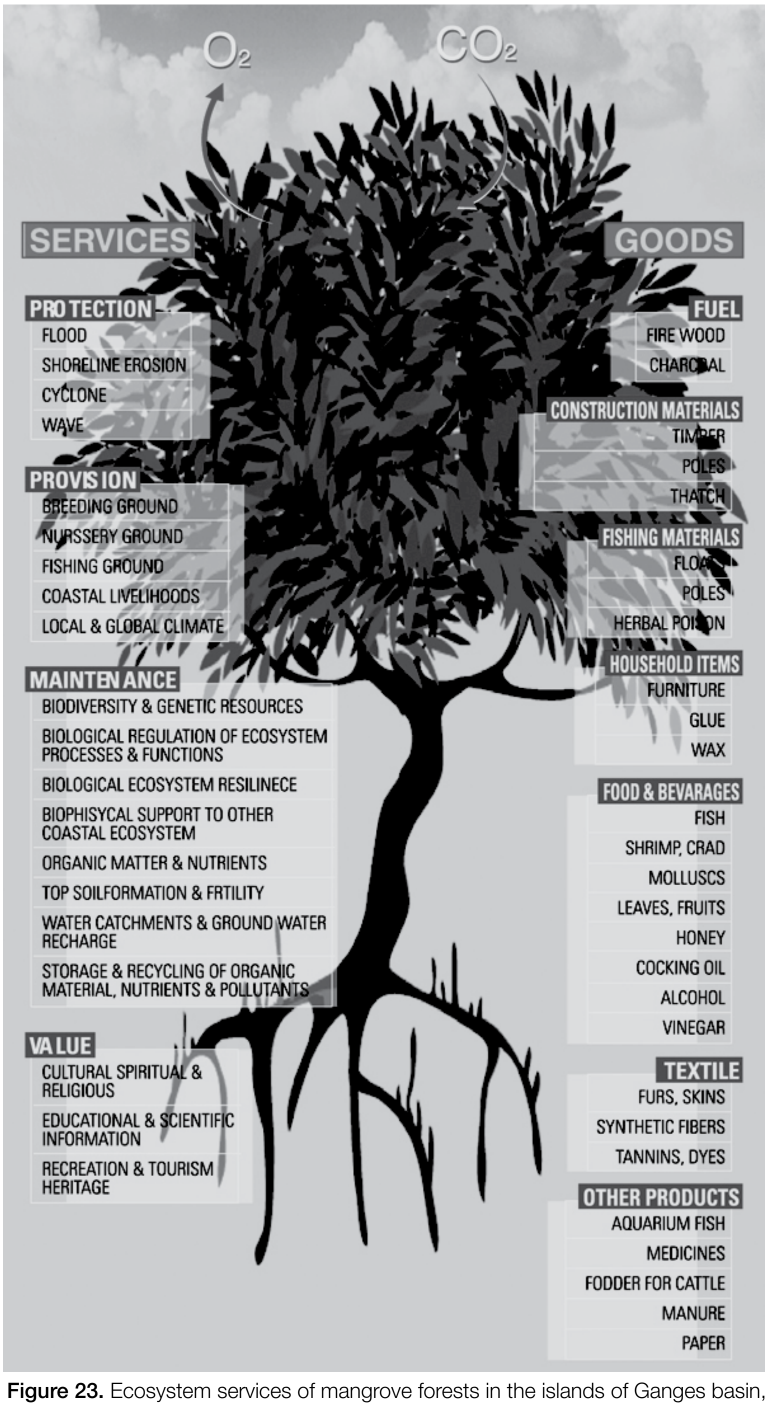


Figure 23. Ecosystem services of mangrove forests in the islands of Ganges basin, Bangladesh (Hossain 2013)

The environmental impacts of ocean acidification on mangrove ecosystem are not well documented. Increased CO_2 causes reduction in water pH which also reducing soil pH and responsible for damaging mangrove vegetations. Low soil pH may damage breathing roots of mangroves and causes mortality. Acidification can also cause physical damage and altered topography and hydrology. Van Breemen et al. (1973), while working in humid tropical mangrove in Thailand found that acidification causes dying from the root upwards. At the site of vegetation damage, fish usually die a year later at the onset of the rainy season. The fiddler crab (*Uca tangeri*) and mudskippers (*Periophthatmus koelreuteri*) that used to be abundant in these areas are becoming less common.

The Bangladesh coast supports about 587,380 ha of natural mangroves and a further 100,000 ha of planted mangroves. Declining of mangrove ecosystem due to acidification will not only causing colossal loss of coastal habitat, aquatic resources and biodiversity, but also will increase soil erosion, changes in sedimentation pattern and shoreline configuration, vulnerability to cyclonic storms, tidal bore and denudation of feeding, breeding and nursery ground for various marine, estuarine and fresh water fishery resources. As a result, natural shrimp fry as well as shrimp brood, which supports exportable shrimp farming in Bangladesh; availability will be greatly reduced in the Bay of Bengal (Hossain 2001).

3.6. Effects on coastal ecosystems

Coastal ecosystems, like most other ocean ecosystems, are feeling the effects of anthropogenic problems such as climate change, ocean acidification and eutrophication due to excessive nutrient runoff. Many of the physiological changes from ocean acidification are expected to affect key functional groups of organisms that play a disproportionately important role in ecosystems. These include expected effects on phytoplankton, which serve as the base of food webs. Such changes may lead to indiscriminate shifts in composition, structure and function of ecosystem and ultimately affect the goods and services provided to society. Mangrove and coral reef ecosystems are providing services and goods such as coastline protection from storm waves and shoreline stabilization. Declining of these ecosystems due to ocean acidification will make coastal development expensive (Cesar et al. 2003). Moreover, without coral reefs and mangrove forest, coastal ecosystems would lose valuable habitat and diversity. Oysters and mussels rely on $CaCO_3$ for the formation of their protective exoskeleton. Likewise many other organisms rely on these molluscs for services such as providing habitat and protection. Thus the effects of ocean acidification will not only affect those organisms dependent on $CaCO_3$ for skeletal construction, but it will also severely affect all those smaller organisms that depend on those larger ones for protection and habitat as well as those organisms (including humans) that rely on them as sources of food. Thus, evidences demonstrating that ocean acidification can damage coastal ecosystems, including species extinction and insecure community livelihoods. However, these impacts are highly species-specific and even population-specific. Probable effects of ocean acidification on coastal ecosystem of Bangladesh are shown in Figure 24.

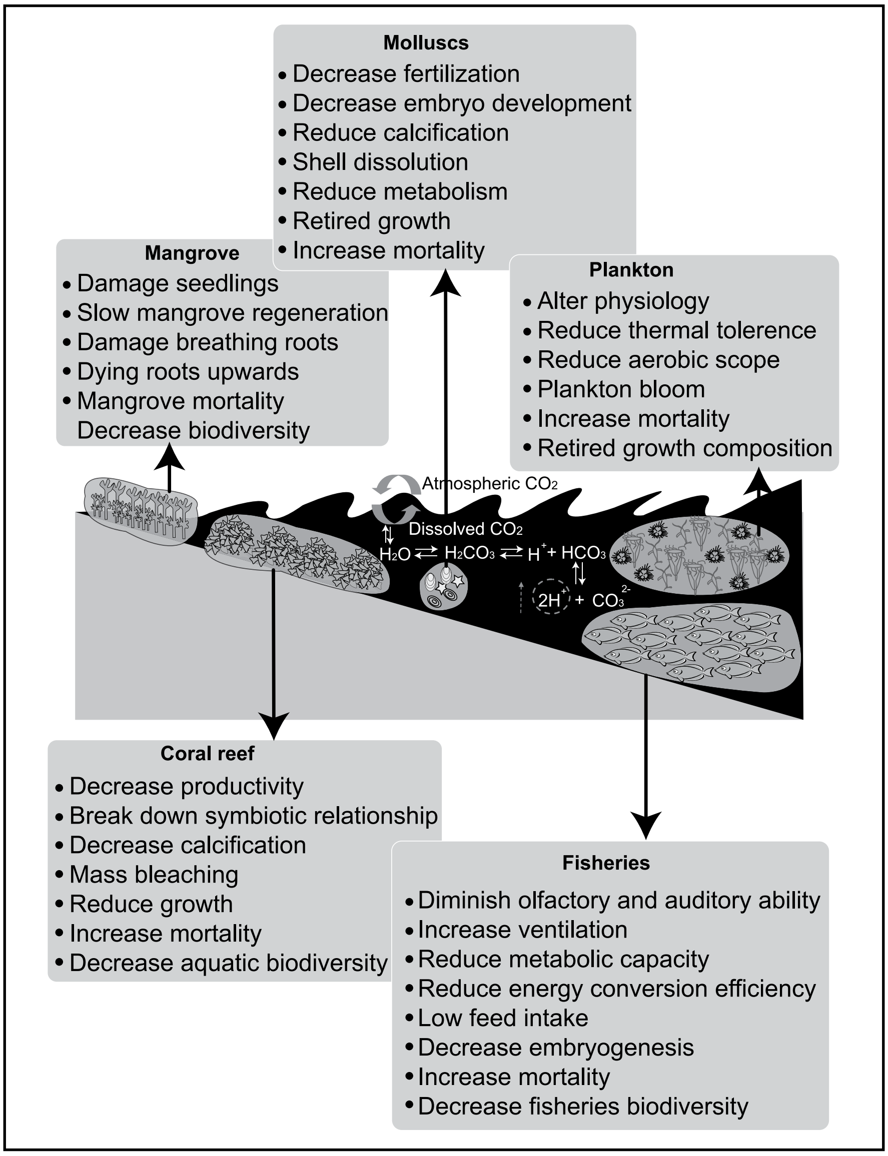


Figure 24. Probable effects of ocean acidification on the coastal ecosystems of Bangladesh

Ocean acidification will badly reduced coastal community's resilience by affecting fish habitats..
© Sumon Karmokar/ Save Our Sea

4. Effects of Ocean Acidification on Coastal Livelihoods

Ocean acidification is likely to affect organisms that support subsistence, commercial, and recreational fisheries, thereby impacting the ability of those ecosystems to provide services upon which humans have been dependent (Cooley et al. 2009). Coastal people naturally have the skills and knowledge on fishing, shrimping, crabbing, agriculture, livestock raising, trading and other occupations in the locality. A typical example of islands occupation diversity from Nijhum Dwip is given in Figure 25. These people, by their skills, are using the natural resources in a responsible way to achieve a higher income and food security.

Changes in climatic conditions will have many health effects, via stresses on human biology, environmentally mediated exposures (infectious diseases, food yields etc.) and the physical risks of injury (McMichael et al. 2006). These effects will occur via direct and indirect pathways and across different timescales. Livelihoods from fisheries, farming and forestry are at risk in many vulnerable regions of the world. The impacts of climate change on food yields and livelihoods will therefore also affect mental health and health-related behaviours. The indirect impacts on health are well illustrated by the consequences of the recent warming of the Arctic region, which is occurring more rapidly than that for the world at large. The resultant loss of ice (both sea-ice and permafrost) has begun to disturb traditional living, hunting and eating patterns among the Inuit communities of northern Canada. This has caused a decline in physical activity and a greater reliance on imported energy-dense processed foods, resulting in a much greater probability of adverse health consequences, especially obesity, cardiovascular disease and the occurrence of diabetes (McMichael et al. 2006).

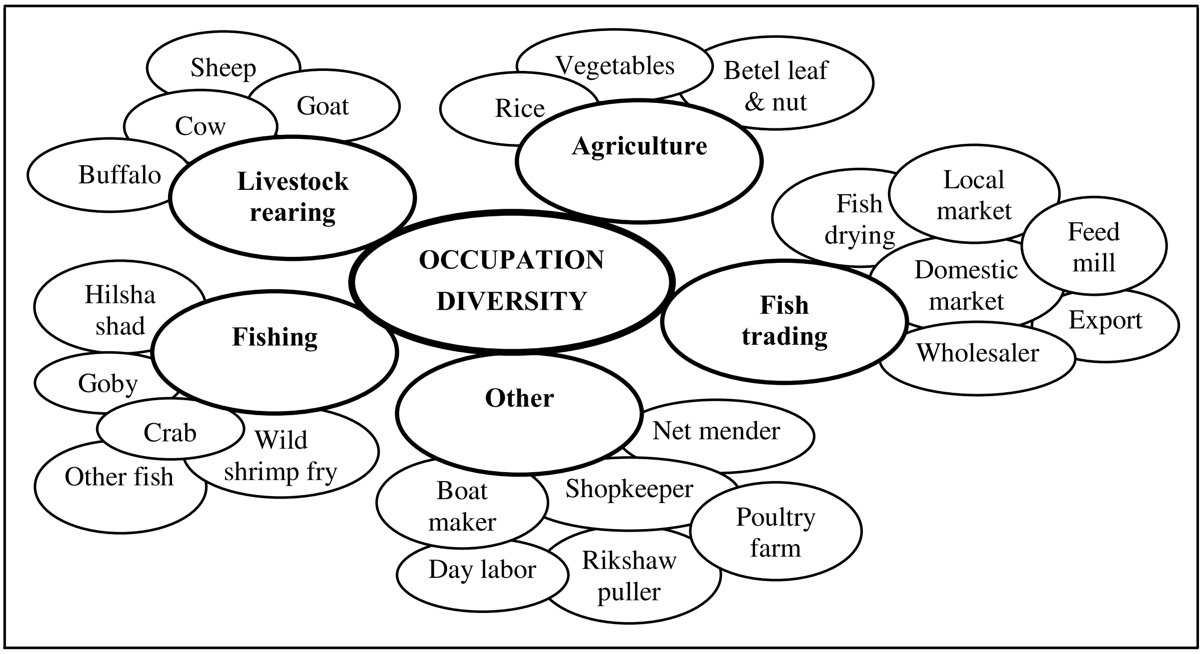


Figure 25. A Venn diagram illustrating the occupation diversity of coastal community at Nijhum Dwip (Hossain et al. 2013)

4.1. Fishing communities and aquafarmers

The global marine capture fisheries and aquaculture industries provided 110 million metric tons of human food in 2006 with a commercial value of $170 billion (FAO 2009). The value of global fisheries associated with coral reefs alone is estimated to be $5.7 billion per year (Conservation International 2008). Changes in these industries due to acidification are likely to disproportionately affect developing nations who often rely more on marine-related economic activities than the developed nations. Projections of population increase and acidification rates suggest that by 2050, low-latitude regions will be most affected, and also the nations that rely upon tropical marine ecosystems, which would adversely affected by acidification (Cooley et al. 2009). The total economic value generated by fisheries, including wild fish and aquaculture, is estimated to be $150 billion per year (Makarow et al. 2009). In 2000, recreational saltwater fishing produced $12 billion income, supported 350,000 jobs, and generated a total economic benefit of $43 billion in the United States (Cooley et al. 2009). If acidification damages marine habitats or reduces harvests, the resulting decline in revenues could produce job losses with additional indirect economic costs (Cooley and Doney 2009b).

4.2. Livestock raiser

Ocean acidification effects on a single organism is not always negative; phytoplankton photosynthesis is generally enhanced (Riebesell and Tortell 2011), and some seagrass species even thrive in low pH environments (Hall-Spencer and Rodolfo-Metalpa 2008), but scientific information on the existence of seagrass beds is lacking. In the coastal region generally sea fronts of newly formed islands and some low-lying coastal areas are found to be carpeted with seagrasses (Hossain 2001). Cow and buffalo are reared on grass (Figure 26) for milk and meat. Milk indigenously preserves for natural yogurt, ghol (indigenous yogurt drink) and ghee (butter for cooking) preparation to supply in city markets.

Figure 26. Grass beds with mangroves and buffalo grazing at the Sonadia Island, Cox's Bazar (August 2012)

Sheeps graze in nearshore coastal grasslands of Hatiya island

5. Mitigation of Ocean Acidification Impact

5.1. National institutional framework

Government Ministries and Agencies

The main ministries of the Government of Bangladesh involved in climate change are the Ministry of Environment and Forests and its agencies (e.g. the Department of Environment – DoE and Department of Forests – DoF); Food and Disaster Management (MoFDM), which includes the Disaster Management Bureau (DMB) and the Comprehensive Disaster Management Programme (CDMP); Water Resources, which includes the Bangladesh Water Development Board and other research and forecasting organizations; Local Government Engineering Department (LGED) and the Department of Public Health Engineering (DPHE); Agriculture, including the National Agricultural Research System, which develops new crops and practices suited to different climatic and salinity conditions in the country; Livestock and Fisheries; Power, Energy and Mineral Resources; Health and Family Welfare; Roads and Railway Division, Ministry of Communication; Ministry of Foreign Affairs and the Planning Commission which is charged with the framing of development plans as well as approval of programmes and projects. Key roles and responsibilities of some of these organizations are given in Table 8.

Table 8. Examples of entity actions to promote, implement, and support adaptation at all scales

Entity	Key roles and responsibilities
The Ministry of Environment and Forests	The Ministry of Environment and Forests is the focal ministry for all work on climate change, including international negotiations. It provides the Unit for the National Environment Committee, which ensures a strategic overview of environmental issues and is chaired by the Prime Minister. Immediately after the Bali Conference (COP 13), the Government formed the National Steering Committee on Climate Change. It is headed by the Minister, the Ministry of Environment and Forests, and comprises secretaries of all relevant ministries and civil society representatives. It is tasked with developing and overseeing implementation of the National Climate Change Strategy and Action Plan. Five technical working groups were also constituted on adaptation, mitigation, technology transfer, financing and public awareness.
The National Disaster Management Council (NDMC)	The National Disaster Management Council (NDMC), headed by the Prime Minister, is the highest-level forum for the formulation and review of disaster management policies. The Inter-Ministerial Disaster Management coordination Committee is in charge of implementing disaster management policies and the decisions of the NDMC, assisted by the National Disaster Management Advisory Committee.
The Ministry of Food and Disaster Management	The Ministry of Food and Disaster Management is the focal ministry for disaster management. Its Disaster Management Bureau (DMB) is the apex organization responsible for coordinating national disaster management interventions across all agencies. It is a technical arm of the Ministry of Food and Disaster Management. It oversees and coordinates all activities related to disaster management at national and local levels. In 2000, the Government published Standing orders on Disasters, which provide a detailed institutional framework for disaster risk reduction and emergency management and defines the roles and responsibilities of different actors. The Comprehensive Disaster Management Programme (CDMP), a donor funded programme, aims to strengthen the DMB and shifts the emphasis away from relief of disaster preparedness and risk reduction.
Bangladesh Meteorological Department (BMD) and Space Research and Remote Sensing Organization (SPARRSO)	BMD and SPARRSO under the Ministry of Defence; the Flood Forecasting and Early Warning Centre (FFEWC) and Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources are two of the key institutions in this field. BMD takes responsibility for preparing all weather forecasts and disaster warnings through interconnected subdivisions (Figure 27). As the coastal people are used to facing multiple hazards each year, their responses to warnings depend on the intensity of wind speed, experience of hazards, local belief in the probability of dangerous climatic events, or the presence of a cyclone signal hoisted by the Bangladesh Meteorological Department.
The Planning Commission	The Planning Commission being the final approving authority under the Ministry of Planning which is preparing the Sixth Five Year Plan will look into the over-all integration of climate change issues within the planning framework as well as be the final approving authority for programmes and projects to be carried out as part of the implementation of the Action Plan.
Others	There are 35 more other ministries also responsible for sectors that are vulnerable to the effects of climate change, including agencies responsible for water resources, health, agriculture, urban planning, roads and transport.

Entity	Key roles and responsibilities
Non-government Organizations (NGOs)	Many non-government entities have been significant actors in the national effort to prepare for climate change by providing assistance that includes planning guidance, implementation tools, contextualized climate information, best practice exchange, and help with bridging the science-policy divide to a wide array of stakeholders. Bangladesh has lots of non-government organizations like BRAC, Grameen Bank, BCAS, ASA, TMSS, CODEC, NACOM, COAST, etc. NGOs has made a major contribution to poverty reduction and has increased the resilience of poor people to natural disasters, through microfinance, income generation, health and education programmes. Their experience and capacity will be used to develop innovative approaches to adaptation. Moreover, international organizations such as IUCN, IIED, WWF, OXFAM, CARITAS, YMCA, etc have been contributed in overall social development.
Universities	Different universities have been addressed climate change issues in the curriculum and conduct research.
Donors	DFID, DANIDA, USAID, EU UNION, GIZ, WB, ADB

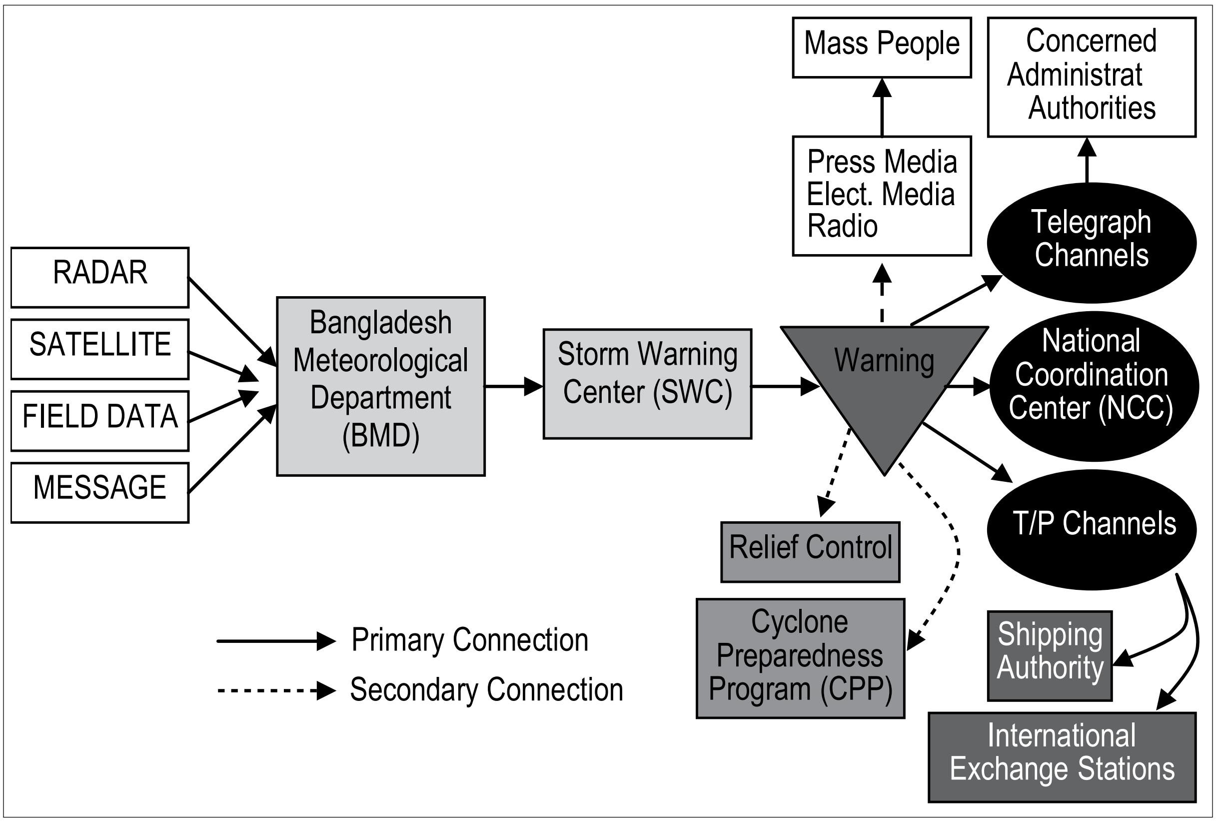


Figure 27. Flow diagram of national warning systems by the Bangladesh Meteorological Department (source: Haque, 1997; Chowdhury et al. 2012).

5.2. International institutional framework

The international distributional challenges of acidification are significant. Developed nations are responsible for the largest portion of historic emissions and therefore for current acidification. They also possess the most diverse economies and food systems. Transfer schemes to compensate developing nations articularly affected by acidification may be warranted. Mechanisms to achieve this include the Adaptation Fund, established by the parties to the Kyoto Protocol (UNFCCC 2010a). The Fund supports adaptation activities in developing countries with Clean Development Mechanism (CDM) funding from developed countries. However, with the expiration of the Kyoto Protocol in 2012, there is uncertainty about the future of the CDM and hence, the Adaptation Fund. The Copenhagen Accord, agreed to by 114 parties in 2009, recommitted developed countries to providing financial resources to support adaptation measures in developing countries (UNFCC 2010b).

Ocean acidification is an unambiguous consequence of increasing atmospheric CO_2 concentrations. While reducing CO_2 emissions will be necessary to limit the most disruptive effects, the process of acidification has begun and will continue in the future. Policy instruments are available to reduce the vulnerability of marine ecosystems and coastal communities to changes in the composition and productivity of the oceans' biological systems. Given the economic and social importance of the oceans to human societies, governments at the local, national, and international levels must begin to assess and implement adaptive approaches to acidification.

5.3. Policy recommendations

Policy makers considering ways to address acidification have a menu of options. The most obvious, and thus far most politically difficult, is to reduce CO_2 emissions in order to avoid the most severe impacts of acidification. Past missions CO_2 in the atmosphere will continue to contribute to future acidification. While limiting the extent of acidification depends upon curtailing future emissions, efforts at mitigation have thus far been unsuccessful. The lack of comprehensive policies to reduce emissions in the U.S. and other nations with significant emissions, as well as the inability of the international community to adopt binding reduction targets to replace the expiring Kyoto Protocol, make meaningful emissions reductions in the near term unlikely. In the absence of significant reductions in emissions, acidification will continue, requiring adaptation based measures. While mitigation will require a global commitment, adaptation actions can be adopted at the local, national, and international levels.

As a potential initiative, coastal plantation, coral/oyster reefs, raising high yielding varieties of rice/fish/livestock hold great promise.

One set of adaptation strategies focuses on limiting the vulnerability of ecosystems to the stresses of acidification. Therefore, policies to limit marine pollution and curtail over fishing may have a positive effect on the ability of marine ecosystems to adapt to acidifying conditions (Cooley et al. 2009). Reducing harvest limits in the near term may result in short term revenue losses, but larger fish stocks and higher revenues in the long term (Cooley et al. 2009). Policy instruments to reduce pressure on fisheries include license or vessel buyouts and regional fishery closures (Cooley et al. 2009). Other strategies include increasing aquaculture operations in order to compensate for losses in wild harvests. In acidifying seas, aquaculture operations may have to use selective breeding techniques to rear species able to withstand these conditions (Cooley et al. 2009). In addition, freshwater aquaculture operations, isolated from acidifying oceans, may become more attractive as a means of supplying protein to consumers.

Within nations, extractive users, such as fishermen and aquaculture operators, face additional costs and economic losses if harvests decline (Cooley et al. 2009). A number of adaptation measures are available to support fishing dependent communities. Possible actions include diverting fishing effort to new or underutilized species, protecting key functional groups, investing in monitoring and research, and decoupling the local economy from fishing (MacNeil et al. 2010). This last action entails the greatest disruption to existing economic and social structures. Therefore, the social costs of lost employment and dislocation may require subsidies from less affected segments of the national population. Social policies such as job retraining and relocation assistance may be required to support formerly fishery-dependent communities (Cooley et al. 2009). For example, the U.S. National Oceanic and Atmospheric Administration (NOAA) requested $8 million to create a National Working Waterfronts grant program to aid fishing-dependent communities diversify their economies (NOAA 2011).

Key recent initiatives

Ocean Acidification Network – International initiative developed by the International Geosphere-Biosphere Programme (IGBP), the Scientific Committee on Oceanic Research (SCOR), the UNESCO's Intergovernmental Oceanographic Commission (IOC) and the IAEA's Marine Environment Laboratories (MEL) as a follow-up of an IOC-SCOR symposium in 2004. This information network community provides a central source of information for ocean scientists on ocean acidification research activities. www.ocean-acidification.net.

Ocean Acidification blog – an information outlet on ocean acidification- oceanacidification.wordpress.com

United Nations Environment Programme (UNEP) World Conservation Monitoring Centre (WCMC), Ocean Acidification info page — www.unep-wcmc.org/resources/ocean_acid_promo.aspx

International Union for Conservation of Nature (IUCN) Coral Reef Resilience to Climate Change — www.iucn.org/cccr/resilience_to_climate_change/#2

International Coral Reef Initiative (ICRI) Recommendation on Acidification and Coral Reefs (2007). www.icriforum.org/secretariat/japangm/docs/Reco_acidification_2007.pdf

Position Analysis: CO_2 emissions and climate change: Ocean Impacts and Adaptation Issues. The Australian Antarctic Climate & Ecosystems—Cooperative Research Centre. June 2008—www.acecrc.org.au/drawpage.cgi?pid=publications&aid=797037

Honolulu Declaration on Ocean Acidification and Reef Management, August 2008, Hawaii, prepared by the IUCN and TNC, August 2008 — cmsdata.iucn.org/downloads/honolulu_declaration_with_appendices.pdf

Monaco Declaration (2008) calling for immediate action by policy makers to reduce CO_2 emissions sharply to avoid possible widespread and severe damage to marine ecosystems from ocean acidification, presented at the end of the Second Symposium on "The Ocean in a High-CO_2 World", October 2008, Monaco — ioc3.unesco.org/oanet/Symposium2008/MonacoDeclaration.pdf

Ocean Acidification – Recommended Strategy for a U.S. National Research Program, recently prepared by the US Ocean Carbon and Biogeochemistry Program, Subcommittee on Ocean Acidification, March 2009 — www.us-ocb.org/OCB_OA_Whitepaper.pdf

Research Priorities for Ocean Acidification prepared by Orr, J.C., Caldeira, K., Fabry, V., Gattuso, J.-P., Haugan, P., Lehodey, P., Pantoja, S., Portner, H.-O., Riebesell, U., Trull, T., Hood, M., Urban, E., and Broadgate, W. (January 2009) —ioc3.unesco.org/oanet/Symposium2008/ResearchPrioritiesReport_OceanHighCO2WorldII.pdf

Inter Academy Panel (IAP) statement on Ocean Acidification calls for world leaders to explicitly recognize the direct threats posed by increasing atmospheric CO_2 emissions to the oceans and its profound impact on the environment and society. June 2009 — www.interacademies.net/?id=9075

European Integrated Maritime Policy, In October 2007, the European Commission presented its vision for an Integrated Maritime Policy (IMP) for the European Union in a Blue Book, providing the overall framework for policy areas related to the sustainable management of European marine waters, including environment and research. The IMP is the central policy instrument to develop a thriving maritime economy in an environmentally sustainable manner. The Action Plan that comes with the Blue Book introduces several actions which are directly or indirectly related to the issue of ocean acidification and greenhouse gas emissions, including actions on reduction of air pollution from ships, marine-based energy infrastructures and resources, and on mitigation and adaptation to climate change. It also considers Carbon Capture and Storage as a crucial element of European actions needed to meet the Community's climate change objectives to reduce impacts of things such as ocean acidification. To this end, the Commission proposed a Directive in January 2008 to enable environmentally-safe capture and geological storage of CO_2 in the EU as part of a major legislative package. The Directive was adopted by the Parliament and the Council in March 2009.

European Climate Change Policy, The EU has been trying to address its own greenhouse gas emissions since the early 1990s with the first (2000) and second (2005) European Climate Change Programme (ECCP) and more recently the Climate Action and Renewable Energy Package (2008) to fight climate change and promote renewable energy up to 2020 and beyond. This package sets out the contribution expected from each Member State to meet these targets of reducing overall emissions to at least 20% below 1990 levels by 2020 and increasing the share of renewables in energy use to 20% by 2020. It also proposes a series of measures to help achieve targets. Central to the strategy is a strengthening and expansion of the Emissions Trading System (EU ETS), the EU's key tool for cutting emissions cost-effectively. Emissions from the sectors covered by the trading system will be cut by 21% by 2020 compared with levels in 2005. A single EU-wide cap on ETS emissions will be set, and free allocation of emission allowances will be progressively replaced by auctioning of allowances by 2020. The climate and renewable energy package also seeks to promote the development and safe use of Carbon Capture and Storage (CCS), a suite of technologies that allows the CO2 emitted by industrial processes to be captured and stored underground where it cannot contribute to global warming.

In April 2009, the European Commission presented a policy paper known as a White Paper, "Adapting to climate change: Towards a European framework for action", which presents the framework for adaptation measures and policies to reduce the European Union's vulnerability to the impacts of climate change. It emphasises that decisions on how best to adapt to climate change must be based on solid scientific and economic analysis. The White Paper is accompanied by several working documents, one of which touches upon water, coasts and marine issues including ocean acidification.

6. Policy and International Negotiation

6.1. Ocean acidification issues in Bangladesh

The ocean has absorbed about 430 billion tons of CO_2 from the atmosphere, or about one-third of anthropogenic carbon emissions. This absorption has benefited humankind by significantly reducing greenhouse gas levels in the atmosphere, thereby minimizing global warming. However, the pH (the measure of acidity) of ocean surface waters has already decreased by about 0.1 units, from an average of about 8.2 to 8.1 since the beginning of the industrial revolution. By the middle of this century atmospheric CO_2 levels could reach more than 500 ppm, and by 2100 they could be well over 800 ppm (IPCC scenario B2, 2007). This would result in an additional mean surface water pH decrease of approximately 0.3-0.4 pH units by 2100, implying that the ocean would be about 100-150% more acidic than at the beginning of the industrial revolution.

Oceanic uptake of atmospheric CO_2 released by humans is altering global seawater chemistry in ways that will affect marine biota, ecosystems, and biogeochemistry. Forecasting these impacts requires an integrated understanding of the linkages among ecosystem components and feedbacks to climate. Ocean acidification could alter the ocean carbon, nitrogen, phosphorus, and metal (e.g., iron and copper) cycles, and marine biota from individual organisms to ecosystems could be negatively influenced. Such changes could alter marine biodiversity and food webs. Consequently, fisher's livelihoods, animal protein supply and export earnings may raise red flags. Ocean acidification is recognized as a high priority research topic in Bangladesh. The important issues on ocean acidification in Bangladesh are as follows:

• OA is the global challenge of climate change but affecting the local places including the poor people of Bangladesh. It is clear evidence of "climate injustice" to the innocent people by the developed nation's activities (e.g. CO_2 emission)

• Establishment of ocean data recording stations and laboratories for precise pH measurement and trend analysis is another issue in Bangladesh. Science recognized changes in oceanic ecosystem i.e. about 0.002 pH units changes to see per year

• Detrimental effects of OA on the ecosystem niche of marine organisms e.g. fishes, shrimps, crabs, molluscs and coral reefs may change and migrate in neighbouring country's territory. Recent decreasing trends of capture fisheries from the Bay of Bengal may be the impact of ocean acidification. The consequences are insecure millions of fisher's livelihood and failure investment on fishing crafts and gears as well as reducing export earning from fisheries commodity

• Development of adaptation capacity with resilient infrastructures (houses, roads, schools, health centers, community places) and income generating options are essential. Coastal plantation, oyster reefs development, high yielding varieties of rice/ fish farming, raising livestock (for meat and milk) and poultry (for egg and meat) may be the potential initiatives

6.2. National ocean acidification policy of Bangladesh

National Adaptation Plans (NAPs)

In Durban, South Africa in December 2011 the guidelines for National Adaptation Plans (NAPs) were agreed. Further discussions focused NAPs in Bonn, Germany in May 2012 under the United Nations Framework Convention on Climate Change (UNFCCC). Financial support at least for LDCs is necessary for the preparation and implementation of these plans in a participatory and transparent manner. National Adaptation Plans can endow developing countries with a strong climate smart strategic planning process and policy dialogue, embracing and integrating sector-wide and programmatic approaches as part of a coherent institutional, policy and regulatory framework. It is expected that NAPs and associated activities will receive funding from newly established institutions, such as the Green Climate Fund (GCF), but also from the Kyoto Protocol Adaptation Fund and others. Since NAPs should reach out to the wider development agenda, it is also important to target bilateral and plurilateral adaptation and development funding streams.

Loss and damage

The Conference of Parties (CoP) in Durban (CoP 17, 2011) took an important step forward by agreeing a work programme on loss and damage through a series of expert workshops. The first expert workshop in Tokyo, Japan in March 2011 focused on the assessment of risks of loss and damage. The discussions showed that there is still a substantial need to further define what should be understood as loss and damage in the UNFCCC context. It is also necessary to address impacts related to extreme weather events and slow onset events.

The Bangladesh-specific component of the Loss and Damage in Vulnerable Countries Initiative is being carried out with three objectives in mind. The first objective is to help GoB, stakeholders and LDC negotiators in the UNFCCC process better understand the concept of loss and damage. Secondly, stakeholder-based activities to move loss and damage forward in Bangladesh will be identified. Finally, the work in Bangladesh to identify possible approaches to loss and damage will inform other LDCs in developing their own loss and damage strategies.

National Adaptation Programme of Action (NAPA, 2005)

The National Adaptation Programme of Action (NAPA) is prepared by the Ministry of Environment and Forest (MoEF), Government of the People's Republic of Bangladesh as a response to the decision of the Seventh Session of the Conference of the Parties (CoP7) of the United Nations Framework Convention on Climate Change (UNFCCC). The National Adaptation Programme of Action (NAPA) has been prepared the adaptation measures as a set of actions complementary to national goals and objectives of other multilateral environmental agreements to which Bangladesh is one of the signatories. The NAPA is also clearly closely related to other environment related policies and programmes in particular the National Action Plan on Biodiversity as well as the earlier implemented National Environmental Management Action Plan (NEMAP). NAPA identified 15 priority activities to combat climate change impacts in Bangladesh, including general awareness raising, technical capacity building, and implementation of projects in vulnerable regions with a special focus on agriculture and water resources.

The basic approach to NAPA preparation was along with the sustainable development goals and objectives of the country where it has recognized necessity of addressing environmental issue and natural resource management with the participation of stakeholders in bargaining over resource use, allocation and distribution. Therefore, involvement of different stakeholders was an integral part of the preparation process for assessing impacts, vulnerabilities, adaptation measures keeping urgency and immediacy principle of the NAPA. Policy makers of Government, local representatives of the Government (Union Parishad Chairman and Members), scientific community members of the various research institutes, researchers, academicians, teachers (ranging from primary to tertiary levels), lawyers, doctors, ethnic groups, media, NGO and CBO representatives and indigenous women contributed to the development of the NAPA for Bangladesh.

At the highest level NAPA has a Project Steering Committee (PSC) headed by Secretary Ministry of Environment and Forest. The Project Steering Committee is represented by high level officials and experts from different government and non-government organizations to provide guidance. In addition to the Ministry of Environment and Forest, other noteworthy government ministries and agencies involved in the PSC are Ministry of Planning, Economic Relation Division, Ministry of Agriculture, Ministry of Food and Disaster Management, Water Resource Planning Organization, Ministry of Fisheries and Livestock, Ministry of Land, Department of Environment etc. The Project Steering Committee is represented by government, non-government and international research institutes including Bangladesh Institute of Development Studies (BIDS), Bangladesh Forestry Research Institute (BFRI) Bangladesh Centre for Advanced Studies (BCAS), IUCN Bangladesh etc.

Bangladesh Climate Change Strategy and Action Plan (BCCSAP, 2009)

In 2009, the Government outlined the BCCSAP, a 10-year program to build capacity and resilience within the country to meet climate change challenges over the next 20–25 years, with six thematic areas: (i) food security, social protection, and health; (ii) comprehensive disaster management; (iii) infrastructural development; (iv) research and knowledge management; (v) mitigation and low-carbon development; and (vi) capacity building and institutional strengthening.

The implementation of BCCSAP will require significant strengthening of the coordination and facilitation capacity of the Ministry of Environment and Forests (MoEF) with relevant line ministries and agencies.

6.3. Capacity building options for mitigating future ocean acidification in Bangladesh

- Develop university curricula addressing climate change challenges, ocean acidification, carbon sequential, aquatic food production, and the likes for quality higher education.
- Establish research collaboration with developed country academic institutions to undertake need-based action research involving
- Arrange short training programmes for managers, extension workers and policy makers to enhance their knowledge on ocean acidification, sea water chemistry and oceanic uptake of atmospheric CO_2 as well as impact on oceanic organisms and ecosystem.
- Funding is necessary to build networks of ocean acidification buoys around 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, Cox's Bazar beach, Chittagong port, Meghna deltaic gateway, Sunderbans mangrove, Swatch of No Ground, South Patches, etc.

It is our responsibility to invest resources in areas where stakeholders are at risk due to the consequences of ocean acidification. When everything is in place, we will be capable to measure ocean acidification from our oceanic area. Scientists will combine collected information with data from other research to develop a model to determine the current and future costs of ocean acidification. The data will be made available to the community in a number of different locations through a partnership with universities and research organizations.

Develop observational and predictive technology

The greatest opportunity for a leap in understanding variation in ocean chemistry would come from represented real-time data covering coastal and marine territories. Installation of in situ high-precision sensors for pH and related biogeochemical variables, including oxygen, nitrate, partial pressure of CO_2 (pCO_2), and particulate inorganic carbon are necessary. More effort is needed to monitor precision and stability of these sensors, develop others especially for key carbonate system variables (e.g. dissolved inorganic carbon and alkalinity), and deploy them not only on moorings but in a new networks of gliders and floats. The Bay of Bengal can be divided into 207 quadrates with 1^{0}N latitude and 1^{0}E longitude (Figure 28). Each quadrate may contains 2 moorings or floats with sensor to measure temperature and salinity in the upper 2 km of the ocean every 7 days, has revolutionized our ability to characterize the ocean's circulation and warming. Likewise, equipping the moorings or floats with multiple biogeochemical sensors would revolutionize our ability to characterize the ocean carbon cycle and quantify how it is being affected by OA.

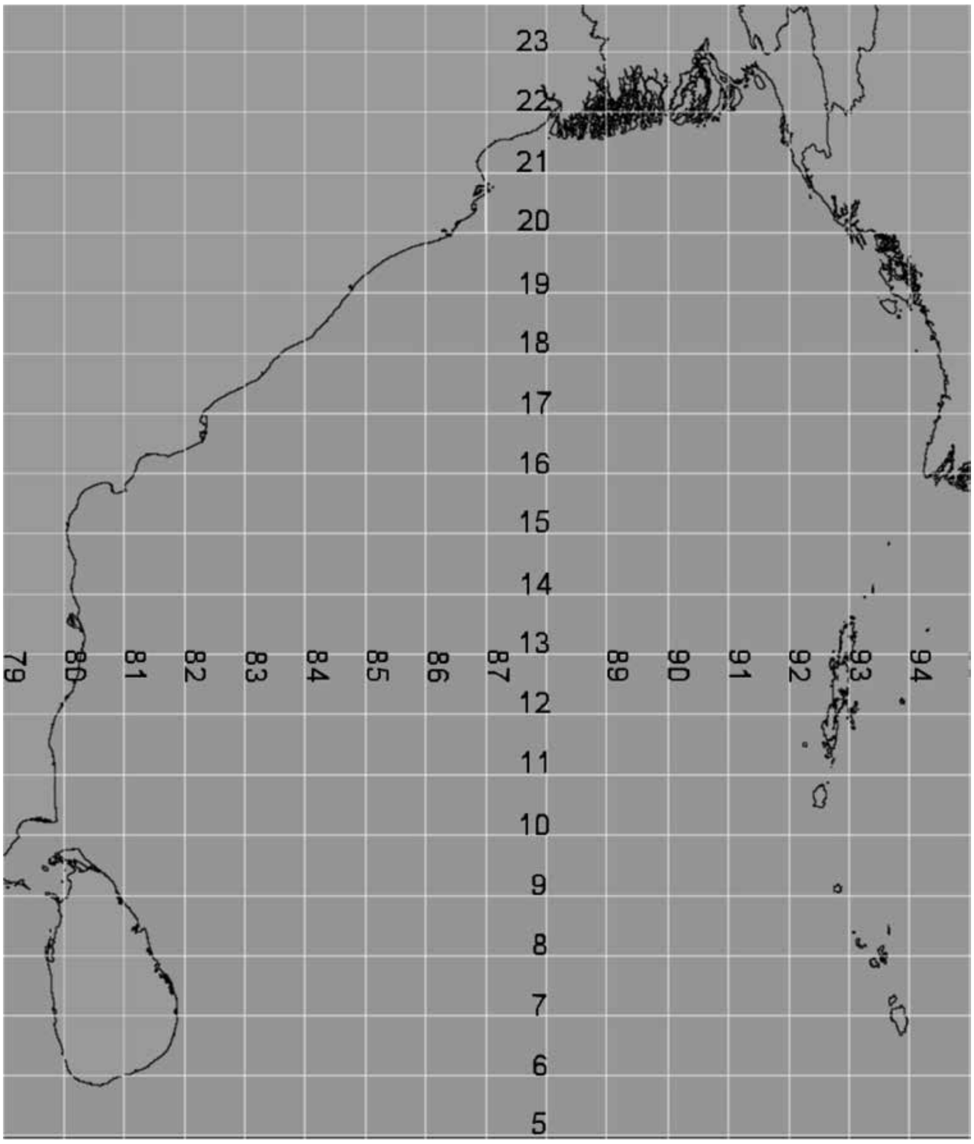


Figure 28. The Bay of Bengal with 1^0 interval quadrates and surrounding countries

Perform long-term and multigenerational experiments
To date, the majority of published OA research involves short-term experiments (days to weeks) that acutely stress organisms using predicted future ocean conditions. Although such experiments are useful for studying physiological processes and identifying major biological effects, they may not provide a true assessment of the longer-term impacts of OA. First, some effects of exposure to acidified conditions may take months to appear. For example, increased costs associated with high CO_2 and low pH may only become evident in whole-organism traits such as growth and survival after several months of continuous exposure (e.g. Langenbuch and Pörtner 2004; Shirayama and Thornton 2005; Kurihara et al. 2008). Alternatively, organisms might acclimate to acidification over time. For example, the crab Necora puber used bicarbonate ions acquired from shell dissolution to regulate extra-cellular pH during a short-term (14 days) exposure to elevated CO_2 (Spicer et al. 2007); however, bicarbonate was acquired from the surrounding seawater to regulate pH after longer-term exposure (30 days) (Small et al. 2010). One of the key questions is to determine what is the relevant time of exposure. In a study on the green sea urchin Strongylocentrotus droebachiensis, Dupont et al. (2012) show that female fecundity was decreased 4.5-fold when acclimated to elevated pCO_2 for 4 months during reproductive conditioning, while no difference was observed in females acclimated for 16 months. Therefore, short-term experiments can both over- and underestimate the impact of OA.

Experiments should also include subsequent life history stages (e.g. –gametes–embryos–larvae–juveniles–adults) that may be critical in understanding the effects of environmental stressors on marine species (Marsahll and Morgan 2011). Carry-over effects between life stages can significantly affect the outcome of environmental stress in subsequent life stages.

6.4. Role of Bangladesh

Decision makers need to take ocean acidification threat seriously, and to carefully consider this environmental challenge in the context of sustainable development. We recommend to take actions that promote:

• Campaign and advocacy at global and regional levels to reduce current rate of ocean acidification by significantly lowering the absolute rate of anthropogenic carbon dioxide emissions

• Improvement of the current state of knowledge of this problem by commitment to research and long-term monitoring of the chemical, biological, and ecosystem impacts of ocean acidification and development of a global ocean acidification observation network

• Continued research to inform ocean acidification adaptation strategies for marine ecosystems and human communities

• Global and regional supports in the form of fund, technology, equipment and human development to promote adaptation capacity with resilient infrastructure.

• Develop area-specific land use models addressing settlement, livelihood options and community places.

Engineering and social consensus on adaptation is a prerequisite for successful adaptation planning, and reaching out to all stakeholders especially those that suffer dis-proportionally. Successful national adaptation planning approaches have to have meaningful engagement and consultation approaches at their centre.

At least three well-equipped laboratories at southeast, central and southwest coastal regions of Bangladesh need to establish to make the precise pH measurements and trend analysis. In this connection, Institute of Marines Sciences and Fisheries from Chittagong University, Department of Marine Science from Noakhali University and Marine Resources Technology Discipline from Khulna University would be the best choice. The existing laboratory facilities of these universities can be renovated with required equipments. It is expected the changes to see are about 0.002 pH units per year.

Monitoring networks
It is highly recommended that Bay of Bengal region countries need to develop oceanic data collection facilities. The "Bay of Bengal Large Marine Ecosystems" project (BOBLEM, www.boblem/fao.org), established under an FAO programme should also be involved. Existing long-time series should be maintained and new sensors and sampling/collecting devices should be developed. The biological pump should be monitored for changes in organic carbon and calcium carbonate production and export, as it has the potential to decrease oceanic natural carbon sequestration. Such data should then be kept access to academic and research organizations of the surrounding countries for further analysis and interpretation.

Dissemination, outreach and capacity building
Communicating on ocean acidification to stakeholders (policy makers, funders, media, public, etc.) is important. Clear messages should be defined

and used consistently across the sector, including confidence limits. A system should be put in place to share best practices and success stories.

- **Communication to research and potential industry**
Many research funding organizations are already aware of ocean acidification and are funding research in this area. However, they are not necessarily aware of the full spectrum of European activities in this area or the gaps in research. Therefore, European research relevant to ocean acidification is too fragmented and poorly coordinated. A strong effort by Europe to coordinate its own ocean acidification research would stimulate activities while enabling resources to be optimized by eliminating gaps and duplications. Equally important will be the social and economic consequences of ocean acidification, meaning that communication with the general public and all potential funders is crucial.

- **Communication to the climate change research community**
Surprisingly, many researchers in climate change, including those working on mitigation and adaptation strategies, are unaware of many of the known implications of ocean acidification. The ocean acidification community has made in-roads to reach members of the global change community, who is not always fully aware of the impacts of ocean acidification (e.g., the IPCC fourth Assessment Report on Climate Change in 2007, the Stern Report on the Economics of Climate Change, several scientific statements and declarations on ocean acidification). Impacts of ocean acidification should be included in all future climate change assessments. The certainty associated with ocean acidification, due to the simplicity of the chemical reaction of CO_2 and water, provides a powerful supplementary reason adding to the certainty of climate change.

- **Communication and Interactions with the international research community**
It is recommended that the European ocean acidification community strengthens links with the international research community in order to stimulate research, share resources, and avoid needless redundancy; for instance, taking full advantage of PAGES, SCOR, GLOBEC, OCCC, the International Council for the Exploration of the Sea (ICES), the Marine Environmental Simulation Study for Future Projection of Marine Ecosystems (funded by the Japan Science and Technology Agency), the US Ocean Carbon and Biogeochemistry program (OCB) as well as some of the ongoing NSF, NASA and NOAA-funded, scientific activities, and a few research projects in Australia and New Zealand.

- **Communication to Stakeholders**
In order to further address socio-economic implications, there is an essential need to establish two-way communication with stakeholders to better understand their problems and questions so that research can be properly designed and information conveyed in a useful manner. These stakeholders include fisheries and marine habitat managers, fishermen, community leaders, conservation groups, etc. Similarly communication with the media and the general public is also important.

Coordination

Coordination of ocean acidification research needs to address:

- Coordination and collaboration of research programmes relevant at national level and at the regional level, taking into account the very different marine environments in Europe (Arctic, Baltic, North Sea, Mediterranean, Black Sea, North-East Atlantic) and of EU projects related to ocean acidification;
- Coordination and collaboration at the international level of European activities with those outside Europe (e.g., United States, Japan, Korea, Australia, China). While coordination within Europe is underway, it will be important to integrate European activities with the global effort on ocean acidification research. European science (and the science of other countries) will benefit from such coordination, including stimulation of new ideas by bringing together scientific perspectives from around the world, sharing of physical resources (e.g., ships, mesocosms, new equipment designs), standardization of protocols and instrumentation, possibilities for coordination of related national efforts to identify overlaps and gaps, and access to parts of the world where European scientists might benefit from other expertise and past experiences.

6.5. International policies and institutional frameworks

The international distributional challenges of acidification are significant. Developed nations are responsible for the largest portion of historic emissions and therefore for current acidification. They also possess the most diverse economies and food systems. Transfer schemes to compensate developing nations particularly affected by acidification may be warranted. Mechanisms to achieve this include the Adaptation Fund, established by the parties to the Kyoto Protocol (UNFCCC, 2010a). The Fund supports adaptation activities in developing countries with Clean Development Mechanism (CDM) funding from developed countries. However, with the expiration of the Kyoto Protocol in 2012, there is uncertainty about the future of the CDM and hence, the Adaptation Fund. The Copenhagen Accord, agreed to by 114 parties in 2009, recommitted developed countries to providing financial resources to support adaptation measures in developing countries (UNFCC, 2010b). Unfortunately, the Obama administration's proposed funding for international adaptation aid has not found support in the current U.S. Congress (Friedman, 2011). This lack of support by the U.S. may deter other nations from meeting their commitments. However, if the impacts of acidification in developing nations intensify, developed nations may face increased pressure to meet these commitments.

other sectors of the economy. Higher energy prices, for example, may slow economic growth, meaning a lower standard of living for many people in the near term. So when policy makers consider emissions policies, they need to weigh the benefits that will be realized far into the future with the social costs that will begin to accrue almost immediately. Whether emission reductions are achieved through economic instruments, such as a carbon tax or cap and trade programme, or through technology mandates, those policies are likely to carry with them significant costs (e.g. OECD 2008; Paltsev et al. 2009; Tol 2010). At the same time, effects of OA and climate change will likely play out on individual marine resources, disproportionately affecting certain groups of people with high dependence on affected ecosystems.

Figure 29 is a conceptual schematic showing how policy decisions, ecological impacts and social

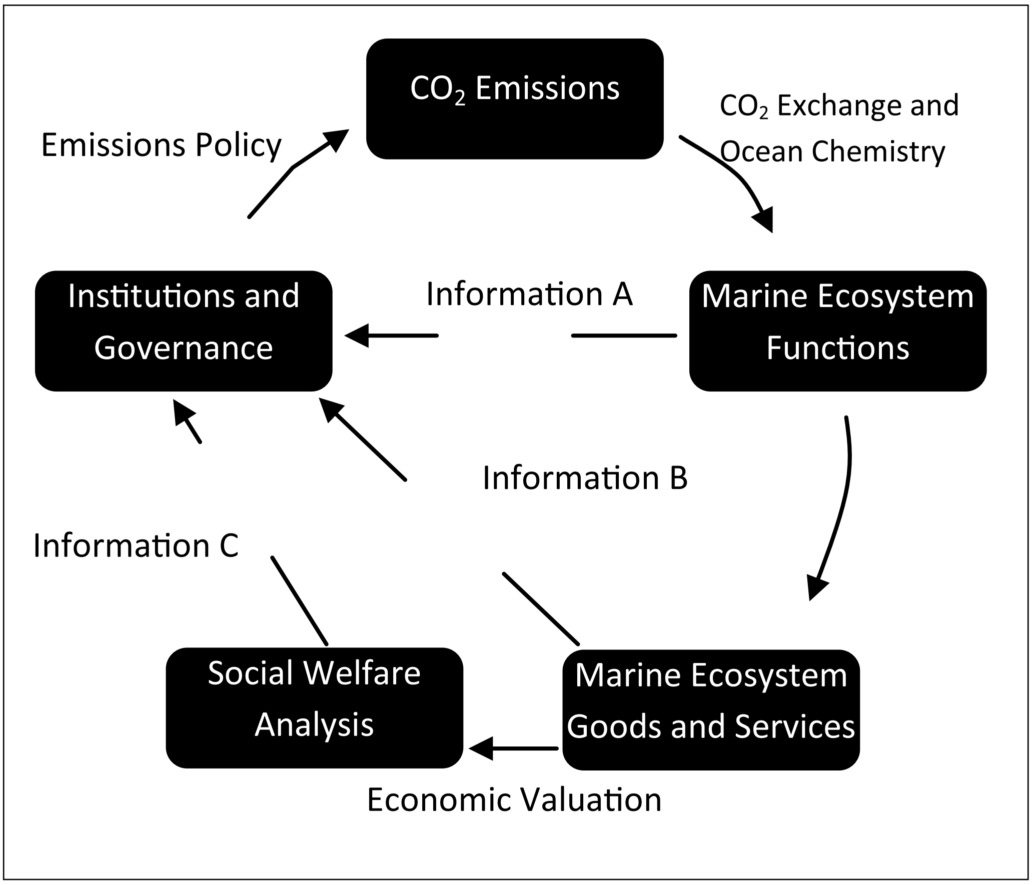


Figure 29. CO_2 impact pathway and flow of information (source: Hilmi et al. 2012)

welfare are related in the context of CO_2 emissions-linked ocean changes such as ocean acidification. The solid arrows represent pathways through which CO_2 emissions impact marine ecosystems and the human systems that rely on them. The dashed lines are flows of information to policy makers whose charge is to maximize social welfare. Policy makers can base decisions on observations of the natural system (information A and B) or on

When designing efficient policies to address CO_2-linked environmental change, issues spanning multiple temporal and spatial scales must be taken into consideration. Reductions in CO_2 emissions large enough to avoid the worst consequences of OA and climate change will require global economy-wide emissions policies and international agreements (Turley and Gattuso 2012). These are likely to be costly and necessitate trade-offs within economic analyses that express costs and benefits of emissions policy in monetary terms (information C). The latter provides the most comprehensive set of information but also requires knowledge embodied in information A and B. This figure also demonstrates the relevance of economic valuation and shows how knowledge of welfare impacts can be used directly by the policy maker, or the natural resource manager, to support policy action since the absence of action will often be associated with high welfare damages (as quantified by the information flow C).

6.6. Negotiating strategies for Bangladesh at the international level

It is necessary to analyze the impacts and adaptation process of ocean acidification following the 'top-down and bottom-up' strategy allowing participations of relevant stakeholder groups (Figure 30). The vertical integration refers to integration between local level and national or international activities and policies. The horizontal integration refers to integration between different sectors (such as fisheries and forestry).

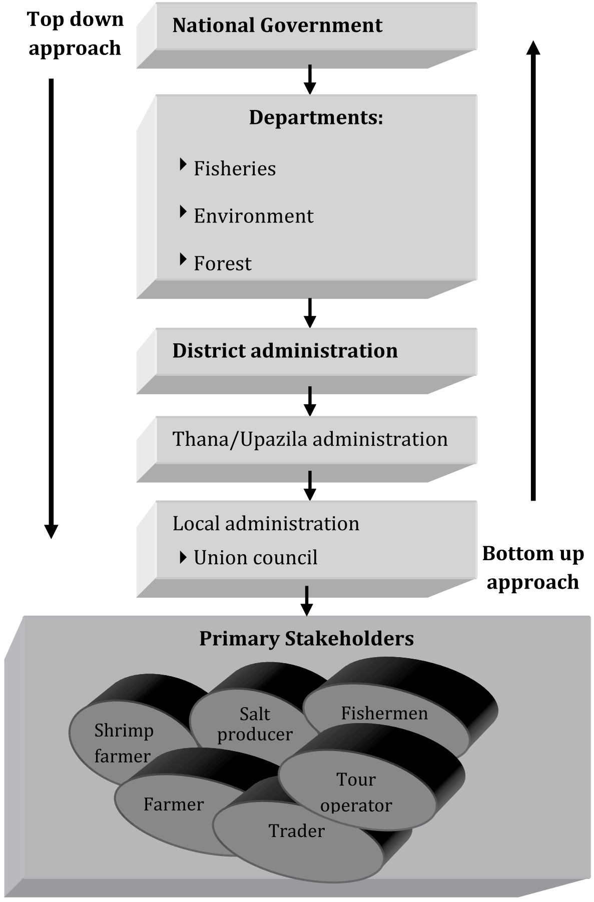


Figure 30. The 'top-down and bottom-up' approach for deploying ocean acidification impacts and adaptation process (after Hossain and Shamsuddoha, 2006)

The impacts and adaptation of ocean acidification with ecosystem, social and economic costs need to formally present in international forum. Bangladesh needs adequate advocacy initiatives at the international level to establish the roles of developed nations on climate justice, vulnerable livelihoods and inadequate adaptation options of developing nations. In this connection, negotiation options can be in the form of fund, technology and collaborative research works (Figure 31). Problem tree analysis for ocean acidification indicates relationships of fossil fuel combustion, water pH, ocean ecosystem and people livelihood (Figure 32).

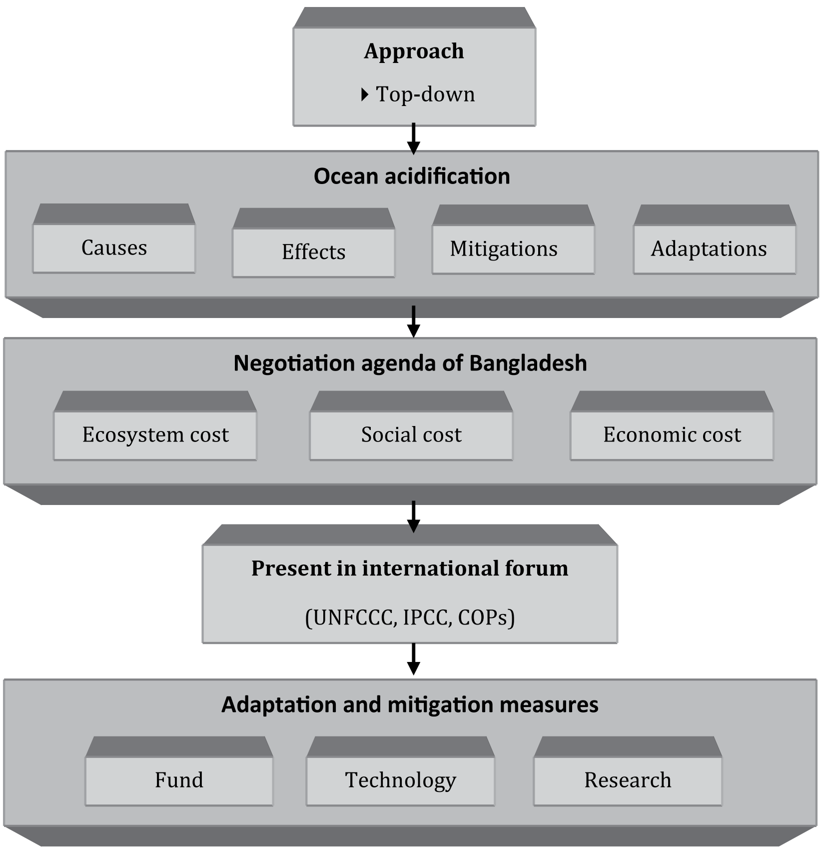


Figure 31. The ocean acidification mitigation and adaptation strategies for Bangladesh at the international level

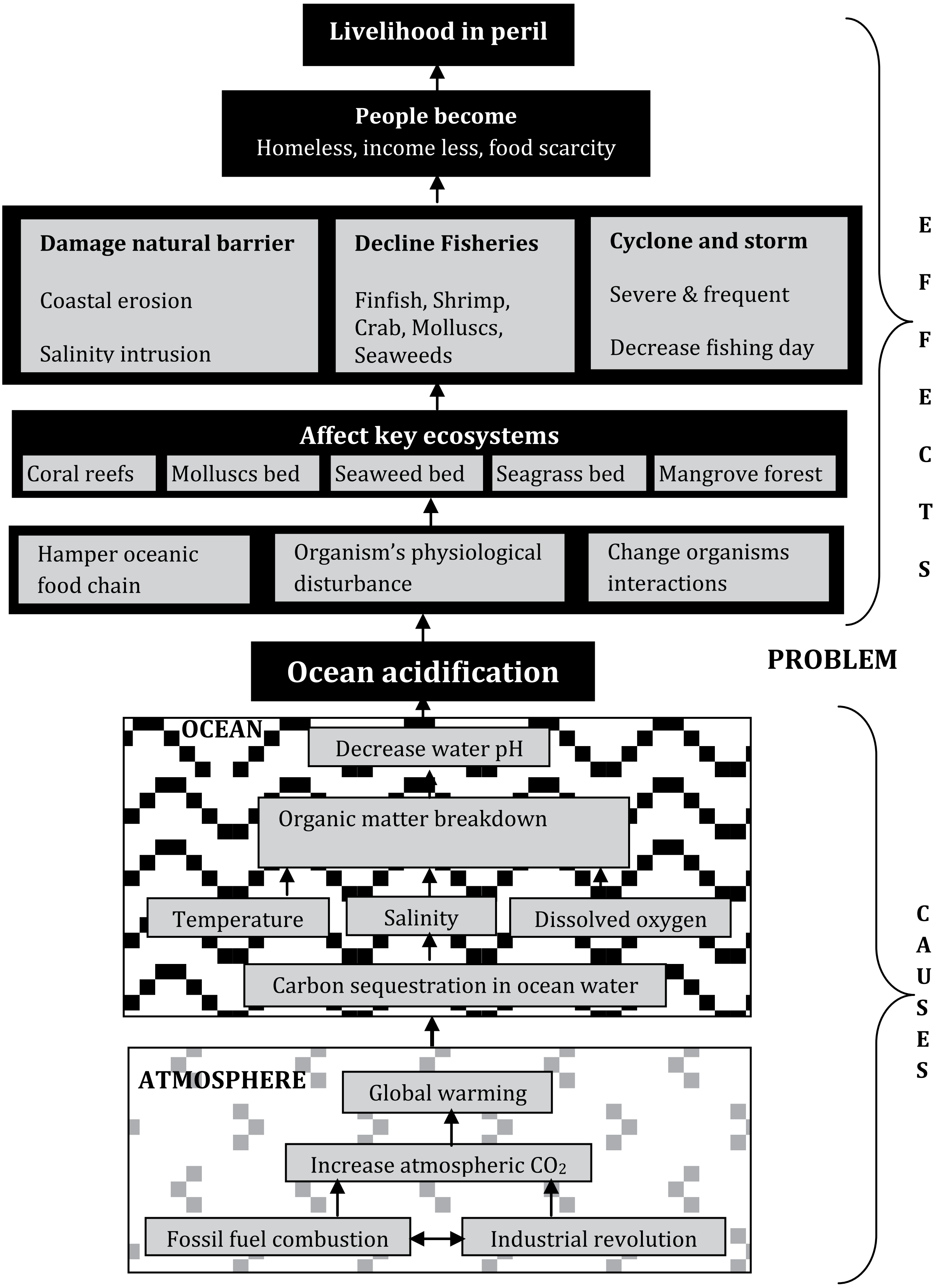


Figure 32. Problem tree analysis shows the causes and effects for ocean acidification

7. Conclusions and Recommendations

Although the changes in seawater chemistry due to oceanic uptake of anthropogenic CO_2 are well characterized, the impacts of ocean acidification on the biological compartment of ocean, i.e. on marine flora and fauna are still poorly understood. New technologies and skills, as well as integrated, multidisciplinary efforts among biologists, chemists and mathematicians are much important to assess and quantify the effects of ocean acidification on marine fauna and the changes in ecosystem structure and function.

Evidence suggests that ocean acidification is happening now and probably will continue to intensify, if global CO_2 emissions are not reduced. Given the potential threat to marine ecosystems and the subsequent impact on human society and economy, especially as it acts in conjunction with anthropogenic global warming, there is an urgent need for immediate action. This 'double trouble' of climate change and ocean acidification is arguably the most critical environmental issue facing humans at the present time. The key recommendations in order to understand and respond to the impacts of ocean acidification are as follows:

- A robust observing network to establish a baseline, and to detect and predict biochemical changes (i.e. from organism to ecosystem level) attributable to acidification. To develop the observing network, it is necessary to identify the appropriate chemical and biological parameters to be measured by the network, ensuring data quality and consistency across space and time.
- Conduct research to fulfil critical information needs. Capacity building (i.e. education and training) of ocean acidification researchers.
- Integrate the researchers of natural and social sciences to help mitigate ocean acidification and to develop adaptation strategies, taking into account the potential impacts on both natural resources and human, including socio-economics.
- Total costs of abating CO_2 emissions, and of carbon capture and storage/sequestration should be considered and evaluated.
- Ensure adequate monitoring of key marine ecosystems and environmental services.
- Facilitate dissemination, communication and capacity building to help deliver scientific knowledge-based advice to relevant stakeholders, and to share success stories with the general public.
- Coordinate and strengthen the regional and national research on the impacts of ocean acidification, including sharing of research infrastructure, resources and knowledgebase.

Need for development of best practices for ocean acidification research

Many of the approaches for ocean acidification research are new and there are currently no common guidelines for best practices. Therefore, it is important to develop common standards so that research carried out by different investigators can be easily compared. Dickson et al. (2007) provided an internationally agreed-upon guide to best practices for carbon measurements, but other measurements relevant to ocean acidification are also need to be standardized.

Data management

Data management and dissemination for ocean acidification research must be planned before new data are collected. Data must be reported and archived in ways that make them readily accessible now and in the future. Likewise, data mining and archiving of historical data may provide useful insights into the evolution of ocean acidification over time.

Education, outreach, and engagement of policymakers

It has recognized the need for interdisciplinary training for policy makers, researchers, and managers to improve research, observations, modeling, and data management. Meetings should be hold with coral reef managers, fisheries managers, other stakeholders, and policymakers to engage them in formulating research questions that will enable scientists to provide results relevant for decision making. Readily accessible presentations and fact sheets on ocean acidification and its effects on marine life should be created for the public and schools, and made available via posters, stickers, holding boards and websites.

Communication within the oceanography community

The research community needs to hear about 'mistakes' and conditions that produced no significant effects, so that public can learn from them. Dissemination of results and conclusions should be accelerated. Communication among disciplines relevant to ocean acidification research should be extended.

8. References

Alam, M. W. 2000. Health hazard bacteria concentration at Karnafully river estuary with water quality parameters. MSc Thesis. Institute of Marine Sciences and Fisheries, University of Chittagong.

Ali, S., Sukanta, S. and Mahmood, N. 1985. Studies on the physicochemical aspects of the Moheshkhali channel, Bay of Bengal. Dhaka University Studies. B. XXXIII (1): 43-49.

Alvarado-Alvarez, R., Gould, M. C., and Stephano, J. L. 1996. Spawning, in vitro maturation, and changes in oocyte electrophysiology induced serotonin in Tivela stultorum. Biological Bulletin, 190: 322–328.

Attrill, M. J., Wright, J., and Edwards, M. 2007. Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea. Limnology and Oceanography, 52: 480–485.

Barbier, E.B., Koch, E.W., Silliman, B.R., Hacker, S.D., Wolanski, E., Primavera, J., Granek, E.E., Polasky, S., Aswani, S., Cramer, L.A., Stoms, D.M., Kennedy, C.J., Bael, D., Kappel, C.V., Perillo, G.M.E., and Reed, D.J. 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. Science 3(19), 321-323.

Bates NR. 2007. Interannual variability of the oceanic CO_2 sink in the subtropical gyre of the North Atlantic Ocean over the last two decades. J Geophys Res 112, C09013.

Beesley, A., Lowe, D., Pascoe, C. and Widdicome, S. 2008. Effects of CO_2 induced seawater acidificatin on the health of Mytilus edulis. Climate Research. 37: 215-225.

Berge, J. A., Bjerkeng, B., Pettersen, O., Schaanning, M. T., and Oxnevad, S. 2006. Effects of increased sea water concentrations of CO2 on growth of the bivalve Mytilus edulis L., Chemosphere, 62, 681–687.

Bijma, J., Honisch, B., and Zeebe, R. E. 2002. Impact of the ocean carbonate chemistry on living foraminiferal shell weight: comment on “Carbonate ion concentration in glacial-age deepwaters of the Caribbean Sea” by W. S. Broecker and E. Clark. Geochemistry, Geophysics, Geosystems, 3: 1064.

Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Hanawa K, Le Quéré C, Levitus S, Nojiri Y, Shum CK, Talley LD, Unnikrishnan A. 2007. Observations: oceanic climate change and sea level. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York.

Biswas, H., Cros, A., Yadav, K., Ramana, V. V., Prasad, V. R., Acharyya, T. and Babu, P. V.R. 2011. The response of a natural phytoplankton community from the Godavari River Estuary to increasing CO_2 concentration during the pre-monsoon period .Journal of Experimental Marine Biology and Ecology 407: 284–293.

Brander, L. M., Rehdanz, K., Tol, R. S. and Van Beukering, P. J. 2009. The economic impact of ocean acidification on coral reegs. Economic and Social Research Institute. Working paper No. 282. Accessed 10/10/2012 from www.esri.ie/UserFiles/publications/20090218113337/WP282.pdf.

Brennand, S., Soars N, Dworjanyn SA, Davis AR and Byrne, M. 2010. Impact of Ocean Warming and Ocean Acidification on Larval Development and Calcification in the Sea Urchin Tripneustes gratilla. PLoS ONE 5(6): e11372.

Brown JN, Sen Gupta A, Brown JR, Muir LC, Risbey JS, Zhang Z, Ganachaud A, Murphy B, and Wijffels SE. 2013. Implications of CMIP3 model biases and uncertainties for climate projections in the western tropical Pacific. Climatic Change. 119(1):147-161.

Bryant, Dirk, Lauretta Burke, John McManus and Mark Spaulding. 1998. Reefs at Risk: A Map-Based Indicator of Threats to the World’s Coral Reefs. WRI/ICLARM/WCMC/UNEP. World Resources Institute, Washington, D.C., 1998& 56 p. Web version: http://www.wri.org/wri/indictrs/reefrisk.htm

Buddemeier, R. W., J. A. Kleypas, and R. B. Aronson. 2004. Coral reefs and global climate change: Potential contributions of climate change to stresses on coral reef ecosystems, report, Pew Cent. on Global Clim. Change, Arlington, Va.

Burke, L., S. Greenhalgh, D. Prager, and E. Cooper. 2008. Coastal Capital–Economic Valuation of Coral Reefs in Tobago and St. Lucia. World Resources Institute, Washington, DC, 76 pp.

Burnett, L., Terwilliger, N., Carroll, A., Jorgensen, D., and Scholnick, D. 2002. Respiratory and acid-base physiology of the purple sea urchin, Stronglyocentratus purpuratus, during air exposure: presence and function of a facultative lung. Biological Bulletin, 203: 42–50.

Caldeira, K., and Wickett, M. E. 2003. Anthropogenic carbon and ocean pH. Science, 425: 365.

Caldeira, K., and Wickett, M. E. 2005. Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. Journal of Geophysical Research, 110: C09S04.

Carpenter, K. E., Abrar, M., Aeby, G., Aronson, R.B., Banks, S., Bruckner, A., Chiriboga, A., Cortes, J., Delbeek, J. C., DeVantier, L., Edgar, G.J., Edwards, A.J., Fenner, D., Guzmán, H. M., Hoeksema, B. W., Hodgson, G., Johan, O., Licuanan, W. Y., Livingstone, S. R., Lovell, E. R., Moore, J. A., Obura, D. O., Ochavillo, D., Polidoro, B. A., Precht, W. F., Quibilan, M. C., Reboton, C., Richards, Z. T., Rogers, A. D., Sanciangco, J., Sheppard, A., Sheppard, C., Smith, J., Stuart, S., Turak, E., Veron, J. E. N., Wallace, C., Weil, E. and Wood, E. 2008. One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. Science 321 (5888), 560-563.

Cecchini J.A., González, C., Carmona, A., Arruza, J., Escartí, A. y Bala- gué, G. 2001. The Influence of the Teacher of Physical Education on Intrinsic Motivation, Self-Confidence, Anxiety, and Pre- and Post-Competition Mood States. European Journal of Sport Science. 1, 4 -22 http://www.humankinetics.com/ejss/content.

Cesar, H., L. Burke, and L. Pet-Soede. 2003. The economics of worldwide coral reef degradation. Cesar Environmental Economics Consulting and WWF-Netherlands, Arnhem and Zeist, The Netherlands. [online] URL: http://pdf.wri.org/ cesardegradationreport100203.pdf.

Cesar, H.J.S., L. Burke, and L. Pet-Soede. 2003. The Economics of Worldwide Coral Reef Degradation. Cesar Environmental Economics Consulting, Arnhem, and WWF-Netherlands, Zeist, The Netherlands, 23pp. Available online at: http://assets.panda.org/downloads/ cesardegradationreport100203.pdf.

Checkley, D. M., Dickson, A. G., Takahashi, M., Radish, J. A., Eisenkolb, N. & Asch, R. 2009. Elevated CO_2 enhances otolith growth in young fish. Science 324, 1683.

Chowdhury, M.S.N., Hossain, M.S., Das, N.G. and Barua, P. 2011. Environmental Variables and Fisheries Diversity of the Naaf River Estuary, Bangladesh. Journal of Coastal Conservation, 15(1): 163-180.

Chowdhury, M.S.N. Hossain, M.S., Chowdhury, S.R. and Das, N.G. 2009. Fisheries Species Composition and Water Quality of the Naaf River Estuary. Bangladesh Journal of Marine Sciences and Fisheries, 1 (1): 1-20.

Chowdhury, S. R., Hossain, M. S., Shamsuddoha, M. and Khan, S.M.M.H. 2012. Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh, CPRD, Dhaka, Bangladesh. 54 pp.

Conservation International. 2008. Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation. Conservation International, Arlington, VA, USA, 23 pp.

Cooley, S.R., and S.C. Doney. 2009a. Anticipating ocean acidification's economic consequences for commercial fisheries. Environmental Research Letters 4, 024007.

Cooley, S. R. and Doney, S. C. 2009b. Ocean acidifications impact on fisheries and societies: A U. S. perspective. The Journal of Marine Educaitn. 25(1): 15-19.

Cooley, S. R., Kite-Powell, H. L. and Doney, S. C. 2009. Ocean acidification's potential to alter global marine ecosystem services. Oceanography. 22: 172-181.

Cooley, A.M., Shefner, L., McLaughlin, W.N., Stewart, E.E., and Wittkopp, P.J. (2012). The ontogeny of color: developmental origins of divergent pigmentation in Drosophila americana and D. novamexicana. Evol. Dev. 14(4): 317-325.

Cooper, T.F., De'ath, G., Fabricius, K.E., and Lough, J.M. 2008. Declining coral calcification in massive Porites in two nearshore regions of the northern Great Barrier Reef. Global Change Biology 14, 529–538.

Davenport, J., III. 1987. A way out of the andragogy morass . Paper presented at the conference of the Georgia Adult Education Association, Savannah, GA.

Desrosiers, R. R., Désilets, J. and Dubé, F. 1996. Early developmental events following fertilization in the giant scallop Placopecten magellanicus. Canadian Journal of Fisheries and Aquatic Sciences - CAN J FISHERIES AQUAT SCI , 53 (6) : 1382-1392.

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to best practices for ocean CO_2 measurements. PICES Special Publication 3, 191 pp.

Dockray, J. J., I. J. Morgan, S. D. Reid, and C. M. Wood. 1998. Responses of juvenile rainbow trout, under food limitation, to chronic low pH and elevated summer temperatures, alone and in combination. Journal of Fish Biology 52:62–82.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean acidification: The other CO_2 problem. Annual Reviews in Marine Science 1:169–192.

Dore, J.E., R. Lukas, D.W. Sadler, M.J. Church, and D.M. Karl. 2009. Physical and biogeochemical modulation of ocean acidification in the central North Pacific. Proceedings of the National Academy of Sciences of the United States of America 106(30):12,235–12,240.

Dupont, P., Besson, M.T., Devaux, J., and Liévens, J.C. 2012. Reducing canonical Wingless/Wnt signaling pathway confers protection against mutant Huntingtin toxicity in Drosophila. Neurobiol. Disease 47(2): 237--247.

Durack PJ, Wijffels S. 2010. Fifty-year trends in global ocean salinities and their relationship to broad-scale warming. Fifty-Year Trends in Global Ocean Salinities and their Relationship to Broad-Scale Warming. J. Climate, 23, 4342–4362.

ECOBAS. 2012. Eco-engineered coastal defense and food production. Wageningen University, The Netherlands and University of Chittagong, Bangladesh.

Erba, E., Bottini, C., Weissert, J.H., Keller, C.E., 2010, Calcareous Nannoplankton response to surface water acidification around Oceanic Anoxic Event 1a: Science, v. 329, p. 428–432.

Fabry, V. J., Seibel, B. A., Feely, R. A., and Orr, J. C. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. – ICES Journal of Marine Science, 65: 414–432.

FAO. 2009. State of Fisheries and Aquaculture 2008. Food and Agriculture Organization of the United Nations, Rome, Italy, 196 pp.

FAO. 2012. Fishery and Aquaculture Country Profiles: Bangladesh. Accessed from: http://www.fao.org/fishery/countrysector/FI-CP_BD/en

Ferrari MCO, Manassa RP, Dixson DL, Munday PL, McCormick MI, Meekan, M. G., Sih, A. and Chivers. D. P. 2012. Effects of Ocean Acidification on Learning in Coral Reef Fishes. PLoS ONE 7(2): e31478.

Foss, A., Røsnes, B. A., and Øiestad, V. 2003. Graded environmental hypercapnia in juvenile spotted wolffish (Anarhichas minor Olafsen): effects on growth, food conversion efficiency and nephrocalcinosis, Aquaculture, 220: 607–617.

Fossa, J. H., P. B. Mortensen & D. M. Furevik, 2002. The deepwater coral Lophelia pertusa in Norwegian waters: distribution and fisheries impacts. Hydrobiologia 471: 1-12.

Franke, A and Clemmesen, C. 2011. Effect of ocean acidification on early life stages of Atlantic herring (Clupea harengus L.). Marine Ecology, Leibniz-Institute of Marine Sciences (IFM-GEOMAR), D¨usternbrooker Weg 20, Kiel 24105, Germany Biogeosciences Discuss., 8, 7097–7126.

Friedman, L., 2011. Deep cuts in proposed U.S. climate aid to developing nations may not be restored. ClimateWire. Accessed 10/10/2012 from: http://www.eenews.net/ cliamtewire/2011/03/02/archive/4?terms=adaptation.

Frommel, A. Y., Maneja, R., Lowe, D., Malzahn, A. M., Geffen, A. J., Folkvord, A., Piatkowski, U., and Clemmesen, C. 2011. Ocean acidification effects on larvae of a commercially important fish species, Atlantic cod (Gadus morhua), Nature Climate change, submitted.

Ganachaud A, Sen Gupta A, Brown JN, Evans K, Maes C, Muir LC, Graham FS (2013) Projected changes in the tropical Pacific Ocean of importance to tuna fisheries. Climatic Change. 119(1):163-179.

Gazeau, F., Quiblier, C., Jansen, J. M., Gattuso, J. P., Middelburg, J. J., and Heip, C. H. R. 2007. Impact of elevated CO2 on shellfish calcification, Geophys. Res. Lett., 34, L07603.

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

Glynn, P.W., 1991. Coral reef bleaching in the 1980's and possible connections with global warming. Trends in Ecological Evolution 6 (6), 175–179.

Green, M. A., Jones, M.E., Boudreau, C.L., Moore, P.L., Westman, B.A. 2004. Limnol. Oceanogr. 49: 727–734.

Guinotte, J. M., Buddemeier, R. W. and Kleypas, J. A. 2003. Future coral reef habitat marginality: temporal and spatial effects of climate change in the pacific basin. Coral reefs. 22: 551-558.

Gattuso, J. P. and Hansson, L. (Eds). 2011. Ocean acidification. Oxford university press. 352pp

Guppy, M. and Withers, P.C. 1999, 'Metabolic depression in animals: physiological perspectives and biochemical generalizations', Biological Review, 74, pp. 1-40.

Haider SMB. 1992. A survey on coast of the Saint Martin's Islands, Bangladesh. MSc. Thesis, Institute of Marine Sciences, University of Chittagong, Bangladesh.

Hall-Spencer JM, Rodolfo-Metalpa R, Martin S, Ransome E, Fine M, Turner SM, Rowley S, Tedesco D & Buia M-C. 2008. Volcanic carbon dioxide vents reveal ecosystem effects of ocean acidification. Nature 454: 96-99.

Hand, S. C. 1991. Metabolic dormancy in aquatic invertebrates. In Advances in Comparative and Environmental Physiology, Vol. 8, pp. 1–50. Ed. by R. Gilles. Springer-Verlag, Heidelberg.

Haque, C.E. 1997. Atmospheric hazards preparedness in Bangladesh: a study of warning, adjustments and recovery from the April 1991 cyclone. Natural Hazards 16:181-202.

Harris, M. J., Naya, J. E., Teegarden, B. J., Cline, T. L., Gehrels, N., Palmer, D. M., Ramaty, R. and Seifert, H. 1999. Transient Gamma Ray Spectrometer Observations of Gamma-Ray Lines from Novae. I. Limits on the Positron Annihilation Line in Five Individual Novae. The Astrophysical Journal 1: 522 -524.

Havenhand, J. N. 2012. How will Ocean Acidification Affect Baltic Sea Ecosystems? An Assessment of Plausible Impacts on Key Functional Groups. AMBIO. 2012 41: 637-644.

Hayashi, H., Sakamoto, M. & Benno, Y. 2004. Evaluation of three different forward primers by terminal restriction fragment length polymorphism analysis for determination of fecal Bifidobacterium spp. in healthy subjects. Microbiol Immunol 48, 1–6.

Hendriks, I. E., Duarte, C. M. and A´ lvarez. 2010. Vulnerability of marine biodiversity to ocean acidification: A meta-analysis Estuarine, Coastal and Shelf Science 86:157–164.

Hilmi N, Allemand D, Dupont S, Safa A, Haraldsson G, Nunes, ALDP, Moore C, Hattam C, Reynaud, S, Hall-Spencer JM, Fine M, Turley C, Jeffree R, Orr J, Munday, PL, Cooley SR, 2012. Towards improved socio-economic assessments of ocean acidification's impacts. Mar Biol. 160(8):1773-1787.

Hobday AJ, Lough J (2011) Projected climate change in Australian marine and freshwater environments. Mar Freshw Res 62:1000–1014

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50: 839–866.

Hofmann GE, Smith JE, Johnson KS, Send U, Levin LA, et al. (2011) High-Frequency Dynamics of Ocean pH: A Multi-Ecosystem Comparison. PLoS ONE 6(12): e28983. doi:10.1371/journal.pone.0028983

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

Hossain, M.S., 2013. Conserving Mangrove Ecosystem for Climate Change Adaptation in the Ganges Basin. Global Challenges in Integrated Coastal Zone Management, Moksness, E and Stottrup, J (ed.), 85-100.

Hossain, M.S., Shamsuddoha, M. and Akhteruzzaman, M., 2004. Mollusc aquaculture for sustainable coastal livelihood. DFID/UGC/Chittagong University, 94 pp.

Hossain, M. S., Chowdhury, S. R. and Nabi, M. R. U. 2007. Resource Mapping of Saint Martin's Island Using Satellite Image and Ground Observations Journal of Forestry & Environment. 5: 23-36

Hossain, M. S., Das, N. G., Sarker, S. and Rahman, M. Z. 2013. Fish diversity and habitat relationship with environmental variables at Meghna River Estuary, Bangladesh. Egyptian Journal of Aquatic Research. In press.

Hossain, M.S., Lin, C.K., Tokunaga, M., Hussain, M.Z., 2003. Remote sensing and GIS application for suitable mangrove afforestation area selection in the coastal zone of Bangladesh. Geocarto International 18(1), 61-65.

Hossain, M.S., Wong, S., Chowdhury, M.Z.R., 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, M.S., Shamsuddoha, M., 2006. Improving Coastal Resource Management for Socio-economic Development of Rural Communities in Cox's Bazar: A Participatory Appraisal. Chittagong University Journal of Social Sciences. XXIV (2): 175-192.

Husebø A, Nøttestad L, Fosså JH, Furevik DM, Jørgensen SB .2002. Distribution and abundance of fish in deep-sea coral habitats. Hydrobiologia 471: 101-110

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

IPCC. 2007. Climate Change 2007: ¬e Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 1,009 pp. Available online at: http://www.ipcc.ch/ipccreports/ar4-wg1.htm (accessed November 29, 2012).

Ishimatsu, A., Kikkawa, T., Hayashi, M., Lee, K., and Kita, J. 2004. Effects of CO_2 on marine fish: larvae and adults. Journal of Oceanography, 60: 731–741.

Ishimatsu, A., Hayashi, M., Lee, K.-S., Kikkawa, T. & Kita, J. 2005 Physiological effects on fishes in a high-CO_2 world. J. Geophys. Res. 110, C09S09.

Ishimatsu, A., Hayashi, M. & Kikkawa, T. 2008 Fishes in high CO_2 , acidified oceans. Mar. Ecol. Prog. Ser. 373, 295–302.

Islam, R.M.M., 1981. Seasonal variation of the phytoplankton of lotic (the Karnafully River estuary) and lentic water (the Foy's Lake) environment. M.Sc thesis, Institute of Marine Sciences and Fisheries, University of Chittagong, 87 pp

Islam MM .2005. Catch composition of Set Bag Net fishery with emphasis on the population dynamics of two commercial important fish species from Chittagong Coastal waters in the Bay of Bengal. MSc Thesis, Institute of Marine Sciences, University of Chittagong, Bangladesh

Islam, M.S., Khan, M.G., Quayam, S.A., Sada, M.N., Chowdhury. Z.A.,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. Jokiel et al., 2008

Kamal MM .2000. Temporal and spatial variation in species diversity of fishes in the Karnafully River Estuary. M.Sc Thesis, Institute of Marine Sciences, University of Chittagong, Bangladesh

Kaniewska P, Campbell PR, Kline DI, Rodriguez-Lanetty M, Miller DJ, et al. (2012) Major Cellular and Physiological Impacts of Ocean Acidification on a Reef Building Coral. PLoS ONE 7(4): e34659.

Khan, Y.S.A., Hossain, M.S., 1996. Impact of shrimp culture on the coastal environment of Bangladesh. International Journal of Ecology and Environmental Sciences 22(2), 145-158.

Kikkawa, T., Ishimatsu, A., and Kita, J. 2003. Acute CO 2 tolerance during the early developmental stages of four marine teleosts, Environ. Toxicol., 18, 375–382.

Kikkawa T, Sato T, Kita J, Ishimatsu A .2006. Acute toxicity of temporally varying seawater CO2 conditions on juveniles of Japanese sillago (Sillago japonica). Mar Pollut Bull 52: 621–625.

Knutzen, J. 1981. Effects of decreased pH on marine organisms. Mar. Pollut. Bull. 12: 25-29.

Kovacs, J.M., 1999. Assessing mangrove use at the local scale. Landscape and Urban Planning 43, 201-208.

Kroeker K, Kordas RL, Crim RN, Singh GG, 2010. Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecology Letters, 13: 1419–1434.

Kurihara, H., Shinji, S., and Shirayama, Y. 2004. Effects of raised CO2 on the egg production rate and early development of two marine copepods (Acartia steuri and Acartia erythraea). Marine Pollution Bulletin, 49: 721–727.

Kurihara H, Matsui M, Furukawa H, Hayashi M, Ishimatsu A. 2008. Long-term effects of predicted future seawater CO2 conditions on the survival and growth of the marine shrimp Palaemon pacificus. J Exp Mar Biol Ecol 367:41–46 .

Kuffner, Ilsa B; Andersson, Andreas J; Jokiel, Paul L; Rodgers, Kuulei S; Mackenzie, Fred T (2007): Decreased abundance of crustose coralline algae due to ocean acidification. Nature Geoscience, 1(2), 114-117.

Langenbuch, M. and P¨ortner, H. O. 2004. High sensitivity to chronically elevated CO2 levels in a eurybathic marine sipunculid. Aquatic Toxicology 70: 55–61.

Le Borgne, T. D. Bolster, M. Dentz, P. de Anna, and A. Tartakovsky (2011) Effective pore-scale dispersion upscaling with a correlated continuous time random walk approach. Water Resour. Res, 47: W12538.

Quéré CL, Raupach MR, Canadell JG, Marland G et al, 2009. Trends in the sources and sinks of carbon dioxide Nature Geoscience, 2:831-836.

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

Lindinger MI, Lauren DJ, McDonald DG .1984. Acid–base balance in the sea mussel, Mytilus edulis III. Effects of environmental hypercapnia on intra- and extracellular acid base balance. Mar Biol Lett 5:371–381.

Lischka, S. and Riebesell, U. 2012. Synergistic effects of ocean acidification and warming on overwintering pteropods in the Arctic. Global Change Biology. 18, 3517–3528.

Lomas, M. W., Hopkinson, B. M., Losh, J. L., Ryan, D. E., Shi, D. L., Xu, Y., Morel, F. M. M. 2012. Effect of ocean acidification on cyanobacteria in the Subtropical North Atlantic. Aquatic Microbial Ecoogy. 66: 211-222.

MacNeil, M. A., Graham, N. A., Cinner, J. E., Dulvy, N. K., Loring, P. A., Jennings, S., Polunin, N. V., Fish, A. T. and McClanahan, T. R., 2010. Transitional states in marine fisheries: adapting to predicted global change. Philosophical Transactions of The Royal Society. 365, 3753-3763.

Makarow, M., Ceulemans, R. and Horn, L. 2009. Sicence policy briefing: Impacts of ocean acidification. European Science Foundation. Accessed 10/10/2012 form : http://www. solas-int.org/resources/ESF_Impacts-OA.pdf

Mahmood, N. and Khan, Y. S. A. 1976. Preliminary observation on the hydrological conditions of the Bay of Bengal off the coast on Bangladesh. J. Asiatic Soc (Sc). Bangladesh. 1 (2): 117-122.

Mahmood, N and Khan, Y.S.A., 1980. On the occurrence of post-larvae and juveniles of Penaeid prawn at Bakkhali estuary and adjacent coastal area of Cox's Bazar with notes on their utilization in aquaculture. Final report to the University Grants Commission, Dhaka, 27 pp.

Mahmood, N., Ahmed, S.U and Loesch, H., 1985. Study on the distribution of finfish larvae in the vicinity of brackish water aquaculture ponds of Satkhira, Bangladesh. Presented in the second international conference on warm water aquaculture – finfish, Brigham Young University Hawaii Campus, USA, 11 pp.

Mahmood, N. 1990. Study on immigration of commercially important penaeid shrimp post larvae in the Estuarine area of Chakaria, Cox's Bazar, Bangladesh. PhD Thesis. Department of Zoology. Rajshai University. Bangladesh. 125pp

Marsahll DJ, Morgan SG (2011) Ecological and evolutionary consequences of linked life-history stages in the sea. Curr Biol 21:R718–R725.

McMichael, A. J., Woodruff, R. E. and Hales, S. 2006. Climate change and human health: present and future risks. Lancet, 367: 859–69.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P and others, 2007. Global climate projections. In: Solomon S, Qin D, Manning M, Chen Z and others (eds) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Inter governmental Panel on Climate Change. Cambridge University Press, Cambridge, p 749–844.

Melzner, F., Gobel, S., Langenbuch, M., Gutowska, M. A., Poertner, H. O., and Lucassen, M. 2009. Swimming performance in atlantic cod (Gadus morhua) following long-term (4–12 months) acclimation to elevated seawater pCO2 , Aquat. Toxicol., 92, 30–37, 2009.

Metzger, R., Sartoris, F. J., Langebuch, M., and Po¨rtner, H. O. 2007.Influence of elevated CO 2 concentrations on thermal tolerance of the edible crab, Cancer pagurus. Journal of Thermal Biology, 32: 144–151.

Michaelidis, B., Ouzounis, C., Paleras, A. and Portner, H. O. 2005. Effects of long term moderate hypercapnia on acid base balance and growth rate in Marine mussels Mytilus galloprovincialis. Marine Ecology Progress series. 293: 109-118

Michaelidis, B., Spring, A., and Poertner, H. O.2007. Effects of long-term acclimation to environmental hypercapnia on extracellular acid-base status and metabolic capacity in Mediterranean fish Sparus aurata, Mar. Biol., 150, 1417–1429

Miller AW, Reynolds AC, Sobrino C, Riedel GF .2009. Shellfish Face Uncertain Future in High CO2 World: Influence of Acidification on Oyster Larvae Calcification and Growth in Estuaries. PLoS ONE 4(5): e5661.

Mortensen, P. 2000. Lophelia pertusa (Scleractinia) in Norwegian waters; distribution, growth and associated fauna Phdthesis, Department of Fish and Marine Biology, University of Bergen

Munday, P. L., Donelson, J. M., Dixon, D. L. and Geoff, G. K. 2009. Effects of ocean acidification on the early life history of a tropical marine fish. Endo Proc. R. Soc. B. 276, 3275–3283

Munday, P. L., Dixson, D. L., McCormick, M. I., Meekan, M., Ferrari, M. C. O. & Chivers, D. P. 2010 Replenishment of fish populations is threatened by ocean acidification. Proc. Natl Acad. Sci. USA 107, 12 930–12 934.

Munday, P. L., Hernaman, V., Dixson, D. L., and Thorrold, S. R.: Effect of ocean acidification on otolith development in larvae of a tropical marine fish, Biogeosciences, 8, 1631–1641.

Muscatine, L., 1973. Nutrition of corals. In: Jones, O.A., Endean, R. (Eds.), Biology and Geology of Coral Reefs, vol. 2. Academic Press, New York, pp. 7–115.

Nabi, M.R.U., Mamun, M.A.A., Ullah, M.H., Mustafa, M.G., 2011. Temporal and spatial distribution of fish and shrimp assemblage in the Bakkhali river estuary of Bangladesh in relation to some water quality parameters. Marine Biology Research 7, 436452.

NOAA, 2011b. Fiscal Year 2012 Blue Book. National oceanic and atmospheric administration. Accessed 3/11/2012 from: http://www.corporateservices.noaa.gov/nbo/fy12_bluebook/ chapter 1_2012_BudgetHighlights.pdf.

OECD. 2008. In: Agrawala S, Frankhauser S (eds) Economic aspects of adaptation to climate change: costs, benefits and policy instruments. OCDE, Paris.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, and others. 2005. Anthropogenic ocean acidification over the twenty 1st century and its impact on calcifying organisms. Nature 437:681–686.

Paltsev S, Reilly JM, Jacoby HD, Morris JF. 2009. The cost of climate policy in the United States. Ener Econ 31(Suppl 2): S235–S243.

Parker, L. M., Ross, P. M. & O'Connor, W. O. 2010 Comparing the effect of elevated pCO_2 and temperature on the fertilization and early development of two species of oysters. Mar. Biol. 157, 2435–2452.

Payan, P., A. Edeyer, H. de Pontual, G. Borelli, G. Boeuf and N. Mayer-Gostan, 1999. Chemical composition of saccular endolymph and otolith in fish inner ear: Lack of spatial uniformity. Am. J. Physiol. Regul. Integr. Comp. Physiol., 46: 123-131.

Pörtner HO, Reipschläger A., 1996. In: Ormerod, B., Angel, M. (Eds.), Ocean Storage of CO_2. Environmental Impact. MIT and International Energy Agency Boston/Cheltenham, pp. 57–81.

Polovina JJ, Dunne JP, Woodworth PA, Howell EA. 2011 Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. ICES J Mar Sci 68:986–995

Purcekk JE, Uye S, Lo W-T, 2007. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Mar. Eco. Pro. Ser. 350:153-174.

Rashid, M. M. 1999. Study on water quality and commercial ichthyofauna of Bakkhali river estuary. MSc Thesis. Institute of Marine Sciences and Fisheries, University of Chittagong.

Raven J, Caldeira K, Elderfield H, Hoegh-Guldberg O, Liss P, Riebesell U, Shepherd J, Turley C, Watson A .2005. Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05, The Royal Society

Reaka-Kudla, M. L. 2001. Coral reefs: Biodiversity and conservation. In: H. M. Hernandez, A. N. Garcia Aldrete, F. Alvarez, and M. Ulloa (eds.), Contemporary Approaches to the Study of Biodiversity, Instituto de Biodiversity, pp. 221-243.

Ridgwell, A. & Schmidt, D. N. 2010 Past constraints on the vulnerability of marine calcifiers to massive carbon dioxide release. Nat. Geosci. 3, 196–200.

Riebesell U., & Tortell P. D., 2011. Effects of ocean acidification on pelagic organisms and ecosystems. In: Gattuso J.-P. & Hansson L. (Eds.), Ocean acidification, pp. 99-121. Oxford: Oxford University Press

Ries, J. B., Cohen, A. L., and McCorkle, D. C.: Marine calcifiers exhibit mixed responses to CO2 -induced ocean acidification, Geology, 37, 1131–1134, 2009.

Roberts, B. W., Walton, K. E., & Viechtbauer, W. (2006). Patterns of mean-level change in personality traits across the life course: A meta- analysis of longitudinal studies. Psychological Bulletin, 132, 1–25.

Roberts, B., Ocaka, K. F., Browne, J., Oyok, T. and Sondorp, E. 2008. Factors associated with post-traumatic stress disorder and depression amongst internally displaced persons in northern Uganda. BMC Psychiatry. 8: 1-9

Ruttimann, J. 2006. Oceanography: sick seas. Nature. 442(7106):978-80

Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., Millero, F.J., Peng, T.H., Kozyr, A., Ono, T., Rios, A.F., 2004. The oceanic sink for anthropogenic CO2. Science 305, 367–371.

Samsuzzaman, M. M. 2009. Temporal and spatial assemblages of fish fauna around the Sandwip Island with special reference to some physico-chemical parameters. MSc thesis. Institute of Marine Sciences and Fisheries, University of Chittagong.

Sayedullah, M., 2003. Seasonal distribution of phytoplankton in the Meghna River stuary of Bangladesh with notes on biodiversity. M.Sc thesis, Institute of Marine Sciences and Fisheries, University of Chittagong, 82 pp.

Shaw CN, Hofmann CL, Petraglia MD, Stock JT, Gottschall JS. 2012. Neandertal Humeri May Reflect Adaptation to Scraping Tasks, but Not Spear Thrusting. PLoS ONE 7(7): e40349.

Shirayama Y, Thornton H. 2005. Effect of increased atmospheric CO_2 on shallow water marine benthos. J Geophys Res 110(C9): C09S08.1–C09S08.7

Small D, Calosi P, White D, Spicer JI, Widdicombe S. 2010. Impact of medium-term exposure to CO_2 enriched seawater on the physiological functions of the velvet swimming crab Necora puber. Aquat Biol 10:11–21.

Spero, H. J., Bijma, J., Lea, D. W., and Bemis, B. E. 1997. Effect of seawater carbonate concentration on foraminiferal carbon and oxygen isotopes. Nature, 390: 497–500.

Spicer JI, Raffo A, Widdicombe S .2007. Influence of CO_2 related seawater acidification on extracellular acid–base balance in the velvet swimming crab Necora puber. Mar Biol 151:1117–1125.

Stock CA, Alexander MA, Bond NA, Brander KM, Cheung WWL, Curchitser EN, Delworth TL, Dunne JP, Griffies SM, Haltuch MA, Hare JA, Hollowed AB, Lehodey P, Levin SA, Link JS, Rose KA, Rykaczewski RR, Sarmiento JL, Stouffer RJ, Schwing FB, Vecchi GA, Werner FE .2011. On the use of IPCC-class models to assess the impact of climate on living marine resources. Prog Oceanogr 88:1–27.

Sultana, D., Hossain, M. M. and Ormond, R. 2008. Coral Associated Fishes & Corals at ST. Martin's Island, BoB, Bangladesh & Deterioration of its Water Quality Due to Anthropogenic Activity - Need Long Term Study. Presented at SAARC Coral Reef Monitoring Workshop, 21-24 May, 2012, Sri-Lanka.

Talmage SC, Gobler CJ (2011) Effects of Elevated Temperature and Carbon Dioxide on the Growth and Survival of Larvae and Juveniles of Three Species of Northwest Atlantic Bivalves. PLoS ONE 6(10): e26941. doi:10.1371/journal.pone.0026941.

Talukdar, M. 2010. Spatial and temporal distribution of fish species with relation to environmental parameters at Moheshkhali channel. MSc thesis. Institute of Marine Sciences and Fisheries, University of Chittagong.

Tol RSJ .2010. The economic impact of climate change. Perspek. Wirtschaftspolitik 11(s1):13–37.

Tomascik, T. 1997. Management Plan for Resources of Narikel Jinjira (St. Martin's Island) Final Report, National Conservation Strategy Implementation Project -1 Ministry of Environment and Forest, Government of Bangladesh 125 pp.

Toresen, R. and Østvedt, O.J. (2000), Variation in abundance of Norwegian spring-spawning herring (Clupea harengus, Clupeidae) throughout the 20th century and the influence of climatic fluctuations. Fish and Fisheries, 1: 231–256.

Trench, R. K. 1979. The cell biology of plant-animal symbiosis. A. Rev. Pl. Physiol. 30, 485-532.

Truchot, J. P. 1987. Comparative aspects of extracellular acid-base balance. Springer-Verlag, Berlin.

Turley, C. & Boot, K. 2010 Environmental consequence of ocean acidification: a threat to food security. UNEP Emerging Issues Bulletin. Nairobi, Kenya: United Nations Environment Programme.

Turley, C., Blackford, J., Widdicombe, S., Lowe, D., Nightingale, P. D., Rees, A. P. in: H.J. Schellnhuber, W. Cramer, N. Nakicenovic, T. Wigley, G. Yohe (Eds.), Avoiding Dangerous Climate Change, Cambridge University Press, Cambridge, 2006, pp. 65–70.

UNFCCC. 2010a. Adaptation Fund. United Nations Framework Convention on Climate CHange. Accessed 3/10/2012 form: http://unfccc.int/cooperation_and_support/financial_mechanism/adaptation_fund/items/3659.php

UNFCCC. 2010b. Cophangen Accord. United Nations Framework Convention on Climate CHange. Accessed 3/10/2012 form: http://unfccc.int/reosurce/docs/2009/cop15/eng/11a01.pdf

Van Breamen, N., Tandatemiya, M and Chanchareonsook, S. 1973. A detailed survey on the actual and potential soil acidity at the Bank Pakong Land Development Centre, Thailand. In Dost. Proceedings of the International Symposium on acid sulphate soils, 13-20 August 1992, Wageningen, The Netherlands. Volume 2. International Institute for Land Reclamation and improvement, Wageningen. Pp 159-168.

Walther, Kathleen; Sartoris, Franz J; Bock, C; Pörtner, Hans-Otto (2009): Impact of anthropogenic ocean acidification on thermal tolerance of the spider crab Hyas araneus. Biogeosciences, 6(10). 2207-2215

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

Wilkinson, Clive (ed.) 2008. Status of Coral Reefs of the World 2008. Australian Institute of Marine Science, Townsville, Australia.

Yamada, Y., and Ikeda, T. 1999. Acute toxicity of lowered pH to some oceanic zooplankton. Plankton Biology and Ecology, 46: 62–67.

Zafar, M. and Alam, M. D. 1997. Occurrence and abundance of Acetes Shrimp in the Kutubdia channel of Bangladesh coastal water. Bangladesh J. Fish. Res. 1(2): 91-96

Appendix-A. Monthly water pH variation in rivers and estuaries of coastal Bangladesh

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ref
Meghna estuary													
Meghna estuary	7.3	7.4	7.3	7.3	-	-	-	-	-	-	7.5	7.5	Hossain et al. 2013
Karnafully river estuary	7.3	7.5	7.3	7.3	7.2	7.1	7.2	7.1	6.9	7.2	7.5	7.7	Mahmood and Khan 1976
Karnafully river estuary	-	-	2.51	2.7	2.01	2.71	-	-	-	-	-	-	Alam 2000
Kutubdia channel	8.22	7.95	7.14	7.9	7	7.5	7.14	8	7.1	7.16	8.3	8.4	Zafar and Mahmodd 1997
Kutubdia channel	-	-	-	-	8.5	8.9	8.7	7.5	8.1	7.8	7.6	-	ECOBAS 2012
Moheshkhali channel	8.3	8.1	7.5	7.5	8.2	7.9	8.2	7	7.7	8.1	-	-	Mahmood et al. 1985
Moheshkhali channel	8.2	8.4	8	7.5	7.3	7.1	7.2	7.3	7.1	7.6	7.9	8.5	Hossain et al. 2003
Moheshkhali channel	-	-	-	-	8.6	8.5	8.5	7.5	7.5	7.5	7.5	-	ECOBAS 2012
Bakkhali river estuary	7.6	7.4	7.3	7.2	7.3	7.4	7.3	7.6	7.7	7.6	7.7	7.8	Mahmood and Khan 1980
Bakkhali river estuary	6.2	6.1	6.2	7.1	7.9	7.8	7.8	7.4	7.9	7.4	6.7	6.2	Rashid 1999
Naaf river estuary													
Naaf river estuary	-	-	8.1	7.8	8	7.6	7.5	7.7	7.5	7.7	-	-	Chowdhury et al. 2009
Mathamuhuri river estuary													

Appendix-B. Monthly water temperature variation in rivers and estuaries of coastal Bangladesh

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ref
Meghna estuary													
Meghna estuary	-	0	0	0	0	-	-	-	-		0	0	Hossain et al. 2013
Karnafully river estuary	3.8	5.58	6.24	4.34	2.95	1.82	0.4	1.44	0.69	1.3	1.32	1.25	Mahmood and Khan 1976
Karnafully river estuary	-	-	0.3	0.3	1.6	1	-	-	-	-	-	-	Alam 2000
Kutubdia channel	30	29.45	25	26	25	18	9.72	10.79	11	20	25.57	27.53	Zafar and Mahmodd 1997
Kutubdia channel	-	-	-	-	13	15	15	11	10	14	-	-	ECOBAS 2012
Moheshkhali chan-nel	28	27	25.9	25	22.7	21	21	20	28	27	-	-	Mahmood et al. 1985
Moheshkhali chan-nel	29.1	28.8	28.05	29.42	25.09	22.7	22	20.9	23.85	27.3	28.55	29.8	Hossain et al. 2003
Moheshkhali chan-nel	-	-	-	-	14	15	16	12	15	18	-	-	ECOBAS, 2012
Bakkhali river estu-ary	22.5	23.9	26.7	30.0	30.2	29.6	28.9	27.7	28.8	28.6	26.5	24.8	Mahmood and Khan 1980
Bakkhali river estu-ary	32.18	34.71	33.47	22.01	12.81	5.81	16.07	14.9	15.58	18.51	22.13	28.08	Rashid 1999
Naaf river estuary													
Naaf river estuary	-	-	29.1	21.2	2.2	5.5	2.3	1.2	3	10.1	-	-	Chowdhury et al. 2009
Mathamuhuri river estuary	19.5	26.24	32.56	34.13	16.49	10.74	2	2.06	1.92	3.34	11.89	13.8	Mahmood 1990

Appendix-C. Monthly water salinity variation in rivers and estuaries of coastal Bangladesh

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ref
Meghna estuary													
Meghna estuary	-	0	0	0	0	-	-	-	-		0	0	Hossain et al. 2013
Karnafully river estuary	3.8	5.58	6.24	4.34	2.95	1.82	0.4	1.44	0.69	1.3	1.32	1.25	Mahmood and Khan 1976
Karnafully river estuary	-	-	0.3	0.3	1.6	1	-	-	-	-	-	-	Alam 2000
Kutubdia channel	30	29.45	25	26	25	18	9.72	10.79	11	20	25.57	27.53	Zafar and Mahmodd 1997
Kutubdia channel	-	-	-	-	13	15	15	11	10	14	-	-	ECOBAS 2012
Moheshkhali channel	28	27	25.9	25	22.7	21	21	20	28	27	-	-	Mahmood et al. 1985
Moheshkhali channel	29.1	28.8	28.05	29.42	25.09	22.7	22	20.9	23.85	27.3	28.55	29.8	Hossain et al. 2003
Moheshkhali channel	-	-	-	-	14	15	16	12	15	18	-	-	ECOBAS 2012
Bakkhali river estuary	26.8	24.4	23.6	23.3	23.8	21.3	21.0	20.5	23.2	24.7	25.2	25.3	Mahmood and Khan 1980
Bakkhali river estuary	32.18	34.71	33.47	22.01	12.81	5.81	16.07	14.9	15.58	18.51	22.13	28.08	Rashid 1999
Naaf river estuary													
Naaf river estuary	-	-	29.1	21.2	2.2	5.5	2.3	1.2	3	10.1	-	-	Chowdhury et al. 2009
Mathamuhuri river estuary	19.5	26.24	32.56	34.13	16.49	10.74	2	2.06	1.92	3.34	11.89	13.8	Mahmood 1990

Appendix-D. Monthly dissolved oxygen variation in rivers and estuaries of coastal Bangladesh

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ref
Meghna estuary													
Meghna estuary	-	4.9	5	5.5	5.6	-	-	-	-	-	5	5	Hossain et al. 2013
Karnafully river estuary	4.97	4.16	3.37	3.36	4.38	4.23	4.34	3.93	3.62	4.43	4.35	4.96	Mahmood and Khan 1976
Karnafully river estuary	-	-	7.6	7.7	8.1	7.2	-	-	-	-	-	-	Alam 2000
Kutubdia channel	8.34	5.35	3.82	4.97	5.35	3.51	4.71	6.97	6.99	5.28	4.63	8.35	Zafar and Mahmodd 1997
Kutubdia channel	-	-	-	-	4.5	4.4	4.2	4.6	5.1	4.7	-	-	ECOBAS 2012
Moheshkhali chan-nel	8.1	7.5	7	6.5	7.6	7.8	7.5	6.5	7	7.9	-	-	Mahmood et al. 1985
Moheshkhali chan-nel	-	-	-	-	4.6	4.9	4.0	5.2	5.3	5.2	-	-	ECOBAS 2012
Bakkhali river estu-ary	4.15	3.98	3.65	3.30	3.30	3.80	3.65	4.20	4.35	4.25	4.40	4.30	Mahmood and Khan 1980
Bakkhali river estu-ary	3.15	2.87	1.91	2.36	2.51	3.71	3.24	3.89	4.3	3.25	3.61	5.44	Rashid 1999
Naaf river estuary													
Naaf river estuary			5.65	5.32	3.5	4.3	3.35	4.44	4.62	4.58	-	-	Chowdhury et al. 2009
Mathamuhuri river estuary	5.42	5.13	4.83	4.03	3.85	4.63	5.28	5.45	5.45	5.34	5.41	5.74	Mahmood 1990

Appendix-E. Examples of the response of marine fauna to ocean acidification (source: Victoria et al., 2008).

Species	Description	CO_2 system parameters	Sensitivity	Reference
Planktonic Foraminifera				
Orbulina universa	Symbiont-bearing	pCO_2 560–780 ppmv	8-14% reduction in shell mass	Spero et al. 1997; Bijma et al. 2002
Globigerinoides sacculifer	Symbiont-bearing	pCO_2 560–780 ppmv	4-8% reduction in shell mass	Bijma et al. 2002
Cnidaria				
Scyphozoa Hydrozoa	Jellyfish	North Sea seawater pH drop from 8.3 to 8.1	Increase in frequency as measured by CPR from 1958 to 2000	Attrill et al. 2007
Mollusca				
Clio pyramidata	Shelled pteropod	Ωarag<1	Shell dissolution	Orr et al. 2005
Mytilus edulis	Mussel	pH 7.1 / 10 000 ppmv	Shell dissolution	Lindinger et al. 1984
Crassostrea gigas	Oyster	pCO_2 740 ppmv	10% decrease in calcification rate	Gazeau et al. 2007
Mytilus galloprovincialis	Mediterranean mussel	pH 7.3, ~5000 ppmv	Reduced metabolism, growth rate	Michaelidis et al. 2005
Placopecten magellanicus	Giant scallop	pH <8.0	Decrease in fertilization and em-bryo development	Desrosiers et al. 1996
Pinctada fucada martensii	Japanese pearl oyster	pH 7.7	Shell dissolution, reduced growth, Increasing mortality	Reviewed in Knutzen 1981
Arthropoda				
Acartia steueri	Copepod	0.2-1%CO2	Decrease in egg hatching success; increase in nauplius mortality rate	Kurihara et al. 2004
Euphausia pacifica	Krill	pH , 7.6	Mortality increased with increasing exposure time and decreasing pH	Yamada and Ikeda 1999
Cancer pagurus	Crab	1% CO_2 , ~10 000 ppmv	Reduced thermal tolerance, aero-bic scope	Metzger et al. 2007
Chaetognatha				
Sagitta elegans	Chaetognath	pH<,7.6	Mortality increased with increasing exposure time and decreasing pH	Yamada and Ikeda 1999
Echinodermata				

Species	Description	CO_2 system parameters	Sensitivity	Reference
Strongylocentrotus purpuratus	Sea urchin	pH ~6.2–7.3	High sensitivity inferred from lack of pH regulation and passive buffering via test dissolution during emersion.	Burnett et al. 2002
Cystechinus sp.	Deep-sea urchin	pH 7.8	80% mortality under simulated CO_2 sequestration	Barry et al. 2002
Vertebrata				
Scyliorhinus canicula	Dog fish	pH 7.7 / 0.13% CO_2 7% CO_2 , ~70 000 ppmv	Increased ventilation, 100% mortality after 72 h	Truchot 1987; Hayashi et al. 2004
Sillago japonica	Japanese whiting	7% CO_2 , ~70 000 ppmv	Rapid mortality in 1-step exposure	Kikkawa et al. 2006
Paralichthys olivaceus	Japanese flounder	5% CO_2 , ~50 000 ppmv	100% mortality within 48 h	Hayashi et al. 2004
Euthynnus affinis	Eastern little tuna	15%CO_2 , ~150 000 ppmv	100% mortality of eggs after 24 h	Kikkawa et al. 2003
Pagrus major	Red sea bream	5%CO_2 , ~50 000 ppmv	>60% larval mortality after 24 h	Ishimatsu et al. 2005
Seriola quinqueradiata	Yellowtail	5% CO_2 , 50 000 ppmv	Reduced cardiac output; 100% mortality after 8 h	Ishimatsu et al. 2004
Dicentrarchus labrax	Sea bass	pH 7.25, 24 mg l –1 CO_2	Reduced feed intake	Cecchini et al. 2001

Appendix-F. Monthly occurrence of different larval fish in Sunderban mangrove ecosystem of Satkhira, Bangladesh (source: Mahmood et al. 1985)

Species recorded	Months (1982-1983)											
	J	J	A	S	O	N	D	J	F	M	A	M
Colia ramcarati												
Setipinna phasa												
Harpadon nehereus												
Puntius bimaculatus												
Ophichthys boro												
Hemirrhamphus ectunctio												
Ichthyocarpus carce												
Panchax melastigma												
Mugil spp.												
Lates calcarifer												
Sillago domina												
Leiognathus ruconius												
Leiognathus equulus												
Pseudosciaena sp.												
Otolithoides pama												
Sicyopterus qymnauchen												
Glossogobius giuris												
Pseudopocryptes lanceolatus												
Odontarblyopus rubicandus												
Trypauchen vaqina												
Platycephalus scaber												
Cynoglossus cynoglossus												
Cynoglossus lida												
Macrognathus aculeatus												
Batrachus grunniens												
Unidentified												

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