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Climate Change Impacts on Wetlands of Bangladesh, its Biodiversity and Ecology, and Actions and Programs to Reduce Risks

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Abstract

Climate change is projected to increase the intensity and frequency of disasters (floods, increased precipitation), the rise in temperature and sea level in Bangladesh, and the consequences of which will be felt across various sectors including wetlands and wetland-dependent ecosystems, biodiversity, agriculture, fisheries, aquaculture, and livelihoods of people. Hence, this will cause significant economic, social, and environmental challenges/problems for Bangladesh. The major negative impacts of climate change would be damage/destruction of wetland ecosystems and their biodiversity such as, loss or shift of breeding grounds of the Gangetic major carps in the Halda River, Chittagong; loss of Royal Bengal Tiger habitats in the Sundarbans; salinization of rice lands, freshwater aquaculture facilities, and aquifers; water quality problems in wetlands, i.e., algal blooms, low dissolved oxygen, and enhancement of toxins in seafood organisms (fish, prawn); and loss of tourism/recreational business (due to loss of biodiversity). The positive impacts of climate change such as floods would reestablish the connection between rivers and shallow lakes/wetlands, disperse biota/seeds, and enhance spawning and reproduction of native fishes. In order to reduce threats to various sectors, Bangladesh would need to adopt climate resilient development programs/actions including conserving wetlands/mangroves (which are biodiversity "hot spots" and act as major carbon sinks); conserving

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B.A.K. Prusty et al. (eds.), *Wetland Science*,
DOI 10.1007/978-81-322-3715-0_10

species with higher genetic diversity; use of 3F models (simultaneous forestry, food, and fish production in coastal areas) to reduce vulnerabilities in coastal communities; floating agriculture (waterlogged/flood-prone areas); and climate-smart aquaculture, rainwater harvesting, and use of renewable energy. Awareness and education programs including inclusion of climate change in curriculum at primary, secondary, and tertiary educational institutions would be essential. Bangladesh needs to act now, act together, and act differently to enhance development and reduce vulnerability to climate change for a sustainable future.

Keywords
Bangladesh • Climate change impacts • Wetlands • Climate resilient development

10.1 Introduction

Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including areas of marine water, the depth of which at low tide does not exceed 6 m (Ramsar 1971). Wetlands are classified into three broad categories: *inland wetlands* (marshes, swamps, lakes, rivers, streams and creeks, arid wetlands, and floodplains), *marine/coastal wetlands* (shallow marine waters, saltwater marshes, seagrass beds, kelp beds, estuaries, mangroves, coastal freshwater lagoons, and coral reefs), and *human-made wetlands* (fish/aquaculture ponds, irrigation channels, seasonally flooded agricultural land, reservoirs/dams, rice fields, canals, and drainage channels and ditches) (Ramsar 1971).

About three-quarters of the total population live in rural Bangladesh, relying on wetlands and its goods and services for livelihoods. Wetlands play an essential role in rural Bangladesh (agriculture, fishing, duck rearing, aquaculture, snail collection, bird hunting, fuelwood, wild food/vegetable, water for drinking, irrigation, recreation and stock and domestic supply, sand extraction, ecotourism, etc.). The total area of wetlands in Bangladesh is about 7–8 million ha, which is about 50 % of the total land area of the country (Islam 2010). Wetlands of Bangladesh encompass *haors* (freshwater marshes of bowl or saucer-shaped shallow depression), *baors* (oxbow lakes – dead arm of rivers), *beels* (saucer-shaped deeper part of the floodplain landscape), fish ponds and *dighi* (large ponds), flooded rice lands and floodplains, natural lakes, man-made reservoir (Kaptai lake), and coastal/estuarine mangroves (the Sundarbans) and marine areas (St. Martin's Coral Island). Several wetlands in Bangladesh are of national and international significances. Eight wetlands, where ecosystems have reached or threatened to reach a critical state, have been declared as ecologically critical area (ECA) (by the Ecologically Critical Area Ordinance, 2010, under the Bangladesh Environment Conservation Act, 1995). These wetlands are (1) Hakaluki Haor (Moulvibazar and Sylhet districts); (2) Tanguar Haor (Sunamganj district); (3) Marjat Baor (Jhenidah district); (4)

Gulshan-Baridhara Lake (Dhaka city); (5) the Buriganga River, the Shitalakhya River, the Turag River, and the Balu River (Dhaka and Narayanganj districts); (6) the Sundarbans mangrove (Khulna, Satkhira, and Bagerhat districts); (7) Sonadia Island (Cox's Bazar district); and (8) St. Martin's Coral Island (Cox's Bazar district) (http://en.banglapedia.org/index.php?title=Ecologically_Critical_Area; https://en.wikipedia.org/wiki/Ecologically_Critical_Area).

Climate change (the rise in temperatures, carbon dioxide, sea level, ocean acidification, intensity and frequency of extreme events – precipitation, floods, droughts, heat waves/hot extremes, cyclones, bushfire, etc.) is a new and an additional threat to wetlands, its ecology, and biodiversity in Bangladesh (in addition to existing threats posed by pollution, river regulations, dams, overexploitation of resources). Bangladesh can be divided into four climate risk "hot spots" (Box 10.1). This chapter highlights the projected impacts of climate change on wetlands of Bangladesh (world climate risk ranks #1) and suggests actions and climate resilient adaptation and mitigation programs to reduce such impacts on wetlands.

Box 10.1: Climate Change "Hot Spots" in Bangladesh

Bangladesh can be divided into four climate change/natural disaster risk "hot spots" as listed below:

(a) *Cyclone and storm surge risk "hot spot"* – areas close to the Bay of Bengal (southern coastal and marine zone), which are prone to cyclones, storms, and tidal surges including Chittagong, Cox's Bazar, Patuakhali, Barisal, Barguna, Bhola, Hatia, Sandwip, Satkhira, and Khulna and would impact marine fishing, saltwater shrimp farming, aquaculture, agriculture, infrastructure, human settlement, life, and property.

(b) *Flood risk "hot spot"* – most areas of Bangladesh, in particular, areas located in the central and northeastern part of Bangladesh and *char** lands. This would impact agriculture, fisheries (both capture and culture), livestock, water, infrastructure, health, energy, and human settlement *(*char* is a low-lying river island*)*.

(c) *Sea-level rise (SLR) and salinity intrusion risk "hot spot"* – southern coastal districts and marine zones where salinity could rise and intrude further inland due to low water flows from the upstream or rise of sea level, in particular, in the southwest region and islands. This would impact agriculture, capture fisheries, aquaculture, water resources, human settlement, electricity supply, and ecological and public health.

(d) *Drought and temperature risk "hot spot"* – northwest region which includes Rajshahi, Kurigram, Nilphamary, Rangpur, and Dinajpur districts and would impact agriculture, fisheries both capture and culture, water availability, electricity supply, and health.

(Based on Rashid et al. 2009; Nishat and Mukherjee 2013a; Kibria 2014a http://www.ldeo.columbia.edu/chrr/research/profiles/pdfs/bangladesh_profile1.pdf)

10.2 Climate Change Impacts on Wetlands of Bangladesh

Climate change [the rise in global temperatures; current 0.8 °C, future – 2 °C by 2040, and 4 °C by 2100 from the preindustrial levels] will cause significant economic, social, and environmental challenges/problems for Bangladesh. Climate change is projected to increase the intensity and frequency of disasters, floods, and sea-level rise (SLR). The consequences of these changes will be felt across various sectors including wetlands and associated ecosystems, biodiversity, water, agriculture, fisheries, aquaculture, human health, and livelihoods (Haque et al. 2010; World Bank 2010; IPCC 2013; Kibria et al. 2013; Rashid and Paul 2014).

10.2.1 Rise of Temperature

Over the past 100 years, Bangladesh has warmed by about 0.5 °C (Ahmad et al. 1996), and the surface temperature from an annual average of 24.46 °C (1969–1990) is projected to reach 28.13 °C (2070–2099) (Cline 2007). In fact, the projected temperature increase will be in the range of 3–3.5 °C by 2100 (http://eprints.nottingham.ac.uk/2040/6/Bangladesh.pdf). The rise in temperature may cause significant impacts on wetland's water quality and biodiversity as discussed below:

The rise in temperature would increase water temperatures in a number of World Rivers including the Ganges-Brahmaputra in Bangladesh by 1.2 °C (van Vliet et al. 2013). Rising water temperatures will reduce dissolved oxygen in water bodies (since oxygen solubility in water is inversely related to temperature) and may cause hypoxic conditions (extremely low level of oxygen <2.8 mg/L) in lakes and rivers. Decreased dissolved oxygen in water can impair fish growth, can alter reproductive success (lower fertilization, hatching success), can cause endocrine disruption (e.g., increased incidence of malformations in fish and may alter fish sex) (Wu et al. 2003; Wu 2009), can affect species diversity, and can create dead zones in coastal/marine systems (Altieri and Gedan 2015). For optimum growth of fish and other aquatic organisms, dissolved oxygen levels in waterbodies should be more than 5.0 mg/L (Kibria et al. 2010).

The expected rise in surface water temperature could accelerate the growth of harmful algal blooms, which produce toxins [microcystins by cyanobacteria/blue-green algae in freshwater, paralytic shellfish poisoning (PSP) and ciguatera fish poisoning (CFP) by dinoflagellates in the marine environment]. For example, increased temperatures may lead to cyanobacterial bloom in freshwater wetlands (Rapala and Sivonnen 1998; Chorus and Bartram 1999; Håkanson et al. 2007). There is a competitive advantage for cyanobacteria to grow better in warmer temperatures since they generally exhibit optimal growth rates at relatively high temperatures, usually in excess of 25 °C (Paerl and Huisman 2008). Cyanobacterial blooms may cause water quality problems (e.g., low dissolved oxygen, unusual tastes and odor, discoloration, and unsightly scum), making such water unfit for irrigation, recreation, livestock and human drinking, fisheries, aquaculture, and other domestic uses (Kibria et al. 2016a). Furthermore, during cyanobacterial blooms, accumulation of microcystins can occur in the gut, liver, kidney, blood, gills and muscle of fish, prawn, crabs, and mussels (Ibelings and Havens 2008) that may damage the vital organs. Cyanobacteria are reported to have caused significant fish kills in ponds in Bangladesh (Kibria 2014b). Several studies reported accumulation of freshwater biotoxins (microcystins) and marine biotoxins (PSP and CFP) in plankton-feeding finfish and filter-feeding shellfish. Microcystins, PSP, and CFP can be transferred to other organisms higher up in the food chain such as humans on eating contaminated seafood (Kibria et al. 2013).

Global warming may enhance bioaccumulation potential of other toxins (pesticides, metals) in aquatic organisms (such as fish). Bioaccumulation is the uptake/accumulation of chemicals by a living organism by all possible routes, including respiratory surfaces (gills), and ingestion (see below). Bioaccumulation of pollutants such as pesticides and heavy metals to aquatic organisms such as fish could be enhanced with increasing temperatures (Noyes et al. 2009; Marques et al. 2010; Anawar 2013; Kibria et al. 2016b). Consequently, there could be a decline of recreational and commercial fisheries in Bangladesh due to lethal and sublethal effects of toxicants on fish growth and reproduction. At higher temperatures, metabolism of aquatic organisms increases, oxygen concentration in water reduces, and the rate of water flow into the aquatic animals (fish) would be higher to extract more oxygen (via gills) resulting in entry of more dissolved pollutants (heavy metals such as cadmium, mercury, and lead and pesticides such as chlorpyrifos, DDT, endosulfan) into the fish and accumulation in fish tissues (Ficke et al. 2007; Marques et al. 2010; Kibria et al. 2016b). These toxins can then be transferred to humans through contaminated seafood (fish, prawn, and shrimp; Kibria et al. 2010, 2013).

Rise in temperature because of climate change may cause significant impacts on biodiversity of wetlands: (i) allow certain species to stay in the environment since they can tolerate/adapt to changes, (ii) cause some species to move out to a suitable environment, (iii) some species may shift to increased depths (e.g., fish) in the oceans to escape heat or warming, or (iv) some species may die out or go extinct (species with restricted distribution and longer generation time may not be able to migrate or adapt to climate change) (Nally et al. 2010). Thus, the rise in temperature may cause some taxa and species (such as fish) to migrate away from coastal Bangladesh to a suitable cooler environment beyond Bangladesh territory. This would affect local seafood catch, local economy, and livelihoods of people associated with fishing (Kibria et al. 2017).

Weeds, insects (pests), and diseases are likely to increase in Bangladesh in a warmer environment (warmer climates are favorable for proliferation of insect pests and vectors), which would potentially reduce crop yields requiring overuse of chemical pesticides (Kibria et al. 2013). In addition, the rise in global temperature will tend to extend shifts and ranges of many invasive aquatic plants, such as the waterweed, *Eichhornia* sp. (water hyacinth), and *Salvinia* sp. (floating fern) (Bates et al. 2008). Water hyacinth is the worst aquatic weed/pest plant in Bangladesh and has already choked many wetlands and waterways. Further invasion of water hyacinth in wetlands of the country would cause extensive environmental, social, and economic problems. Furthermore, changing global temperatures may increase the susceptibility of fish to diseases since the bacterial, whirling disease in aquaculture systems often peaks at high temperatures (Kibria et al. 2010).

10.2.2 Sea-Level Rise (SLR)

Sea-level rise (SLR) is the average increase in the level of world's oceans. Global warming or increases in temperature cause the oceans to warm and expand in volume inducing a rise in the sea levels. Furthermore, warmer climate facilitates melting of glaciers, ice caps, and ice sheets causing further addition of water to the oceans. The average SLR in the Ganges-Brahmaputra delta in Bangladesh (1 inch. or 25.4 mm) has been recorded in sections of the Ganges-Brahmaputra delta (Alam 1996; Ericson et al. 2005), which is much higher than global SLR (0.12 in. or 3.05 mm per year recorded during 1993–2003, IPCC 2007). It is projected that Bangladesh could lose nearly one-quarter of land area it had in 1989 by the end of this century due to SLR in a worst-case scenario (Ericson et al. 2005).

Bangladesh is highly vulnerable to the effects of SLR. It would lead to contamination of both surface and groundwater with chloride (salt), in particular in the low-lying coastal areas, and have the potential to affect thousands of wells that supply freshwater to approximately 17 million people (UNEP 2006). More than 30 % of the cultivable land in Bangladesh is in the coastal area. Because of SLR, agriculture land (rice lands) in coastal districts (Bagerhat, Khulna, and Satkhira) would be salinized, thus, seriously threatening food security in Bangladesh by making water and soil too salty for rice and other crops. Increased salinity inhibits rice growth and reduces yield. Salinization will also affect freshwater aquaculture and reduce the area available for the same (Kibria 2014a). Furthermore, SLR may cause loss/shift of natural breeding grounds of native fish species – the Gangetic major carps (rui, *Labeo rohita*; katal, *Catla catla*; mrigal, *Cirrhinus cirrhosus*) in the Halda River, Chittagong (http://archive.thedailystar.net/newDesign/news-details.php?nid=184249, http://archive.thedailystar.net/newDesign/story.php?nid=121231) *[note: Halda is the only tidal river in the world, from where fertilized eggs of the Gangetic carps are collected].*

SLR of 1 m would cause complete loss of the Sundarbans mangrove of Bangladesh resulting in the loss of heritage, biodiversity, and fisheries (World Bank 2000). A 28 cm SLR is projected to cause a 96 % decline of the Royal Bengal tiger (*Panthera tigris tigris*) habitats in the Sundarbans (Loucks et al. 2010). Nursery and breeding grounds of many estuarine fish and migratory species residing in the Sundarbans mangroves may be affected due to SLR (World Bank 2000), and this would impact aquaculture (shrimps/prawns/fish/crab) seed supply and fisheries in general. The SLR may cause replacement of the most dominant, freshwater-loving important trees in the Sundarbans, *Sundari* trees (*Heritiera fomes*) by salt-tolerant trees such as Goran (*Ceriops decandra*, *C. tagal*) and Keora (*Sonneratia apetala*) (World Bank 2000). *[Note: Sundari trees are most common and important timber producing trees, used for building houses, boats, furniture, electric poles and hardboard, whereas Goran and Keora trees are used as fuel wood and for charcoal production].* As a consequence of SLR, low salinity tolerant species/freshwater-loving mangrove plants of the Sundarbans such as *H. fomes* and *Nypa fruticans* (Goal pata) will most likely be affected (Table 10.1). It is also projected that the distribution and habitat of the globally endangered Ganges river dolphin (*Platanista* *gangetica gangetica*) and Irrawaddy dolphin (*Orcaella brevirostris*) in the Sundarbans offshore areas, preferring lower salinity, may be totally lost due to SLR in Bangladesh (Smith et al. 2009). Loss or damage of ecosystems and biodiversity in the Sundarbans mangroves would affect livelihoods of millions of people dependent on these wetlands for wood, food, timber, water, medicines, honey, fruits, and fisheries.

10.2.3 Ocean Acidification (OA)

The ocean absorbs approximately 30% of CO_2 added to the atmosphere from human activities including fossil fuel burning, industries, cement manufacturing, deforestation, and land use changes. CO_2 dissolves in water, forms carbonic acid (H_2CO_3), and causes decrease in ocean pH (due to increase in hydrogen ion concentration or H^+). This phenomenon is called as ocean acidification (Roessig et al. 2005; Meehl et al. 2007; Turley et al. 2010). The higher absorption of CO_2 has already acidified the surface layers of the ocean causing an overall decrease of 0.1 pH units since the preindustrial period, which is equivalent to a 30 % increase in hydrogen ion concentration or acidity. The surface ocean pH is projected to decrease by 0.3–0.4 pH units by 2100 relative to preindustrial conditions, equivalent to 150 % increase in acidity (H^+) and 50 % decrease in CO_3^{2}- (Meehl et al. 2007; Wittmann and Pörtner 2013).

Ocean acidification will adversely affect many organisms that require calcium carbonate for their skeletons and shells, such as corals, mollusks, pteropods, and some phytoplankton (Kibria 2015a). Ocean acidification has already caused much effect on calcareous animals and plants (e.g., coral bleaching) (Doney et al. 2009; Turley et al. 2010). Wittmann and Pörtner (2013) conducted sensitivities of five living animal taxa (corals, echinoderms, mollusks, crustaceans, fishes) to a wide range of CO_2 concentrations. They found that all animal groups examined were affected negatively by higher CO_2 concentrations; of these, corals, echinoderms and mollusks were very sensitive to a decline in water pH. It is reported that ocean acidification caused tissue damage in many internal organs of cod fish larvae (liver, pancreas, kidney, eye, and the gut) (Frommel et al. 2012) and reduced survival and growth rates of early life stages of silverside fish (Baumann et al. 2012); therefore, it (like other chemical stressors) could cause a decline in valuable wild fisheries (Nugegoda and Kibria 2016). In the case of Bangladesh, ocean acidification may cause significant consequences on biodiversity of St. Martin's Coral Island (the only Coral Island, locally known as *Narikel Jinjira*). St. Martin's Island is a biodiversity "hot spot" with 66 species of corals, 234 species of fish (of which 89 species are coral reef associated), 187 species of mollusks, 12 species of crabs, and 154 species of marine algae including 10 species of seaweeds (Thompson and Islam 2010, http://www.fao.org/docrep/field/003/ab727e/AB727E03.htm). Loss of biodiversity (corals, etc.) in St. Martin's Island due to ocean acidification would mean the loss of seafood security, tourism revenues, and livelihoods of people as fishing and tourism are the main occupations for the Island's 5,500 residents. However, ocean

Table 10.1 Possible threats of SLR on key mangrove plants of the Sundarbans of Bangladesh

Mangrove species	Threats of SLR
Local name: **Sundari**; English name: Sundar; Scientific name*:* *Heritiera fomes;* Conservation status: endangered	**Freshwater loving plants**; found in the upstream estuarine areas; SLR is a major threat if there is no back area to expand and landward movement of the species is blocked due to coastal development. With the rise in sea level, the habitat requirement of this species will be disrupted, will suffer mortality in their present locations, and may establish at higher elevations in areas that were previously landward
Local name: **Gewa**; English name: Gewa; Scientific name: *Excoecaria agallocha;* Conservation status: Least concerned	**Tolerates moderately saltwater**; SLR is a major threat if there is no back area to expand and landward movement of the species is blocked due to coastal development; this species will suffer mortality in their present locations and may establish at higher elevations in areas that were previously landward
Local name: **Goran**; English name: Indian/spurred mangrove; Scientific name: *Ceriops decandra;* Conservation status: Near threatened	Found in the intermediate estuarine zone, **optimal growth at 15 ppt salinity**; with the rise in sea level, the habitat requirement of this species will be disrupted and suffer mortality in their present locations and may establish at higher elevations in areas that were previously landward. If SLR is a continued trend over this century, then there will be continued mortality and new establishment of species zones
Local name: **Goal pata;** English name: Nypa/mangrove palm; Scientific name: *Nypa fruticans;* Conservation status: Least concerned	This species **prefers more freshwater environments**, found in brackish to tidal freshwater creeks and rivers; hypersaline conditions can threaten the species; SLR is a major threat if there is no back area to expand for the species and landward movement is blocked due to coastal development; species will suffer mortality in their present locations and may establish at higher elevations in areas that were previously landward
Local name: **Keora/kewora;** English name: Sonneratia mangrove; Scientific name: *Sonneratia apetala;* Conservation status: Least concerned	Found in the upstream estuarine zone, tolerates **polyhaline condition;** with the rise in sea level, the habitat requirements of the species will be disrupted, will suffer mortality in their present locations, and may establish at higher elevations in areas that were previously landward. If SLR is a continued trend over this century, there will be continued mortality and new establishment of this species zone
Local name: **Baen;** English name: Indian mangrove; Scientific name: *Avicennia officinalis;* Conservation status: Least concerned	**High tolerance of hypersaline conditions**; with the rise in sea level, the habitat requirements of the species will be disrupted, and species will suffer mortality in their present locations and establish at higher elevations in areas that were previously landward. If sea-level rise is a continued trend over this century, then there will be continued mortality and reestablishment of species zones

(continued)

Table 10.1 (continued)

Mangrove species	Threats of SLR
Local name: **Kankara;** English name: Oriental mangrove; Scientific name: *Bruguiera gymnorrhiza;* Conservation status: Least concerned	**Tolerates salinity up to 50 ppt**, optimal growth at 8–34 ppt; with the rise in sea level, the habitat requirements of the species will be disrupted, and species will suffer mortality in their present locations and may establish at higher elevations in areas that were previously landward. If sea-level rise is a continued trend over this century, then there will be continued mortality and new establishment of species zones
Local name: **Garjan;** English name: Red mangrove/Asiatic mangrove; Scientific name: *Rhizophora mucronata; R. apiculate;* Conservation status: Least concerned	**Tolerates salinity up to 40 ppt**, optimal growth at 8–33 ppt; with the rise in sea level, the habitat requirements of the species will be disrupted and species will suffer mortality in their present locations and may establish at higher elevations in areas that were previously landward zones. If SLR is a continued trend over this century, then there will be continued mortality and new establishment of species zones

Based on http://www.iucnredlist.org/details/-IUCN Red List of Threatened species; Aziz 2009

acidification would also enhance the productivity of seaweeds in the Island since CO_2 is a major component for photosynthesis of plants and would help those people engaged in seaweed culture and harvesting business (dry seaweed export to China, Myanmar, and Singapore).

10.2.4 Extreme Events

Climate change would likely increase the intensity and frequency of extreme weather events (heavy precipitation, floods, cyclones, storms, droughts, heat waves, and high sea level) across the globe (IPCC 2007). According to a World Bank report, Bangladesh is threatened by extreme river floods, more intense tropical cyclones, rising sea levels, and very high temperatures (http://www.worldbank.org/en/news/press-release/2013/06/19/warming-climate-to-hit-bangladesh-hard-with-sea-level-rise-more-floods-and-cyclones-world-bank-report-says). Precipitation and fluvial (river) flooding are projected to increase in Bangladesh in the future with climate change (DECCUK 2010). Bangladesh has experienced extreme floods during 1974, 1987, 1988, 1998, 2004, and 2007 and cyclones (Bhola cyclone 1970, Bangladesh cyclone 1991, Cyclone Sidr 2007, Cyclone Aila 2009) in recent times.

Climate change would increase flooded areas in Bangladesh by at least 25 % (range 23–29 %) with a global temperature rise of 2 °C (Mirza 2003; Kundzewicz et al. 2007), which would have both negative and positive effects. Floods may damage wetland ecosystems and their biodiversity. Extreme flood and rainfall events will increase runoff of contaminants/pollutants (pesticides, nutrients, polycyclic aromatic hydrocarbons/oil, human and animal wastes, and pathogens) into waterways and deteriorate water quality. Large floods can injure larval and juvenile fish and other aquatic organisms and may displace adult fish. Floods would cause loss or damage of property, human lives, crops, vegetables, and livestock in the country.

On the other hand, floods would help recharge groundwater and reestablish connectivity between rivers and shallow lakes and wetlands; increase movement of sediments, nutrients and energy, vital for ecosystem functions; enhance migration of aquatic biodiversity and help dispersal of biota and seeds; and enhance spawning of native fishes (flood pulse is a cue for spawning of the Gangetic major carps and many native fishes). Floods will also improve water quality by flushing out salt from coastal rivers/lands, reducing the problem of dissolved oxygen or algal blooms and dilution of chemical and biological pollutants. Projected increase in rainfall would increase the amount of water available for irrigation in Bangladesh.

10.3 Climate Change Adaptation and Mitigation Measures for Bangladesh

To reduce impacts of climate change on wetlands of Bangladesh (to protect/restore/enhance ecology and biodiversity/reduce pressure/enhance livelihoods of people associated with wetlands of Bangladesh), a number of climate resilient/climate-smart adaptation (adjustment/actions to reduce vulnerability and exploit beneficial opportunities) and mitigation (reduce or enhance sinking of Greenhouse Gases – CO_2, CH_4, N_2O) measures would be required. Some simple, low-carbon, low-cost, and environment-friendly adaptation and mitigation models in the context of Bangladesh are proposed in Fig. 10.1a–f. Adaptation and mitigation measures to reduce vulnerability in wetlands and its ecology and biodiversity are briefly discussed in the following sections.

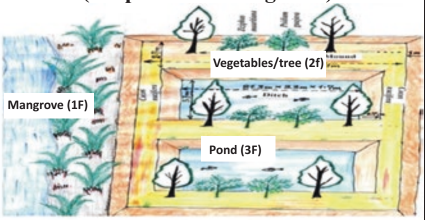
Climate change is now recognized as a major threat to the survival of aquatic species and integrity of wetland ecosystems worldwide. Wetlands that are already being affected by other stressors (dams, pollution, and overexploitation of resources, deforestation, and pest species invasion) are likely to have faster and more acute reactions to climate change. Stress on wetlands can be prevented or reduced by adopting different adaptation strategies as listed below (based on Fischlin et al. 2007; World Bank 2010; Sovacool et al. 2012, Staudinger et al. 2012, Kibria 2015b):

1. Conserving species diversity with higher genetic diversity
2. Conserving wetlands/mangrove habitats (which are biodiversity "hot spots" and act as major carbon sinks; see Fig. 10.1)
3. Restoring habitat structure to increase rare habitat abundance
4. Reducing water stress on water dominant biodiversity
5. Preserving existing and intact floodplain rivers (as strategic global resources such as Ramsar wetlands of the Sundarbans mangrove forest and Tanguar *haor* in Bangladesh)
6. Removing barriers and assisting in the migration of species (to help move species and populations from current locations to those areas expected to become more suitable in the future)
7. Seed banking and captive breeding (conserve live germplasm)

10.1A Afforestation/reforestation/REDD (mitigation)

Afforestation/reforestation/REDD/conservation of mangroves (such as the Sundarban mangroves) would help to reduce CO_2 from the atmosphere (via photosynthesis, carbon sinks in sediments/soils); reduce impacts of disasters (cyclones/ storms/ floods) as forest wall; minimize soil erosion; enhance forest resources/biodiversity, water quality, fisheries; tourism, livelihoods, and mitigate climate change (Kibria et al. 2013); REDD= Reducing Emissions from Deforestation and Forest Degradation (image source: https://www.google.com.au)

10.1B 3F Models (forestry, food and fish) (adaptation & mitigation)



3F models (simultaneous forestry, food, fish production) would reduce the vulnerability of coastal communities of Bangladesh. Mangroves (1F) should be planted along the perimeter of the elevated homesteads to protect against cyclones/ storms; vegetables (2F) at the backyard, and fish/shrimp farming (3F) in dug-out ponds/ gher (Rawlani et al. 2011, Kibria et al. 2013) (image source: Rawlani et al. 2011)

10.1C Floating/hydroponics agriculture (adaptation)

Floating agriculture on beds of rotten water hyacinths stacked together where hyacinth act as compost can be a solution and climate resilient adaptation to regular water logging/prolonged flooding areas in a flood prone country like Bangladesh. It would alleviate poverty, enhance food security, support capacity for poor/ landless people, allow both men and women to work on this simple technology leading to better gender equity (Kibria et al. 2013) (image source: https://www.google.com.au)

10.1D Climate smart aquaculture (adaptation)

Herbivorous fish farming/aquaculture; integrated rice-fish-duck farming; integrated brackish water aquaculture-mangrove etc. have good potential to adapt to and mitigate climate change effects. Such practices would enhance farmer's income, diversify livelihoods, recycle wastes for food production and are energy and resource efficient (Kibria et al. 2013) (image source: https://www.google.com.au)

Fig. 10.1 Examples of climate change/climate-smart adaptation and mitigation models for Bangladesh

10.1E Sustainable water- rainwater (adaptation)	**10.1F Renewable/clean energy (mitigation)**
	
Surface water and groundwater in Bangladesh are contaminated with microbial pathogens and arsenic respectively. Sea-Level Rise would cause salinization of freshwater aquifers and coastal freshwater resources. Bangladesh receives significant amount of rainfall (1,640-2,831 mm/ annum; average 2,347 mm/ annum) (Nishat and Mukherjee 2013b). Rainwater collected from house roofs is a free, natural, sustainable resource and has nil/minimal Greenhouse Gas (GHG) emissions. This can help mitigate scarcity of drinking water along the entire southern coastal areas and reduce pressure on wetland's water resources (Kibria et al. 2013) (image source: https://www.google.com.au)	Renewable Energy (RE) (solar) is a clean energy with nil/minimal GHG emissions and creates opportunity to mitigate climate change/global warming. The availability of plenty of the sunshine in Bangladesh provides potential for solar energy revolution (Kibria et al. 2013). Solar power can be used in rural houses, for irrigation pumping and small transports etc. It would reduce fossil fuels use, carbon pollution and health hazards associated with the use of forest wood, charcoal, cattle dung for cooking in rural Bangladesh. Solar power use reduces impacts on wetlands and biodiversity from climate change/GHG emissions (image source: https://www.google.com.au)

Fig. 10.1 (continued)

8. Reducing non-climate stressors (e.g., habitat fragmentation/destruction, pollution, alien species) to help fish, wildlife, plants, and ecosystems adapt to a changing climate and to enhance resilience to climate change
9. Provision/allocation for environmental water for wetlands to be affected by droughts
10. Increase awareness education to safeguard fish, wildlife, and plants

Other adaptation and mitigation measures to reduce climate change impacts on wetlands of Bangladesh are illustrated in Fig. 10.1b (simultaneous forestry, food, and fish production), Fig. 10.1c (floating agriculture), Fig. 10.1d (climate-smart aquaculture), Fig. 10.1e (sustainable water-rainwater use), and Fig. 10.1f (renewable/clean energy use). In addition, awareness and education programs should be continued so that local communities are more aware of climate change impacts on wetlands and plan for climate resilient adaptation and mitigation-related development programs to reduce impacts on wetlands (as highlighted in Fig. 10.1a–f). It will also be essential to include climate change issues and implications in the curriculum at primary, secondary, and tertiary educational institutions in Bangladesh.

10.4 Conclusion

Climate change will impact Bangladesh severely. Local people do not have the skills/technology/expertise to adapt to climate change efficiently and effectively or manage increasing climate risks. Therefore, Bangladesh needs to act to reduce impacts of climate change on climate-sensitive natural resources like wetlands, its ecology, and biodiversity and wetland-dependent agriculture, fisheries, aquaculture, and water resources on which majority of Bangladeshi people depend for food, water, and their very livelihoods. Some of the adaptation and mitigation models proposed in Fig. 10.1a–f are simple, low-carbon/low-cost technology, environmentally friendly, and easily adaptable to Bangladesh. Secondly, climate change is a global crisis; therefore, Bangladesh would need to act and work unitedly to reduce global emission of GHGs and keep global warming to <2 °C. For example, a 2 °C warming above the preindustrial temperature level could result in permanent reduction in GDP of 4–5 % for South Asia and Africa. Lastly, Bangladesh would have to act differently to build infrastructures/assets, shift cropping patterns and lifestyle, and ensure energy revolution so that the country can withstand new climatic conditions and transit toward low emissions/low-carbon growth paths and climate change and disaster resilient development (e.g., integrating climate risks in all development programs and making development more resilient to climate change) for the foreseeable future while preserving ecosystems. It is imperative that Bangladesh formulates and implements climate-smart policies and programs (based on new information and recent scientific evidence) to enhance climate resilient development and reduce vulnerability to climate-sensitive wetlands, its biodiversity, and ecosystems while significantly reducing its own carbon footprints for a sustainable future.

Acknowledgments We have acknowledged sources of data and information and figures/images both in the reference section and in the texts.

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