Marine Pollution Bulletin 194 (2023) 115431

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Review

Coastal aquaculture in Bangladesh: Sundarbans's role against climate change

Shahanaj Parvin[a,1], Md. Hashmi Sakib[a,1], Md. Latiful Islam[a,*], Christopher L. Brown[b,2], Md. Saiful Islam[c], Yahia Mahmud[c]

[a] Bangladesh Fisheries Research Institute, Brackishwater Station, Paikgacha, Khulna 9280, Bangladesh
[b] FAO World Fisheries University Pilot Programme, Pukyong National University, Busan 47340, South Korea
[c] Bangladesh Fisheries Research Institute, Mymensingh 2201, Bangladesh

ARTICLE INFO

Keywords:
Sundarbans
Coastal aquaculture
Climate change

ABSTRACT

The Sundarbans, a natural shield on earth, is one and only place that has many noteworthy environmental and geographical values with breathtaking natural beauties. Near the Sundarbans area, proliferation of aquaculture in this delta contributes appreciably to the national economy. Although aquaculture has become a means of daily livelihood, this sector is nevertheless threatened by a complex of climate change impacts. Cyclones, rising temperatures, rising sea levels, coastal flooding, and erosion make coastal farming difficult. As a panacea, the Sundarbans can play a critical role in preserving coastal aquaculture. As noticed, forests have high potential to recover from unusual consequences of climate change. Practicing safe aquaculture should be opted to refrain from endangering the Sundarbans. This review addressed various climate change impacts on coastal farming and identified the capabilities of the Sundarbans to protect coastal aquaculture from calamitous impacts. Findings show clues for researchers to analyze problems, consequences, and mitigations.

1. Introduction

In December 2022, the United Nations reached a broad, sweeping agreement on ocean conservation for the maintenance of marine biodiversity. This multilateral, global treaty is the culmination of about nine years of complex negotiations (Sasmito et al., 2023), and the resultant documentation (UN General Assembly, 2023) emphasizes coastal ecosystems that figure prominently in the physical protection of land/sea interfaces, while serving as nurseries for a range of marine organisms. Mangroves act as an interface between marine and terrestrial habitats, serving numerous ecosystem services, including carbon capture, but a mangrove deforestation trend continues to threaten coastal and ocean ecosystems (Adegboyega et al., 2019; Mukherjee et al., 2014). Coastal development for agriculture and aquaculture has resulted in heavy degradation of mangrove forests (Richards and Friess, 2016), and the conservation and restoration of mangrove ecosystems is critically important. Destructive early aquaculture practices led to acute mangrove deforestation, underscoring the need for sustainable farming practices and ecologically sensitive patterns of land use (Thomas et al., 2017).

The Sundarbans is a mysterious reservoir of natural beauty that holds the world's largest mangrove forest with an area of 10,000 km^2 along Bangladesh's and India's coastal borders (Aziz and Paul, 2015). Bangladesh has about six thousand square kilometers of the total area, and the rest is in India (Ishtiaque and Chhetri, 2016; Giri et al., 2007). The Sundarbans, located in the delta of the Ganga, Brahmaputra, and Meghna rivers, were designated a UNESCO World Heritage Site in 1997 (Alam and Mohammad, 2018; Das and Mandal, 2016; Rahman and Asaduzzaman, 2010; Islam and Gnauck, 2008; Gopal and Chauhan, 2006). The soothing and pleasant environment of the Sundarbans has unique environmental and ecological features: season, rainfall, temperature, humidity, water pH, water salinity, water flow, tides, soil salinity, cyclone and so on (Hoq, 2008; Biswas et al., 2007). As can be seen, there are four seasons: i. pre-monsoon, ii. monsoon, iii. post-monsoon, and iv. dry winter (Hoq, 2008). In general, this forest environment comprises rainfall ranging from 1600 to 2000 mm, fluctuating

---

* Corresponding author.
E-mail address: latiful.bfri@gmail.com (Md.L. Islam).
[1] These first authors contributed equally to this work.
[2] Present address: 1212 E. Schwartz Blvd., Lady Lake, FL 32159, USA.

https://doi.org/10.1016/j.marpolbul.2023.115431
Received 24 May 2023; Received in revised form 10 August 2023; Accepted 16 August 2023

from west to east; temperature ranges from higher (26–34 °C) to lower (12–25 °C); humidity 70 to 80 %; pH 6.5 to 8; and water salinity ranges from low (0–5 ppt) to moderate (5–18 ppt) to high (>18 ppt) in different parts of the Sundarbans (Mondal and Debnath, 2017; Neogi et al., 2016; Hoq, 2008; Islam and Gnauck, 2008; Biswas et al., 2007). Water flow in the rivers of the Sundarbans mainly originates from the Ganges- Padma via the Gorai-Madhumati and the lower Meghna via the Swarupkathi-Kocha rivers (Hoq, 2008). These river sediments deposited and formed the delta, which qualifies the Sundarbans as the world's largest mangrove forest (Islam and Wahab, 2005; Islam, 2003). During May to June and October to November, cyclonic storms occur in the Sundarbans (Hoq, 2008). The Sundarbans is considered one of the most complex and delicate ecosystems in the world (Islam, 2019; Islam et al., 2018; Ghosh et al., 2016) and is highly vulnerable to climate change.

The Sundarbans mangrove ecosystem supports the nation's rich aquatic biodiversity, where 53 pelagic fish species and 124 demersal fish species, 20 species of shrimp, 8 species of lobster, 7 species of crab, and 42 species of mollusks are found (Habib et al., 2017; Dasgupta et al., 2017; Ishtiaque and Chhetri, 2016; Ghosh et al., 2015; Minar et al., 2013; Rahman and Asaduzzaman, 2010; Giri et al., 2007; Gopal and Chauhan, 2006; Islam, 2003). The ecosystem of the Sundarbans is highly generative owing to its open system, interconnected upstream with the land and downstream with the sea (Sharmin et al., 2021; Ghosh et al., 2015; Hoq, 2008; Kathiresan and Bingham, 2001). Nutrients are primarily derived from upstream catchments or through tidal flooding, while organic materials are transported seaward (Chakraborty, 2011). The Sundarbans is an important food source, shelter, and nursery for many species (Roy et al., 2012; Adeel and Pomeroy, 2002). For these climatic and ecological reasons, the coastal area of the Sundarbans is highly suitable for aquaculture (Afroz and Alam, 2013; Hossain, 2001). The opportunity for coastal aquaculture expansion is accompanied by socio-economic benefits, including the provision of food, improved nutrition and health, and the generation of income and employment (Das and Mandal, 2016; Hasanuzzaman et al., 2010; Adeel and Pomeroy, 2002). Around the mangrove areas, most of the culture fisheries are shrimp farms (Kabir et al., 2019; Azad et al., 2009; Adeel and Pomeroy, 2002). Various crustaceans and mollusks are also being cultivated on the mud flats (Islam, 2003). Crabs are rich in variety, with many species occupying coastal estuaries or brackishwater habitats (Hoq, 2008). In Bangladesh, the export-oriented shrimp culture is primarily confined to coastal aquaculture areas. Shrimp farming is rapidly burgeoning in the Sundarbans area. In the 2021–2022 fiscal year, Bangladesh earned US$ 407.25 million from frozen export shrimp products (EPB, 2022). Different districts like Bagerhat, Khulna, Satkhira, and others in the Khulna division covered 146,212 ha for Bagda and 65,871 ha for Galda farming (DoF, 2022). Bagda and Galda production from these farms were 54,290 metric tons and 47,900 metric tons, respectively (DoF, 2022). More than 50 % of the post-larvae of black tiger shrimp and >90 % of the post-larvae of freshwater shrimp are collected from wild sources (Azad et al., 2009). Besides this due to disease outbreaks in shrimp culture, mud crabs fattening has become popular (Islam, 2018; Nandi et al., 2016). Crab fattening started in the first half of the 1990s in Bangladesh. The most preferable area is the Bagerhat district, which includes 1400 crab ponds (Islam, 2018), but coastal crab culture is most severely vulnerable to climate change (Sharmin et al., 2021; Islam et al., 2020). Extreme saline water logging due to increasing sea levels as a result of climate change made the coastal area unsuitable (Sharmin et al., 2021; Dasgupta et al., 2016; Haque, 2006). Temperature fluctuation is a consequence of climate change working as an influencer to cause natural calamities such as cyclone *Sidr* which damaged 26 % of forest (Rahman et al., 2010). In addition, even slightly increased environmental temperatures have a range of disruptive impacts on fish physiology (Shahjahan et al., 2022) reproduction and larval development (Ashaf-Ud-Doulah et al., 2021), thereby causing extensive damage of ecosystem. Similarly, salinity changes can be highly disruptive to developing larval and juvenile fishes (for example, see Hossain et al., 2021). In spite of these difficulties, coastal aquaculture has grown at a moderate pace. For these reasons, we need to conduct this study to know the core challenges faced by climate change disasters and their solutions. In addition, this review will also investigate the key role of the Sundarbans in protecting coastal aquaculture from the earth's ever-changing climate.

2. Methodology

This paper is based on a review of published literature and focuses mainly on appropriate strategies for the Sundarbans to resist climate change and its effects on coastal aquaculture. From the public domain and official websites of several governmental agencies, many potential sources of literature, reports, information, and available scientific data were identified and reviewed in order to write this review paper. In addition, some information was collected from the Bangladesh Fisheries Research Institute (BFRI) library. Sundarbans, climate change, and coastal aquaculture were used as keywords for finding relevant literature. After collecting all the relevant data, they were analyzed by applying the Critical Literature Review (CLR) method to perceive all the related and most significant information that is relevant to the objectives of this paper (Sakib et al., 2021; Saunders et al., 2009).

Overall, in this Critical Literature Review (CLR) method, firstly, we have done topic formulation and secondly, we have studied various published literature (journal articles, books, reports, and conference papers). Thereafter, we have gone into the third step, where we selected appropriate lessons and did comparisons and determinations among the selected information. Finally, we have extracted the final results that delivered all the related information about this topic and fulfilled the objectives of this manuscript (Fig. 1).

3. Results and discussion

3.1. Influential factors for climate change

In the current state of our civilization, climate change has come to be an urgent issue. Worldwide climate parameters have drastically changing compared to patterns observed as recently as fifty years back (Chen et al., 2007). Such a dramatic change in climate certainly poses a substantial threat to nature. There are some key factors that are provoking to climate change (Fig. 2). These climate change drivers are categorized as either man-made issues and natural events (Sorvali et al., 2021; Swim and Whitmarsh, 2018; Khanom, 2016; Stern and Kaufmann, 2014; Mitra, 2013; Mitchell et al., 2006; Pielke Jr, 2004). The most common natural factors are volcanic activity, El Niño -Southern Oscillation (ENSO), wildfires and so on. In general, releasing carbon dioxide owing to volcanic activity is about 130–230 million tons per year, which is gradually warming the world and changing the climate (Nda et al., 2018). Another strong climate driver is the El Nino-Southern Oscillation or ENSO. It originates in the tropical area of the Pacific Ocean, in where water oscillates between warm (El Niño) and cold (La Niña) and its negative consequences have already been felt by the world (Nda et al., 2018; Tung and Zhou, 2013; Compo and Sardeshmukh, 2010; Joseph and Nigam, 2006; Harley et al., 2006). ENSO's water is warm, it's called an El Niño and it brings less rainfall or drought in Australia, Indonesia, and other neighboring countries, whereas quite opposite weather in South America, such as heavy rainfall (McPhaden et al., 2006). About 90 % of carbon dioxide discharges from wildfires and contributes as one of the potential greenhouse gases to the environment (Xi-Liu and Qing-Xian, 2018).

Climate change is mainly caused by manmade factors such as releasing greenhouse gases like carbon dioxide (CO_2), nitrous oxide (N_2O), fluorinated gases (CFC), methane (CH_4), and others (Maulu et al., 2021; Kweku et al., 2017). Among the greenhouse gases, CO_2 is a highly potential candidate for being responsible for climate change (Ollila, 2012; Solomon et al., 2010). Carbon dioxide emissions account for 77 %

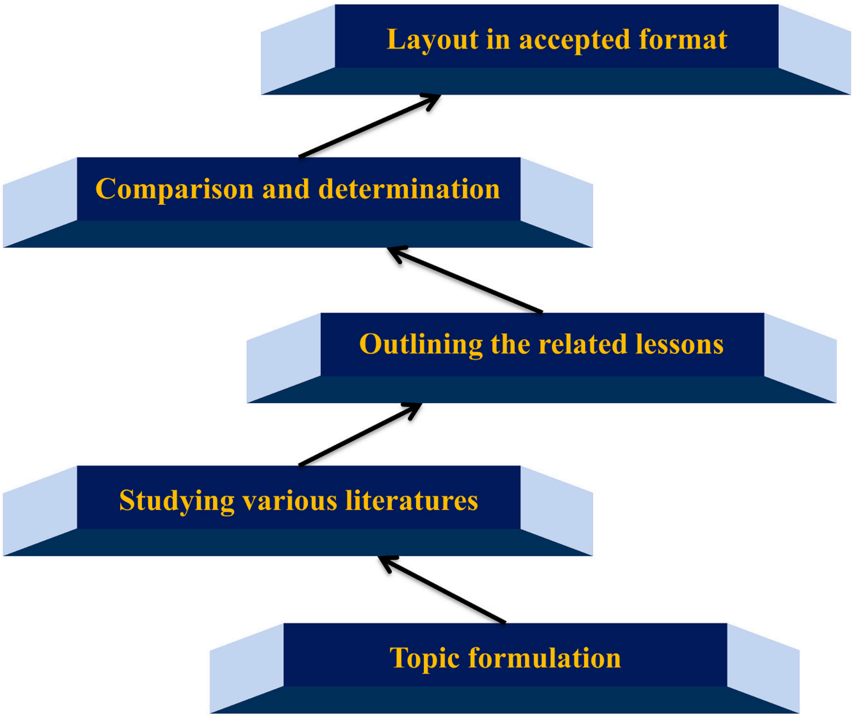

Fig. 1. A flowchart of Critical Literature Review (CLR) method.

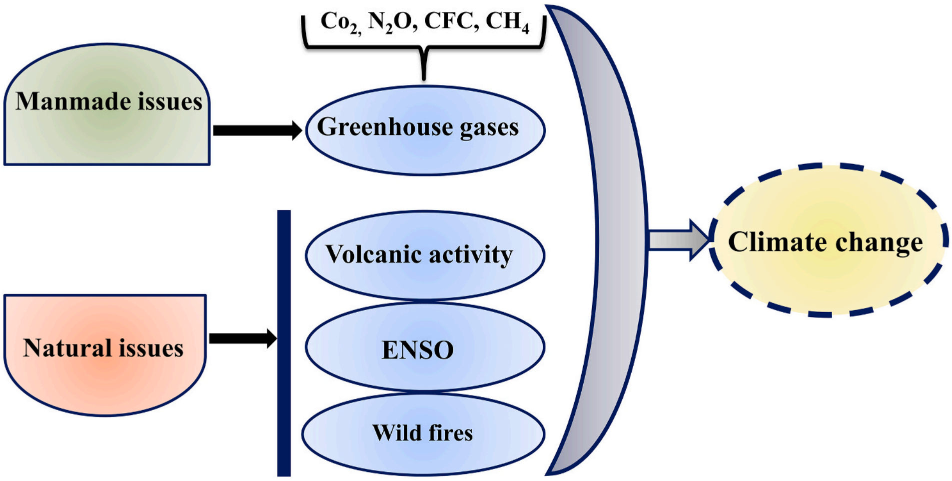

Fig. 2. Drivers responsible to change climate.

of total greenhouse gas emissions (Jalota et al., 2018). Carbon dioxide gas is produced in different human activities viz. emitting smoke from motor vehicles, burning petroleum to run mills and factories, using CFC to produce and pack commercial products, operating nuclear power plants, burning wood and coal to make bricks, etc. (Chatterjee, 2017; Kweku et al., 2017; Yazdi and Shakouri, 2010). The agricultural sector is also responsible for substantial greenhouse gas emissions, accounting for 32 % of total greenhouse gases (Jalota et al., 2018). As a result, our atmosphere has been polluted by a massive load of CO_2 gases, and our climate has been changing. Apparently, these consequences provoke global warming, which leads to an ultimate change in temperature, evaporation and precipitation rates (Manabe, 2019; Kais and Islam, 2019; Mousavi et al., 2011).

In Bangladesh, fossil fuels are the primary source of energy different industries for industrial production, transport, household consumption and other activities. Brick kilns have been contributing to increases in greenhouse gas emissions by the annual combustion of 2.2 million tons of coal (Khandker et al., 2022). By 2030, projected greenhouse gas emissions are expected to be 72.34 % in the energy sector, 2.68 % in the cement and fertilizer industries, 13.44 % in agriculture and livestock, and 7.55 % in the waste sector (MoEFCC, 2021). Bangladesh's current contribution to global greenhouse gas (GHG) emissions is negligible, coming in at just 0.4 % (The World Bank, 2022). This nation's expanding population may result in higher costs for fossil fuels, which are ultimately to blame for climate change (Bell and Masys, 2020).

3.2. *Vulnerable coastal aquaculture*

In the world, all life and motionless objects are suffering from the scary consequences of climate change as hydrological cycles are badly affected by climate change impacts (Atilgan et al., 2023). In continuation of this, coastal aquaculture has severely harmed and destroyed by climate change (Fig. 3). Climate change enhances environmental disturbance such as atmospheric temperature augmentation, imbalance meteorological events, high tidal waves, sea level rise, coastal flooding, soil erosion, cyclones which push coastal aquaculture at stake (Maulu et al., 2021; Ghosh, 2018; Islam et al., 2017; Chaudhuri et al., 2015; Dastagir, 2015; Ghimire and Vikas, 2012; Rosa et al., 2012; McLeod and Salm, 2006). High temperatures make ocean water more acidic, which may finally affect coastal animal farming (Ahsan and Brandt, 2015; Doubleday et al., 2013; Dupont et al., 2010). In fact, temperature variations interrupt and can alter normal physiological activities of aquatic animals including fish (Allison et al., 2009; Hughes et al., 2003; Somero, 2002). Shrimp growth is hampered due to declining essential nutrients in the water of ponds with hot atmospheres (Harley et al., 2006). A report revealed that 85.42 % of shrimp farmers mentioned shrimp disease, deterioration of water quality, oxygen depletion, and disfigurement and discoloration of shrimp in their farms due to rising temperatures (Islam et al., 2019a). Similar research identified shifting fish breeding seasons and declining feeding activity as the temperature fluctuated (Islam et al., 2016). Likewise, others also reported that fish growth, abundance, and nutrition are drastically affected by the change in climate (Ficke et al., 2007; Jobling, 1997).

Dissolved oxygen level fluctuates with increasing temperature. That causes harmful algal blooms to occur more frequently. There are also parasitic disease outbreaks and an imbalance in the dissolved CO_2 level that can be lethal to fish (Islam et al., 2019b; Chatterjee, 2017). While increasing the sea surface temperature of the Bay of Bengal, phytoplankton growth was being influenced, which shifted planktonic community structure in the direction of harmful algal blooms, causing them to become a source of infectious bacterial diseases (Jutla et al., 2011). Seemingly, climate change becomes a potential threat to coastal communities because of the gradually rising sea level (Mondal and Haque, 2018; Payo et al., 2016). An approximate 45 cm rise in sea level by the end of the twenty-first century will lead to the destruction of 75 % of the Sundarbans coastal area (Sultana and Anwar, 2021). Many parts of the coastal area are inundated by saline water and, these phenomena do displace fishing accommodations, bring down the onrush of fresh water, and altering soil salinity when sea level rises (Sarker et al., 2020; Islam et al., 2019b; Islam et al., 2016; Khanom, 2016; Ghimire and Vikas, 2012; Mousavi et al., 2011). In addition, Coastal aquaculture can be affected by increases or reductions in rainfall, which can lead to reduced primary productivity by disrupting photosynthesis in pond eutrophication (Ahmed and Glaser, 2016).

The frequent attack of cyclones on coastal areas is being induced by changing our climate (Sen, 2020; Youdon, 2020;). In each year, around eight storms originate from the Bay of Bengal with wind speeds of 63 kmhr^{-1} or higher (Sen, 2021). Thirteen years ago, cyclone *Aila* ravaged the coastal communities of Khulna and Satkhira districts in 2009, and another devastating cyclone *Sidr* inflicted massive destruction on Bagerghat, Barguna, Patuakhali, and Pirojpur districts in 2007 (Mondal and Haque, 2018; Kabir et al., 2016). In addition, *Sidr* and *Aila* storms impaired or washed away most of the shrimp farms in the most southerly part of Bangladesh (Kais and Islam, 2018; Mallick et al., 2017). Due to *Sidr*, soil salinity in coastal areas is being partially increased but soil on the landmass was greatly damaged by the storm *Aila* (Islam et al., 2016). A sudden change in salinity may impact the breeding season, thereby reducing the availability of post-larvae of fish and shrimp from the wild, threatening the sustenance of established populations as well the availability of juveniles for aquaculture purposes (Ahmed and Diana, 2015a; Hossain et al., 2021). When a natural disaster occurs and the environment degrades, disease spreads rapidly, resulting in a huge mortality rate of aquaculture farm animals in different coastal areas (Paz et al., 2007). Mandal et al. (2019) and Rahman and Rahman (2015) discovered that potential cyclones for instance, *Sidr* (2007), *Nargis* (2008), *Aila* (2009) and *Mahasen* (2013) destroyed nearly USD 1700, 10,000, 553, and 200 million, respectively, worth of crops.

Coastal flooding is usually caused by cyclones that induce environmental pollution of coastal areas with various harmful industrial substances (Rahman et al., 2010). A shortage of natural food and dissolved oxygen occurs in response to turbid water flow into the farm just after a cyclone attack (Ahmed and Diana, 2015b; Roy et al., 2011). The proposed coal-fired Rampal Power Station, which was planned to establish on land 14 km north of the Sundarbans at Rampal Upazila in Bagerhat district of Bangladesh, was anticipated to further damage this unique mangrove forest (Aziz and Paul, 2015). In the future, hot water and fly ash will be mixed into coastal land through high tides and coastal inundations. Besides, highly hazardous elements are trace elements, and those are also highly toxic but are unable to undergo auto-biodegradation or be absorbed by sediments due to cyclonic events

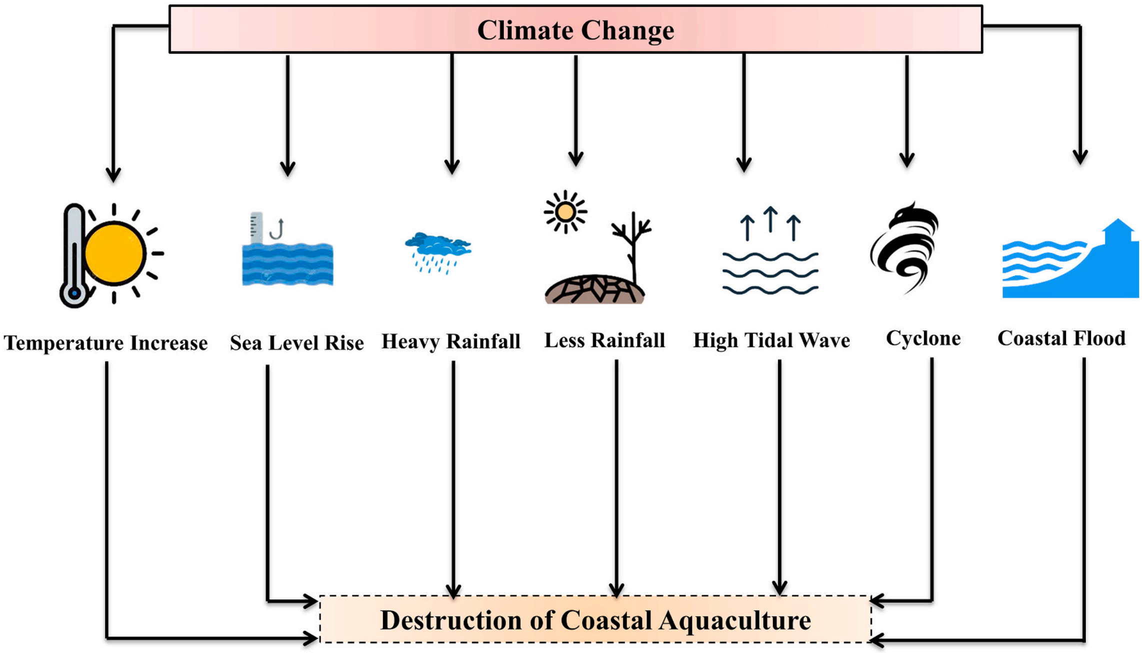

Fig. 3. A schematic diagram of adverse effects on coastal aquaculture.

(Ranjan et al., 2018; MacFarlane and Burchett, 2001). Potentially hazardous substances such as heavy metals accumulate in places like water, soil, and plants where they endanger the environment's health because they are not biodegradable (Topaldemir et al., 2023). Similarly, organic pesticides accumulate in aquatic ecosystems and can inflict damage throughout aquatic communities for an extremely prolonged duration (Islam et al., 2022). Moreover, these elements have been found in tissues of many species and caused intense cellular damage inside their muscles (MacFarlane and Burchett, 2001).

The ecologically delicate and vulnerable nature of coastal wetlands can be fortified against environmental damage to some degree by careful planning and sensible environmental engineering. Mangrove protection and restoration are responsive to ecosystem management in and around the tidal zone, for example the establishment of plant/bivalve communities with a positive history of enhancing mangrove community restoration (Gagnon et al., 2020). Reef-building bivalves provide a range of ecosystemic services including beneficial physical, water-quality, and community structure enhancements; these promote diversification in the plant and animal communities that they support and protect, and can help protect biodiversity and ensure thriving and growing coastal ecosystems (Ysebaert et al., 2019).

3.3. *Combating climate change*

A considerable quantity of carbon dioxide is absorbed by the world's forests and tends to lessen climate change (Palmer, 2021; Zeng et al., 2020; Griscom et al., 2017; Buditama, 2016; Pendleton et al., 2012; McLeod and Salm, 2006). To confront the effects of climate change, trees in the forest are one of the most potential parts (Scheidel and Work, 2018). Trees assimilate extra carbon dioxide and protect coastal areas from the excess wind pressure of cyclones (Fargione et al., 2021; Bastin et al., 2019; Nave et al., 2019).

Among various forests in the world, mangrove forests have super powers in fighting against climate change by curbing carbon dioxide (Barua et al., 2010). Mangroves are very effective for sinking and storing carbon (Sidik et al., 2018; Alongi, 2014; McLeod et al., 2011; Bobbink et al., 2006). Mangroves dissipate wave energy along the coast and act as natural preventers against storms, floods, and erosion (Alongi, 2008; Mazda et al., 2007).

The Sundarbans, a world's largest mangrove forest, can act as a strong protector in combating against climate change impacts (Fig. 4). At first *Golpata* tree which is growing in the coastal area of the Sundarbans fighting against natural disaster (Sen, 2021). The trees of the Sundarbans have a high tolerance capacity against extreme wind originating from cyclones. *Sundari* and *Baen* trees have high resistance powers to resist even 11,000 psi loads (Sen, 2021). Sundarbans have an enormous capacity for sucking up CO_2 and other greenhouse gases and storing large amounts of carbon, which helps to keep slowing in changing climate (Ghimire and Vikas, 2012). It plays a key role as a shock absorber and protects against high tidal waves by slowing the movement of water, trapping sediments, and stabilizing waves and flooding (Sen, 2021).

3.4. *Sundarbans' complaints*

Worldwide, the mangroves foster coastal aquaculture and protect it from adverse impacts of climate change. However, this coastal aquaculture has become a potential gradual threat to the mangroves. Now, despite having economic potentialities, coastal aquaculture has come to under the canopy of controversy. Coastal farming has widespread damaging effects on the Sundarbans because of its unplanned and unregulated using systems. The inflow of chemicals, nutrients, and pollutants from coastal aquaculture farms has very destructive effects on mangroves (Ahmed and Glaser, 2016). Besides, carbon emissions have increased and resulted in the loss of mangrove forests due to coastal aquaculture (Ahmed and Glaser, 2016). Valiela et al. (2001) reported that world mangrove forests have lost 38 % for shrimp culture and 14 % for other forms of coastal territories. Therefore, so many countries have restricted to replace mangroves by unplanned shrimp farms (Ahmed and Glaser, 2016). Also, Chokoria Sundarban has been entirely damaged for

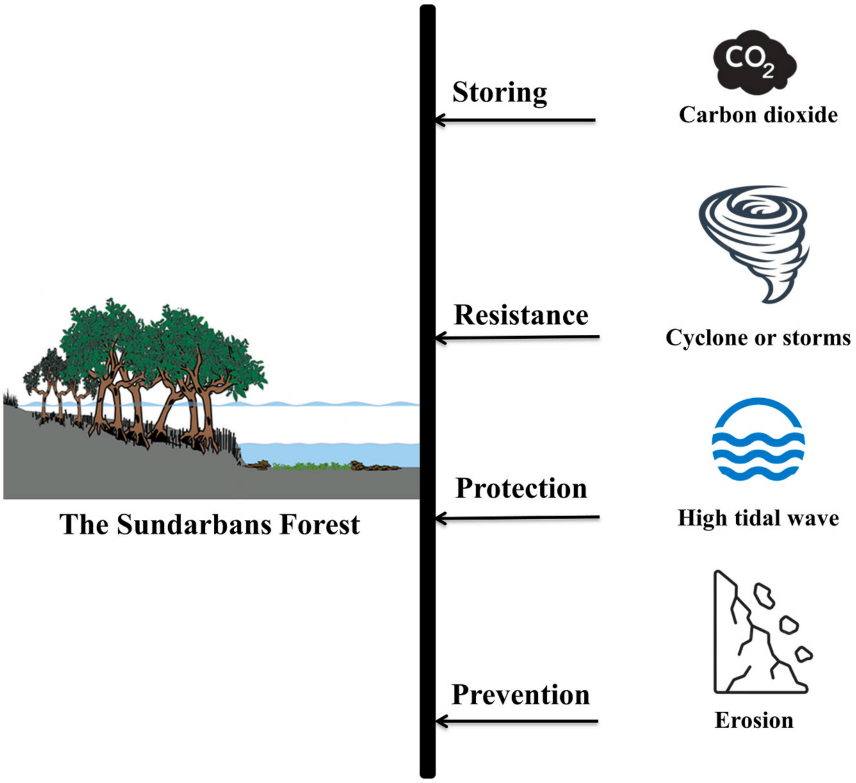

Fig. 4. Significant roles of the Sundarbans against impacts of climate change.

the exclusive farming of shrimps in Bangladesh (Iftekhar and Islam, 2004). As documented, a huge area of the Sundarbans has already been cleared for shrimp farming. Besides, shrimp post larvae are being supplied from wild habitat to the shrimp farms without even thinking about the sustainability of resources and rapid loss of the mighty Sundarbans (Rahman et al., 2010).

Among all of the world's mangrove forests, Bangladesh is home to 3 % of them (Ahmed et al., 2017). The Sundarbans mangrove forest is highly feasible for shrimp farming due to its ecological value. Shrimp is among the leading frozen export items in Bangladesh, earning substantial foreign currency. It also helps to meet the growing population's demand for protein. More or less 10,000 ha of the Sundarbans have been lost in accounts of shrimp farming (Ahmed et al., 2017). To turn mangroves areas into shrimp farms, various trees are being cut down. This increased blue carbon emission and also mangrove soil became the massive carbon store. As a result, the climate has changed and the mangrove ecosystem has been disrupted.

Farmers inject high doses of antibiotics into shrimp farms. Among those, some antibiotics have undesirable impacts on the mangrove environment, such as killing of beneficial microbes, fish, crustaceans, and benthic organisms (Paul and Vogl, 2011). Every day, a huge amount of waste water from aquafarms is flushed into the mangrove environment, contributing environmental pollution. These antibiotics and chemicals have ecotoxicological effects which can create prolonged toxicity on living organisms in the environment (Yuksel et al., 2021). Moreover, some of these chemicals have carcinogenic effects on human body too (Yuksel et al., 2022). Similarly, to the situation in Bangladesh, mangrove forests in Indonesia (55 %), The Philippines (67 %), Thailand (84 %), Vietnam (37 %), and Mexico (30 %) have been damaged by shrimp farming (Hossain et al., 2013).

3.5. Mitigation measures

Fighting climate change is urgent for human existence. It is serious objection for human to be maintained climate change at a certain rate or level (Zhao et al., 2023). Some principles and scientific knowledge can be adopted for this purpose (Creutzig et al., 2023). The Sundarbans mangrove forest is analogous to a mother's womb for the coastal communities of southern Bangladesh. For saving the Sundarbans, possible initiatives may be taken to protect our mighty mangrove forest (Fig. 5).

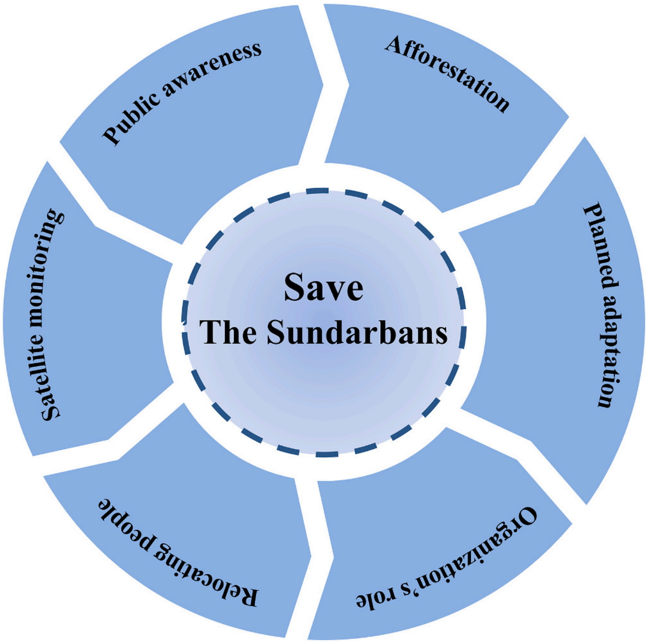

Fig. 5. Possible approaches to save the Sundarbans.

A sustainable management approach is required to adopt and implement for the conservation of the Sundarbans (Islam and Bhuiyan, 2018). Afforestation is a valuable solution to conserve the Sundarbans (Khairnar et al., 2019). Mangrove afforestation and reforestation are increasingly recognized as essential components of forward-looking coastal and wetland engineering efforts (Sasmito et al., 2023; Sen, 2021; Alam and Collins, 2010). Conserved and replenished mangroves provide an extensive assortment of ecosystem services, including but not limited to carbon sequestration and the provision by tree roots, trunks, and branches of suitable habitat for open-water and other aquatic animals (Sunyowati et al., 2016). These are enormous sources of bacteria that process leaf litter into detritus, helping the proper balance and functionality of coastal food webs (Kathiresan and Bingham, 2001; Nagelkerken et al., 2008). IUCN-Bangladesh has recently initiated a pilot project to propagate and plant mangrove trees (Iftekhar and Islam, 2004).

Planned adaptation is required to fight against climate change impacts on the Sundarbans (Danda et al., 2019; Mustafa Saroar et al., 2019; Woodson et al., 2019; Morecroft et al., 2019; Miller et al., 2018; Islam and Shafie, 2017; Abedin and Shaw, 2013; Berrang-Ford et al., 2011; Ford et al., 2011). Various scientific master plans are required for implementing sustainable adaptation strategies as climate change impacts are heterogeneous crises (Liu and Masago, 2023). Coastal areas are affected by the increasing salinity range. So, the coastal people should plant salinity tolerant tree species and farm salinity tolerant fish species. It also makes sure to increase freshwater flow from upstream, which may help reduce the extent of salinity in rivers (Hassan et al., 2019; Hoq, 2008). Coastal embankments and other infrastructure must be built and maintained properly (Mallick et al., 2011; Yazdi and Shakouri, 2010). Though infrastructure is needed to reduce the risk of flood, erosion, and shelter for people, it also has some negative impacts on the Sundarbans ecosystem (Auerbach et al., 2015; Takagi et al., 2015). Therefore, planned infrastructure and resettlement are very important when considering the permissible limit of the forest environment (Sarker et al., 2020; Schuerch et al., 2018). Devising well-balanced coastal land-use plans and maintaining sustainable limits in the harvesting of forest resources are a must (Islam and Wahab, 2005). Regular monitoring should be done in order to control pollution and regulate sustainable forest management (Islam and Bhuiyan, 2018).

People should stop being dependent on wild stock for shrimp postlarvae, instead producing good-quality, high-resistance, and specific pathogen-free post-larvae in indoor hatcheries (Kabir et al., 2019). Public and private sectors should work together to boost this activity for conserving the Sundarbans (Keus et al., 2017; Karim et al., 2016). Organizations should participate spontaneously to enhance the hatchery sector, which will ultimately increase the seed production of all coastal aquaculture species (Keus et al., 2017). Moreover, they can arrange advanced training for farmers on better pond management and to promote good quality fish seed, specific pathogen free shrimp post-larvae, the breeding of crab and a pure source of live food that are needed for hatchery operations (Keus et al., 2017). This kind of initiative will reduce bycatch during collection of shrimp larvae, helping to preserve rich biodiversity within the mangrove ecosystem. Crustaceans such as mangrove crabs contribute meaningfully to carbon and nitrogen cycles within these ecosystems (Tongununui et al., 2021).

The local people of the Sundarbans are fully dependent on this forest. Many have been consuming the resources of the Sundarbans without fully comprehending forest conservation measures, facts, or the importance of the mangroves (Islam and Bhuiyan, 2018). By reducing this dependency, restoration of Sundarbans may take place. Some efforts have focused on diversifying the livelihood of the local people by relocating their homes and business activities with financial and technical support (Islam and Bhuiyan, 2018). Organizations and local dwellers should come forward to save the Sundarbans and reduce the intensity of climate change impacts (Islam and Bhuiyan, 2018; Aheto et al., 2016; Moser and Ekstrom, 2010; Iftekhar and Islam, 2004).

The world moves faster with the latest technologies; thus, stakeholders should be aware of more advanced tools to protect the Sundarbans by resisting its rapid changes and degradation, including some that use satellites (Halder et al., 2021; Giri et al., 2007). Data can be extracted from satellite images for further analysis for long-term monitoring of the Sundarbans (Halder et al., 2021). In India, some studies were carried out using Landsat satellite data to know the spatio-temporal variation in the Sundarbans for a period of about 30 years, whereas another research effort was conducted in Bangladesh and India to know its degradation and deforestation status as changing over the decades (Halder et al., 2021; Giri et al., 2007). Thus, hazard maps, time series data and socio-economic data are very helpful for management decision to get a suitable solution to climate change challenges (Crespi et al., 2023). Apparently, spatial planning is the most fundamental multiple climate change risks analyzer for identifying hazards to cope with them in applying adaptation tactics (Liu and Masago, 2023).

However, natural disasters are the main cause of the degradation of the Sundarbans (Islam and Bhuiyan, 2018). Natural calamities cannot be stopped fully but their damage can be reduced to some extent by anticipatory planning to curb the intensity of climate change (Gopal and Chauhan, 2006). Public awareness must be increased, and frequent campaigns such as “Save the Sundarbans” should be disseminated among the stakeholders of the forest (Islam and Bhuiyan, 2018).

Recently, Indonesia was recognized by the United Nations with a special award for progressive efforts at the restoration of its mangrove forests (see Sasmito et al., 2023; Murdivarso et al., 2015). It is an example for all countries to save mangroves. Indonesia has taken some steps to ensure that a semi-permeable sea wall consists of natural elements, producing a protective deadfall for mud and sediments. In the course of time, soil will deposit at the root of the mangrove and prevent overflow. When the mangrove trees’ roots bind deeply, this will prevent erosion. This method is more successful than simply planting trees. Also, their specialists have helped to build up shrimp farms and improve sustainable operations adjacent to mangroves.

4. Conclusion

Coastal area is most suitable for coastal aquaculture because of its soil, water and climate have different physical, chemical, biological and environmental attributes. But coastal aquaculture has been being faced a lot of threats due to climate change. Over time, there have been significant changes to the climate. The main contributors to climate change include both anthropogenic and natural forces. Different disasters like sea-level rise, less rainfall, salinity intrusion, coastal flooding, tidal surge, cyclones are finally damaged the coastal aquaculture. To overcome these problems, strong defenses against climate change and its impacts are provided by forests. Also, the Sundarbans has unique abilities to combat any natural disasters brought on by climate change. So, our top focus is the Sundarbans because it shields us from the ravages of climate change. The Sundarbans can be safeguarded in a variety of ways. Undoubtedly, it has stood as a safeguard between the coastal district and fierce winds during the danger of natural disasters. It is already proven that the mangrove forest has contributed largely to reduce the severity of the effects of climate change. Therefore, in order to regulate sustainable forest management and control pollution, regular monitoring should be carried out. By giving the local people financial and technical support to relocate their homes and businesses, their income source can be diversified. Besides, increased public awareness is necessary, and stakeholders in the forest should be informed on a regular basis about campaigns like “Save the Sundarbans”. Reforestation is a beneficial strategy for protecting the Sundarbans. Also, coastal aquaculture near the Sundarbans needs to adapt to climate change by employing a variety of visionary methods.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

We are grateful to Bangladesh Fisheries Research Institute for providing unconditional support and scope to complete this review.

References

Abedin, M., Shaw, R., 2013. Agriculture adaptation in coastal zone of Bangladesh. In: Shaw, R., Mallick, F., Islam, A. (Eds.), Climate Change Adaptation Actions in Bangladesh. Disaster Risk Reduction. Springer, Tokyo, pp. 207–225. https://doi.org/10.1007/978-4-431-54249-0_12.

Adeel, Z., Pomeroy, R., 2002. Assessment and management of mangrove ecosystems in developing countries. Trees. 16 (2), 235–238. https://doi.org/10.1007/s00468-002-0168-4.

Adegboyega, S.A., Oloukoi, J., Olajuyigbe, A.E., Ajibade, O.E., 2019. Evaluation of unsustainable land use/land cover change on ecosystem services in coastal area of Lagos state, Nigeria. Appl. Geomat. 11, 97–110. https://doi.org/10.1007/s12518-018-0242-2.

Afroz, T., Alam, S., 2013. Sustainable shrimp farming in Bangladesh: a quest for an Integrated Coastal Zone Management. Ocean Coast. Manag. 71, 275–283. https://doi.org/10.1016/j.ocecoaman.2012.10.006.

Aheto, D.W., Kankam, S., Okyere, I., Mensah, E., Osman, A., Jonah, F.E., Mensah, J.C., 2016. Community-based mangrove forest management: implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. Ocean Coast. Manag. 127, 43–54. https://doi.org/10.1016/j.ocecoaman.2016.04.006.

Ahmed, N., Diana, J.S., 2015a. Threatening “white gold” impacts of climate change on shrimp farming in coastal Bangladesh. Ocean Coast. Manag. 114, 42–52. https://doi.org/10.1016/j.ocecoaman.2015.06.008.

Ahmed, N., Diana, J.S., 2015b. Coastal to inland: expansion of prawn farming for adaptation to climate change in Bangladesh. Aquac. Rep. 2, 67–76. https://doi.org/10.1016/j.aqrep.2015.08.001.

Ahmed, N., Glaser, M., 2016. Coastal aquaculture, mangrove deforestation and blue carbon emissions: is REDD+ a solution? Mar. Policy 66, 58–66. https://doi.org/10.1016/j.marpol.2016.01.011.

Ahmed, N., Cheung, W.W., Thompson, S., Glaser, M., 2017. Solutions to blue carbon emissions: shrimp cultivation, mangrove deforestation and climate change in coastal Bangladesh. Mar. Policy 82, 68–75. https://doi.org/10.1016/j.marpol.2017.05.007.

Ahsan, D., Brandt, U.S., 2015. Climate change and coastal aquaculture farmers’ risk perceptions: experiences from Bangladesh and Denmark. J. Environ. Plan. Manag. 58 (9), 1649–1665. https://doi.org/10.1080/09640568.2014.942414.

Alam, E., Collins, A.E., 2010. Cyclone disaster vulnerability and response experiences in coastal Bangladesh. Disasters. 34 (4), 931–954. https://doi.org/10.1111/j.1467-7717.2010.01176.x.

Alam, S., Mohammad, S.N., 2018. Applying the ecosystem approach to the Sundarbans of Bangladesh: possibilities and challenges. Rev. Eur. Comp. Int. Environ. Law. 27 (2), 115–129. https://doi.org/10.1111/reel.12230.

Allison, E.H., Perry, A.L., Badjeck, M.C., Neil Adger, W., Brown, K., Conway, D., Dulvy, N.K., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish. 10 (2), 173–196. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

Alongi, D.M., 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. Estuar. Coast. Shelf Sci. 76 (1), 1–13. https://doi.org/10.1016/j.ecss.2007.08.024.

Alongi, D.M., 2014. Carbon cycling and storage in mangrove forests. Annu. Rev. Mar. Sci. 6, 195–219. https://doi.org/10.1146/annurev-marine-010213-135020.

Ashaf-Ud-Doulah, M., Islam, S.M.M., Zahangir, M.M., Islam, M.S., Brown, C.L., Shahjahan, M., 2021. Increased water temperature interrupts embryonic and larval development of Indian major carp rohu, *Labeo rohita*. Aquac. Int. 29, 711–722. https://doi.org/10.1007/s10499-021-00649-x.

Atilgan, A., Yücel, A., Kocięcka, J., Rolbiecki, R., Şenyiğit, U., Taş, İ., Liberacki, D., 2023. The effect of climate change on stream basin hydrometeorological variables: the example of dim stream (Turkey). Ecohydrol. Hydrobiol. https://doi.org/10.1016/j.ecohyd.2023.07.003.

Auerbach, L.W., Goodbred Jr., S.L., Mondal, D.R., Wilson, C.A., Ahmed, K.R., Roy, K., Ackerly, B.A., 2015. Flood risk of natural and embanked landscapes on the Ganges–Brahmaputra tidal delta plain. Nat. Clim. Chang. 5 (2), 153–157.

Azad, A.K., Jensen, K.R., Lin, C.K., 2009. Coastal aquaculture development in Bangladesh: unsustainable and sustainable experiences. Environ. Manag. 44 (4), 800–809. https://doi.org/10.1007/s00267-009-9356-y.

Aziz, A., Paul, A.R., 2015. Bangladesh Sundarbans: present status of the environment and biota. Diversity. 7 (3), 242–269. https://doi.org/10.3390/d7030242.

Barua, P., Chowdhury, S., Sarker, S., 2010. Climate change and its risk reduction by mangrove ecosystem of Bangladesh. Bangladesh Res. Publ. J. 4 (3), 208–225.

Bastin, J.F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Crowther, T. W., 2019. The global tree restoration potential. Science. 365 (6448), 76–79. https://doi.org/10.1126/science.aax0848.

Bell, C., Masys, A.J., 2020. Climate change, extreme weather events and global health security a lens into vulnerabilities. In: Masys, A.J., lzurieta, R., Ortiz, M.R. (Eds.), Global Health Security: Recognizing Vulnerabilities, Creating Opportunities. Springer Cham, pp. 59–78. https://doi.org/10.1007/978-3-030-23491-1_4.

Berrang-Ford, L., Ford, J.D., Paterson, J., 2011. Are we adapting to climate change? Glob. Environ. Chang. 21 (1), 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012.

Biswas, S.R., Choudhury, J.K., Nishat, A., Rahman, M.M., 2007. Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh? For. Ecol. Manag. 245 (1–3), 1–9. https://doi.org/10.1016/j.foreco.2007.02.011.

Bobbink, R., Whigham, D.F., Beltman, B., Verhoeven, J.T., 2006. Wetland functioning in relation to biodiversity conservation and restoration. In: Wetlands: Functioning, Biodiversity Conservation, and Restoration. Springer, pp. 1–12.

Buditama, A., 2016. Blue carbon for reducing the impacts of climate change: an Indonesian case study. Glob. Ecol. Biogeogr. 154, 157.

Chakraborty, S.K., 2011. Mangrove ecosystem of Sundarbans, India: biodiversity, ecology, threats and conservation. In: Mangroves: Ecology, Biology and Taxonomy. Ed. Metras JN: NOVA publisher, USA, pp. 83–112.

Chatterjee, T., 2017. Climate change and its collision on fisheries resource in Sundarban region of South 24 Pargana, West Bengal. In: Suresh Gyan Vihar University International Journal of Environment, Science and Technology, 3(2), pp. 10–13.

Chaudhuri, P., Ghosh, S., Bakshi, M., Bhattacharyya, S., Nath, B., 2015. A review of threats and vulnerabilities to mangrove habitats: with special emphasis on east coast of India. J. Earth Sci. Clim. Chang. 6 (4) https://doi.org/10.4172/2157-7617.1000270.

Chen, Y.N., Li, W.H., Xu, C.C., Hao, X.M., 2007. Effects of climate change on water resources in Tarim River Basin, Northwest China. J. Environ. Sci. 19 (4), 488–493. https://doi.org/10.1016/S1001-0742(07)60082-5.

Compo, G.P., Sardeshmukh, P.D., 2010. Removing ENSO-related variations from the climate record. J. Clim. 23 (8), 1957–1978. https://doi.org/10.1175/2009JCLI2735.1.

Crespi, A., Renner, K., Zebisch, M., Schauser, I., Leps, N., Walter, A., 2023. Analysing spatial patterns of climate change: climate clusters, hotspots and analogues to support climate risk assessment and communication in Germany. Clim. Serv. 30, 100373 https://doi.org/10.1016/j.cliser.2023.100373.

Creutzig, F., Goetzke, F., Ramakrishnan, A., Andrijevic, M., Perkins, P., 2023. Designing a virtuous cycle: quality of governance, effective climate change mitigation, and just outcomes support each other. Glob. Environ. Chang. 82 https://doi.org/10.1016/j.gloenvcha.2023.102726.

Danda, A., Ghosh, N., Bandyopadhyay, J., Hazra, S., 2019. Managed retreat: adaptation to climate change in the Sundarbans ecoregion in the Bengal Delta. J. Indian Ocean Reg. 15 (3), 317–335. https://doi.org/10.1080/19480881.2019.1652974.

Das, C.S., Mandal, R.N., 2016. Coastal people and mangroves ecosystem resources vis-à-vis management strategies in Indian Sundarban. Ocean Coast. Manag. 134, 1–10. https://doi.org/10.1016/j.ocecoaman.2016.09.025.

Dasgupta, S., Huq, M., Mustafa, M., Sobhan, M.I., Wheeler, D., 2016. Impact of climate change and aquatic salinization on fish habitats and poor communities in southwest coastal Bangladesh and Bangladesh Sundarbans. In: World Bank Policy Research Working Paper, 7593.

Dasgupta, S., Sobhan, I., Wheeler, D., 2017. The impact of climate change and aquatic salinization on mangrove species in the Bangladesh Sundarbans. Ambio. 46 (6), 680–694. https://doi.org/10.1007/s13280-017-0911-0.

Dastagir, M.R., 2015. Modeling recent climate change induced extreme events in Bangladesh: a review. Weather Clim. Extrem. 7, 49–60. https://doi.org/10.1016/j.wace.2014.10.003.

DoF. (Department of Fisheries), 2022. Yearbook of Fisheries Statistics of Bangladesh, 2019–20. Fisheries Resources Survey System (FRSS), Department of Fisheries. Bangladesh: Ministry of Fisheries and Livestock, 37, 141. http://www.fisheries.gov.bd.

Doubleday, Z.A., Clarke, S.M., Li, X., Pecl, G.T., Ward, T.M., Battaglene, S., Stoklosa, R., 2013. Assessing the risk of climate change to aquaculture: a case study from south-east Australia. Aquac. Environ. Interact. 3 (2), 163–175. https://doi.org/10.3354/aei00058.

Dupont, S., Ortega-Martínez, O., Thorndyke, M., 2010. Impact of near-future ocean acidification on echinoderms. Ecotoxicology. 19 (3), 449–462. https://doi.org/10.1007/s10646-010-0463-6.

EPB, 2022. Pocket Export Statistics FY 2021-2022. Export Promotion Bureau, Dhaka, Bangladesh. https://epb.gov.bd/sites/default/files/files/epb.portal.gov.bd/miscellaneous_info/8405d990_9311_41c8_88df_19b340500b6c/2022-11-13-08-36-88a5847c9a8380c752183eacce9c0a1d.pdf.

Fargione, J., Haase, D.L., Burney, O.T., Kildisheva, O.A., Edge, G., Cook-Patton, S.C., Guldin, R.W., 2021. Challenges to the reforestation pipeline in the United States. Front. For. Glob. Change 4, 629198. https://doi.org/10.3389/ffgc.2021.629198.

Ficke, A.D., Myrick, C.A., Hansen, L.J., 2007. Potential impacts of global climate change on freshwater fisheries. Rev. Fish Biol. Fish. 17 (4), 581–613. https://doi.org/10.1007/s11160-007-9059-5.

Ford, J.D., Berrang-Ford, L., Paterson, J., 2011. A systematic review of observed climate change adaptation in developed nations. Clim. Chang. 106 (2), 327–336. https://doi.org/10.1007/s10584-011-0045-5.

Gagnon, K., Rinde, E., Bengil, G.T., Carugati, L., Christianen, M.J.A., Danovaro, R., Gambi, C., Govers, L.L., Kipson, S., Meysick, L., Pajusalu, L., Kızılkaya, İ.T., van de Koppel, J., van der Heide, T., van Katwijk, M.M., Boström, C., 2020. Facilitating foundation species: the potential for plant–bivalve interactions to improve habitat restoration success. J. Appl. Ecol. 57 (6), 1161–1179. https://doi.org/10.1111/1365-2664.13605.

Ghimire, K.M., Vikas, M., 2012. Climate change impact on the Sundarbans, a case study. Int. Sci. J. Environ. Sci 2 (1), 7–15.

Ghosh, N., 2018. Climate change and agrarian systems: adaptation in climatically vulnerable regions. Indian J. Agric. Econ. 73 (1), 38–53.

Ghosh, A., Schmidt, S., Fickert, T., Nüsser, M., 2015. The Indian Sundarban mangrove forests: history, utilization, conservation strategies and local perception. Diversity. 7 (2), 149–169. https://doi.org/10.3390/d7020149.

Ghosh, M.K., Kumar, L., Roy, C., 2016. Mapping long-term changes in mangrove species composition and distribution in the Sundarbans. Forests 7 (12), 305. https://doi.org/10.3390/f7120305.

Giri, C., Pengra, B., Zhu, Z., Singh, A., Tieszen, L.L., 2007. Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuar. Coast. Shelf Sci. 73 (1–2), 91–100. https://doi.org/10.1016/j.ecss.2006.12.019.

Gopal, B., Chauhan, M., 2006. Biodiversity and its conservation in the Sundarban mangrove ecosystem. Aquat. Sci. 68 (3), 338–354. https://doi.org/10.1007/s00027-006-0868-8.

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Fargione, J., 2017. Natural climate solutions. Proc. Natl. Acad. Sci. 114 (44), 11645–11650. https://doi.org/10.1073/pnas.1710465114.

Habib, K.A., Kim, C.G., Oh, J., Neogi, A.K., Lee, Y.H., 2017. Aquatic Biodiversity of Sundarbans. Korea Institute of Ocean Science and Technology (KIOST), Bangladesh, p. 394.

Halder, S., Samanta, K., Das, S., Pathak, D., 2021. Monitoring the inter-decade spatial–temporal dynamics of the Sundarban mangrove forest of India from 1990 to 2019. Reg. Stud. Mar. Sci. 44, 101718 https://doi.org/10.1016/j.rsma.2021.101718.

Haque, S.A., 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pak. J. Bot. 38 (5), 1359–1365.

Harley, C.D., Randall Hughes, A., Hultgren, K.M., Miner, B.G., Sorte, C.J., Thornber, C.S., Williams, S.L., 2006. The impacts of climate change in coastal marine systems. Ecol. Lett. 9 (2), 228–241. https://doi.org/10.1111/j.1461-0248.2005.00871.x.

Hasanuzzaman, A.F.M., Sayeed, M.A.B., Rahaman, S.B., Huq, K.A., 2010. Implications of climate change for fisheries and aquaculture in the Sundarbans region of Bangladesh. In: Khulna University Studies Special Issue, pp. 73–82.

Hassan, K., Higham, J., Wooliscroft, B., Hopkins, D., 2019. Climate change and world heritage: a cross-border analysis of the Sundarbans (Bangladesh–India). J. Policy Res. Tourism Leisure Events 11 (2), 196–219. https://doi.org/10.1080/19407963.2018.1516073.

Hoq, M.E., 2008. Sundarbans Mangrove: Fish and Fisheries Ecology, Resources, Productivity and Management Perspectives. Graphic Media, Dhaka, Bangladesh, p. 271.

Hossain, M.S., 2001. Biological aspects of the coastal and marine environment of Bangladesh. Ocean Coast. Manag. 44 (3–4), 261–282. https://doi.org/10.1016/S0964-5691(01)00049-7.

Hossain, M.S., Uddin, M.J., Fakhruddin, A.N.M., 2013. Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. Rev. Environ. Sci. Biotechnol. 12, 313–332. https://doi.org/10.1007/s11157-013-9311-5.

Hossain, F., Islam, S.M.M., Ashaf-Ud-Doulah, M., Ali, M.S., Islam, M.S., Brown, C.L., Shahjahan, M., 2021. Influences of salinity of embryonic and larval development of striped catfish, *Pangassianodon hypothalamus*. Front. Mar. Sci. 8 https://doi.org/10.3389/fmars.2021.781951.

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Roughgarden, J., 2003. Climate change, human impacts, and the resilience of coral reefs. Science. 301 (5635), 929–933. https://doi.org/10.1126/science.1085046.

Iftekhar, M.S., Islam, M.R., 2004. Managing mangroves in Bangladesh: a strategy analysis. J. Coast. Conserv. 10 (1), 139–146. https://doi.org/10.1652/1400-0350(2004)010[0139:MMIBAS]2.0.CO;2.

Ishtiaque, A., Chhetri, N., 2016. Competing policies to protect mangrove forest: a case from Bangladesh. Environ. Dev. 19, 75–83. https://doi.org/10.1016/j.envdev.2016.06.006.

Islam, M.S., 2003. Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. Ocean Coast. Manag. 46 (8), 763–796. https://doi.org/10.1016/S0964-5691(03)00064-4.

Islam, M.S., 2018. Mass engagement of the local communities in mud crab culture in the Sundarban Area, Bangladesh: a potential livelihood under threats of climate change. Pro. Aqua Farm. Mar. Biol. 1 (1), 180007.

Islam, S.N., 2019. Sundarbans a dynamic ecosystem: an overview of opportunities, threats and tasks. In: Sen, H. (Ed.), The Sundarbans: A Disaster-Prone Eco-Region. Coastal Research Library. 30, 29-58. https://doi.org/10.1007/978-3-030-00680-8_2.

Islam, S.D.U., Bhuiyan, M.A.H., 2018. Sundarbans mangrove forest of Bangladesh: causes of degradation and sustainable management options. Environ. Sustain. 1 (2), 113–131. https://doi.org/10.1007/s42398-018-0018-y.

Islam, S.N., Gnauck, A., 2008. Mangrove wetland ecosystems in Ganges-Brahmaputra delta in Bangladesh. Front. Earth Sci. China 2 (4), 439–448. https://doi.org/10.1007/s11707-008-0049-2.

Islam, Z., Shafie, H., 2017. Anthropology of Climate Change: Culture and Adaptation in Bangladesh. Bangladesh Climate Change Trust (BCCT), Ministry of Environment and Forests and Department of Anthropology. University of Dhaka.

Islam, M.S., Wahab, M.A., 2005. A review on the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. Aquat. Biodivers. II, 165–190. https://doi.org/10.1007/1-4020-4111-X_19.

Islam, M.A., Islam, M.S., Wahab, M.A., 2016. Impacts of climate change on shrimp farming in the South-West coastal region of Bangladesh. Res. Agric. Livest. Fish. 3 (1), 227–239. https://doi.org/10.3329/ralf.v3i1.27881.

Islam, S.N., Reinstädtler, S., Ferdaush, J., 2017. Challenges of climate change impacts on urban water quality management and planning in coastal towns of Bangladesh. Int. J. Environ. Sustain. Dev. 16 (3), 228–256. https://doi.org/10.1504/IJESD.2017.085058.

Islam, S.N., Reinstädtler, S., Gnauck, A., 2018. Vulnerability of Mangrove Forests and Wetland Ecosystems in the Sundarbans Natural World Heritage Site (Bangladesh). In. Makowski, C., Finkl, C. (eds) Threats to Mangrove Forests. Coastal Research Library, 25, pp. 223–243. https://doi.org/10.1007/978-3-319-73016-5_11.

Islam, M.A., Akber, M.A., Ahmed, M., Rahman, M.M., Rahman, M.R., 2019a. Climate change adaptations of shrimp farmers: a case study from southwest coastal Bangladesh. Clim. Dev. 11 (6), 459–468. https://doi.org/10.1080/17565529.2018.1442807.

Islam, M.M., Barman, A., Kundu, G.K., Kabir, M.A., Paul, B., 2019b. Vulnerability of inland and coastal aquaculture to climate change: evidence from a developing country. Aquac. Fish. 4 (5), 183–189. https://doi.org/10.1016/j.aaf.2019.02.007.

Islam, M.M., Rahman, M.A., Paul, B., Khan, M.I., 2020. Barriers to climate change adaptation: insights from the Sundarbans mangrove-based fisheries of Bangladesh. Asian Fish. Sci. 33, 175–186. https://doi.org/10.33997/j.afs.2020.33.2.008.

Islam, M.A., Amin, S.M.N., Rahman, M.A., Juraimi, A.S., Uddin, M.K., Brown, C.L., Arshad, A., 2022. Chronic effects of organic pesticides on the aquatic environment and human health: a review. Environ. Nanotechnol. Monit. Manag. 18, 100740 https://doi.org/10.1016/j.enmm.2022.100740.

Jalota, S.K., Vashisht, B.B., Sharma, S., Kaur, S., 2018. Understanding Climate Change Impacts on Crop Productivity and Water Balance. Academic Press. https://doi.org/10.1016/C2015-0-05656-8.

Jobling, M., 1997. Temperature and growth: modulation of growth rate via temperature change. In: In Seminar Series-society for Experimental Biology, 61. Cambridge University Press, pp. 225–254.

Joseph, R., Nigam, S., 2006. ENSO evolution and teleconnections in IPCC's twentieth-century climate simulations: realistic representation. J. Clim. 19 (17), 4360–4377. https://doi.org/10.1175/JCLI3846.1.

Jutla, A.S., Akanda, A.S., Griffiths, J.K., Colwell, R., Islam, S., 2011. Warming oceans, phytoplankton, and river discharge: implications for cholera outbreaks. Am. J. Trop. Med. Hyg. 85 (2), 303 doi: 10.4269%2Fajtmh.2011.11-0181.

Kabir, R., Khan, H.T., Ball, E., Caldwell, K., 2016. Climate change impact: the experience of the coastal areas of Bangladesh affected by cyclones Sidr and Aila. J. Environ. Public Health 9. https://doi.org/10.1155/2016/9654753.

Kabir, K.A., Saha, S.B., Phillips, M., 2019. Aquaculture and fisheries in the Sundarbans and adjacent areas in Bangladesh: resources, productivity, challenges and opportunities. In: Sen, H. (Ed.), The Sundarbans: A Disaster-Prone Eco-Region. Coastal Research Library, pp. 261–294. https://doi.org/10.1007/978-3-030-00680-8_9.

Kais, S.M., Islam, M.S., 2018. Impacts of and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh: a preliminary investigation. Aquaculture. 493, 406–415. https://doi.org/10.1016/j.aquaculture.2017.05.024.

Kais, S.M., Islam, M.S., 2019. Perception of climate change in shrimp-farming communities in Bangladesh: a critical assessment. Int. J. Environ. Res. Public Health 16 (4), 672. https://doi.org/10.3390/ijerph16040672.

Karim, M., Keus, H.J., Ullah, M.H., Kassam, L., Phillips, M., Beveridge, M., 2016. Investing in carp seed quality improvements in homestead aquaculture: lessons from Bangladesh. Aquaculture. 453, 19–30. https://doi.org/10.1016/j.aquaculture.2015.11.027.

Kathiresan, K., Bingham, B.L., 2001. Biology of mangroves and mangrove ecosystems. Adv. Mar. Biol. 40, 81–251. https://doi.org/10.1016/S0065-2881(01)40003-4.

Keus, E.H.J., Subasinghe, R., Aleem, N.A., Sarwer, R.H., Islam, M.M., Hossain, M.Z., Bhuiya, M.H., 2017. Aquaculture for Income and Nutrition. Final Report. WorldFish, Penang, Malaysia.

Khairnar, S.O., Solanki, B.V., Junwei, L., 2019. Mangrove Ecosystem - Its Threats and Conservation. Aquafind. College of Fisheries, Ocean University of China, Qingdao, Shandong, Peoples Republic of China.

Khandker, S., Mohiuddin, A.S.M., Ahmad, S.A., McGushin, A., Abelsohn, A., 2022. Air Pollution in Bangladesh and Its Consequences. https://doi.org/10.21203/rs.3.rs-1184779/v1.

Khanom, T., 2016. Effect of salinity on food security in the context of interior coast of Bangladesh. Ocean Coast. Manag. 130, 205–212. https://doi.org/10.1016/j.ocecoaman.2016.06.013.

Kweku, D.W., Bismark, O., Maxwell, A., Desmond, K.A., Danso, K.B., Oti-Mensah, E.A., Adormaa, B.B., 2017. Greenhouse effect: greenhouse gases and their impact on global warming. J. Sci. Res. Rep. 17 (6), 1–9. https://doi.org/10.9734/JSRR/2017/39630.

Liu, F., Masago, Y., 2023. An analysis of the spatial heterogeneity of future climate change impacts in support of cross-sectoral adaptation strategies in Japan. Clim. Risk Manag. https://doi.org/10.1016/j.crm.2023.100528.

MacFarlane, G.R., Burchett, M.D., 2001. Photosynthetic pigments and peroxidase activity as indicators of heavy metal stress in the grey mangrove, *Avicennia marina* (Forsk.). Vierh. Mar. Pollut. Bull. 42 (3), 233–240. https://doi.org/10.1016/S0025-326X(00)00147-8.

Mallick, B., Rahaman, K.R., Vogt, J., 2011. Coastal livelihood and physical infrastructure in Bangladesh after cyclone Aila. Mitig. Adapt. Strateg. Glob. Chang. 16 (6), 629–648. https://doi.org/10.1007/s11027-011-9285-y.

Mallick, B., Ahmed, B., Vogt, J., 2017. Living with the risks of cyclone disasters in the south-western coastal region of Bangladesh. Environments. 4 (1), 13. https://doi.org/10.3390/environments4010013.

Manabe, S., 2019. Role of greenhouse gas in climate change. Tellus A Dyn. Meteorol. Oceanogr. 71 (1), 1620078. https://doi.org/10.1080/16000870.2019.1620078.

Mandal, U.K., Maji, B., Mullick, S., Nayak, D.B., Mahanta, K.K., Raut, S., 2019. Global climate change and human interferences as risk factors, and their impacts on geomorphological features as well as on farming practices in Sundarbans eco-region. In: Sen, H. (Ed.), The Sundarbans: A Disaster-prone Eco-region. Coastal Research Library, pp. 405–437. https://doi.org/10.1007/978-3-030-00680-8_14.

Maulu, S., Hasimuna, O.J., Haambiya, L.H., Monde, C., Musuka, C.G., Makorwa, T.H., Nsekanabo, J.D., 2021. Climate change effects on aquaculture production: sustainability implications, mitigation, and adaptations. Front. Sustain. Food Syst. 5, 70. https://doi.org/10.3389/fsufs.2021.609097.

Mazda, Y., Wolanski, E., Ridd, P., 2007. The Role of Physical Processes in Mangrove Environments: Manual for the Preservation and Utilization of Mangrove Ecosystems. TERRAPUB, Tokyo.

McLeod, E., Salm, R.V., 2006. Managing Mangroves for Resilience to Climate Change. The World Conservation Union (IUCN), Gland, Switzerland, p. 64.

McLeod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Silliman, B.R., 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Front. Ecol. Environ. 9 (10), 552–560. https://doi.org/10.1890/110004.

McPhaden, M.J., Zebiak, S.E., Glantz, M.H., 2006. ENSO as an integrating concept in earth science. Science. 314 (5806), 1740–1745. https://doi.org/10.1126/science.1132588.

Miller, D.D., Ota, Y., Sumaila, U.R., Cisneros-Montemayor, A.M., Cheung, W.W., 2018. Adaptation strategies to climate change in marine systems. Glob. Chang. Biol. 24 (1), e1–e14. https://doi.org/10.1111/gcb.13829.

Minar, M.H., Hossain, M.B., Shamsuddin, M.D., 2013. Climate change and coastal zone of Bangladesh: vulnerability, resilience and adaptability. Middle-East J. Sci. Res. 13 (1), 114–120. https://doi.org/10.5829/idosi.mejsr.2013.13.1.64121.

Mitchell, J.F., Lowe, J., Wood, R.A., Vellinga, M., 2006. Extreme events due to human-induced climate change. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 364 (1845), 2117–2133. https://doi.org/10.1098/rsta.2006.1816.

Mitra, A., 2013. Climate change and its impact on brackish water fish and fishery. In: Sensitivity of Mangrove Ecosystem to Changing Climate, 62. Springer, pp. 143–157. https://doi.org/10.1007/978-81-322-1509-7_6.

MoEFCC, 2021. Nationally Determined Contributions (NDCs) 2021. Ministry of Environment, Forest and Climate Change, Bangladesh. https://unfccc.int/sites/default/files/NDC/202206/NDC_submission_20210826revised.pdf.

Mondal, S.H., Debnath, P., 2017. Spatial and temporal changes of Sundarbans reserve forest in Bangladesh. Environ. Nat. Resour. J. 15 (1), 51–61. https://doi.org/10.14456/ennrj.2017.5.

Mondal, M., Haque, S., 2018. Risk factors associated with destruction of Sundarbans mangrove forest, Bangladesh: a review from climate change perspective. Int. J. Conserv. Sci. 9 (3), 513–522.

Morecroft, M.D., Duffield, S., Harley, M., Pearce-Higgins, J.W., Stevens, N., Watts, O., Whitaker, J., 2019. Measuring the success of climate change adaptation and mitigation in terrestrial ecosystems. Science. 366 (6471) https://doi.org/10.1126/science.aaw9256.

Moser, S.C., Ekstrom, J.A., 2010. A framework to diagnose barriers to climate change adaptation. Proc. Natl. Acad. Sci. 107 (51), 22026–22031. https://doi.org/10.1073/pnas.1007887107.

Mousavi, M.E., Irish, J.L., Frey, A.E., Olivera, F., Edge, B.L., 2011. Global warming and hurricanes: the potential impact of hurricane intensification and sea level rise on coastal flooding. Clim. Chang. 104 (3), 575–597. https://doi.org/10.1007/s10584-009-9790-0.

Mukherjee, N., Sutherland, W.J., Dicks, L., Huge, J., Koedam, N., Dahdouh-Guebas, F., 2014. Ecosystem service valuations of mangrove ecosystems to inform decision making and future valuation exercises. PLoS One 9 (9), e107706. https://doi.org/10.1371/journal.pone.0107706.

Murdivarso, D., Purbopuspito, J., Kauffman, J.B., Warren, M.W., Sasmito, S.D., Donato, D.C., Manuri, S., Krisnawati, H., Taberma, S., Kurnianto, S., 2015. The potential of Indonesian mangrove forests for global climate change. Nat. Clim. Chang. 5 (12), 1089–1092. https://doi.org/10.1038/nclimate2734.

Mustafa Saroar, M., Mahbubur Rahman, M., Bahauddin, K.M., Rahaman, M.A., 2019. Ecosystem-based adaptation. In: Huq, S., et al. (Eds.), Opportunities and Challenges in Coastal Bangladesh, Confronting Climate Change in Bangladesh: Policy Strategies for Adaptation and Resilience, pp. 51–63. https://doi.org/10.1007/978-3-030-05237-9_5.

Nagelkerken, I.S.J.M., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Somerfield, P.J., 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquat. Bot. 89 (2), 155–185. https://doi.org/10.1016/j.aquabot.2007.12.007.

Nandi, N.C., Pramanik, S.K., Roy, D.M., 2016. Mud crab culture: relevance of species identity in production economics with reference to Sundarban coast. J. Fish. Sci. 10 (4), 84.

Nave, L.E., Walters, B.F., Hofmeister, K.L., Perry, C.H., Mishra, U., Domke, G.M., Swanston, C.W., 2019. The role of reforestation in carbon sequestration. New For. 50 (1), 115–137. https://doi.org/10.1007/s11056-018-9655-3.

Nda, M., Adnan, M.S., Ahmad, K.A., Usman, N., Razi, M.A.M., Daud, Z., 2018. A review on the causes, effects and mitigation of climate changes on the environmental aspects. Int. J. Integr. Eng. 10 (4) https://doi.org/10.30880/ijie.2018.10.04.027.

Neogi, S.B., Dey, M., Lutful Kabir, S.M., Masum, S.J.H., Kopprio, G.A., Yamasaki, S., Lara, R.J., 2016. Sundarban mangroves: diversity, ecosystem services and climate change impacts. Asian J. Med. Biol. Res. 2 (4), 488–507. https://doi.org/10.3329/ajmbr.v2i4.30988.

Ollila, A.V., 2012. The roles of greenhouse gases in global warming. Energy Environ. 23 (5), 781–799. https://doi.org/10.1260/0958-305X.23.5.781.

Palmer, L., 2021. How trees and forests reduce risks from climate change. Nat. Clim. Chang. 11 (5), 374–377. https://doi.org/10.1038/s41558-021-01041-6.

Paul, B.G., Vogl, C.R., 2011. Impacts of shrimp farming in Bangladesh: challenges and alternatives. Ocean Coast. Manag. 54 (3), 201–211. https://doi.org/10.1016/j.ocecoaman.2010.12.001.

Payo, A., Mukhopadhyay, A., Hazra, S., Ghosh, T., Ghosh, S., Brown, S., Haque, A., 2016. Projected changes in area of the Sundarban mangrove forest in Bangladesh due to SLR by 2100. Clim. Chang. 139 (2), 279–291. https://doi.org/10.1007/s10584-016-1769-z.

Paz, S., Bisharat, N., Paz, E., Kidar, O., Cohen, D., 2007. Climate change and the emergence of *Vibrio vulnificus* disease in Israel. Environ. Res. 103 (3), 390–396. https://doi.org/10.1016/j.envres.2006.07.002.

Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S., Baldera, A., 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PLoS One 7 (9). https://doi.org/10.1371/journal.pone.0043542.

Pielke Jr., R.A., 2004. What is climate change? Energy Environ. 15 (3), 515–520. https://doi.org/10.1260/0958305041494576.

Rahman, M.R., Asaduzzaman, M., 2010. Ecology of Sundarban, Bangladesh. J. Sci. Found. 8 (1–2), 35–47. https://doi.org/10.3329/jsf.v8i1-2.14618.

Rahman, M.A., Rahman, S., 2015. Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. Weather Clim. Extrem. 7, 84–95. https://doi.org/10.1016/j.wace.2014.12.004.

Rahman, M.M., Rahman, M.M., Islam, K.S., 2010. The causes of deterioration of Sundarban mangrove forest ecosystem of Bangladesh: conservation and sustainable management issues. Aquac. Aquar. Conserv. Legis. 3 (2), 77–90.

Ranjan, P., Ramanathan, A.L., Kumar, A., Singhal, R.K., Datta, D., Venkatesh, M., 2018. Trace metal distribution, assessment and enrichment in the surface sediments of Sundarban mangrove ecosystem in India and Bangladesh. Mar. Pollut. Bull. 127, 541–547. https://doi.org/10.1016/j.marpolbul.2017.11.047.

Richards, D.R., Friess, D.A., 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proc. Natl. Acad. Sci. 113 (2), 344–349. https://doi.org/10.1073/pnas.1510272113.

Rosa, R., Marques, A., Nunes, M.L., 2012. Impact of climate change in Mediterranean aquaculture. Rev. Aquac. 4 (3), 163–177. https://doi.org/10.1111/j.1753-5131.2012.01071.x.

Roy, S., Rahman, M.M., Sarkar, S.N., Mondal, B., 2011. Training manual on improved shrimp culture in Gher: a course manual for shrimp farmers. In: Cereal Systems Initiative for South Asia in Bangladesh (CSISA-BD). Project WorldFish Center, Dhaka.

Roy, M., Ray, S., Ghosh, P.B., 2012. Modelling of impact of detritus on detritivorous food chain of Sundarban mangrove ecosystem, India. Procedia Environ. Sci. 13, 377–390. https://doi.org/10.1016/j.proenv.2012.01.035.

Sakib, M.H., Afrad, M.S.I., Harun-Al-Rashid, A., Kausar, A.G., 2021. Agribusiness in South Asia: current status, obstacles, and policy options. In: Opportunities and Strategic Use of Agribusiness Information Systems. IGI Global, pp. 73–92. https://doi.org/10.4018/978-1-7998-4849-3.ch005.

Sarker, A.R., Nobi, M.N., Roskaft, E., Chivers, D.J., Suza, M., 2020. Value of the storm-protection function of Sundarban Mangroves in Bangladesh. J. Sustain. Dev. 13 (3), 128–137. https://doi.org/10.5539/jsd.v13n3p128.

Sasmito, S.D., Basyuni, M., Kridalaksana, A., Saragi-Sasmito, M.F., Lovelock, C.E., Murdiyarso, D., 2023. Challenges and opportunities for achieving Sustainable Development Goals through restoration of Indonesia's mangroves. Nat. Ecol. Evol. 7, 62–70. https://doi.org/10.1038/s41559-022-01926-5.

Saunders, M.N.K., Lewis, P., Thornhill, A., 2009. Research Methods for Business Students, 6th ed. FT Prentice Hall, Harlow.

Scheidel, A., Work, C., 2018. Forest plantations and climate change discourses: new powers of 'green' grabbing in Cambodia. Land Use Policy 77, 9–18. https://doi.org/10.1016/j.landusepol.2018.04.057.

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M.L., Wolff, C., Lincke, D., Brown, S., 2018. Future response of global coastal wetlands to sea-level rise. Nature. 561 (7722), 231–234. https://doi.org/10.1038/s41586-018-0476-5.

Sen, S., 2020. Sunderban mangroves, post Amphan: an overview. Int. J. Creat. Res. Thoughts 8 (6), 2751–2755.

Sen, S., 2021. Combating tropical cyclones Amphan, Yaas and after: eco-restoration of coastal zones. Harvest. 6 (1), 33–38.

Shahjahan, M., Islam, M.J., Hossain, M.T., Mishu, M.A., Hasan, J., Brown, C.L., 2022. Blood biomarkers as diagnostic tools: an overview of climate-driven stress responses in fish. Sci. Total Environ. 843, 156910 https://doi.org/10.1016/j.scitotenv.2022.

Sharmin, A., Hossain, M., Mollick, A.S., 2021. Farmers' perceptions and attitudes toward aquasilviculture in the periphery of the Sundarbans forest of Bangladesh. Small-Scale For. 20 (3), 391–405. https://doi.org/10.1007/s11842-021-09473-w.

Sidik, F., Supriyanto, B., Krisnawati, H., Muttaqin, M.Z., 2018. Mangrove conservation for climate change mitigation in Indonesia. Wiley Interdiscip. Rev. Clim. Chang. 9 (5), 529. https://doi.org/10.1002/wcc.529.

Solomon, S., Daniel, J.S., Sanford, T.J., Murphy, D.M., Plattner, G.K., Knutti, R., Friedlingstein, P., 2010. Persistence of climate changes due to a range of greenhouse gases. Proc. Natl. Acad. Sci. 107 (43), 18354–18359. https://doi.org/10.1073/pnas.1006282107.

Somero, G.N., 2002. Thermal physiology and vertical zonation of intertidal animals: optima, limits, and costs of living. Integr. Comp. Biol. 42 (4), 780–789. https://doi.org/10.1093/icb/42.4.780.

Sorvali, J., Kaseva, J., Peltonen-Sainio, P., 2021. Farmer views on climate change—a longitudinal study of threats, opportunities and action. Clim. Chang. 164 (3), 1–19. https://doi.org/10.1007/s10584-021-03020-4.

Stern, D.I., Kaufmann, R.K., 2014. Anthropogenic and natural causes of climate change. Clim. Chang. 122 (1), 257–269. https://doi.org/10.1007/s10584-013-1007-x.

Sultana, S., Anwar, M.T., 2021. Review assessment of biodiversity loss and ecosystem deterioration due to build-form considering the implementation of Rampal power plant near Sundarban Forest. Int. J. Res. Innov. Soc. Sci. 5 (8), 247–255. https://doi.org/10.47772/IJRISS.2021.5817.

Sunyowati, D., Hastuti, L., Butar-Butar, F., 2016. The regulation of sustainable mangroves and coastal zones management in Indonesia. J. Civ. Leg. Sci. 6 (1), 1–7. https://doi.org/10.4172/2169-0170.1000220.

Swim, J.K., Whitmarsh, L., 2018. Climate change as a unique environmental problem. In: Environ. Psychol. An Introduction, 26-35. https://doi.org/10.1002/9781119241072.ch3.

Takagi, H., Ty, T.V., Thao, N.D., Esteban, M., 2015. Ocean tides and the influence of sea-level rise on floods in urban areas of the Mekong Delta. J. Flood Risk Manag. 8 (4), 292–300. https://doi.org/10.1111/jfr3.12094.

The World Bank, 2022. Urgent Climate Action Crucial for Bangladesh to Sustain Strong Growth. Press Release, The World Bank, Washington, D.C.. https://www.worldbank.org/en/news/press-release/2022/10/31/urgent-climate-actioncrucial-for-bangladesh-to-sustain-strong-growth

Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A., Simard, M., 2017. Distribution and drivers of global mangrove forest change, 1996–2010. PLoS One 12 (6), e0179302. https://doi.org/10.1371/journal.pone.0179302.

Tongununui, P., Kuriya, Y., Murata, M., Sawada, H., Araki, M., Nomura, M., Adachi, K., 2021. Mangrove crab intestine and habitat sediment microbiomes cooperatively work on carbon and nitrogen cycling. PLoS One 16 (12), e0261654. https://doi.org/10.1371/journal.pone.0261654.

Topaldemir, H., Taş, B., Yüksel, B., Ustaoğlu, F., 2023. Potentially hazardous elements in sediments and Ceratophyllum demersum: an ecotoxicological risk assessment in Miliç Wetland, Samsun, Türkiye. Environ. Sci. Pollut. Res. 30 (10), 26397–26416. https://doi.org/10.1007/s11356-022-23937-2.

Tung, K.K., Zhou, J., 2013. Using data to attribute episodes of warming and cooling in instrumental records. Proc. Natl. Acad. Sci. 110 (6), 2058–2063. https://doi.org/10.1073/pnas.1212471110.

UN General Assembly, 2023. Draft agreement under the United Nations convention on the law of the sea on the conservation and sustanable use of marine biologial diversity of areas beyond national jurisdiction. In: Intergovernmental conference on an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction Resumed fifth session. New York, 20 February–3 March 2023. https://www.un.org/bbnj/sites/www.un.org.bbnj/files/draft_agreement_advanced_unedited_for_posting_v1.pdf.

Valiela, I., Bowen, J.L., York, J.K., 2001. Mangrove forests: one of the world's threatened major tropical environments: at least 35% of the area of mangrove forests has been lost in the past two decades, losses that exceed those for tropical rain forests and coral reefs, two other well-known threatened environments. Bioscience. 51 (10), 807–815. https://doi.org/10.1641/0006-3568 (2001)051[0807:MFOOTW]2.0.CO;2.

Woodson, C.B., Micheli, F., Boch, C., Al-Najjar, M., Espinoza, A., Hernandez, A., Torre, J., 2019. Harnessing marine microclimates for climate change adaptation and marine conservation. Conserv. Lett. 12 (2), e12609 https://doi.org/10.1111/conl.12609.

Xi-Liu, Y.U.E., Qing-Xian, G.A.O., 2018. Contributions of natural systems and human activity to greenhouse gas emissions. Adv. Clim. Chang. Res. 9 (4), 243–252. https://doi.org/10.1016/j.accre.2018.12.003.

Yazdi, K.S., Shakouri, B., 2010. The effects of climate change on aquaculture. Int. J. Environ. Sci. Dev. 1 (5), 378.

Youdon, C., 2020. Climate change impact on mangrove ecosystems in India's coastal regions. In: National Maritime Foundation, pp. 8–60.

Ysebaert, T., Walles, B., Haner, J., Hancock, B., 2019. Habitat modification and coastal protection by ecosystem-engineering reef-building bivalves. In: Smaal .C., A, Ferreira, J.G., Grant, J., Petersen, J.K., Strand, O. (Eds.), Goods and Services of Marine Bivalves. Springer, Cham, Switzerland, pp. 253–273. https://doi.org/10.1007/978-3-319-96776-9_13.

Yuksel, B., Ustaoglu, F., Arica, E., 2021. Impacts of a garbage disposal facility on the water quality of çavuşlu stream in Giresun, Turkey: a health risk assessment study by a validated ICP-MS assay. Aquat. Sci. Eng. 36 (4), 181–192. https://doi.org/10.26650/ASE2020845246.

Yuksel, B., Ustaoglu, F., Tokatli, C., Islam, M.S., 2022. Ecotoxicological risk assessment for sediments of Çavuşlu stream in Giresun, Turkey: association between garbage disposal facility and metallic accumulation. Environ. Sci. Pollut. Res. 29 (12) https://doi.org/10.1007/s11356-021-17023-2.

Zeng, Y., Sarira, T.V., Carrasco, L.R., Chong, K.Y., Friess, D.A., Lee, J.S.H., et al., 2020. Economic and social constraints on reforestation for climate mitigation in Southeast Asia. Nat. Clim. Chang. 10 (9), 842–844. https://doi.org/10.1038/s41558-020-0856-3.

Zhao, R., Li, X., Wang, Y., Xu, Z., Xiong, M., Jia, Q., Li, F., 2023. Assessing resilience of sustainability to climate change in China's cities. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2023.165568.