IMPACT OF BRACKISH WATER AQUACULTURE AND MANGROVE DEGRADATION ON GLOBAL CARBON BALANCE: A REVIEW

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ABSTRACT

One of the most productive and supportive ecosystems, the mangroves, have faced a sharp decline of 1.04 million hectares globally, mostly due to population pressure and environmental changes related to the recent effects of global warming and climate change. The loss of area, species migration, altered ecological services etc. are among the most discussed concerns, as evident from the volumes of literatures. However, these issues have overshadowed the fact that along with biodiversity, globally we are losing an important and efficient carbon sink - the mangrove lands. The lost mangrove patches and their conversion to aquaculture, agriculture, or simply settlement areas significantly alter the carbon budget. Sometimes conversion of mangroves to agriculture or aquaculture farms even reverses the roles and the sink has been reported to have become a source of carbon - alternatively known as blue carbon emission. This article provides an overview of the impacts of coastal aquacultures, particularly established in expense of mangrove lands and its consequence on global carbon budget. It has been observed that this globally predominant land use change practices not only significantly reduce the carbon sink capacity but also frequently act as indirect source of the same.

Keywords: *carbon sequestration, blue carbon, shrimp farming, mangrove*

INTRODUCTION

Aquaculture is one of the fastest growing sectors due to significant increases in demand for fish and seafood worldwide [1, 2]. With the growing human population and continuous demand for food, the global food fish consumption is growing. Thus, from the human health point of view, the production of safe and quality aquatic food will be a great concern for global food safety in the upcoming years. In terms of food safety, it indicates that aquaculture has great potential to produce more fish, and the development of aquaculture will be of the utmost importance for global protein supply and economic trade soon [3]. Despite high market demand for fish and possibility to make a profit on foreign market, the growth of aquaculture poses several environmental consequences. The rapid and unplanned practice of aquaculture often leads to deterioration of its environment, which are consequences of the cumulative effect of aquaculture development activities. So, its sustainability has become controversial. Therefore, for sustainable and long-term growth of the aquaculture industry, the impacts of aquaculture must be addressed and need both environmentally sound practices and sustainable resource management [4]. Although various environmental consequences have been discussed in earlier studies [1, 4], the impact on mangrove carbon sequestration has not been fully established. This article aims to highlight key issues for brackish water aquaculture in mangrove destruction and carbon storage.

MANGROVE AND BLUE CARBON

Coastal ecosystems are known to be one of the most efficient carbon sinks on Earth and play a significant role in regulating the regional and global carbon cycle [5 - 7]. The vegetal biomass of the coastal wetlands is deposited and conserved in sediments for long periods and thus plays a crucial role in supporting carbon accumulation [8, 9]. This accumulated and sequestrated carbon stored in marine and coastal ecosystems is known as “blue carbon” and is released from coastal and marine ecosystems, including mangroves, seagrasses and salt marshes, commonly referred to as blue carbon ecosystems [10, 11]. The mangroves are known to be one of the most productive ecosystems [12 - 15] with reportedly up to five times higher gross primary production and twice the carbon accumulation rates in comparison with non-vegetated areas within estuaries, shelf, and deltaic environments [9]. It is also capable of storing four times more carbon than tropical upland forests and recognized as a powerful sink for atmospheric carbon [16, 17]. Mangrove has the largest carbon stock of any ecosystem, estimated to 617 x 10^{10} kg of organic carbon in the global tropical ocean, accounting for 17 % of total tropical marine carbon stocks [18]. Historically, mangroves have been under direct pressure from aquaculture or more specifically shrimp farming which is often known as an economically more productive than other practices [19]. Several studies found that mangroves are facing a major loss due to rapid and unplanned shrimp farming, which is now considered as one of the most damaging activities responsible for mangrove loss [16, 20 - 23].

DESTRUCTION OF MANGROVE AND IMPACT ON CARBON STORAGE

Aquaculture and agricultural expansions have been the main causes behind global mangroves destruction, followed by land use changes for industrial and settlement purpose [24, 25]. Aquaculture is one of the most damaging human activities responsible for mangroves degradation [9, 16, 20, 26 - 29]. Indonesia [30], Sri Lanka [31], Bangladesh [10], China [32], Thailand [33] and many other countries are known as trend-leaders in massive shrimp farming activities (Table 1). The mangrove deforestation rates are much higher compared to the average rates of global deforestation, which accounts for 10 % of global emission in deforestation [10, 34]. Estimated annual blue carbon emissions from mangroves to aquaculture conversion range from 112 to 392 t/ha [15].

Table 1. Estimated changes of mangrove area due to brackish water aquaculture

Country/ Area	Time series (year)	Total mangrove area (ha)	Current mangrove area (ha)	Converted mangrove area (ha)	Ref.
Indonesia	1800 - 2012	4,133,000	3,220,000	913,000	[30]
Thailand	1961 - 1993	364,000	168,700	195,300	[33]
China	1966 - 2009	3679	1041	2638	[32]
Sri Lanka	1990 - 2012	-	-	439.01	[31]

Mangroves differ from other terrestrial forests in their huge potential to store large amounts of carbon in their soils. Mangrove sequester most of its carbon in the below-ground carbon pools in soils and below-ground vegetation

[23, 35, 36]. The presence of aerial roots in mangroves helps to trap allochthonous organic matter in the sediment. Low nutrient levels and a high lignin content in the roots cause below-ground organic matter to decompose slowly, resulting accumulation of large reserves of peat and carbon rich sediments. Continuous sediment accumulation and vertical accretion do not allow the carbon to reach its saturation in mangrove sediment and thus, the size of the carbon store increase over time [36]. These organic-rich deposits can be formed up to several meters deep and may remain underground for centuries when left undisturbed [16, 35]. The conversion of mangroves into shrimp ponds alters the key biophysical variables in soil, like soil moisture content which control CO_2 flux. The duration of tidal inundation is also another controlling factor, as pond construction changes the topography of land, sometimes reversing the carbon sink [16]. The brackish water aquaculture, including deforestation followed by canal, dykes, and pond construction, alter the natural tidal regime and expose an undisturbed carbon stock that results in carbon emission [37]. Tides and waves provide an additional energy subsidy to mangrove forests, allowing them to store and transport new fixed carbon and sediments [35]. Changes in drainage patterns lead to alteration of soil chemistry and result in rapid emission rates of greenhouse gases, especially CO_2 [20, 38]. The constructions of aquaculture pond cause significant carbon loss through removal of trees and around 1.5 m of the top soil with sparse vegetation. Even the piled up excavated soil increases oxidation rate of the soil carbon stocks [16, 39]. These activities cause potential disturbance in the soil carbon and lead to the remineralization to CO_2. Once disrupted, the mangrove soil carbon takes thousands of years to form, it can't be restored by simply restoring the forest within meaningful human timescales. As a result, the remineralization of mangrove soil carbon may contribute significantly to the anthropogenic GHG emissions categorized as "land-use change" [39]. It has been estimated that carbon emission from 1 ha of mangrove forest conversion is equal to emissions of about 5 ha of conversion of tropical evergreen forest and 11.5 ha of tropical dry forest [10]. Therefore, mangrove conversion to shrimp ponds may have resulted in the loss of 58 - 82 % of the ecosystem carbon stocks [23]. One of the less known impacts of aquaculture is the effect of pond effluents on the soil productivity, particularly on carbon cycling and storage [40]. Pond effluents containing high amount of nutrients [40] and wastes [1] significantly affect microbial activities and alter soil organic carbon content [17]. Under anaerobic condition in mangrove forest soil, pyrite remains in high concentration due to regulation by tidal regime and precipitation [40]. High NO_3 concentration in pond effluent, produced from the nitrification process of ammonia [1], degrades the pyrite, leading to decay of organic carbon and carbon emission. However, greater carbon stock is quantified in the top 40 cm of mangrove soil, which is unaffected by wastewater effluent [40].

After years of cultivation, shrimp ponds are sometimes abandoned, for various reasons. Inadequate tidal flushing and evaporation cause salt crystallization and accumulation at the pond bottom, which increase water salinity, make an unfavourable condition for shrimp growth, and ultimately leads to frequent pond abandonment. However, soil acidification, disease outbreak, dyke collapse, pollution and market situation were also responsible for abandonment of the practice in several cases [41]. These abandoned ponds also show significantly lower amount of carbon stock than the mangrove forest [16, 41]. When the abandoned ponds are drained and there is no tidal flow, an aerobic environment makes favourable condition for carbon oxidation. As a result, the carbon that was once buried under saturated and anoxic condition get exposed and released to the atmosphere in CO_2 form [16, 41].

Global blue carbon emissions from mangrove conversion to aquaculture practice are aggravating (Table 2). The major aquaculture producing countries are reportedly responsible for as much as 54 % of total mangrove loss during the 1980s -1990s [4]. Asia has already lost 1.2 million ha of mangrove due to deforestation for shrimp farming. Global mangrove derived blue carbon emission rate is 58.7 million tons annually, of which 53.5 million tons originated from mangrove carbon losses [10]. The life cycle of shrimp farming practice, from mangrove destruction to pond abandonment, causes depletion and emission of carbon storage. The potential loss of blue carbon stock, caused by mangrove conversion to shrimp farming, ranged from 661 to 1135 t/ha [34].

Table 2. Blue carbon emission of different countries related to mangrove degradation

Country	CO_2 emission (Mg CO_2 eq ha^{-1})	Reference
Brazil	1371	[23]
Indonesia	1925	[41]
Dominican Republic	2165 - 3554	[42]
Mexico	2610	[18]
Honduras	1068.4	
Costa Rica	1811.9	

CONCLUSION

Shrimp farming, as one of the fastest growing production sectors in brackish water aquaculture, has the potential to meet the needs of growing world population for food as well as to strengthen the economy. Despite of huge growth and demand of this sector, it silently contributes to the global greenhouse gas emission, especially CO_2. The disruption of carbon sequestration in coastal habitats through human activities can cause a shift from the carbon sink to the carbon source. Therefore, for sustainable and long-term growth of the shrimp farming, the environmental impacts must be addressed and environmentally sound practices and sustainable resource management need to be implemented. Mangrove restoration and consequent reduction in blue carbon emission are considered to be an effective part of climate change adaptation today. In this context, REDD+ programme should be initiated to conserve and/or restore the mangrove. The REDD+ programme can be an economical solution for climate change mitigation that can play an important role in blue carbon emission reduction. Restoring mangrove forests, which help to sequester carbon, could possibly compensate the mangrove losses caused by coastal aquaculture [34]. This approach can be most suitable as it considers the socio-economic support to the community, as well as the prevention of mangrove deforestation and degradation. To put this into global perspective, further scientific studies are needed to understand and estimate the carbon dynamics and find out the factors causing depletion of global blue carbon storage and emission. The estimation of storage and emission of blue carbon should involve both regional and global scale study, to understand the linkages and for systematic incorporation of all the factors involved.

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