



IMPLICATIONS OF CLIMATE CHANGE FOR FISHERIES AND AQUACULTURE IN THE *SUNDARBANS* REGION OF BANGLADESH

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Abstract: This review synthesizes the available information on the climate variability, fisheries resources and aquaculture activities in the *Sundarbans*. The article also focuses on the possible impact of temperature and sea level rise, salinity intrusion, impaired freshwater supply, precipitation variability, acidification, and tropical storm surges on the fisheries and aquaculture in and adjacent areas of the *Sundarbans* as well as dependent fisher-folk communities. It prescribes some adaptation and mitigation measures as well. The synthesis implies that the distribution, abundance, and spawning habit of the *Sundarbans* fisheries stock of more than 227 species and their recruitment processes needs to be changed. The sea level rise (0.30-1.5m by 2030) and salinity intrusion (16% by 2050) may open door for marine fisheries of euryhaline type and crustacean species, and coastal-aquaculture (e.g. farming of sea-bass, mullet, shrimp, and mud crab). Nevertheless, stenohaline fish species may extinct. The frequent tropical cyclone and flood in recent years resulted in the alteration of the *Sundarbans* ecosystem, loss of biodiversity and damages to aquaculture farms, and thus livelihood of fisher-folks are at risk. Breeding protocol and adaptive farming technology of suitably saline tolerant fisheries species, reforestation, river restoration, integrated protected area management, and the resilience capacity of the fisher-folk communities must be developed for sustainable fisheries and aquaculture in the *Sundarbans* and adjacent areas.

Key words: *Sundarbans*, climate change, fisheries, aquaculture, sustainability

Introduction

With well documentation on the experienced and possible effects of global climate change such as changes in temperature and CO₂, glaciers melting, altered precipitation patterns, frequent storms, sea level rise and salinity intrusion; climate change is deemed as the greatest global challenge of today- the earth's next apocalypse. Like other countries of the world, the impacts of climate variability and changes are now exceedingly tangible in Bangladesh which is now widely recognized as one of the most climate vulnerable countries in the world (UNDP, 2004). Heavier and more erratic rainfall, higher river flows and river bank erosion, increasingly frequent and severe tropical cyclones are now-a-days very common natural hazards in Bangladesh, particularly for the coastal areas.

A wide belt in the south of the country could come across inundation and salinity ingression if the sea level rises by 0.18 to 0.79 meters (IPCC, 2007), and evidently the *Sundarbans*- a world heritage site of about one million hectares in southwest Bangladesh, and south-eastern part of the State of West Bengal in India, will be crucially vulnerable to storm surges, sea level rise and salinity ingression (WHOI, 1986). A 45 cm sea level rise would inundate 75% of the *Sundarbans*, and 67 cm sea level rise could inundate all of the system (World Bank, 2000). In a

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nutshell, the *Sundarbans* is severely threatened from such effects which have been also exacerbated by human interventions such as illegal exploitation of mangrove trees and aquatic resources, conversion of mangrove forest into shrimp ponds, oil and gas exploration inside the mangrove, urbanization, and construction of embankments, polders, and roads etc.

The Bangladesh part of the *Sundarbans* with an area of some 6017 km² (7620 km² including the marine zone) has a diverse natural gene pool for flora and fauna, and provides shelters and livelihoods for about 2.5 million people of Bangladesh. More than 500,000 people are involved in wood-cutting, fishing, honey and golpata (*Nypa sp.*) collecting for their subsistence. On the year-round availability of fish and shrimp seed, the coastal aquaculture ventures have been developed around the *Sundarbans* region. The *Sundarbans* fisheries accounts for about 2% of the total capture fisheries production in Bangladesh, and overall contribution of the *Sundarbans* fisheries to the country's total fish production is about 1% (Hoq, 2008). Most fin-fishes are sun-dried while large and valuable fin-fishes and shrimps are sold as fresh and frozen at domestic and export markets.

While the contributions of the *Sundarbans* fisheries and aquaculture to nutrition and livelihoods of local coastal poor people, Bangladesh's food security, and national economy are clearly defined; the implications of climate change for these sectors and for *Sundarbans* coastal communities are reasonably to be addressed. Thus, through reviewing scientific articles, proceedings, books relevant to the *Sundarbans* ecosystem, climate variability, and fisheries interventions; this paper was documented to provide an overview of the possible impacts of climate change on fisheries and aquaculture in and around the *Sundarbans*.

The Sundarbans environment and climate change: The *Sundarbans* mangrove forest is interconnected by an elaborate network of rivers, canals, and creeks, which makes its river-salinity very complex. The *Sundarbans* is a deltaic swamp which receives large volumes of freshwater from inland rivers, and of saline water from the twice-daily tidal inundation from the Bay of Bengal. The climate of the *Sundarbans* is predominated by the south-west monsoon characterized by high rainfall. The mean annual rainfall varies from about 2000 mm in the east to 1600 mm in the west. Being located at the apex of the Bay of Bengal, the *Sundarbans* is accompanied with frequent cyclonic storms during May-June and severe cyclones with tidal surges during October-November (Hoq, 2008).

The Bangladesh *Sundarbans* Reserve Forest (BSRF) classifies the river systems in three different series as *Raimanagal-Sibsa*, *Passur-Sibsa* and *Passur-Baleswar* series. Hoq (2008) reported that mean monthly stream flow varies from 190 m³/sec in March to 7,650 m³/sec in August. The water salinity of south-eastern, middle-northern, and western part of the *Sundarbans* are delineated as 0-5 ppt, 5-18 ppt, and >18 ppt, respectively.

The *Sundarbans* is now victim of excessive sedimentation which has resulted in the rise of forest floor, and in the absence of flushing of the forest floor by tidal water, the habitat condition changes and new species may start establishing themselves (Hoq, 2008). The shifting of the main course of the river Ganges eastward over the past few centuries, and the silting up of some smaller rivers feeding freshwater to western *Sundarbans* have caused a major reduction in freshwater supply to the western portion of the *Sundarbans*. This has influenced the changes in the *Sundarbans* mangrove species.

Two estimates of potential future sea level rise in Bangladesh are 0.30-1.5m for 2030 and 0.30-0.50m for 2050 (DOE, 1993). Majority of the mesohaline areas in the *Sundarbans* will be transformed into polyhaline areas, while oligohaline areas would be reduced to only a small pocket along the lower- Baleswar river in the eastern part of the forest. (Ahmed and Alam, 1998). The effects of climate change on the *Sundarbans* would be considerably more critical during dry season extending from November to April. In winter, a different environmental condition is

expected with lesser freshwater supply in the rivers facilitating greater saline ingress into the *Sundarbans*.

The Sundarbans Fisheries and Aquaculture

Fisheries resources: The *Sundarbans* waters are highly productive and abound with a good number of fishes, crustaceans, molluscs, lobsters, crocodiles, reptiles, zooplankton, phytoplankton, and aquatic plants. The *Sundarbans* water-bodies provide homes for 53 species of pelagic fish, 124 species of demersal fish, 24 species of shrimp, 7 species of crab, 2 species of gastropoda, 6 species of pelecypoda, 8 species of locust lobster, and 3 species of turtle (Acharya and Kamal, 1994). Hoq (2008) and Acharya and Kamal (1994) reported that hilsa (*Tenualosa ilisha*), Asian sea-bass (*Lates calcarifer*), pangas (*Pangasius pangasius*), grey eel-catfish (*Plotosus canius*) and giant riverine prawn (*Macrobrachium rosenbergii*) are abundant in low salinity zone of the *Sundarbans*. Major commercial fishes and crustaceans such as hilsa, sea-bass, silver spotted grunt (*Pomadasyus hasta*), Indian threadfin (*Polynemus indicus*), paradise threadfin (*P. paradiseus*), silver croaker (*Johnius argentatus*), black croaker (*J. dussumieri*), giant tiger shrimp, Indian white shrimp (*Penaeus indicus*), brown shrimp (*Metapenaeus monoceros*), *Parapenaeopsis* sp., and mud crab (*Scylla serrata*) are found in moderate saltwater zone. In high-saline water zone, Bombay-duck (*Harpadon nehereus*), *Trichiurus haumela*, gangetic hairfin anchovy (*Setipinna phasa*), scaly hairfin anchovy (*S. taty*), pama croaker (*Pama pama*), sardine (*Sardinella* sp.), sharks (Family: Carcharhinidae and Sphyrnidae) and rays (Family: Dasyatidae) are available. Goldspot mullet (*Liza parsia*), gray mullet (*L. tade*), flathead grey mullet (*Mugil cephalus*), corsula (*Rhinomugil corsula*), milkfish (*Chanos chanos*) and long whiskers catfish (*Mystus gulio*) are also common in the *Sundarbans* estuaries.

There are 23 ichthyoplankton species of 19 families in the Coxali river estuary in Satkhira range (Mahmood *et al.*, 1987). Zafar and Mahmood (1989) identified zooplankters of 13 major taxa namely, copepods, amphipods, mysids, acetes, chaetognaths, polychaetes, lucifers, hydromedusae, shrimp larvae, fish larvae, crab larvae, squilla larvae and horse-shore crab larvae.

Aquaculture: The aquaculture activities in the *Sundarbans* region are mainly centered on tiger shrimp and riverine prawn farming. Banglapedia (2006) states that shrimp and prawn farms in Bangladesh are primely located in the vicinity of the *Sundarbans* Reserve Forest i.e. 29% at Khulna, 19% at Satkhira, and Bagerhat (29%). An estimated 217,877 ha of shrimp cultivation is reported in 2005-06 in the Khulna and Satkhira districts (Hoq, 2008). In perspective of prawn farming, most of the country's prawn farms (about 30,000 ha) are concentrated in Bagerhat, Khulna, Patuakhali, Barisal, and Gopalganj districts adjacent to the *Sundarbans* (Alam *et al.*, 2007). Since the last decade, the fish farmers around the *Sundarbans* coasts practice mud crab fattening in ponds as well as bamboo-cages in tidal rivers. Besides, polyculture of finfish (major carps, sea-bass, mullets, and tilapia) with freshwater prawn, and monoculture of pangas are also being practised in the *Sundarbans* coastal regions (*Personal communication*).

Fisheries products: About 60 % of artisanal inland and offshore fisheries in the *Sundarbans* areas are processed as sun-dried, 20-30 % as smoked and 10-20 % as salted products (Hoq, 2008). Bombay duck, ribbon fish (*Trachipterus* sp.), pomfret (*pampus* sp.) and croakers are the popular dried product of coastal Bangladesh. Hilsa are salted by local fishermen mainly in the Sibsra river basin and in the river *Baleswar* for exporting abroad. Shrimps are smoked in 100 shrimp smoking units operated in and around the *Sundarbans* (Hoq, 2008).

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The Sundarbans fisheries as livelihood of coastal fisher-folks: The *Sundarbans* with its diverse fisheries resources play a significant role in providing basic subsistence activity for the poor coastal fisher-folks. About 200,000 fishermen fish daily for their subsistence. An estimated 225,000 people are involved in shrimp fry collection, and in addition about 20,000 people in shrimp fry trading. Approximately 30,000 to 35,000 people (fishermen, fish processor and laborer) temporally inhabit the Dubla Island in the *Sundarbans* during fish drying season (Hoq, 2008). The coastal fish farmers are mostly dependent on the *Sundarbans* wild seed for farming of shrimp, prawn, crab, and some commercially worth fin-fish species, though some fish hatcheries have recently been established.

Facets of the *Sundarbans* fisheries and aquaculture response to climate change

Implications for the Sundarbans capture fisheries: It has been implicated that capture fisheries which depend on naturally recruited and occurring wild populations may be affected by global changes in air and sea surface temperature, rainfall, sea level, wind patterns, salinity and acidity of water bodies, and intensity of storm surges through a diverse range of pathways and drivers (FAO, 2009; Handisyde *et al.*, 2006; Harley *et al.*, 2006; Schindler, 2001). Though species-specific characteristics and interactions among species make the prediction of the specific effects of climate change on fish species composition, abundance, spawning, migration, nutrition and growth difficult, it has been reported that fish reproduction, growth and migration patterns are all affected by change in temperature, rainfall and hydrology (Ficke *et al.* 2007; Jobling, 1997; Rombough, 1997; Van der Kraak and Pankhurst, 1997).

All coastal ecosystems are vulnerable to global warming, sea level rise, salinity ingression, ocean acidification and cyclones. The *Sundarbans* will be completely lost with 1 meter sea level rise (World Bank, 2000). At present there are 12.6% high saline areas in and around the *Sundarbans* regions, which may increase by 15.7% in 2050 and 17.9% in 2100 (CEGIS, 2006). The loss of the *Sundarbans* valuable buffer mangrove forests due to sea level rise and increased salinity intrusion, reduction in fresh water supply, excessive siltation, and acidification will severely alter the *Sundarbans* ecosystem and thus fisheries production can be influenced as changes in species diversity, composition, distribution and evolution, as well as alteration of fishes' breeding and nursery grounds (Table 1).

The reduced influx of freshwater and increased salinity in the *Sundarbans* ecosystem may threaten low saline-tolerant fish species while, at the same time, create home for euryhaline fish species. Several fishes will be eliminated from these areas as they cannot quickly adapt to the changing salinity levels (Gopal, 2009). Badjeck (2008) reported increased mullet fishery in northern Peru due to changes in estuarine salinity patterns. There is much more likelihood of less availability of *pangas* in *Bhola* river, *Sela* river and *Baleswar* river of the *Sundarbans* while the catch of euryhaline species such as sea-bass, grunter, grey eel-catfish, Bombay-duck, goldspot mullet, tade mullet may be increased. An expanding distribution pattern of anchovies (e.g. *S. phasa*, *S. taty*), sardines (e.g. *S. melanura*) may be observed.

Under the scenario of 2-6°C global warming, the precipitation in Bangladesh is forecasted to decline during the dry season and increase during the wet season (WorldFish Center, 2007). The changes in temperature, rainfall pattern, and salinity will alter the distribution pattern of hilsa fish, sea-bass, prawn, and mud crab fisheries in and around the *Sundarbans*. Temperature changes in the Pacific Islands would lead to a spatial redistribution of tuna resources to higher latitudes within the Pacific Ocean (World Bank, 2000). Hoq (2008) reported 50% reduction in hilsa catch

Table 1. Potential impacts of climate change on the *Sundarbans* fisheries (modified from FAO, 2009 and Allison *et al.*, 2005)

Climate changes variables	Processes	Potential impacts on fisheries
Sea level rise	Loss of coastal fish breeding and nursery habitats Salinity ingress ion	Changes in production and yield of related fisheries Loss of low saline-tolerant species; increased catch of marine fishes; changes in abundance and distribution of brackish-water fish larvae
	Increased exposure of coastal areas to storm damage	Increased vulnerability of the <i>Sundarbans</i> communities
Water temperature	Changes in sex ratios; altered time of spawning; altered time of migrations; altered time of peak abundance.	Distribution, spawning and composition of the <i>Sundarbans</i> fishes will be altered; Shifts in distribution of aquatic species and thus reduced diversity in the <i>Sundarbans</i> waters. Changes in plankton communities and distribution of <i>Sundarbans</i> pelagic fisheries; Increased variability in fisheries yield.
Precipitation	Changes in upwelling Reduced rainfall in winter and increased rainfall in wet season	Changes in spawning habits
Acidification	Problems in calcification of crustaceans, mollusks and zooplankton	Potentially reduced production for shrimps, crabs, mollusks in yields
Increased frequency of storms	Sudden shock on fish population More days at sea lost to bad weather, risks of accidents increased	Hampered in physiological process, and sometimes die-off of fishes Increased risks associated with fishing, making it less viable livelihood options for the poor

in *Baleswar*, *Bhola* and *Passur* rivers, which may be related to changes in spawning and migratory habits as result of changes in hydrology of rivers, and other anthropogenic pressures. Recently, hilsa fish are found to shift into the deeper part of the Bay of Bengal (*Personal Communication*); CMFRI (2008) reported the similar fact of Indian mackerel (*Rastrelliger kanagurta*) descending deeper during the last two decades. The variability of salinity and rainfall in the *Sundarbans* region could result in spawning migration of river prawn, marine shrimp, sea-bass, silver-jew fish, and mud crab.

As upwelling is inherent characteristic of coastal water-bodies, the change in upwelling patterns due to global warming might result in a major change in the plankton communities of the *Sundarbans* waters. Goes *et al.* (2005) reported over 350 percent increase in summertime phytoplankton biomass due to increased upwelling along the Arabian Sea coast. There is a possibility of alteration in food-web of the *Sundarbans* aquatic ecosystem, and thus the *Sundarbans* aquatic food-web may be impaired; benthic and demersal fishes may tend to shift

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their distribution southward and thus decline in abundance. Pelagic species are also likely to shift their distribution southwards.

Acidification in the *Sundarbans* would influence spawning success of the fisheries species through causing reduced sperm motility and fertilization rate as reported in sea urchin reported by Havenhand *et al.* (2008), and make difficulties in shell calcification of crustaceans, molluscs and other species in the Sundarban waters.

Implications for the Sundarbans aquaculture: As on the fisheries sector, the changes in hydrology, sea-level and temperature rise, monsoonal rain patterns, extreme climatic events and water stress may bring on both positive and negative impacts on the aquaculture industries in the *Sundarbans* region. The impacts of climate change on the breeding and nursery ground of the *Sundarbans* euryhaline fishes could affect site-specific aquaculture ventures in context of seed supply which is associated with the distribution and abundance of sea-bass, mullet, prawn and shrimp larvae abundant in the *Sundarbans* waters.

In responding to the sea level rise (SLR) and salinity intrusion, prawn and *pangas* farming must be relocated, while extra space for farming shrimp (WorldFish Center, 2007), sea-bass, mullet and other high-value saline-tolerant strains will be available. CEGIS (2006) reported that a 32 cm SLR by 2050 would result in about 11% decrease of suitable areas for prawn farming, while about 20% suitable areas for shrimp culture is likely to increase. The cage and pen culture of mud crab, sea-bass, and mullet in mangrove swamps and tidal rivers will be possible. Opportunity for seaweed and mollusc farming in the *Sundarbans* waters may be created with increased nutrient availability and primary production, respectively.

As predicted temperature rise itself will be within the optimal ranges for most species cultured in marine and brackish waters (FAO, 2009), increased growth of fish cultures in the *Sundarbans* region and thus overall aquaculture production in such areas will be anticipated. On the other hand, susceptibility to diseases and even to toxicants can be increased, and occurrence of algal blooms as well as toxic tides can negatively affect production and also increase the possibilities of human health risk. The changes in monsoonal patterns and occurrence of frequent extreme climatic events such as cyclones, tidal surge and floods make the *Sundarbans* fisheries and aquaculture most vulnerable to climatic stress. Destruction of fish/shrimp farms, and other facilities due to these extreme events has recently been very tangible along the *Sundarbans* coasts.

Livelihoods of the Sundarbans coastal fisher-folks and climatic stress: Fishing and fish-farmer communities, and related industries concentrated in coastal or low lying zones are increasingly at risk from sea level rise, extreme weather events and a wide range of human pressures (Nicholls *et al.*, 2007). In the *Sundarbans* coastal regions, there are a large number of poor people directly dependent on fisheries for a significant part of their livelihood, and they are severely exposed to a number of natural hazards.

Fishing is a high-risk profession, and income from fishing is uncertain and seasonal. Fishers' assets, in the form of boats and gear, landing facilities are more exposed to natural hazards. It is estimated that around 1900 km² in the eastern part of the *Sundarbans* was affected by cyclone Sidr on 15 November 2007 (Hoq, 2008). MoFDM (2008) reported that a total of 2,761 fishing vessels (non-motorized and motorized) were affected by *Sidr* in 11 coastal districts of Bangladesh. However, in association with climate change, coastal fishermen may have increased opportunity to harvest on marine fisheries such as anchovies, sardines, mullet etc.

The livelihoods of fish framers around the *Sundarbans* are also affected by the climate change directly and indirectly. Any climate-change-driven development or shift to farming high-value

saline tolerant fishes will affect the socio-economic condition of the poor Sundarban fisher-folks. Recently, the *Sundarban* fish farmers have been encountering storm surges frequently, and their aquaculture ponds, infrastructures, cages, brood-stock and other productive assets have been lost or damaged. It is estimated that the super cyclone Sidr wrought havoc on fish culture farms of 17,700 ha in 42 upazillas of coastal 11 districts of Bangladesh. In highly affected upazilas, about 60% of fish culture enclosures (*ghers*) had been affected as well as 85% of fish ponds, and in moderately affected upazilas, these figures were estimated to be 40% and 75%, respectively. Approximately 208,000 finfish, 16,000 shrimp and 38,000 prawn farms were affected. Total estimated production loss was about 2,120 MT, 1,600 MT and 51,000 MT for shrimp, prawn and carp, respectively (MoFDM, 2008).

Recommendations for adaptation and mitigation

- Conservation of the *Sundarbans* mangrove fisheries and development of sustainable Sundarbans fisheries: Ensuring effective law enforcement toward illegal exploitation of mangrove forests and fisheries through strengthening Sundarban Reserve Forest (SRF); developing alternative income generation options such as tree nursing, community based bee-keeping for honey production, hatchery produced shrimp PL nursing in the *Sundarbans* waters, small scale fish-farming in waters and swamps, and livestock rearing, reed (*mele*) cultivation etc.; and reforestation of mangroves.
- Development of public-private partnership: Managing the *Sundarban* fisheries; conducting research on predicting migration routes and availability of the *Sundarban* fish stocks; technology improvement and development.
- River restoration to ensure sound water flow through the *Sundarbans* basin.
- Diversification of products and markets: Relevant research is required on the *Sundarbans* aquaculture to streamline works on issues such as breeding program and adaptive technology for new and better adapted species, new diseases and preventive treatments, aquatic animal physiology, better feeds and feeding practices that are more ecosystem friendly such as Multitrophic Integrated Aquaculture, non-fed aquaculture e.g. mollusc culture.
- Diversifying livelihoods: Traditional practices or links with alternative livelihoods such as cage culture of tilapia, se-bass, and mud crab; water gardening; fish-cum-duck rearing can be taken into account.
- Sector-wise zoning the *Sundarbans* through environmental impact assessment (EIA) and monitoring tools: Identifying suitable lands for fish farming, paddy cultivation, and silviculture, as well as developing national policy for each sector with special reference to *Sundarbans* ecosystem and climate change.
- Rehabilitation and disaster response: Building capacity of the *Sundarbans* coastal community; introducing early warning systems e.g. community based warning system; weather warning system e.g. community radio etc.
- Developing insurance program: Governments could consider making insurance mandatory for aquaculture businesses above a certain size and accordingly reduce long term losses in production, livelihoods and potential environmental damages.

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