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Coastal afforestation in Bangladesh to combat climate change induced hazards

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ABSTRACT

The coastal zone of Bangladesh is extremely vulnerable to the impact of climate change. The coastal populations are mostly poor, some of them are landless and they earn their livelihood through agriculture, fishing, shrimp farming, salt farming etc. As the poor groups they are severely affected by climate related disaster and hazards. Climate change induced disasters destroy their livelihood options and increase peoples vulnerabilities. The devastating cyclone that occurred in 1991, Sidr in 2007, Nargis in 2008 and Aila in 2009, that killed thousands of people and destroyed inhabitation and infrastructures in the coastal areas of Bangladesh. Creation of mangrove and non-mangrove plantations along the coastal belt is highly desirable for reducing vulnerabilities and hazards of extreme weather events like cyclone and storm surges as green shelterbelt. Bangladesh Forest Department has already been raised large scale plantations mainly with Sonneratia apetala in all along the coastal belt to create a green shelterbelt. But these established plantations are facing tremendous pressure due to insect infestation, rising up forest floor and lack of inundation resulted large gaps inside plantations. From the available research findings, some of the other mangrove species are found suitable for planting inside the gaps of these plantations. Moreover, some of the non-mangrove species are found promising for planting in the raised coastal lands and embankment. Therefore, the selected promising species can be planted in the accreted lands, roadside, embankment and marginal lands for creating dense vegetation which can reduce the impact of all weather events resulting from climate change. Multi-species mangrove plantations can also be established in the accreted lands for long term sustainability of coastal ecosystem. The coastal community can be incorporated to the afforestation programmes for the sustainable development of coastal forestry. Thus they will be socially and environmentally benefited.

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I. Introduction

Climate change is an extremely crucial issue in Bangladesh resulting from global warming. It is severely affecting the natural environment (Hossain *et al.*, 2010). The climate in Bangladesh is changing day by day and it is becoming unpredictable every year. Greenhouse gases like ethane, methane, CFC, carbon dioxide and carbon monoxide are mainly responsible for climate change and contributing to increased global temperature (Nordell, 2003; Fearnside, 2006). As a low lying country, Bangladesh is one of the most vulnerable countries in the world that are facing the early impact of climate change (MoEF, 2008). The observed and projected impacts of climate change and vulnerability include sea level rise, increasing salinity trends, growing drainage congestions, greater monsoonal rains and reduced dry season precipitation, increasing frequency and intensity of tropical cyclones and storm surges, erosion of soil and coastal embankment and deteriorating coastal ecosystem (MoEF, 2005; Alam, 2010). The risk of climate change issues have become a serious threat to the lives, livelihoods and sustainable development of the country (CCC, 2009).

The coastal zone of Bangladesh covers an area of 47,201 km^2 extending along the Bay of Bengal. It lies between latitude 21^0-23^0 N and longitude 89^0-93^0 E. The coastal zone constitutes 20% of the country's area and 28% of the population of Bangladesh (Islam, 2004). The population of this area is 36.8 million and more than half of them (52%) are poor (Islam, 2008). As the poor lives in the coastal belts, they are the most vulnerable and the prime victims of the detrimental effects of climate change. The people of Bangladesh particularly in the coastal areas and char islands are being affected by disaster more frequently as a result of climate change. The road infrastructures, power, housing, sanitation, transportation and coastal protection are poor in the coastal areas. The rural coastal people built their houses with locally available woodcraft, artesian using wood, bamboo, CI sheet (tin) and other thatching materials. Hence, they lost their houses every year due to natural disaster especially by cyclone and wind storm. Coastal embankment was raised during 1960-1980 with an intention to save agricultural lands as well as to intensify rice production all through the coastal region. A total of 5017 km of embankments were raised throughout the coastal region against the will of nature (Rahman and Rahman, 2015). But the embankments are under threat due to sea level rise and cyclonic storm surges. In order to reduce the impact of climate change, it needs to develop sustainable forests along the coastal belt of Bangladesh. Mangroves and non-mangrove coastal forests can play an important role to reduce the damages and protect human lives by acting as a protective shelterbelt during extreme natural events. Mangrove afforestation is a soft adaptation measure that has significantly contributed to reduce the loss of lives and properties against tropical cyclones and storm surges in the coastal areas (Nandy and Ahammad, 2012). Mangrove forests also serve to conserve and stabilize newly accreted land and development of suitable environment for the biodiversity (Papry, 2014).

Bangladesh Forest Department (BFD) started afforestation programme in 1966 in the coastal belt with the primary objective of saving lives and properties of coastal dwellers from cyclones and tidal bores (Das and Siddiqi, 1985). Approximately 190,000 ha of accreted lands have been brought under coastal mangrove plantations till 2010 (Islam *et al.*, 2013). Among them, *Sonneratia apetala* (keora) is the most successful planted species and *Avicennia officinalis* (baen) is the second most successful species of the coastal mangrove plantations (Siddiqi, 2001). Presently, *S. apetala* alone accounts for about 94.4% while *A. officinalis* accounts only 4.8% of the total established mangrove plantations (Siddiqi and Khan, 2004). Other major mangrove species like *Heritiera fomes* (sundri), *Excoecaria agallocha* (gewa), *Xylocarpus mekongensis* (passur), *Aegiceras corniculatum* (khalshi), *Nypa fruticans* (golpata), etc. were also found to be promising as experimental trials inside *S. apetala* plantations (Siddiqi *et al.*, 1992; Siddiqi, 2001; Islam *et al.*, 2013). After a long investigation, some of the mainland tree species like *Samanea saman* (rain tree), *Casuarina equisetifolia* (jhao), *Pithecilobium dulce* (payra), *Acacia nilotica* (babla) and *Albizia procera* (sil koroi) were found suitable for planting in the raised coastal lands (Siddiqi, 2002; Islam *et al.*, 2014). But the previous and existing afforestation programmes fail to incorporate the research based findings and to involve coastal communities for forestry development to cope with the climate change related hazards. This paper highlights some climate induced extreme weather events in Bangladesh that have manifested key vulnerabilities to the coastal areas. In addition, this paper provides an overview of coastal afforestation programmes started from 1960-61 and some of the research activities that are needed for reducing the climate change induced problems. It is expected that this would be a realistic solution to the planner and forest managers for the development and management of costal ecosystem scientifically.

II. Results and Discussion

Climate change induced problems in Bangladesh

Bangladesh is geographically located in the low-lying deltaic plain of Ganges-Brahmaputra-Meghna river network which remains at risk to natural disasters and climatic vulnerability (Nandy and Islam, 2010). The coastal regions cover 19 districts out of 64 districts of Bangladesh (Figure 01). The area forms the lowest landmass and is part of the delta of the extended Himalayan drainage ecosystem (Siddiqi, 2001). Climate change is one of the greatest threats to human lives and properties in coastal regions. World Bank (2000) identified four key types of primary physical effects as key vulnerabilities in the coastal area. These are i) saline water intrusion, ii) drainage congestion, iii) extreme weather events and iv) changes in coastal morphology. Climate change significantly aggravates existing hazards such as flooding from cyclones and storm surges (Parvin *et al.*, 2008). Climate change induced problems such as scarcity of fresh water due to higher salinity in the dry season, higher water levels in the confluence with the rise of sea level, river bank erosion, frequent floods and prolonged drought, wider salinity in the soil is increasing day by day in the coastal zone (Minar *et al.*, 2013).

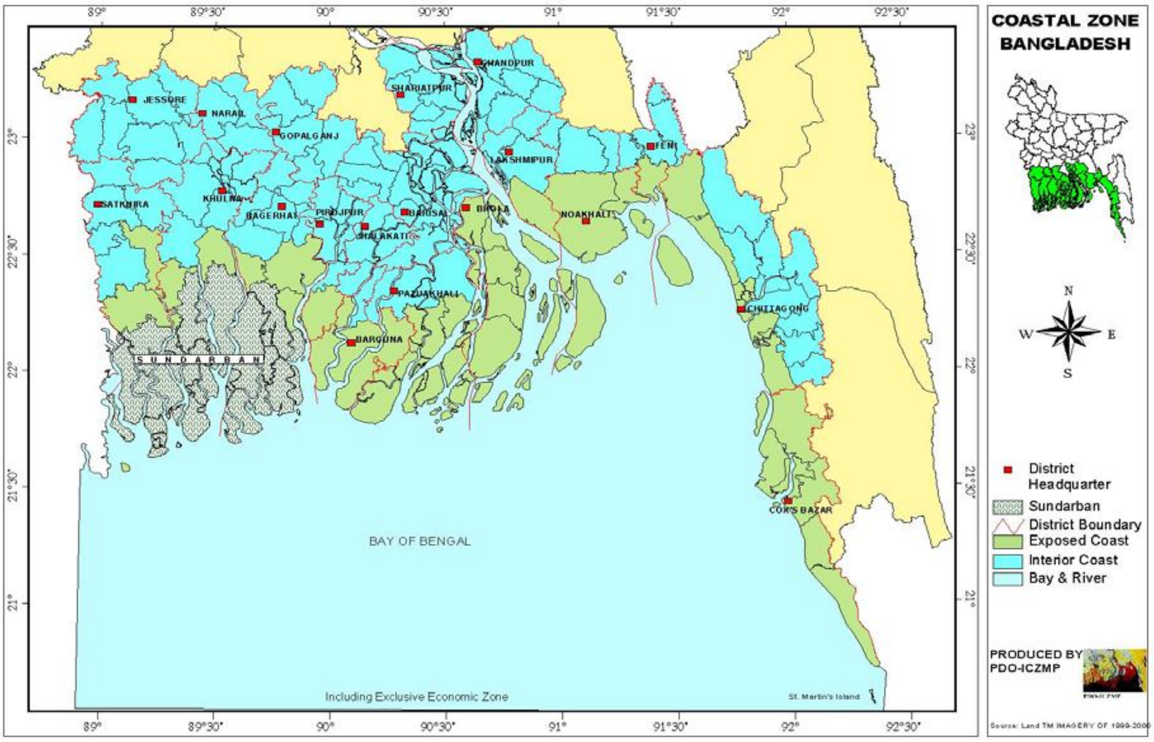

Figure 01. Map showing the coastal area of Bangladesh (Source: MoWR, 2006)

a) Sea level rise

Sea level rise is a major concern faced by the entire coastal region in southern Bangladesh. It is projected that the possible sea level rise will affect 18% area of the southern parts of the country by inundating coastal region (Alam, 2010). These will dislocate millions of people from homes, occupations and livelihoods (Rahman *et al.*, 2008). It is predicted that at least 30cm and 50cm sea level will rise by

2030 and 2050 respectively (WB, 2000). Bangladesh Water Development Board however, believe the combined effect of global warming and subsidence will only result in a net sea level rise 30 cm by 2030 and 50 cm by 2100 (Jenkins, 2006) by taking lower estimates for both. MoEF (2005) expected that land permanently lost to the sea may amount to 3% and 6% of Bangladesh by 2030s and 2050s respectively. The potential impacts of a 45cm sea level rise in Bangladesh may dislocate about 35 million people from 19 coastal districts by 2050 (Rabbani *et al*., 2010). Greenpeace (2008) stated that sea level rise will affect Bangladesh very widely and one meter sea level rise could flood 17% of Bangladesh. Sea level rise have aggravated vulnerability of coastal livelihood of agriculture and aquaculture and reduced adaptive capacity of the ecosystem.

b) Saline water intrusion

Water and soil salinity is a common hazard in many parts of the coastal zone that has already increased. Intrusion of salinity is contributed by less flow of fresh water from the Ganges and ingress salt water from Bay of Bengal. The salt water penetration is increasing day by day through the groundwater and along the rivers to inland from the coast. The adverse effects of saline water intrusion will be significant on coastal agriculture and the availability of fresh water for public and industrial purposes (MoEF, 2005).

Saline intrusion from sea level rise will degrade water quality in coastal rivers, canals, ponds and wetlands. This degradation will in turn put stress on the existing drinking water sources—which is already a problem affecting Bangladesh to varying extents. About 6 million people are already affected by high salinity (>5 ppt), but this is expected to increase into 13.6 million by 2050 due to climate change (Mohal and Hossain, 2007). High saline water is moving gradually towards north and will reach 40-60 km inland from the coast by 2100 (MoEF, 2005). An increase in salinity generally affects agricultural productivity and may significantly damage fresh water aquatic ecosystems in the coastal region, which might have adverse impacts on sensitive flora and faunal species. It has already been documented from different studies that agricultural crop production, fisheries, livestock, and mangrove forests are affected by higher salinity (MoEF, 2008).

c) Cyclones and storm surges

Bangladesh is among the most disaster prone countries in the world and the coastal zone is perceived cyclones and storm surges every year. About 10% world tropical cyclone form in the Bay of Bengal and more than 40% death of the world total due to cyclones took place in Bangladesh (Hossain *et al*., 2010). Tropical cyclones hit Bangladesh 29 times in the second half of the last century (Rabbani *et al*., 2010). Without serious climate change, in between 1907 and 2004 a natural disaster survey group recorded 137 cyclones and 64 floods with the estimated loss of worth US $30 billion which is equivalent to four years national budget of Bangladesh (Ahammad and Baten, 2008) and it is predicted to increase in number and severity. Records of 200 years show that at least 70 major cyclones hit the coastal belt of Bangladesh (Islam and Ahmad, 2004). The most severe cyclone occurred on 12 November, 1970 with wind speed up to 224 km per hour that killed at least 3,00,000 people and on 29 April, 1991 with wind speed up to 225 km per hour that killed 140,000 people (Chowdhury, 2002). More recently on 15 November 2007, super cyclone *Sidr* (i.e., a tropical very severe cyclonic storm) struck the south-west coast of Bangladesh with wind up to 240 km per hour. The storm was accompanied by tidal waves up to 5-6 meters high in some areas, breaching coastal and river embankments, flooding low-lying areas and causing extensive physical destruction. The number of deaths caused by *Sidr* was estimated at 3,406 and over 55,000 people sustaining physical injuries. Cyclones and storm urges are expected to become more intense with climate change. Coastal erosion, cyclones and storm surges will severely affect the coastal infrastructure - housing, industrial facilities, energy and sanitation systems, transportation and communication networks (Hossain *et al*., 2010).

d) Floods and water logging

Tidal floods are typical for the coastal zone. Tidal fluctuations vary considerable across the coast, as well as vertically inward from the coastline that sometimes affects the agriculture and aquaculture.

Floods caused by storm surges severely affected the low-lying coastal area. Storm surges generated by tropical cyclones causes widespread damage to property and the loss of life (Mirza, 2002). Storm surge floods severely damage agricultural crops that also affect on rural incomes, where employs 70% of the population (Alam, 2010). Floods may be more devastating creating major problems of livelihood and macro-economic dislocations, migration, slowing growth and pushing people down the poverty line (Rahman *et al.*, 2008). Storm surge flood water sometimes enters the inland through damaging coastal embankment. In latest, severe cyclone *Aila* (i.e., a tropical severe cyclonic storm) hit the south-western coastal region of Bangladesh on 25 May, 2009 caused widespread devastation, affected the residents, homesteads, roads, embankments, crops and agricultural lands (Jahan, 2012). Khulna and Satkhira district of south-western coastal area were hit the hardest by cyclone *Aila* destroying homes and thousands of people leaving home from their flooded villages. In total, over 3.9 million people were affected and nearly 350,000 acres of crop land were destroyed by flooding (UN, 2010). *Aila* not only broke down the overall infrastructure but also drop the people into an insecure position and forcing villagers to migrate (Kumar *et al.*, 2010). The damage to embankments extended to an area of 1743 km (UN, 2010), which is one of the main causes of a serious secondary disaster of widespread and prolonged post-cyclone water logging in the broken polders.

e) Drainage congestion

Drainage congestion is already a growing important problem in the coastal areas of Bangladesh and is likely to be made worse by climate change (Mohal *et al.*, 2006). Climate change will cause drainage congestion and gradually increase water logging problems (Khadim *et al.*, 2013). This will be made even worse by the expected rise in monsoonal rainfall and its effect will be particularly strong in the coastal zone. The combined effect of higher sea water levels, siltation of estuary branches, higher riverbed levels and reduced sedimentation in flood-protected areas will impede drainage and gradually increase water logging problems (Awal, 2014). This water logging will harm agriculture; make flooding worse and increase water borne diseases (CCC, 2009). The problem will be aggravated by the continuous development of infrastructure (e.g. roads, embankment) reducing natural drainage capacity in the delta. Increased periods of inundation may hamper agricultural productivity, and will also threaten human health by increasing water borne disease.

Coastal afforestation programmes in Bangladesh

Bangladesh Forest Department (BFD) started afforestation programme in the coastal areas of Bangladesh since 1960-61. Afterward different forest divisions of Coastal Circle and Chittagong, Feni and Cox's Bazar Forest Division carried out massive afforestation programmes along the coastal belt under various development projects.

Table 01. List of coastal afforestation projects implemented by the Bangladesh Forest Department

Sl. no.	Name of the project	Starting year	Completion year
1.	Afforestation in the coastal belt and offshore islands	1960–61 1965–66	1964–65 1969–70
2.	Afforestation Project in the coastal regions of Chittagong, Noakhali, Barishal and Potuakhali	1974–75	1979–80
3.	Mangrove Afforestation Project	1980–81	1984–85
4.	Second Forestry Project	1985–86	1991–92
5.	Forest Resources Management Project-FRMP	1992–93	2001–2002
6.	Extended Forest Resources Management Project	2002–03	2003–04
7.	Coastal Embankment Rehabilitation Project (CERP)	1997	2003
8.	Coastal Green Belt Project-CGP	1995–96	2001–02
9.	Forestry Sector Project	1997-98	2005-06
10.	Sundarbans Biodiversity Conservation Project (SBCP)	1999-2000	2004-05

11.	Char Development and Settlement Project (CDSP)	2000-05	2005-10
12.	Coastal Char Land Afforestation Project	2005–06	2009–10
13.	Management Support Project for Sundarban Reserve Forest	2005–06	2009–10
14.	Plantation of BWDB's Embankment in the Coastal Belt and its adjacent Char Areas	2009-10	2011-12
15.	Afforestation in the Coastal Areas to Mitigate Adverse Effect of Climate Change Project	Nov. 2010	June 2013
16.	Community Based Adaptation to Climate Change Through Coastal Afforestation Project in Bangladesh	July-2009	June-2014

Source: Bangladesh Forest Department (BFD), 2012

Till 2013, a total of 1,92,395 ha mangrove, 8,690 ha non-mangrove, 2,873 ha Nypa and 12,127 km strip plantations have been raised in the coastal areas (Hasan, 2013). Among the mangrove plantations, about 80% area of the early plantations consisted of *S. apetala*, about 15% consisted of *A. officinalis* and the remaining percentage is consist of *E. agallocha*, *Bruguiera sexangula* (kankra), *Ceriops dacandra* (goran), *H. forms* and *X. mekongensis* which are more valuable species for timber, fuel wood and paper pulp production. *S. apetala* is the most successful planting species showed promising survival and growth performance in all along the coastal belt. *A. officinalis* is the second successful species in the eastern coastal belt. These two species dominate the overall mangrove plantations throughout the coastal belt. But other valuable mangrove species did not survive in the accreted lands probably due to lack of planting experience and scientific knowledge. However, there are few trees of other mangrove species are found sporadically along with the existing *S. apetala* and *A. officinalis* plantations in the coastline. Therefore, *S. apetala* has been planted massively under almost all development projects as it stands successful in newly accreted *char* lands. But no regeneration has been found in *S. apetala* forests due to continuous siltation on the forest floor, lack of seed sources of other mangrove species and grazing by cows and buffalos. Plantations with 37 different non-mangrove species have been raised mostly on the slop of coastal embankment, roadsides and raised coastal lands (Nandy *et al.*, 2002). Nevertheless, all coastal afforestation projects implemented by the BFD are anticipated to make sustainable buffer zones that create shelterbelt, prevent erosion, trapping sediment and reduce potential loss of lives and properties during natural disaster. Many projects from 1960 to 2014 have been implemented and some projects are being implemented to develop a coastal forest ecosystem (Table 01). The main objectives of all the projects were to increase forest coverage, arrest depletion of forest resources and enhance conservation of mangrove forests.

Key weaknesses in the previous afforestation projects

The large scale monoculture plantations of *S. apetala* encounter a number of problems. These plantations are facing tremendous pressure due to geographical changes in forest floor, plant succession, seedling mortality and lack of inundation (Islam et al., 2013). Large scales stem borer attack with *Zeuzera conferate* are observed in *S. apetala* plantations for a long time (Baksha, 1996). These effects led to considerable losses of planted trees and created large opening in coastal greenbelt structures (Siddiqi, 2001).

The previous afforestation projects were not thought about people's participation and ownership to mangrove forest management. The coastal afforestation projects are undertaking community in training activities, labour and plantation watcher but did not consider additional livelihood support and diversification activities that could complement and sustain afforestation programme over the longer period of time. Coastal plantations of the forest department do not include a clear-cut forest product sharing arrangement with the adjacent communities resulting increased community livelihood detachment followed by grazing problem, illicit tree felling, encroachment, etc. As per existing Social Forestry Rules 2004 (amended in 2009 and 2011), the beneficiaries in coastal areas mangrove forest will not get wood share but allowed only to collect other minor forest products (Non Timber Forest Product-NTFP) like grasses, hogla pata, honey and fishes.

The coastal plantations are mostly under tremendous threats due to illegal grazing, illicit tree felling, forest land encroachment led by influential people tend to serious damage of plantations (Siddiqi 2001). At the maturity stage of mangrove plantations (after 15 years), only 800- 900 trees per hectare survive out of 4,444 seedlings that had originally been planted. All these reasons might represent a loss of up to 80% of planted mangrove trees and creates big gaps in *S. apetala* plantations. Besides, government of Bangladesh did not give emphasis to incorporate other recommended mangrove species in coastal afforestation programmes.

Cooperation and collaboration is required to increase among inter-ministerial bodies such as BFD, BFRI, ministry of land and other govt. agencies and institutes. However, motivation of local institutes should be developed to establish and conserve forest for long time. In addition, the major issues those hindering the government's mangrove resource conservation initiatives are infrastructural development, logistic support, appropriate technical knowledge, staff training and GIS database.

Research undertaken by BFRI for coastal afforestation

Plantation Trial Unit Division of Bangladesh Forest Research Institute (BFRI) has been conducting research on various aspects of coastal ecosystem since 1985. By this time, some technologies have been generated on nursery and plantation techniques of different mangrove and non-mangrove species for coastal afforestation in Bangladesh. These are as follows:

a) Mangrove trial plantations

The established *S. apetala* plantations in the coastal belt threatening the sustainability of the plantations due to rapid sedimentation in the plantation sites, species succession and insect infestation under the traditional management practices (Siddiqi *et al.,* 1992). As a result, the sites become unsuitable for the optimal growth of *S. apetala* and *A. officinalis*. The mortality of planted seedlings of these species in the coastal areas is high. As a result gaps are created inside plantations. Moreover, no regeneration appeared under these plantations due to rising of forest floor, compactness of soil and non-availability of seed source of other mangrove species. After harvesting of matured *S. apetala* trees, there will be no second rotation crops for sustainability of this forest. Therefore, in order to maintain a continuous forest cover in the coastal belt and to enhance the production of coastal forest, underplanting with other valuable mangrove species was carried out by Bangladesh Forest Research Institute since 1990 in the coastal belt. Eleven commercially important mangrove species were planted on experimental basis. The trial plots were laid out in several sites under Rangabali island of Patuakhali district; and Char Kukri-Mukri island of Bhola district. Seedlings of all mangrove species (Table 2) were raised in polybags except *N. frutican* which sown in muddy soil. The trial plots were raised under 9-12 years old *S. apetala* plantations at a spacing of 1.5m x 1.5m. Ten-month-old seedlings were planted in the selected sites, except for *N. fruiticans* seedlings, which were planted when three months old.

Table 02. Growth performance of mangrove species from 16-21 years old experimental stands at Rangabali and Char Kukri-Mukri islands of Bangladesh

Common name	Scientific name	Rangabali Island			Char Kukri-Mukri Island		
		Mean Survival (%)	Mean Height (m)	Mean DBH (cm)	Mean Survival (%)	Mean Height (m)	Mean DBH (cm)
Sundri	*Heritiera fomes*	51.34	6.19	5.87	39.21	5.65	5.34
Gewa	*Excoecaria agallocha*	61.76	9.31	9.83	58.64	9.29	9.49
Passur	*Xylocarpus mekongensis*	47.87	6.84	7.97	26.18	6.84	7.34
Dhundul	*Xylocarpus granatum*	30.32	4.70	5.24	-	-	-
Kankra	*Bruguiera sexanula*	13.90	5.04	5.46	-	-	-
Khalshi	*Aegiceras corniculatum*	62.84	5.90	6.13	46.02	6.61	7.96
Shingra	*Cynometra ramiflora*	35.85	6.54	5.24	18.38	4.96	4.27
Goran	*Ceriops decandra*	23.38	4.98	5.04	-	-	-
Kirpa	*Lumnitzera racemosa*	43.95	5.24	6.31	11.66	5.30	7.51
Hantal	*Phoenix paludosa*	58.28	6.39	6.03	71.29	5.25	6.11

Golpata	*Nypa fruticans*	40.06	4.59	-	56.00	3.43	-

Source: Islam et al., 2013

The growth performance of some mangrove species showed promising in both Rangabali and Char Kukri-Mukri islands. On the basis of survival, height and diameter growth, *H. fomes*, *E. agallocha*, *X. mekongensis*, *A. corniculatum*, *Cynometra ramiflora* (shingra) *Phoenix paludosa* (hantal) and *N. fruticans* were found promising at the age of 16-21 years in the western coastal belt (Table 02). Therefore, these promising mangrove species are suitable for raising second rotation crops inside *S. apetala* plantations for sustainable management of coastal forests. A successful under planting will also result in the creation of mixed and multi-storied forests.

b) Non-mangrove trial plantations

As the coastal environment is highly dynamic, sedimentation in some areas of the shoreline is quite high. For the gradual rise of forest floor, the lands become unsuitable for *S. apetala* and *A. officinalis*. Other mangrove species do not grow and survive in this situation. So, the feasibility of non-mangrove species in the raised but vacant lands was studied using 13 important mainland species. The trial plots were laid out in both Rangabali and Char Kukri-Mukri islands. Seedlings of all species were raised in polybags and maintained up to 5-6 months. The trial plots were raised on the heaps 60cm x 60cm wide and 40cm high at 2.0m x 2.0m spacing. Six-seven months old seedlings were planted in the selected sites.

Table 03. Growth performance of mainland tree species at the age of 17 years planted at Rangabali island

Common name	Scientific name	Survival (%)	Mean height (m)	Mean DBH (cm)
Payra	*Pithecellobium dulce*	81	10.49 ± 0.24	12.94 ± 0.29
Rain tree	*Samanea saman*	80	13.21 ± 0.30	24.34 ± 1.25
Jhao	*Casuarina equisetifolia*	69	15.26 ± 0.38	19.45 ± 0.33
Babla	*Acacia nilotica*	32	11.69 ± 0.19	11.66 ± 0.18
Kala koroi	*Albizia lebbeck*	73	9.90 ± 0.22	13.97 ± 0.46
Sada koroi	*Albizia procera*	59	11.28 ± 0.44	16.52 ± 0.68
Sonboloi	*Thespesia populnea*	52	7.19 ± 0.29	13.77 ± 0.35

Source: Islam *et al.*, 2014

Table 04. Growth performance of mainland tree species at the age of 17 years planted at Char Kukri-Mukri island

Common name	Scientific name	Survival (%)	Mean height (m)	Mean DBH (cm)
Babla	*Acacia nilotica*	66	7.87 ± 0.18	14.02 ± 0.26
Jhao	*Casuarina equisetifolia*	25	11.64 ± 0.61	15.23 ± 0.80
Kala koroi	*Albizia lebbeck*	14	8.48 ± 0.59	14.75 ± 0.98
Payra	*Pithecellobium dulce*	63	9.99 ± 0.26	17.24 ± 0.73
Rain tree	*Samanea saman*	32	11.11 ± 0.40	19.74 ± 0.98
Sada koroi	*Albizia procera*	14	11.27 ± 0.80	14.13 ± 1.54

Source: Islam *et al.*, 2014

Considering the survival, height and diameter growth, 6 non-mangrove species such as *S. saman*, *C. equesetifolia*, *P. dulce*, *A. nilotica*, *Albizia lebbeck* (kalo koroi) and *A. procera* were found promising for planting in the raised coastal lands (Table 3 and 4). Some other palm species like *Cocos nucifera* (coconut), *Phoenix sylvestries* (date palm) and *Borassus flabellifer* (palmyra palm) were also found suitable in the foreshore coastal areas of Bangladesh (Islam *et al.*, 2014).

c) Coastal embankment plantations

The coastal afforestation proceeded with planting non-mangrove species on the slopes of embankment and roadside under the Green Belt Project in 1995 and Coastal Embankment Rehabilitation Project in 1997. A total of 37 non-mangrove species were planted on inner and outer slope of the embankment. Timber, fuel wood and fruit tree species were included in this programme. Nandy *et al.* (2002) made a survey for assessment of growth performance of the planted species and their adaptability on the coastal embankment.

In the eastern part of the coastal belt, among planted 14 species *Leucaena leucocephala* (ipil ipil), *Acacia auriculiformis* (akashmoni), *C. equisetifolia*, *S. saman* and *C. nucifera* appeared promising. In the central coastal belt 20 species were planted. Of these, *A. auriculiformis, Acacia mangium* (mangium), *Embelica officinalis* (amloki)*, C. equsetifolia*, *P. sylvestris*, and *C. nucifera* showed good performance. In the western coastal belt, 31 species were planted. Among them *C. equsetifolia*, *A. auriculiformis*, *Terminalia arjuna* (arjun), *A. nilotica*, *S. saman*, *P. dulce*, *C. nucifera* were found most successful. The embankment plantations are contributing to green considerable areas of the barren coastal belt.

Role of coastal forests to combat the impact of climate change

The impact of climate change over Bangladesh is likely to increase frequency of cyclones, storm surges, flood, salinity level, soil erosion and sedimentation (Siddiqi, 2008a). As the natural disaster hit the coastal areas every year and hence a need for the creation of greenbelts has long been recognized. Afforestation along the coastal belt is the cheaper and ecologically more beneficent than any other measure to protect the coastal areas and offshore islands from cyclone and storm surges (Siddiqi, 2008b). Mangrove forests are the most productive ecosystem on the earth and they perform a variety of useful ecological, bio-physical and socio-economic functions, which bring multiple benefits to coastal populations (Siddiqi 2001). Mangrove and other coastal forests can reduce wind and storm wave impact as well as current velocities (Fritz and Blount, 2007). Thick and dense vegetation diminishes the height of tides and thus arresting the magnitude of devastation (Siddiqi 2002). The dense forests along the coastline can protect human habitation, lives, properties, and agricultural crops from extreme weather events resulting from climate change (Islam et al. 2015). Silori (2010) also stated that coastal protection is important function of mangrove forests, serving as a natural barrier against storms, typhoons, and tsunami, and thus protecting coastal inhabitants. Recent experiences of tsunami and major storms in Southeast Asia and other parts of the world have shown that mangroves can and have played important roles in absorbing and weakening wave energy as well as preventing damage caused by debris movement (Latief and Hadi, 2007). For the development of mangrove vegetation cover in the exposed Bangladesh coastline, a healthy environment has already been developed. Some of the mangrove species can survive against natural disaster and differently inundated coastal habitats to cope with different scenarios of sea level rise (Nandy and Ahammad, 2012). The entangled roots of mangrove forests help to stabilize coastal areas through sediment capture and bio-filtration of nutrients and some pollutants from the water (Prasetya, 2007). The aerial roots of mangroves hold back sediments and reduce pollutants from sewage and aquaculture in estuaries and coastal waters (Silori, 2010). Islam *et al.*, (2015) also stated that the mangrove plantations are trapping soil particles and sediments with their root system and thus accelerate accretion and stabilize newly accreted lands in the coastline of Bangladesh. The root system also can protect river/canal banks from soil erosion. Mangrove forests play an important role in providing breeding grounds and habitats to a variety of fishes and other marine species of high commercial value, including mud crabs, mollusks, and prawns. Thus, mangrove forests offer a unique and highly efficient approach to climate change mitigation and adaptation.

Even some non-mangrove species can grow and survive in low-lying areas and survive in a stressful environment (Nandy et al., 2002). Alam *et al.* (1991) provided a list of 150 plant species (mangrove and non-mangrove) that are suitable for low-lying areas or tolerate to different degrees of inundation. Siddiqi (2008a) mentioned that some non-mangrove species such as *A. mangium*, *A. auriculiformis*, *S. saman*, *Mangifera indica* (mango), *T. arjuna*, *Lagerstroemia speciosa* (jarul) etc. could withstand flooding. Some other tree species such as *P. dulce*, *C. equisetifolia*, *A. nilotica*, *A. procera*, *C. nucifera*, *P. sylvestris*, *B. flabellifer* and *Areca catechu* (betel nut) can grow well and tolerate moderate to strong saline condition (Islam *et al.*, 2014). Palm plantations can serve as a strong shelterbelt, only palmyra palm can withstand wind speed of up to 300 miles/hour and it is the best windbreak against the cyclonic storms (Islam *et al.*, 2014). The coastal embankments are designed for protecting salinity intrusion from Bay of Bengal. An embankment plantation with suitable non-mangrove species not only serves as shelterbelt but also plays an important role in reducing damage of embankment from cyclonic floods and storm surges.

Forests are globally important reservoirs, sources and sink of carbon, store carbon in the leaves, branches, trunks and roots of trees and in forest soils (Patil *et al.*, 2012). Ecosystems are clearly influencing the concentration of Greenhouse Gases (GHG) to the atmosphere as it works both sinks and sources (Lal, 2004). Richards and Stokes (2004) stated that world forest could sequester 7.0 billion tons CO_2 per year globally. Mangroves play a significant role in sequestering of carbon and reducing greenhouse gases. Mangroves are important carbon sinks and sequester approximately 25.5 million tons of carbon every year (Patil et al. 2012). Studies indicate that mangroves are able to sequester some 1.5 tons of carbon per hectare per year (Spalding *et al.*, 1997). The capacity of mangroves, sea grasses and salt marshes to sequester carbon dioxide from the atmosphere is becoming increasingly recognized. Of all the biological carbon, also termed as 'green carbon', captured in the world, over half (55%) is captured by mangroves, sea grasses, salt marshes, and other marine living organisms, which are also known more specifically as 'blue carbon' (Silori, 2010). These coastal vegetations sequester carbon far more effectively (up to 100 times faster) and more permanently than terrestrial forests (Hasan, 2013).

III. Conclusion and Recommendations

Bangladesh is very vulnerable to climate change due to its geographical location, dense population and socio-economic condition. Some coping strategies generally can reduce the adverse impacts of climate change those can be implemented through coastal afforestation. Bangladesh Forest Department has already established large scale plantations with *S. apetala* along the coastal belt and thus created a healthy environment. In different times, these established plantations had protected the lives and properties of coastal population from the attack of natural disaster like cyclone and tidal surges. Mangrove plantations have accelerated sedimentation process and a large amount of landmass has been established at different chars lands and offshore islands. On the other hand, mangrove trial plantations act as a seed sources in the coastal areas. Huge seedlings mainly of *E. agallocha* and *H. fomes* have been regenerated inside *S. apetala* forest in the western coastal belt that creating second generation dense sustainable mangrove forest in some areas.

The mono specific plantations of *S. apetala* are facing some serious problem resulted huge gapes inside forests due to heavy mortality. There is an urgent necessity to restore these gaps through reforestation, establishing a second rotation mangrove plantation by introducing recommended mangrove species with adaptive capabilities for a sustainable long term shelterbelt along the coastline. Bangladesh Forest Research Institute worked over the last two decades and selected some suitable mangrove species for the coastal areas to overcome the stated problems. On the other hand, BFRI has selected some of the non-mangrove species suitable for planting on coastal raised lands and embankment. Therefore, large scale plantations can be initiated urgently with promising mangrove species applying the acquired knowledge, experience, technology and expertise for the development of a second generation forest in the gaps of *S. apetala* plantations. Plantation programme with other site-suitable non-mangrove and palm species can be initiated in the raised coastal lands, foreshore lands and coastal embankment for enriching coastal ecosystem.

In this regard, new afforestation and reforestation programmes need to be design, developed and managed. With this view, lesson from past should be incorporated in new project design. The projects should have right selection of diversified mangrove and non-mangrove species needs to be chosen to withstand present climate change situation to enhance the natural adaptive capacity of coastal mangrove forests. So, the government will able to increase coastal forest coverage as well as carbon sink which have a positive impact on the local and global environment.

Local community participation in coastal afforestation programmes needs to be reinforced beyond paid labour to generate their adaptive capacities in withstanding climatic variations and extreme weather event. Proper management of coastal forest resources can also be a worth and can be seen as an integral part of climate change adaptation and mitigation efforts.

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V. References

Ahammad, R. & Baten, A. M. (2008). Impacts of climate change: global to local. *The Daily Star, Dhaka*, February 15, 2008.

Alam, M. E. (2010). Impact of sea level rise on rice production and ecosystem of Bangladesh. In: Ahmed. M.F. and Tanveer, S.A. (eds). *Bangladesh Environment 2010. 3rd International Conference on Bangladesh Environment, Bangladesh Poribesh Andolon (BAPA) and Bangladesh Environment Network (BEN)*. pp 16-24.

Alam, M. K., Mohammed, M. & Guha, M. K. (1991). Trees for Low-lying Areas of Bangladesh. *Bangladesh Forest Research Institute, Chittagong*. pp. 98.

Awal, M. A. (2014). Water logging in southwestern coastal region of Bangladesh: local adaptation and policy options. *Science Postprint*, 1(1): e00038. doi: 10.14340/spp.2014.12A0001.

Baksha, M. W. (1996). Beehole borer infestation in coastal plantations in Bangladesh and possible management options. *Wallacena*, 77: 17-20.

BFD (2012). Bangladesh Forest Department. Available at http://www.bforest.gov.bd (Last accessed on 19 May 2015).

Chowdhury, A. (2002). Disasters: issues and responses. In: Gain, P. (ed). Bangladesh Environment: Facing the 21st Century. *Society for Environment and Human Development (SHED), Dhaka, Bangladesh*. pp 217 –235.

Climate Change Cell (CCC) (2009). Climate Change and Vulnerability of Bangladesh. *Department of Environment, Sher-E-Bangla Nagar, Dhaka, Bangladesh*. pp. 12.

Das, S. & Siddiqi, N.A. (1985). The Mangroves and Mangrove Forests of Bangladesh. Mangrove Silviculture Division. Bulletin No. 2, *Bangladesh Forest Research Institute*. pp. 142.

Fearnside, P. M. (2006). Tropical deforestation and global warming. *Science*, 312 (5777): 1137.

Fritz, H. M. & Blount, C. (2007). Role of forests and trees in protecting coastal areas against cyclone. In: Braatz, S., Fortuna, S., Broadhead, J. & Leslie, R, (eds). Coastal Protection in the Aftermath of the Indian Ocean tsunami: What Role for Forests and Trees*? Proceeding of the Regional Technical Workshop, Khao Lak, Thailand*, 28-31 August 2006. pp 37-60.

Greenpeace (2008). Sea Level Rise. Available at http://www.greenpeace.org/international/campaigns/climate-change/impacts/sea_level_rise (Last accessed on May 10, 2013).

Hasan, D. Z. (2013). Plants in Mangroves and Coastal Afforestation in Bangladesh. *Dewan House, Ukilpara, Naogaon-6500, Bangladesh*, pp. 164.

Hossain, M. L., Hossain, M. K. & Das, S. R. (2010). Vulnerability of Bangladesh to Natural and Anthropogenic Disasters. *Vision Publication, Dhaka, Bangladesh*. pp. 219.

Islam, M. R. (2008). ICZM initiatives and practices in Bangladesh. In: Krishnamurthy, R.R. (ed). Integrated Coastal Zone Management. *Research Publishing Services, Singapore*. pp 81-82.

Islam, M. R. (ed) (2004). Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh. *University Press Limited, Dhaka, Bangladesh*. pp. 317.

Islam, M. R. & Ahmad, M. (2004). Living in the Coast. Problems, Opportunities and Challenges. Program Development Office for Integrated Coastal Zone Management Plan (PDO-ICZMP), Water Resource Planning Organization, *Ministry of Water Resources, Dhaka, Bangladesh*. pp. 43.

Islam, S. A., Miah, M. A. Q. & Habib, M. A. (2015). Performance of mangrove species planted inside *Sonneratia apetala* Buch.-Ham. plantations in the coastal belt of Bangladesh. *Journal of Bioscience and Agriculture Research*, 3 (1): 38-44.

Islam, S. A., Miah, M. A. Q., Habib, M. A. & Moula, M. G. (2014). Performance of some mainland trees and palm species planted in the coastal islands of Bangladesh. *Journal of Asiatic Society of Bangladesh, Science,* 40(1): 9-15.

Islam, S. A., Miah, M. A. Q., Habib, M. A., Moula, M. G. & Rasul, M. G. (2013). Growth performance of underplanted mangrove species in *Sonneratia apetala* (Keora) plantations along the western coastal belt of Bangladesh. *Bangladesh Journal of Forest Science*, 32 (2): 26-35.

Jahan, I. (2012). Cyclone Aila and the Southwestern Coastal Zone of Bangladesh: In the Context of Vulnerability. *Master's Thesis, Lund University, Centre for East and South-East Asian Studies.* pp. 61.

Jenkins, A. (2006). The Bangladesh Integrated Planning for Sustainable Water Management (IPSWAM) Programme and Climate Change. *Bangladesh Water Development Board, Dhaka, Bangladesh*.

Khadim, F. K., Kar, K. K., Halder, P. K., Rahman, M. A. & Morshed, A. K. M. M. (2013). Integrated water resources management (IWRM) impacts in south west coastal zone of Bangladesh and fact-finding on tidal river management (TRM). *Journal of Water Resource and Protection*, 5: 953-961.

Kumar, U., Baten, M. A., Masud, A. A., Osman, K. S. & Rahman, M. M. (2010). Cyclone *Aila*: One year on, Natural Disaster to Human Sufferings. *Unnayan Onneshan-The Innovators, Dhaka, Bangladesh*. pp. 20. Available at http://www.unnayan.org/reports/climate/ailareport_final.pdf (Last accessed on 19 May, 2015).

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304 (5677): 1623-1627.

Latief, H. & Hadi, S. (2007). The role of forests and trees in protecting coastal areas against tsunamis. In: Braatz, S., Fortuna, S., Broadhead, J. and Leslie, R, (eds). Coastal Protection in the Aftermath of the Indian Ocean tsunami: What Role for Forests and Trees? *Proceeding of the Regional Technical Workshop, Khao Lak, Thailand*, 28-31 August 2006. pp 5-24.

Minar, M. H., Hossain, M. B. & Shamsuddin, M. D. (2013). Climate change and coastal zone of Bangladesh: vulnerability, resilence and adaptability. *Middle-East Journal of Scientific Research*, 13 (1): 114-120.

Mirza, M. M. Q. (2002). Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Global Environmental Change*, 12: 127-138.

MoEF (2005). National Adaptation Programme of Action (NAPA). Ministry of Environment and Forest, *Government of the People's Republic of Bangladesh*. pp. 46.

MoEF (2008). Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forest, *Government of the People's Republic of Bangladesh*. pp. xvi, 68.

Mohal, N. & Hossain M. M. A. (2007). Investigating the Impact of Relative Sea Level Rise on Coastal Communities and their Livelihoods in Bangladesh. Draft Final Report, *Institute of Water Modeling (IWM) and Center for Environmental and Geographic Information Services (CEGIS), Dhaka, Bangladesh*.

Mohal, N., Khan, Z. H. & Rahman, N. (2006). Impact of Sea Level Rise on Coastal Rivers of Bangladesh. 9th *International Conference on River Symposium and Environmental Flows*, 4-7 September 2006, Brisbane. pp. 66.

MoWR (2006). Coastal Development Strategy. Water Resources Planning Organizations, Ministry of Water Resources, *Government of the People's Republic of Bangladesh*. pp. 1, 4-5.

Nandy, P. & Ahamad, R. (2012), Navigating mangrove resilience through the ecosystem based adaptation: lessons from Bangladesh. In: Macintosh, D.J., Mahindapala, R. and Markopoulos, M.

(eds). *Proceedings and A Call for Action from An MFF Regional Colloquium on Mangrove Restoration. Mamallapuram, India*, 30–31 August 2012. pp 243–254.

Nandy, P. & Islam, M. A. (2010). Climate resilience coastal zone development in Bangladesh: participatory governance for common resources management. In: Ramanathan, A.I., Bhattcharya, P., Dittmar, T., Prashad, M.B.K. and Neupane, B.R. (eds). Management and Sustainable Development of Coastal Zone Environments. *Capital Publishing Company, New Delhi*. pp. 58-72.

Nandy, P., Haider, M. R., Islam, M. R., Alam, M. J., Moula, M. G. & Habib, M. A. (2002). Growth Performance of 37 Species Raised in the Embankments of Eastern, Central and Western Coastal Belts of Bangladesh. *Research Bulletin. Coastal Greenbelt Project, Bangladesh Forest Department*. pp. 41.

Nordell, B. (2003). Thermal pollution causes global warming. *Global and Planetary Change*, 38 (3-4): 305-312.

Papry, R. I. (2014). Status of coastal plantation in Chittagong Coastal Forest Division. *IOSR Journal of Environmental Sciences, Toxicology and Food Technology*, 8 (1): 79-83.

Parvin, G. A., Takahashi, F. & Shaw, R. (2008). Coastal hazards and community-coping methods in Bangladesh. *Journal of Coastal Conservation*, 12: 181-193. Doi 10.1007/s 11852-009-0044-0.

Patil, V., Singh, A., Naik, N., Seema, U. & Sawant, B. (2012), Carbon sequestration in mangrove ecosystem. *Journal of Environmental Research and Development*, **7** (IA): 576-583.

Prasetya, G. (2007). The role of coastal forests and trees in protecting against coastal erosion. In: Braatz, S., Fortuna, S., Broadhead, J. and Leslie, R, (eds). Coastal Protection in the Aftermath of the Indian Ocean tsunami: What Role for Forests and Trees? *Proceeding of the Regional Technical Workshop, Khao Lak, Thailand*, 28-31 August 2006. pp 103-131.

Rabbani, G., Rahman, A. A. & Islam, N. (2010). Climate change and sea level rise: issues and challenges for coastal communities in the Indian Ocean Region. In: Michel, D. and Pandya, A. (eds). Coastal Zones and Climate Change. *The Henry L. Stimson Center, Washington, DC*. pp 17-29.

Rahman, A., Rollinson, J. & Mohsin, N. (eds) (2008). Challenging Climates: Adapting to Change. *Bangladesh Baseline Study, Bangladesh Centre for Advanced Studies, Dhaka, Bangladesh*. pp. 66.

Rahman, S. & Rahman, M. A. (2015). Climate extremes and challenges to infrastructure development in coastal cities in Bangladesh. *Weather and Climate Extremes*, 7: 96-108.

Richards, K. & Stokes, C. (2004). A Review of forest carbon sequestration cost studies: a dozen years of research. *Climate Change*, 63: 1-48.

Siddiqi, N. A. (2001). Mangrove Forestry in Bangladesh. Institute of Forestry and Environmental Science, *University of Chittagong, Chittagong, Bangladesh*. pp. 201.

Siddiqi, N. A. (2002). Development and sustainable management of coastal plantations in Bangladesh. *Journal of Asiatic Society of Bangladesh, Science*, 28(2): 144-166.

Siddiqi, N. A. (2008a). Probable impact of climate change and sea level rise on mangrove forests and biodiversity of Bangladesh. *Bangladesh Journal of Forest Science*, 31 (1&2): 1-15.

Siddiqi, N. A. (2008b). Mangrove afforestation in Bangladesh: experience and lessons for the future. In: Tan, K.H., Ong, J.E. and Prima, V.J.H. (eds). Proceedings of the International Conference and Exhibition on Mangroves of Indian and Western Pacific Oceans (21-24 August 2006). *Maritime Institute of Malaysia, Kuala Lumpur*. pp. 258-271.

Siddiqi, N. A. & Khan, M. A. S. (2004). Human-induced succession of vegetation on new accretions in the coastal areas of Bangladesh. *Journal of Tropical Forest Science*, 16(2): 187-198.

Siddiqi, N. A., Khan, M. A. S., Islam, M. R. & Hoque, A. K. F. (1992). Underplanting - a means to ensure sustainable mangrove plantations in Bangladesh. *Bangladesh Journal of Forest Science*, 21:1-6.

Silori, C. (2010). Mangroves more Carbon Rich and Important for Climate Change. Available at http://www.recoftc.org/project/grassroots-capacity-building-redd/news-and-features/mangroves-more-carbon-rich-and-important-climate-change (Last accessed on 20 May, 2015).

Spalding, M. D., Blasco, F. & Field, C. D. (1997). World Atlas of Mangroves. Okinawa, Japan. *International Society for Mangrove Ecosystems (ISME)*. pp. 178.

United Nations (UN) (2010). Cyclone Aila: joint UN Multi-Sector Assessment and Response Framework. *United Nations, New York*. pp. 43.

World Bank (WB) (2000). Bangladesh: Climate Change and Sustainable Development. *Rural Development Unit, South Asia Region, The World Bank*, Report No. 21104- BD. pp. 166.