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# Solutions to blue carbon emissions: Shrimp cultivation, mangrove deforestation and climate change in coastal Bangladesh

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ABSTRACT

In Bangladesh, export-oriented shrimp farming is one of the most important sectors of the national economy. However, shrimp farming in coastal Bangladesh has devastating effects on mangrove forests. Mangroves are the most carbon-rich forests in the tropics, and blue carbon (i.e., carbon in coastal and marine ecosystems) emissions from mangrove deforestation due to shrimp cultivation are accumulating. These anthropogenic carbon emissions are the dominant cause of climate change, which in turn affect shrimp cultivation. Some adaptation strategies including Integrated Multi-Trophic Aquaculture (IMTA), mangrove restoration, and Reducing Emissions from Deforestation and forest Degradation (REDD+) could help to reduce blue carbon emissions. Translocation of shrimp culture from mangroves to open-water IMTA and restoration of habitats could reduce blue carbon emissions, which in turn would increase blue carbon sequestration. 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.

## 1. Introduction

Bangladesh is one of the world's leading aquaculture producing countries with a production of 2.06 million tons in 2014–2015[1] [1]. Globally, Bangladesh is ranked 6th in aquaculture production after China, Indonesia, India, Vietnam, and the Philippines [2]. Bangladesh is one of the most suitable countries in the world for coastal aquaculture because of its favorable biophysical resources and agro-climatic conditions [3]. The coastal aquaculture sector is dominated by tiger shrimp (*Penaeus monodon*) farming. Over three-quarters of shrimp farms are located in southwest Bangladesh with the remainder in the southeast. In 2014–2015, total annual shrimp production in Bangladesh was estimated at 75,274 t from 216,468 ha area, with an average annual productivity of 348 kg/ha [1]. Shrimp culture has diversified livelihood opportunities for the coastal poor, with over two million people involved in shrimp farming, marketing, processing, and exporting [4].

Shrimp farming is currently one of the most important sectors of the national economy. The sector has become a multimillion dollar industry in Bangladesh due to huge demand for shrimp in global markets, particularly the European Union (EU) and the United States of America (USA). In 2014–2015, Bangladesh exported 44,278 t of prawn and shrimp valued at US$506 million, of which US$364 million (72%) was shrimp [1]. As a whole, the sector is the 2nd largest export industry after readymade garments. Overall, shrimp production plays an important role in export earnings, food production, diversifying livelihoods, and income for farming households and associated groups [3].

Despite economic benefits, shrimp farming in coastal Bangladesh has devastating effects on mangroves [5–7]. Globally, shrimp farming has been under intense criticism because of its socioeconomic and environmental impacts [8–10]. During the 1980s and 1990s, the rapid growth of shrimp farming caused widespread destruction of mangroves in a number of countries, including Bangladesh, Brazil, China, India, Indonesia, Malaysia, Mexico, Myanmar, Sri Lanka, the Philippines, Thailand, and Vietnam [11,12]. However, mangroves are the most carbon-rich forests in the tropics and blue carbon emissions[2] have been seriously augmented due to devastating effects on mangroves [13–16]. Carbon emissions with other greenhouse gases ($CH_4$, $N_2O$) are likely to have been the dominant cause of climate change [17]. It is, therefore, crucial to reduce blue carbon emissions from mangrove deforestation to tackle anthropogenic[3] climate change.

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[1] Bangladesh fiscal year: 1 July – 30 June.

[2] Emissions refer to the release of carbon into the atmosphere over a specified area and period of time.

[3] Anthropogenic climate change refers to the production of greenhouse gases emitted by human activity.

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Preventing mangrove loss and conserving mangrove forests can help to reduce blue carbon emissions for climate change mitigation [14,15,18]. The aim of this paper is to highlight key issues in reducing blue carbon emissions from mangrove deforestation due to shrimp cultivation in coastal Bangladesh. The conversion of mangrove forests into shrimp farms and the impacts of climate change on shrimp culture, mangrove fisheries, and coastal communities are also discussed. Finally, some adaptation strategies are proposed to reduce blue carbon emissions for resilience to climate change.

## 2. Shrimp cultivation and mangrove deforestation

### 2.1. The blue revolution of shrimp cultivation

As part of agricultural development in coastal Bangladesh, shrimp farming was initiated in the 1970s and began to expand rapidly in the 1980s [19]. During the 1990s, the rapid development of shrimp farming has been likened to the blue revolution, which is an approach to food production and economic growth [3]. Shrimp culture has developed extensively in coastal Bangladesh over the last three decades. Overall, shrimp production has significantly improved socioeconomic conditions of farming households. Most farmers willingly switched from rice to shrimp culture because of the higher income [20]. Environmental consequences were ignored due to the broader economic benefits, with shrimp referred to as “white gold” in Bangladesh, because of its high export value. Despite environmental concerns, shrimp culture seems to have had positive benefits for economic sustainability [3].

Shrimp production in Bangladesh has increased considerably from 56,569 t in 2010–2011 to 75,274 t in 2014–2015. The average annual growth rate of shrimp production is 5.38% [1,21]. Shrimp farming in low-lying coastal Bangladesh is extensive with farmers cutting a portion of dikes to allow tidal water to trap wild shrimp fry. Wild caught and hatchery produced shrimp postlarvae are also stocked. There are three types of shrimp farming systems in coastal Bangladesh: (1) shrimp alternate rice, (2) shrimp alternate salt, and (3) shrimp-only. In the shrimp alternate rice farming system, rice is produced during the monsoon when water salinity goes down and favors the growth of rice plants. In the shrimp alternate salt farming system, shrimp is grown during the monsoon when farms are inundated by tidal water while salt is produced during the dry season. Shrimp-only culture is practiced where water salinity is comparatively high for a period of 6–9 months annually and rice farming is not possible because of water salinity [3].

### 2.2. Mangrove forests in Bangladesh

Globally, Bangladesh is ranked 9th in mangrove area, covering 3% of the world's mangrove forests [11]. The Sundarbans is the largest continuous mangrove forest in the world, covering an area of over one million ha, located along the mouth of the Bay of Bengal between Bangladesh (60%) and India (40%). The Sundarbans in Bangladesh covers an area of 601,672 ha, of which 414,259 ha (70%) of land and 187,413 ha (30%) of water [22]. The Sundarbans lies on the delta of the Ganges, Brahmaputra, and Megna rivers within Bagerhat, Khulna, and Satkhira districts in southwest Bangladesh (Fig. 1). Including the Sundarbans, the total mangrove area in Bangladesh is 436,570 ha [23].

The Sundarbans mangrove forest contains diverse and rich natural resources, which has long been recognized for its wide range of biodiversity as it provides feeding, breeding, and nursery grounds for many ecologically and commercially important species [24,25]. The biodiversity of the Sundarbans includes about 334 plant species, 260 bird species, 210 fish species, 59 reptile species, 49 mammal species, and 8 amphibian species. In addition, the Sundarbans is the habitat for the largest population (400–450) of the Royal Bengal Tiger (*Panthera tigris tigris*), and many rare and endangered species, including the Ganges river dolphin (*Platanista gangetica*) and estuarine crocodile (*Crocodylus porosus*) [22]. The Sundarbans is also famous for its sundari (*Heritiera* spp.) tree. A transboundary forest of the Sundarbans is designated a Ramsar site since 1992, and a World Heritage Site of the United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1997 [11].

The Sundarbans in Bangladesh provides a wide range of ecosystem goods and services, including climate regulation, coastal protection, fisheries, fuel, medicine, nutrient cycling, shelter, timber, and tourism [25]. According to Barbier [26], the total annual value of mangrove ecosystem services is US$10,158–12,392 per ha in Thailand. At this rate, the annual economic value of mangroves in Bangladesh is over US $4.43 billion (Table 1). Overall, mangrove ecosystem services have an important role in coastal economies of Bangladesh, supporting human wellbeing, including livelihoods, income, and food supply [27]. The livelihoods of over 3.5 million people are directly or indirectly dependent on the Sundarbans in Bangladesh [28,29].

### 2.3. Mangrove deforestation by shrimp cultivation

Mangrove forests are one of the world's most threatened tropical ecosystems [30]. Over 3.6 million ha of global mangrove forests were lost between 1980 and 2005 due to agriculture, aquaculture, overexploitation, pollution, tourism, and urbanization [11]. Among deforested mangroves, about 1.89 million ha (52%) were lost by coastal aquaculture, of which 1.4 million ha (38%) and 0.49 million ha (14%) of mangrove loss has resulted from shrimp culture and other forms of aquaculture, respectively. In Asia, coastal aquaculture accounts for 1.69 million ha of mangrove loss with shrimp farming accounting for 1.2 million ha of total deforestation [30].

Mangrove deforestation by shrimp cultivation is also common in Bangladesh. The unique Chakaria Sundarbans in southeast Bangladesh, which had 8500 ha of mangroves, was deforested due to shrimp culture [31,32]. Moreover, 290 ha of mangroves on Maiskhali Island and 133 ha of mangroves on Jaliardwip Island were cleared for shrimp ponds. In addition, 104 ha of mangroves on Matabar Island were lost due to shrimp cultivation. Around 670 ha of mangroves along the Naf River were also deforested for shrimp production [32]. According to Hossain [33], 1800 ha of mangroves in the Naf River estuary and off-shore islands were converted into shrimp farms. Overall, 10,000 ha of mangrove loss has resulted from shrimp culture in Bangladesh (Table 2). According to Shahid and Islam [32], over 9700 ha of mangrove loss has been attributed to shrimp culture since 1975. A recent study reported that mangroves in Bangladesh declined from 452,444 ha in 1976 to 441,455 ha in 2010 [34]. When mangroves are cleared for shrimp ponds, land values decrease by approximately US$10,000 per hectare [26]. At this rate, the annual economic value of mangrove loss to shrimp culture in Bangladesh is over US$100 million. It is, therefore, more valuable and economically profitable to conserve mangroves than shrimp culture [35]. In recent years, however, Bangladesh has made tremendous progress on mangrove conservation [11,12].

## 3. Mangrove deforestation and blue carbon emissions

### 3.1. Blue carbon ecosystems

Blue carbon[4] is the carbon stored, sequestered, and released from coastal and marine ecosystems, including mangroves, salt marshes, and seagrasses [14,16,36]. These three habitats are commonly referred to as blue carbon ecosystems. Globally, blue carbon ecosystems are about 51 million ha that store 11.5 billion tons of carbon, of which the highest blue carbon pool[5] is mangroves (6.5 billion tons) [15]. Policy initiatives on blue carbon have recently started as policymakers and scientists are increasingly cooperating on developing blue carbon concept to benefit

[4] The colors of carbon are fossil fuels “brown carbon”, dust particles “black carbon”, terrestrial ecosystems “green carbon”, and coastal and marine ecosystems “blue carbon” [36].

[5] A carbon pool is a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period.