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Bringing back the Chakaria Sundarbans mangrove forest of South-east Bangladesh through sustainable management approach

SHOURAV DUTTA[1,♥], MOHAMMED KAMAL HOSSAIN[2]
[1]Department of Forestry and Environmental Science, Faculty of Biological Science, Rangamati Science and Technology University. Rangamati-4500, Bangladesh. Tel. +8801319052645, ♥email: shourav.forestry@gmail.com.
[2]Institute of Forestry and Environmental Sciences, University of Chittagong. Chattogram-4331, Bangladesh

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Abstract. *Dutta S, Hossain MK. 2020. Bringing back the Chakaria Sundarbans mangrove forest of Southeast Bangladesh through sustainable management approach. Asian J For 4: 65-76.* The oldest mangrove forest of Indian sub-continent namely Chakaria Sundarbans (CS) is currently in a critical situation. Destructive anthropogenic and natural impacts coupled with shrimp farming and excessive grazing have caused severe damage to this oldest mangrove ecosystem. A study was carried out based on the extensive literature survey and tried to explore the overall situation and conservation practices for CS of Bangladesh. This paper analyzed, reviewed, and identified the impacts of natural and man-made effects on CS mangroves. Finally, we recommended the sustainable management approach (SMA) including policy and participation of the local people for bringing back this potential natural mangrove forest resource of CS along with rich forest diversity.

Keywords: Bangladesh, Chakaria Sundarbans, mangrove, shrimp farming, sustainable forest management

INTRODUCTION

Mangroves are an association of halophytic plants growing in brackish to saline tidal waters, and this vegetation type is quite different from upland forests in terms of composition, structure, function, and diversity (Kauffman and Donato 2012; Mitsch and Gosselink 2007). Mangrove forests are affected by climatic factors, such as temperature and moisture, and distributed latitudinally within the tropics and subtropics reaching their maximum development between 25°N to 25°S (Uddin et al. 2014). Spalding et al. (1997) estimated mangrove ecosystems covered 18 million hectares worldwide, while FAO (2003; 2007) estimated 15.2 million hectares of mangroves to exist worldwide distributed in 100 countries. Uddin et al. (2014) reported that the most extensive mangrove area is found in Asia, followed by Africa, and North and Central America. Five countries (Indonesia, Australia, Brazil, Nigeria, and Mexico) together are account for 48% of the total global mangroves (FAO 2007). In Asia and Southeast Asia, the greatest concentration (41.5%) of the world's mangroves exists (Primavera 2000).

Mangrove ecosystems are the most threatened and rapidly disappearing natural environments worldwide (Valiela et al. 2001). In many areas of the world, mangrove forests are degraded and their area is substantially reduced relative to their historic range (FAO 2007; Spalding et al. 2014). Due to aquaculture expansion and over-exploitation for its timber, approximately 30-50% of global mangrove forests have been lost over 50 years (Donato 2011). Mangrove ecosystems cover only 0.7% of tropical forest area, and such forests account for 10% of carbon emission from deforestation (Donato 2011). Research conducted by Njisuh and Ajonina (2011) predicted that around 25% of developing countries' mangrove forests will be lost by 2025. The mangroves of Asia are experiencing faster, long-term, and large-scale clearances due to agricultural and aquacultural activities, and also confront severe policy challenges to their protection, production and maintenance (Richards and Friess 2016). Bangladesh, a developing country in South Asia, contributes about 4% of the world mangrove forest and is placed at the sixth position in terms of area coverage (Hossain 2015a).

Bangladesh, located in the northeastern part of South Asia with geographical coverage of 14.76 million ha, is exceptionally endowed with a wide variety of flora and fauna due to its unique geophysical location (Dutta et al. 2014), and possesses a rich biological heritage of flowering plants, algae, fungi, ferns, mammals, birds, reptiles, amphibians, insects, microbes, and fishes (Dutta et al. 2015; Hossain 2015b). It has the largest delta on the earth situated at the 24˚N to 90˚E, passing about 700 rivers and 8,046 km of inland waterways. The total forest area of Bangladesh is 2.57 million ha, which is 17.72% of the total land area of Bangladesh (Hossain 2015b). Mangrove forest is considered one of the main forest types in Bangladesh which provides a large number of products and ecosystem services, and supports a very diverse flora and fauna (Das and Siddiqi 1985). Both natural and planted mangrove forests of Bangladesh are well developed in the Sundarbans on the Ganges-Brahmaputra delta, but very poorly developed in the Chakaria Sundarbans (CS) on the Matamuhury delta (Siddiqi 2001).

The mangrove forests of Bangladesh are divided into three forest zones according to their location. First one is the Sundarbans, the largest single tract of mangrove forest ecosystem in the world. It is situated in the south-western part of Bangladesh having an area of 600,386 ha, of which 4111,230 ha is forest area and 189,156 ha of water bodies like rivers, channels, and creeks (Iftekhar and Saenger 2008; SRDI 1999). The second one is the Chakaria Sundarbans (CS); the most excruciating case appears to be the total destruction, once the pristine forest, and the second-largest mangrove forest of Bangladesh. The CS in Cox's Bazar was originally 8510 ha (Hossain et al. 2004). And the third one is the coastal mangrove plantations, which started during the mid-sixties (NFTRA 2007). The CS is located in the eastern part of Bangladesh whereas the Sundarban mangrove is in the extreme south-western part of Bangladesh (Choudhury et al. 1990; Siddiqi 2001).

As the oldest mangrove forests of the Indian sub-continent, the Chakaria Sundarbans mangroves are widely distributed in the south-eastern part of Bangladesh including Chattogram District and Cox's Bazar coastal zone (Siddiqi 2001). Due to shrimp farming, over-extraction of wood and non-wood resources, population pressure, deforestation, settlement, urbanization and unscientific management practices, mangrove forests in CS are continuously depleted (Alam et al. 2014; Siddiqi 2001). In this regard, sustainable forest management is an effective approach to achieve the management goals without undue undesirable impacts on the environment. This study analyzed and reviewed the changes in area, floral composition, and forest reserves in CS over time. It compiled and clearly stated the influence of shrimp firming and anthropogenic disturbances on the oldest mangrove in Bangladesh. This paper also evaluated the impacts of several actions on the degradation of CS and recommended probable mitigation measures through sustainable management approach (SMA).

MATERIALS AND METHODS

Distribution of Chakaria Sundarbans (CS) in south-east Bangladesh

The CS lies in the district of Cox’s Bazar and occupies the central part of the Matamuhury delta (Siddiqi 2001). The Cox's Bazar coastal zone and CS have been important since prehistoric times for the abundance of natural resources. In the past, the area of the CS was about 18,200 ha (Cowan 1926). On 19th December 1903, the government formed the CS range (8510 ha) and announced it as a reserve mangrove forest (7490 ha) and a protected forest (1020 ha) (Cowan 1926; Hossain et al. 2001). In the early 20th century, one of the major areas of this forest was cleared for settlement, salt pan, and agricultural use under the British colonial role (Figure 1). Over the last century, local people and outsiders or settlers have been haphazardly utilizing the natural resources, resulting in complete destruction of CS (Hossain et al. 2001). Now this area is no longer belonging to mangrove swamp (Alam et al. 2014; Siddiqi 2001). The general description of the CS was presented in Table 1.

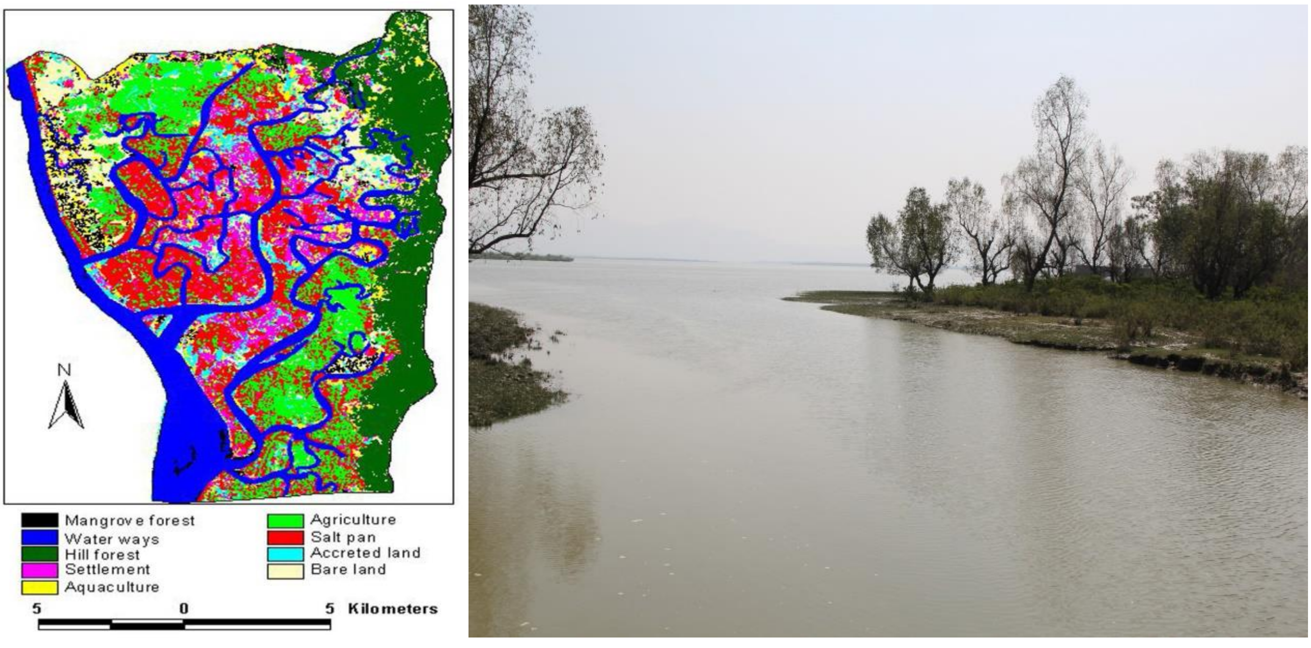

Figure 1. Landsat image (2012) showing the land use patterns (*left*) and a forest patch (*right*) of Chakaria Sundarbans in south-east Bangladesh

Table 1. Geographical and environmental information of the mangroves of Chakaria Sundarbans

Parameters	Data	Source
Latitudes	21º36′to 21º45′ North	Alam et al. 2014, Hossain et al. 2001, Siddiqi et al. 1994
Longitudes	91º58′to 92º05′ East	
Mean annual temperature (Maximum)	32°C	
Mean annual temperature (Minimum)	20°C	
Average annual rainfall	3,500 mm	
Water salinity	23ppt to 34ppt	
pH range	< 4.5	Anon 1973, Richards and Hassan 1988
Soil type	Acid sulfate soils	

Collection and compilation of data

The present review was carried out based on secondary information. The methodology of this review consisted of collection of data/information from different sources, consulting associated consultants and researchers, and data analysis. The authors consulted different books, journals, and research reports related to CS mangrove forests according to the objectives of the present study. Then, the authors examined collections of secondary data, and analyzed the literature extensively.

For more justification, information on CS mangroves was compiled through personal communication, and informal interview from renowned researchers/experts in the field of forestry, ecology, mangrove ecosystems, and environmental science. Further, we analyzed several reports from Governmental and non-governmental organizations to evaluate the socio-economic and environmental conditions of local communities in the CS mangrove areas. The impacts of several underlying actions on the disappearance of CS mangroves were also assessed, and designed a sustainable management approach (SMA) to rehabilitate the CS mangrove ecosystems.

SWOT analysis

A SWOT analysis was carried out to assess the opportunities and available strengths to bring back the forest resources of CS mangroves. SWOT analysis is logical thinking applied to optimize strengths and opportunities, minimize external threats, transform weaknesses to strengths, and summarize key management issues (Hong and Chan 2010; Saaty 1987). SWOT is a recognized and effective analysis technique to be used in compiling, synthesis, and analysis of information for Forestry development (FAO 1989). We conducted SWOT analysis through an extensive literature survey developed by Hong and Chan (2010). We identified several external and internal factors systematically to formulate an efficient strategy for bringing back the CS mangroves as proposed by Murtini et al. (2018). Top strengths, weaknesses, opportunities, and threats of CS mangrove restoration were identified systematically through SWOT analysis and enlisted in an organized list. Finally, we expressed the major findings in a simple two-by-two grid.

RESULTS AND DISCUSSIONS

Disturbances to biological diversity

Due to the lack of appropriate guidelines for natural resource utilization and conservation, land use conflicts occur and sometimes the coastal zone is turned into an area of major conflicts, and ultimately resulting in land degradation in CS. Chaffey et al. (1985); Das and Siddiqi (1985); Hossain et al. (2001); IUCN (2000) reported that the excessive use of natural resources accelerated the deforestation and destroyed the plant and animal diversity of that swamp.

A trace of deterioration of the forest vegetation in CS was first noticed in the nineteen sixties (Chowdhury 1967). Destructive deforestation by clear-cutting of mangrove vegetation of CS was first noticed to be widespread on the aerial photographs of 1981 taken by SPARRSO (Choudhury et al. 1990). There are several factors responsible for the degradation of mangrove forests, viz. overexploitation, excessive collection of non-wood products, overgrazing, encroachments, urbanization, diversion of freshwater flows, over fishing and land conversion for aquaculture, agriculture, mining, salt extraction, and shrimp firming (Alongi 2002; Siddiqi 2001; Valiela et al. 2001). After stereoscopic examination of the aerial photographs, it was found that about 2,104 ha of forest cover had been completely opened for shrimp farming (Choudhury and Ahmed 1994). Deforestation of CS greatly affected the socio-economics of more than 90% of the local community (Hossain et al. 2001). On the other hand, the rapid expansion of shrimp farming has drastically reduced the stock of indigenous fish varieties and destroyed mangrove flora and fauna (Jahan and Ancev 2014). CS mangrove forest was the home of tigers, deer, wild cats, wild boars, foxes, etc. These all animals are now rarely seen in the CS due to the disappearance of the mangrove forests (Rahman 2015).

Cowan (1926) recorded 53 plant species belonging to 42 genera and 22 families from the CS mangroves. Almost seven decades later, Siddiqi et al. (1994) reported a very poor species diversity (18 plant species belonging to 18 genera and 14 families) and abundance of species in CS. Recent reviews on the status of plant diversity of CS showed a very poor condition of the forest flora (Alam et al. 2014; Iftekhar and Islam 2004). Iftekhar and Islam (2004) reported that the most important plant species of CS were Sundri (*Heritiera fomes*), Gewa (*Excoecaria* *agallocha*), Kankra (*Bruguiera gymnorrhiza*), Hargoza (*Acanthus ilicifolius*), and Ananta kata (*Dalbergia spinosa*). According to the report of Alam et al. (2014), the notable feature of CS mangrove area was the total absence of Goalpata (*Nypa fruticans*). The present review revealed that the floral diversity of CS was reduced over time (Figure 2).

Imbalance in coastal ecology

The shrimp activities in the coastal zone of Bangladesh upgrade the lifestyle and obviously increase the income level of many poor coastal people with increasing environmental degradation (Barua and Chakraborty 2011). Shrimp farming is expected to continue to play an important role in ensuring food security and poverty alleviation for the coastal poor communities (Barua and Chakraborty 2011; Siddiqi 2001). Thia-Eng et al. (1989) reported that coastal aquaculture, particularly shrimp aquaculture, is an important coastal industry in Bangladesh. But, this industry highly destroys coastal communities and ecosystems by mangrove destruction, loss of fishery communities and biodiversity, pollution of land and water, loss of employment activity, and even violation of human rights (Barua and Chakraborty 2011; Salequzzaman 2001; Yeh 2002).

In coastal Bangladesh, shrimp farming is the most destructive form of resource utilization, which contributed tremendously to mangrove ecology destruction with a corresponding loss of biological resources (Islam and Wahab 2005; Islam et al. 2019). During the last two decades, coastal ecosystem of Bangladesh has experienced notable degradation due to shrimp farming (Sohel and Ullah 2012). Research findings of Barua and Rahman (2020) indicated that unplanned growth of shrimp culture in coastal areas of CS has a serious effect on alteration of coastal ecology. Unplanned shrimp farming has multifarious impacts in terms of salinity increase on soil, adverse effects on population health, destroying biodiversity and ecosystems, environmental changes, and imbalance in sustainability (Barua and Rahman 2020; Rashid 2019). Vast area of tidal land previously used for cultivation in CS has been changed into shrimp farms. Due to shrimp farming, marine pollution has reached a level that could create an unmanageable situation in near future (Islam 2003). Inundation of arable lands by saline water to cultivate shrimp has become a common occurrence in CS. A large number of people both male and female including children are getting increasingly engaged in fry collection. Islam (2003) clearly stated that most of the commercially important fish stocks are either overexploited or under threat in CS. Our review clearly demonstrated that shrimp farming and aquaculture have caused serious ecological imbalances in coastal ecology of CS.

Similarly, unplanned expansion of salt production led to destruction of forest ecosystem and already reduced the 70% forest area. During the last few decades, CS has extensively been used for salt production and almost 38,328 people are professionally dependent on this sector (Hossain et al. 2017). Hence, CS mangroves have been declining sharply and their long-term survival is at great risk (Duke et al. 2007).

Impact of shrimp farming

Shrimp farming is a growing sector in Bangladesh because of its suitable agro-climatic conditions, adequate water resources, cheap labor force, interest of international donor agencies, and the involvement of multinational corporations (Paul and Vogl 2011). Shrimp farming is profitable and highly traded export-oriented industry for the last few decades because of its export earning potentials (Islam 2003; Siddiqi 2001). It not only provides immediate economic benefits, contributing to poverty reduction and food security, but also generates employment from shrimp fry collectors to exporters (Paul and Vogl 2011). Therefore, this farming is often encouraged by government agencies. Since the 1950s, two of the most important transformations in land use along the coastal region of southeast Bangladesh have been the growth of solar evaporative salt production and the introduction of export shrimp culture (Pokrant and Peter 2005). From the late 1970s, the government of Bangladesh encouraged the conversion of reserved mangrove forests of the CS to shrimp ponds (Siddiqi 2001). In the late 1970s, commercial shrimp farming began in coastal Bangladesh, which then represents the second-largest export sector after garments in the nation (Ishtiaque and Chhetri 2016). Bangladesh's shrimp industry has been rapidly expanding since the early 1980s and is now a major source of export earnings (Ahmed 2004; Barua and Chakraborty 2011). Government of Bangladesh, several businesses, and international aid agencies supported the monoculture of shrimp production integrated into global trading networks at the expense of local resource extraction activities including forestry (Pokrant 2014). Such rapid expansion of shrimp activities threatens the natural mangrove ecosystems, particularly across the vulnerable coastal regions of CS (Ishtiaque and Chhetri 2016). As a result, the area of CS that became the most vulnerable to climate change has lost its natural protector (Khan 2009).

The entire 8,500 ha of the mangroves of CS have been replaced by shrimp ponds (Table 2) (Siddiqi 2001). High rate of economic return in shrimp farming is constantly inducing the farmers to convert more and more forest land into shrimp farms. This has resulted in over-exploitation of shrimp juveniles from the wild, leading to ecological imbalance and change in forest pattern, increasing conflict, leasing of land of small farmers, depriving them of their rights to own land, and other socio-economic and environmental consequences (Rahman and Hossain 2015). In Bangladesh, shrimp farming has devastating effects on the most carbon-rich mangrove forests (Ahmed et al. 2017). Mangrove forest areas of CS were reduced over time with the development of shrimp farming (Figure 3).

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Table 2. Changes in land use in Chakaria Sundarbans (in ha) over time

Land use	Area (in ha) with year			
	1974	1984	1994	2012
Mangrove forest	6127	3048	123	170
Agriculture	7847	6556	2832	1582
Salt pan	432	1484	4363	5078
Shrimp culture	0	3456	4601	5583
Water bodies	3096	2484	2463	3308
Accreted land	1180	1254	1949	2113
Bare land	136	421	1350	1680
Reserve (hill) forest	2650	2677	2625	2646
Settlement	422	510	602	712
Total area	21890	21890	21890	21890

(Source: Rahman and Hossain 2015; Siddiqi 2001)

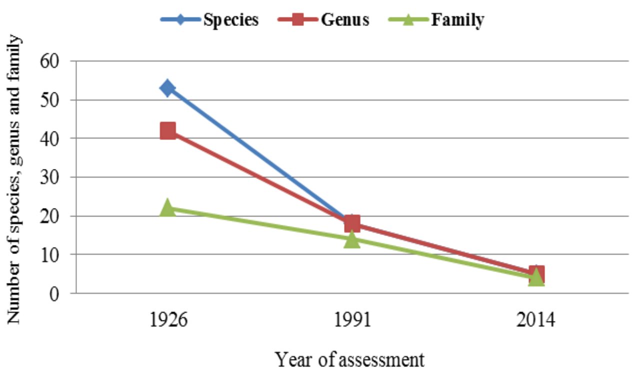

Figure 2. Disappearance of floral diversity in Chakaria Sundarbans over time

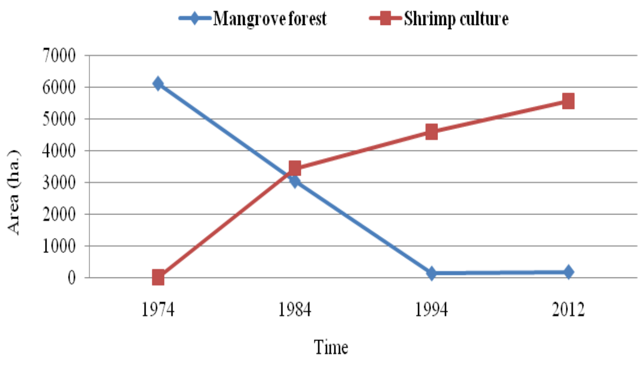

Figure 3. Degradation of natural resources against expansion of shrimp culture in Chakaria Sundarbans mangroves with time

Impacts of aquaculture on mangrove environment

Coastal aquaculture is a century-old practice in Bangladesh (Barua and Chakraborty 2011). Destruction of mangroves is of great consequence because shrimp farms are constructed by clearing mangroves. This also results in shrinking of grazing land and destruction of inland forests. Horizontal expansion of traditional extensive shrimp farming reduces grazing land and affects the fruit-bearing trees like mango, rose apple, betel nut, and coconut due to prolong retention of saline water. Production of crops and green vegetables has alarmingly fallen down due to increased salinity. Hossain et al. (2001) reported 5 major causes for mangrove forest destruction, and showed 9 direct and 4 indirect effects from these destruction related issues. Some ecological consequences of mangrove destruction are higher level of soil salinity, loss of agricultural lands, decline in biological diversity, increased risk of flooding and natural disasters, etc. (Pokrant 2014).

Although coastal shrimp farming is an important industry in Bangladesh (Sen 2010), but it is not sustainable due to its impacts on the local socio-economic, environmental, ecological and cultural environment of coastal Bangladesh on a long-term basis (Barua and Chakraborty 2011). Aquaculture and shrimp farming have been connected with environmental degradation, enhanced social and economic differences, and also involved in violation of human rights (Barua and Rahman 2020).

Shrimp growers indiscriminately cut the embankments at several points and also open the sluice gates frequently for intrusion of saline water inside the embankment, causing harm to the standing crops. However, minimum salinity is not detrimental to land fertility, but it becomes hazardous when it exceeds the minimum level (Rahman and Hossain 2015). The salinity level in the coastal lands has presently increased manifolds than the minimum level. The farmers should cultivate shrimps in scientific manner to obtain higher production and at the same time protect environment. Unavailability of hatchery-produced shrimp on the one hand and expansion of shrimp culture in the coastal area increased pressure on the collection of wild shrimp fry (Siddiqi 2001; Rashid 2019). Local women gain financial benefit from shrimp fry collection, which has reduced fish diversity and increased salinity in the CS mangroves (Chaudhury 2008).

In the present study, we reviewed the potential environmental impacts of several actions on the degradation of CS and recommend probable mitigation measures (Table 3). Mangrove restoration by the REDD+ program also has the potential to conserve mangroves for resilience to climate change. However, institutional support is needed to implement the proposed adaptation strategies (Ahmed et al. 2017).

Findings from SWOT analysis

Human population growth, coastal embankment, upstream withdrawal of river and canal water, brackish water shrimp farming, salt production, use of agro-chemicals, industrial activities, commercial activities, over-exploitation of mangrove flora, etc. are responsible for the degradation of both resources and production environments of mangrove ecosystems, specifically for CS (Miah et al. 2010). After reviewing several literature (e.g., Alam et al. 2014; Barua and Rahman 2020; Siddiqi 2001), we found that the major strength in mangrove CS is the silvicultural activities using local mangrove species and effective reforestation programs (Table 4). The soil in most of the mangrove areas is suitable for supporting and growing mangrove species till now. Collaboration and cooperation of local communities and shrimp firm owners are useful to make a successful rehabilitation program (Iftekhar 2008).

The weaknesses identified are that the lease of forest lands for shrimp culture and unscientific management of remnant mangrove forests. Ecologically and economically valuable mangrove and wetland habitats and the debasement of adjacent coastal and marine ecosystems can be devastated due to excessive shrimp culture. Shrimp farming also negatively affects biodiversity conservation as well as coastal ecosystem healthiness (Barua and Rahman 2020).

Policy and law enforcement are not strong enough to protect the existing mangroves. Sedimentation by newly accreted sand and silt cover the pneumatophore especially in the new plantations that restrict the growth performance (Alam et al. 2014). Local communities and settlers are haphazardly utilizing natural resources for their livelihoods. According to the report of Hoque and Datta (2005), adequacy of knowledge and lack of responsiveness of the Forest Department (FD) to the social issues are remarkable problems for the CS mangrove utilization. Lack of consciousness of the local people is also responsible for the destruction of mangrove plantations (Table 4). Proper attention is needed in every aspect of mangrove resource exploitation, handling and processing, export and marketing of shrimp and aquatic resources as well as in biological and institutional management strategies (Islam 2003).

The opportunity is that the soil and water salinity are within the optimal range for healthy growth of commercially important mangrove species (Table 4). Involvement of local communities in mixed silvi-aquaculture practices also provides hope for mangrove restoration and conservation (Rahman and Mahmud 2018). Shrimp farming, excessive collection of non-wood products, over-grazing, human settlement, salt production, etc. are the major threats to the conservation of mangrove species in CS mangroves (Ahmed et al. 2017; Barua and Rahman 2020; Rashid 2019).

Importance of CS mangrove restoration

Influence of the degraded CS mangroves on the environment is alarming due to the disappearance of natural forests. Nowadays, soil of the mangroves turned into salty, human health at risk, seawater in absence of forests often flooded the adjacent area, has abolished the natural mangrove ecosystems (Rahman 2015). Though the restoration process of CS mangroves is quite challenging, but it is very important to restore the CS mangrove ecosystems soon.

According to Hamid and Frank (1999), mangroves are the most productive natural habitats. Giri et al. (2011) and Rahman (2011) reported the following significant aspects of mangrove ecosystems: (i) provide important and unique ecosystem goods and services to human society, and coastal and marine systems; (ii) protect shorelines; (iii) reduce the devastating impact of natural disasters; (iv) provide breeding and nursing sites for marine and pelagic species; (v) catch metals and nutrients; (vi) trap sediments; (vii) supply food, medicine, fuel and building materials for local communities.

In Bangladesh, about two-thirds of people depend on wetlands and coastal mangroves (e.g. CS) for different purposes (Chaudhury 2008; Haroon and Kibria 2017). CS mangrove ecosystems are the source of a variety of natural products such as food production, water, fishing, livestock grazing, bird hunting, fire and fuelwoods, construction materials, medicinal plants, wild food, honey, grasses, seafood, and tourism activities (Daudouch-Guebas et al. 2000; FAO 2007; Haroon and Kibria 2017; Rasolofo 1997; Ronnback et al. 2007).

CS mangroves provide protective habitat for shrimp, prawn, spawning, nursery, and feeding ground for juvenile fish and crustacean species that spend part of their lives in these habitats. Mangroves and surrounding areas contribute many different functional ways to fisheries (Rahman 2011; Robertson et al. 1992). Not only biodiversity and livelihood support, but also the CS coastal mangrove ecosystem provides tremendous significance as a source and sink for greenhouse gases, and climate change mitigation in Bangladesh.

Mangrove forests play a potential role in carbon cycle by storing carbon and act as distributors of dissolved organic carbon to the oceans (Dittmar et al. 2006; Rahman 2011). CS mangrove generates various ecosystem services, i.e. protecting coastal areas from cyclone, floods, and storms, saving coastal lands from tidal surge and wind erosion, reduction of coastal and riverbank erosion, maintenance of water quality through salinity and sediment regulation, harboring a wide range of flora and fauna, etc. (Saenger et al. 1983; Vantomme 1995; Ewel et al. 1998; Moberg and Ronnback 2003; Forbes and Braodhead 2007; Shah and Datta 2010). Further, CS mangroves help to protect the aquatic resources and are also considered an attractive landscape for ecotourists (Hamid and Frank 1999; Roy and Hossain 2015). So, it is urgently needed to restore this oldest mangrove forest. A list of ecosystem services derived from the CS mangrove forests is shown in Table 5.

Table 3. Adverse impacts of actions in the Chakaria Sundarbans and their mitigation measures

Actions affecting Environment	Potential environmental impacts	Recommended mitigation measures
Shrimp culture	Changed topography Submergence of adjacent homestead and garden areas Contamination of ponds	To use least amount of topsoil for dike construction To make dikes wide enough to practice agriculture To take protective measures to prevent entry of saline water
Fry collection	Reduction of fish biodiversity	To regulate wild fry collection from natural sources To motivate only catching of mother shrimp and target fries To establish hatcheries for Baghda shrimp culture in the CS mangrove areas To ensure quality management of hatchery process Personal training, public education and social services
Loss of forest land for shrimp culture	Reduction forest production Reduced employment in agriculture and forestry Changed livelihood some of a farmers' group Permanent or temporary migration of some people	To implement "donation" for shrimp culture To use improved traditional method of shrimp culture To rehabilitate the affected people To cultivate salt-tolerant agricultural crops Schemes for green belt around the affected areas of the CS mangroves

Table 4. SWOT analysis of Chakaria Sundarbans mangrove conservation

Strengths	Weaknesses
1. Adequate silvicultural considerations 2. Effective reforestation programs 3. Collaboration among several stakeholders	1. Unscientific management 2. Lack of people's consciousness 3. Lack of policy and law enforcement
Opportunities	**Threats**
1. Good soil and water quality 2. Silvi-aquaculture practices 3. Involvement of local people	1. Shrimp firming 2. Overgrazing and encroachment 3. Excessive fishing

Table 5. Ecosystem services from the Chakaria Sundarbans mangrove forests

Category	Ecosystem services from the CS mangroves
Provisioning services	Food products; Salt; Energy; Water; Natural medicines
Supporting services	Habitat formation; Soil formation; Breeding ground; Coastal protection; Primary and secondary production; Nutrient cycling; Thermal buffering; Biological diversity (flora and fauna)
Regulating services	Air quality regulation; Climate regulation; Water regulation; Erosion control; Water purification; Waste treatment; Water chemistry; Disease regulation; Pest regulation; Pollination; Natural hazards regulation; Char formation; Coastal processes
Cultural services	Recreation and ecotourism; Aesthetic values; Spiritual and religious values; Educational; Literary

Effectiveness of CS mangroves to mitigate climate change

Climate change has severe impacts on the biodiversity, ecosystem, and functions of CS mangroves. According to Rahman et al. (2011), the coastal mangrove of Bangladesh has lost a significant amount of resources since the 1970s, greatly attributed to the effects of sea-level rise (SLR). Agriculture, aquaculture, and coastal livelihoods are vulnerable due to the impacts of SLR (Islam and Rahman 2015). Huxham et al. (2010) suggested multispecies mangrove forests for increasing the resilience to SLR. CS mangroves play a vital role to increase the surface elevations through biogenic processes (Lang'at et al. 2014) and are also essential for the long-term resilience to SLR (Islam and Rahman 2015; Ward et al. 2016).

Coastal erosion, cyclones, storm surges, and several disasters severely affect the coastal infrastructure, specifically housing, industrial facilities, energy and sanitation systems, transportation, and communication networks (Hossain et al. 2010). CS mangroves are likely to be increasingly disturbed by such high-magnitude, low-frequency events, and obviously protect the coastal areas from tidal storms (Ward et al. 2016). Fritz and Blount

(2007) reported that CS mangroves can reduce tidal wind and storm wave effects along with velocities. Meanwhile, dense vegetation of CS mangroves has significant aspects to reduce the height of tides (Islam and Rahman 2015; Siddiqi 2002). Islam and Rahman (2015); Patil et al. (2012) reported that mangroves can play an important action in the sequestering of carbon and reducing greenhouse gases. An estimated 25.5 million tons (approximately) of carbon are sequestering by mangroves every year (Patil et al. 2012).

Climate-change related physical processes have substantial influences on CS mangrove communities. Coastal mangroves of CS serve as a natural barrier against storms, typhoons, tsunami, hurricanes, and other natural calamities, and also protect coastal inhabitants (Islam and Rahman 2015; Islam et al. 2015). Hence, we can consider CS mangrove as a unique and highly efficient natural resource to combat and mitigate climate change.

Restoration and bringing back the CS mangroves

Sustainable aquaculture development can bring real and lasting benefits to dependent coastal communities. But the environmental consequences of inappropriate or excessive development would adversely impact the plant communities and the farmers themselves. Hence, there is an increasing need for good planning and management of CS mangroves along with shrimp farming (Barua and Chakraborty 2011). Forest Department of Bangladesh (BFD), without having proper social management tools, is unable to protect the lands of CS with legal instruments (Khan 2009). Haroon and Kibria (2017) suggested that livelihood diversification, awareness, and education of local communities and surrounding people on protection, preservation, and conservation of wetlands and coastal zones would be needed to reduce excessive pressure on coastal resources.

Biswas et al. (2009) recorded three challenges for mangrove restoration in Southeast Asia, i.e. the effect of intensive human intervention, poor socio-economic conditions of the local communities and poor knowledge on mangrove ecology. Islam and Wahab (2005) reported that the mangrove ecosystem of CS has been under intensive pressure of exploitation for the last few decades in addition to direct clearance and conversion have placed the mangroves under extreme threats.

According to the report of Iftekhar (2008), few common elements in mangrove management are choice of silvicultural system, protection of existing natural forests, people's participation, biodiversity conservation, zoning, promotion of non-exploiting uses, plantation for land reclamation and water infrastructure protection, etc. To rehabilitate the CS, we urgently need a sustainable management approach. Sustainable management requires trade-offs between society, economy, and the environment (Swart and Bakkes 1995). Meanwhile, beneficiaries and stakeholders at all levels of resource exploitation must take part and contribute to conservation and management of mangroves (Islam and Wahab 2005).

Sohel and Ullah (2012) recommended an ecohydrology-based shrimp farming (ESF) approach which has the potential to reverse the degradation of coastal ecosystems. Jahan and Ancev (2014) reported the necessity of a well-defined shrimp policy that would focus on new environmentally friendly technologies and ensure sustainability to conserve coastal ecology. Hossain et al. (2017) suggested an integrated bio-economic and environmental modeling for sustainable management of CS mangrove forests.

Mangroves integrated with shrimp farming (integrated silvofishery) could be the best economic and ecological composition for the society to accept and adapt a mangrove restoration idea (Rahman and Mahmud 2018). Proper implementation of resilient strategies, such as incorporating all stakeholders, awareness programs, reduced forest dependency of local people, implementation of legal bindings, adequate research and monitoring, ecological and silvicultural considerations, etc. can be useful for sustainable management of CS mangroves (Islam and Bhuiyan 2018).

Paul (2012) suggested alternative farming of shrimp and rice for the sustainability of CS mangroves. Afroz and Alam (2013) suggested that policy integration is mandatory to create a balance between the expansions of shrimp farming and protecting the environment of CS. Rahman and Mahmud (2018) reported that without social and political will, restoration efforts are difficult and quite challenging in the CS mangrove areas. However, management of coastal mangroves of CS requires clear guidance, a well-organized government structure, and a well-defined set of actions (Hossain 2001). Recent information is also needed on forest conditions along with cause-effect relationships, and socio-economic and environmental effects of policy measures.

A serious thought needs are given to rehabilitate the CS with mangroves at least partially. Under proper designed management system, it may be possible to develop a compatible and coexisting system for aquaculture and mangrove reforestation model (Figure 4). This would be beneficial from both the economic and conservation points of view, and ultimately would play a considerable role in improving the socio-economic conditions of the local people.

Conclusion

The oldest mangrove forest of the Indian subcontinent, Chakaria Sundarbans mangrove forest, is now only a space for producing large amount of shrimp and salt rather than wood, non-wood or natural products. Though such production is contributing greatly to the national economy of Bangladesh, but enormously disturbed the biodiversity, and depleted the forest products. So, this mangrove forest of Bangladesh needs to be protected with strong emphasis on prevention and conservation of mangrove biodiversity through strict controls of shrimp farming and grazing. To combat the growing human pressures on natural resources along with biodiversity loss, sea-level rise and climate change, restoration of mangrove forest species through sustainable management approach (SMA) should be considered. Proper forest management should be ensured to improve the potentiality of this oldest mangrove forest of Bangladesh. Effective land management should be encouraged by ensuring the local peoples' participation with the help of political awareness and the implication of forest law.

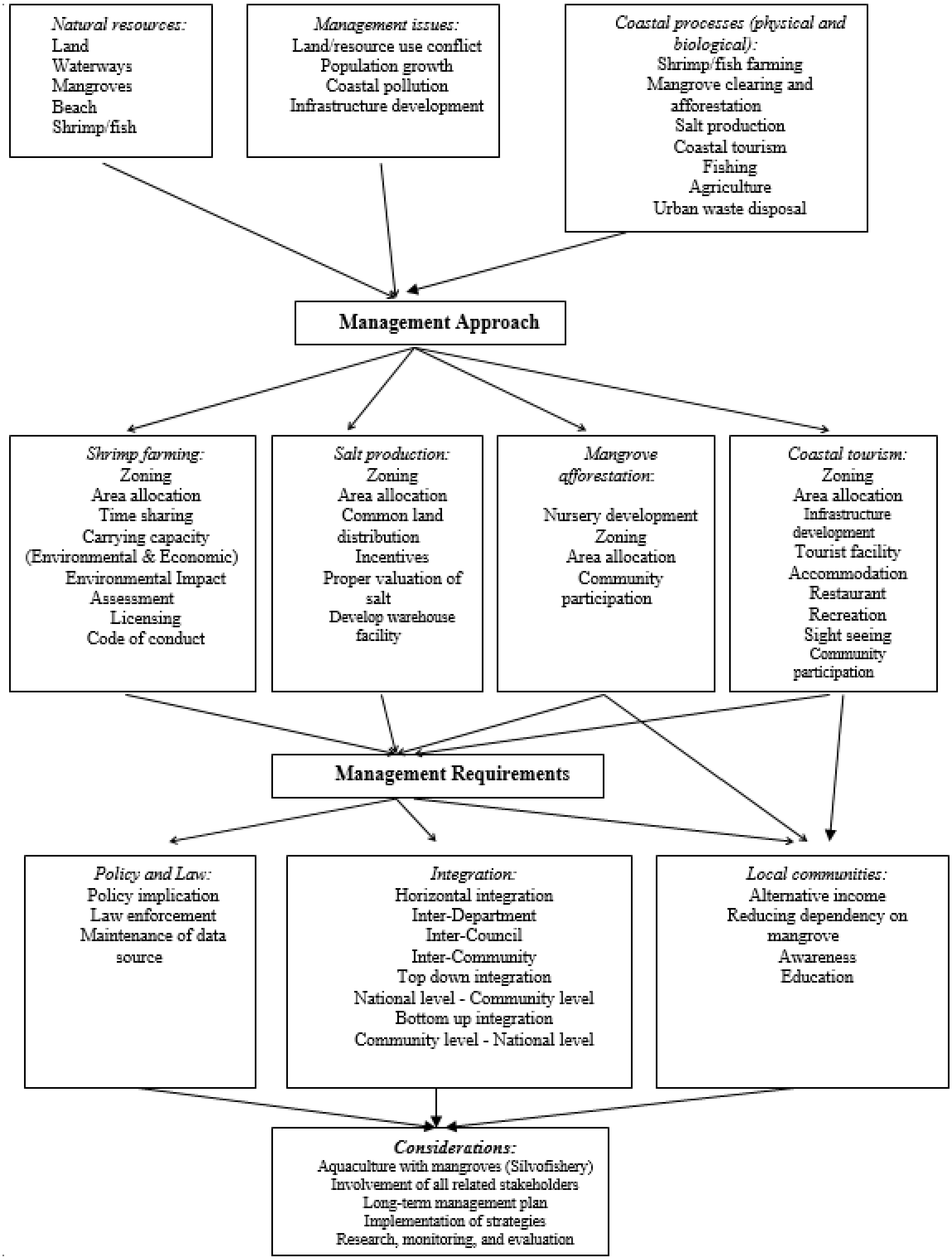

Figure 4. Bringing back the CS mangroves through proper designed sustainable management approach (SMA)

Recommendations

The management of CS would be effective when the forest resources maintain in its natural condition (FAO 1994). In this review, we highly recommended the sustainable management approach (SMA) to restore and rehabilitate the natural CS mangroves. We also made the following recommendations after consulting the major findings of the review: (i) Amalgamation of aquaculture, silviculture, and conservation (Silvo-fishery) is the best practice for bringing back the CS. (ii) Reforestation of mangrove plant species should be increased in degraded areas to restore and conserve the plant diversity in different ecological zones of CS. (iii) Policymakers should give emphasize coastal conservation and environmental amelioration rather than aquaculture expansion and salt production. (iv) Formulation of the new policy about ecological aspects to maintain the existing CS mangroves could be considered. (v) Synergies among governmental, non-governmental, and international organizations and local communities including all stakeholders should develop to ensure the sustainable management of the CS mangroves.

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