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Seagrass Ecosystem and Climate Change: An Indian Perspective

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Abstract: The significance of the seagrass ecosystem as global carbon sinks has been well studied worldwide; however, studies in India are sparse. Most research in India focuses on the distribution and ecology of seagrass and biogeochemistry has often been less studied. This paper describes the potential carbon sequestration, particularly carbon burial and uptake by seagrass ecosystems of India. The results reported the higher dissolved carbon uptake rates by seagrass ecosystem followed by high net ecosystem productivity. Below ground biomass dominated in the seagrass ecosystem which is a storehouse of buried carbon. High storage capacity of seagrass ecosystem is described through a case study of Chilika lagoon where the carbon pool in the biomass and sediments were observed to range from 2.3 to 2.5 Gg C and 4.5 to 5.7 Gg C respectively. The study emphasized on the need of focused research, particularly, on the role of carbon in seagrass ecosystems in India.

Key words: Seagrass; C Sequestration; Blue carbon economy; Ecosystem service.

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) estimates, the global CO_2 emissions would be reduced by 85% by the year 2050 from the levels observed in 2000 to prevent a global mean temperature increase of 2°C (IPCC, 2007). A more recent combined approach, that includes reduction of anthropogenic CO_2 sources (mitigation) along with supporting CO_2 uptake and storage through the conservation of natural ecosystems with high C sequestration rates and capacity, has been suggested in order to reduce atmospheric CO_2 concentrations. However, the effective mitigation of anthropogenic emissions of CO_2 takes place through net C sink provided by an ecosystem, when its C sequestration potential increases resulting from an increase in areal extent or the rate of primary productivity (McLeod et al., 2011). The longevity of the above and below ground C sink is uncertain due to the saturation of soil C storage in terrestrial ecosystems (Schlesinger and Lichter, 2001); hence, the coastal and ocean areas have been looked upon with greater prospects. Oceans are estimated to sequester more than one third of the anthropogenic carbon through the solubility pump and biological pump.

Coastal vegetative ecosystems namely marshes, mangroves and seagrass, termed “blue carbon”, are well known for their effective high rates of annual carbon sequestration and the storage of the sequestered C on longer time scales (Purvaja et al., 2008). The magnitude

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of the coastal ecosystems is about one to two orders smaller than that of terrestrial forests despite their global area (~0.5% of the sea bed). Nevertheless, the high efficiency of vegetative coastal habitats in trapping suspended matter and associated organic C during tidal inundation (having 70% of the ocean's carbon storage capacity) has much greater contribution per unit area to long-term C sequestration (McLeod et al., 2011; Duarte et al., 2010; Fourqurean et al., 2012). It has been estimated that in the first metre of sediments alone, soil organic carbon averages 500 t CO_2e/ha (tonnes of carbon dioxide equivalent per hectare) for seagrass, 917 t CO_2e/ha for salt marshes, 1060 t CO_2e/ha for estuarine mangroves, and nearly 1800 t CO_2e/ha for oceanic mangroves. Hence, about 95-99% of total carbon stocks of salt marshes and seagrass are stored in the soils beneath them, relatively.

Even though seagrass meadows occupy less than 0.2% of the area of the world's oceans it is estimated that they bury 48 to 112 Tg C yr^{-1} globally (McLeod et al., 2011), which accounts for ~10% of the yearly estimated C_{org} burial in the oceans (Fourqurean et al., 2012). The C burrial rate in seagrass sediments could reach up to 190 g C m^{-2} yr^{-1} with a mean value of 138 ± 38 g C m^{-2} yr^{-1} (Durate et al., 2013). These sediments are largely anaerobic, thus preserving C_{org} in the sediments for millennia (Fourqurean et al., 2012).

The Government of India advocates for low carbon rise by reducing the emission intensity from 20% to 25% by 2020 with respect to its emissions, thus necessitating mitigation strategies using natural ecosystems with high C sequestration capacity (Ray et al., 2015). Various agencies (SAC, FSI etc.) have accurately mapped the blue carbon ecosystems covering the net forest area and mangrove tree cover of India using state-of-the-art techniques. However, the comprehensive database for seagrass ecosystem is still lacking. Present paper reviews the status of seagrass research being carried out in India and its significance in the context of global climate change.

Seagrass Ecosystems of India

Seagrass habitats in India (Figure 1) are restricted from the lower intertidal zone to the open shores and in the lagoons mainly mudflats and sandy environment (Purvaja et al., 2008). The exact area covered by seagrass vary annually as well as seasonally (Purvaja et al., 2008).

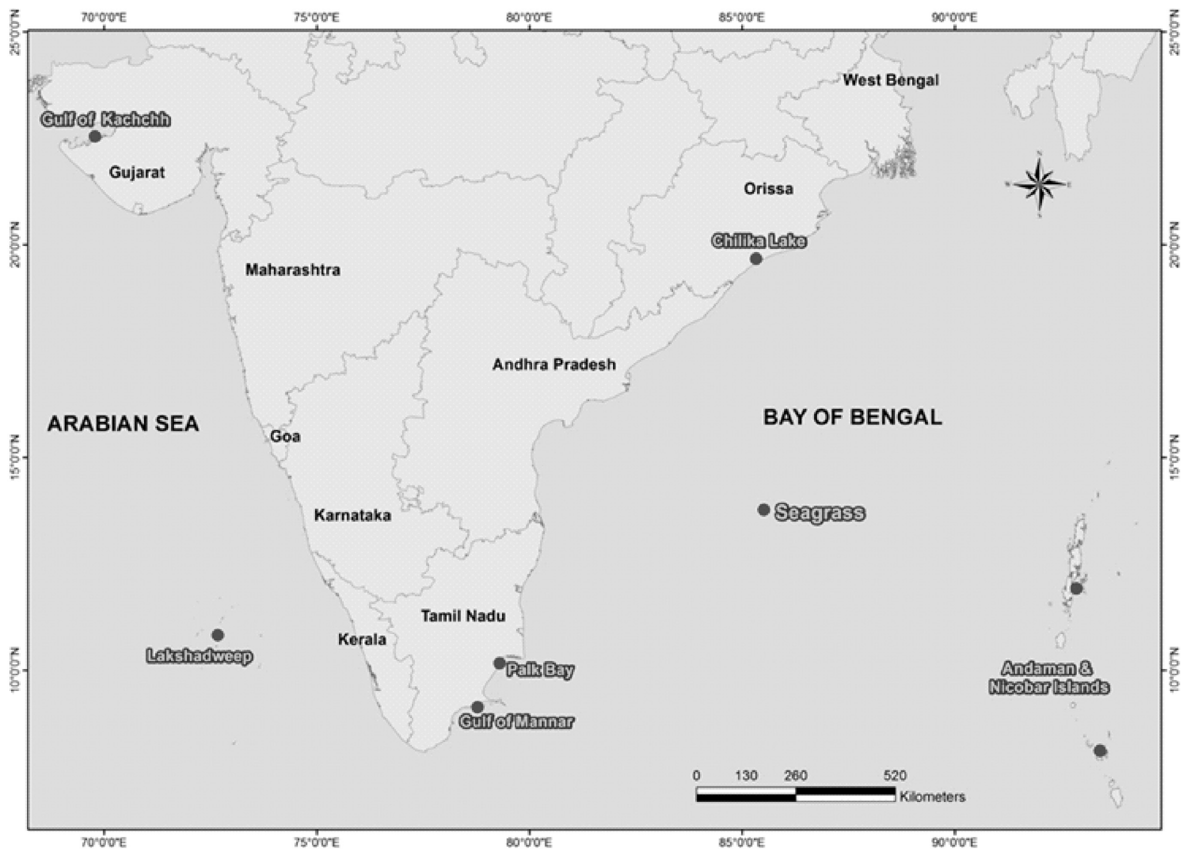


Figure 1: Distribution of seagrass ecosystems of India.

In India, luxuriant beds of seagrass are observed at Chilika lagoon; Gulf of Mannar and Palk Bay (southeast coast); Gulf of Kachchh; a number of islands of Lakshadweep (Arabian Sea) and a few islands in Andaman and Nicobar (Bay of Bengal) (Jagtap et al., 2003). Gulf of Mannar and Palk Bay are associated with most densely covered area of seagrass in India. Maximum seagrass distribution, abundance, and species richness are usually associated with regions (e.g. Palk Bay) with high salinity having little or no variation in salinity throughout the year. Lagoon and bays viz. Chilika, with a fluctuating range of salinity are usually associated with a limited number of species with maximum distribution only in the dry season (Purvaja et al., 2008). Seagrass beds quite often become silted and degraded during monsoon with freshwater flooding in.

Seagrass has been one of the poorly studied ecosystem in India as compared to other coastal ecosystems such as mangrove and seaweeds, although there have been a considerable amount of research carried out in the temperate and tropical ecosystem of other countries (Jagtap et al., 2003; Durate et al., 2013). Majority of studies carried out in India during last decades (1990-2015) focused on distribution and ecology of the seagrass ecosystem, although in recent years the focus is towards understanding the biogeochemistry and carbon sequestration services of these blue carbon ecosystems.

Carbon Sequestration in Seagrass Ecosystems of India

Seagrass, mangroves and salt marshes can capture two-thirds of the organic C in oceanic environment signifying them as the most valuable carbon sinks on the earth. Carbon sequestration rate of seagrass ecosystem is 35× faster than tropical rainforests, and their sediments never become saturated (McLeod et al., 2011). Additionally, the turnover time of carbon in terrestrial forests is in decades, whereas for seagrass ecosystems it is millennial scale (Macreadie et al., 2012). Seagrass ecosystems are often CO_2 limited and photosynthetically less active in seawater, due to their inefficient utilization of bicarbonate (HCO^-_3 that forms the majority of dissolved inorganic carbon, for photosynthesis. Seagrass actively uses dissolved CO_2 thereby constantly increasing growth rates (Figure 2). The biological capture of CO_2 by seagrass ecosystem is distinctly observed from the variation of pCO_2 concentration between seagrass and non-seagrass beds. Subtropical and tropical marginal seas are well known as the net sources of atmospheric CO_2 and the waters are characterized by high pCO_2 values. Russell et al. (2013) recently showed a positive growth response of seagrass (*Cymodocea serrulata)* under the high pCO_2 condition. High primary productivity provides relatively low pCO_2 in coastal waters, which can cause a higher degree of aragonite/calcite saturation and could be beneficial for the adjacent coral reef ecosystems (seaward). With their potential to increase their productivity during the enrichment of CO_2, autotrophic seagrass has the capability to offset the ocean acidification, thus increasing the rate of calcification in the surrounding corals (Figure 2). The DIC is effectively consumed by high photosynthetic activities, thus resulting in an increase.

Carbon sequestration is best understood by studying the uptake, release and burial rates of the carbon in seagrass ecosystem as C is stored in the biomasses

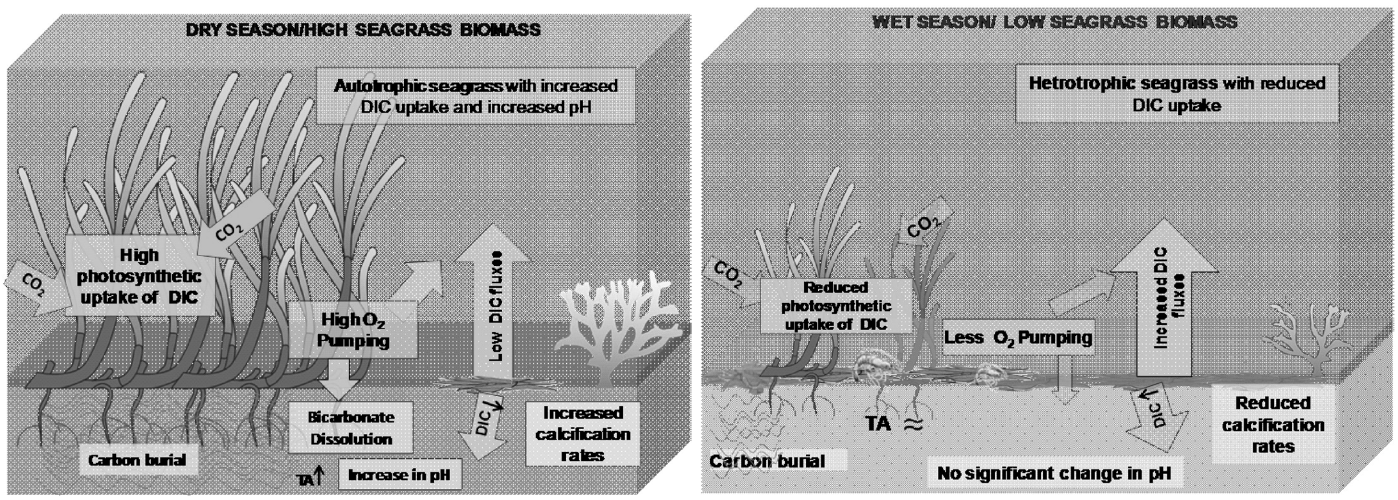


Figure 2: Conceptual diagram depicting ecosystems functions in seagrass ecosystem (redrawn from Unsworth et al., 2012).

through productivity and sediments (Macreadie et al., 2012). In order to understand the carbon sequestration potential of a seagrass ecosystem, data on the following are imperative:

1. Rate of carbon uptake or oxygen release through metabolic activity
2. Net ecosystem productivity and carbon utilization
3. Carbon removal rates (as biomass and as in sediment profile)
4. Carbon leakage to the ambient system (as in a degraded ecosystem)

Oxygen measurements are the most widely used technique for capturing the metabolic process [Net ecosystem production (NEP) = Gross primary production (GPP) –total ecosystem respiration (TR)] associated with seagrass meadows. Measurements of oxygen level in surrounding water using probes or light/dark bottle method has been widely used as proxies for productivity and carbon uptake. Roots and rhizomes are the potential components of seagrass, which forms the long-term C stock. Above and below ground biomass, litter and sediment C stocks are measured to understand the carbon stock and burial. Most importantly, characterization of organic matter at different profiles of the sediment, supported by isotopic dating provides the measure of the net sequestration rate of seagrass ecosystem (Macreadie et al., 2014).

Improving Oxygenation of Surrounding Waters

High dissolved oxygen concentration can be taken as a proxy for enhanced photosynthesis rates by the seagrass thus reducing the probability of phytoplankton. Coastal sediments with high organic matter input may result in adverse environmental conditions for the seagrass bed. High inputs of organic matter lead to increased bacterial activity, thus creating an anoxic environment. This often results in the accumulation of phytotoxic compounds, such as sulphide (Hemminga and Durate, 2000). However, under healthy conditions, seagrass acts as an oxygen pumping agent to the surrounding areas, creating a relatively oxidized rhizosphere (Hemminga and Durate, 2000). In our study, conducted at NCSCM (unpublished results), significantly higher dissolved oxygen concentrations in seagrass bed were observed as compared to degraded bed, indicating enhanced photosynthetic rates (Figure 3). Dissolved oxygen maximum was observed during moderate sunlight conditions, as high temperature and sunlight restricts productivity. The results highlighted the importance of seagrass as ‘bioshields’, reducing or mitigating impacts of hypoxia in the coastal water due to unsustainable land use practices/pollution.

Transforming Oxygen into Productivity: Carbon Utilization

Reliable and accurate data range of seagrass biomass is essential for estimating productivity and establishing links between other estuarine components. High rates of primary productivity in seagrass ecosystem indicate the higher consumption of micronutrients thus reducing the instance of eutrophication. In addition, high productivity also reduces the levels of pCO_2 in the overlying waters by consuming large amounts of dissolved inorganic carbon (Durate et al., 2013). This causes high degree

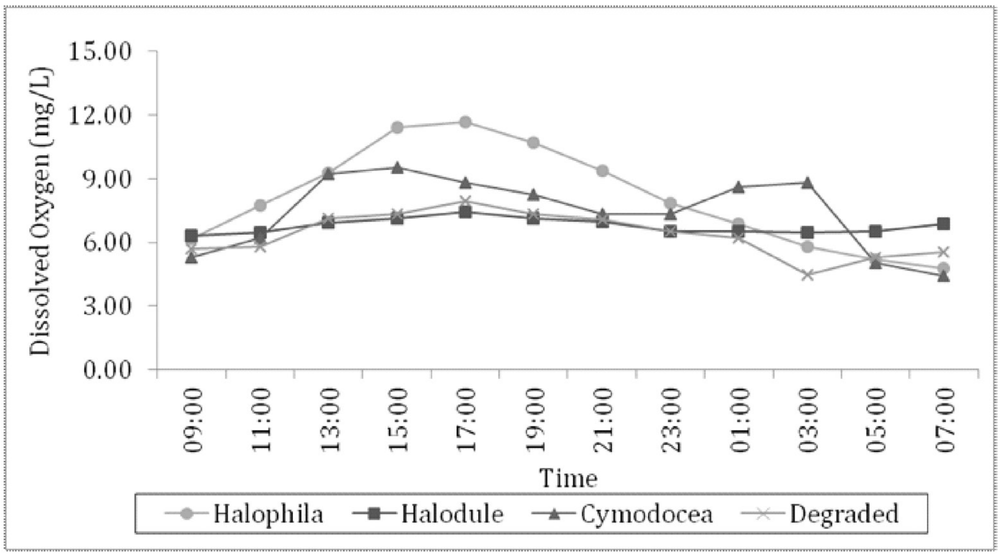
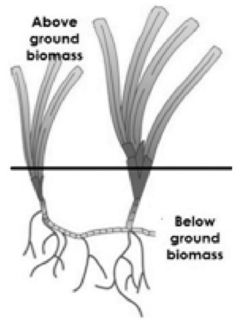


Figure 3: Diurnal variations in dissolved oxygen concentration in seagrass ecosystems.

Table 1: Biomass partitioning in a few seagrass species

No.	*Species*	*AGB (%)*	*BGB (%)*	*Total dry wt. of individual species in gm (mean)*
1	*Halophilaovalis*	40.75	59.25	0.43
2	*Cymodocea serrulata*	23.40	76.60	1.78
3	*Cymodocea rotundata*	54.50	45.50	0.70
4	*Haloduleuninervis*	29.70	70.30	0.51
5	*Syringodium isoetifolium*	40.75	59.25	0.57
6	*Enhalusacoroides*	27.40	72.60	8.27



of aragonite/calcite saturation which is beneficial to the adjacent coral reef ecosystem. Subtropical and tropical marginal seas are well known as the net sources of atmospheric CO_2 and the waters are characterized by high pCO_2 values. Russell et al. (2013) recently showed a positive growth response of seagrass (*Cymodocea serrulata)* under the high pCO_2 conditions.

It has been estimated that the average net metabolic capture of carbon by seagrass communities is 9.9±2.2 mol C m^2yr^{-1}, approximately, though the capacity varies from species to species and region to region (Durate et al., 2010). In a study conducted by Govindsamy and Arulpriya (2013), it was observed that *Syringodium isoetifolium* and *Cymodocea serrulata* showed higher above-ground biomass (AGB) and below-ground biomass (BGB) with marked seasonal variation. Our study suggests the clear dominance of BGB over AGB for most of the species except *Cymodocea rotundata* (Table 1). ABG varied between 21.6 and 47.44 g dry wt m^2 and BGB between 37.064 and 63.6 g dry wt m^2. The ratios (dry wt.) of below to above ground biomass ranged between 0.92 and 3.27 (unpublished results).

It is an established fact that BGB of primary producers with root systems can be buried for centuries to millennia. This makes the seagrass ecosystem a potential CO_2 sink and can be effective in mitigating the negative impacts on the ocean ecosystems during ocean acidification events.

Carbon Sequestration and Storage by Seagrass Ecosystem

Net ecosystem production of an ecosystem is the measure of organic carbon in an ecosystem available for storage whereas biological carbon sequestration is the process of capture (by photosynthesis) and long-term storage of atmospheric carbon dioxide (Lovett et al., 2006). Several analytical methods are available to measure NEP from seagrass meadows with varying degree of accuracy(Silva et al., 2009). However, there may be discrepancy in the measurement of NEP as a result of factor such as transport of litters due to wave action, natural death, boat and human activities. Therefore, efforts should be made to accurately determine the actual rate of carbon sequestration by the seagrass ecosystem by exact quantification of natural and human induced loss of captured carbon.

An attempt was made to quantify the net ecosystem productivity and storage of carbon in various compartments of Chilika lagoon. Different pools of carbon were calculated for Chilika having a seagrass area cover of ~85.5 km^2 (average depth 1.5 m). Gaseous pool was calculated by measuring CO_2 and CH_4 whereas the dissolved carbon pool was computed by estimating DOC carbonates, bicarbonates and dissolved CO_2. Biomass of seagrass (AGB and BGB) was estimated and converted into carbon. Sediment organic carbon in depth profile was measured for estimation of total buried organic carbon (Figure 4). It was observed that sediments were the largest storehouse of the captured carbon (4.5-5.7 Gg C). Carbon in gaseous phase was much lower than other pools. Considering the total area (85.5 sq. km) covered with thick seagrass vegetation (>70% live biomass), biomass carbon as a result of NEP was estimated to be 2.3-2.5 Gg C in Chilika lagoon (Figure 4).

Impacts due to Degradation of Seagrass Beds

The seagrass ecosystems are among the world's most threatened ecosystems, with annual global loss rates of seagrass extent averaging 1.5% since the beginning of the twentieth century and accelerating in recent decade (Waycott et al., 2009). As per an estimate by Fourqurean et al. (2012), this loss in seagrass bed has resulted in a substantial decrease in C sequestration by seagrass ecosystems of 6 to 24 Tg C yr^{-1}. It is important to note that the seagrass ecosystems in India are often considered as wastelands of the coast by

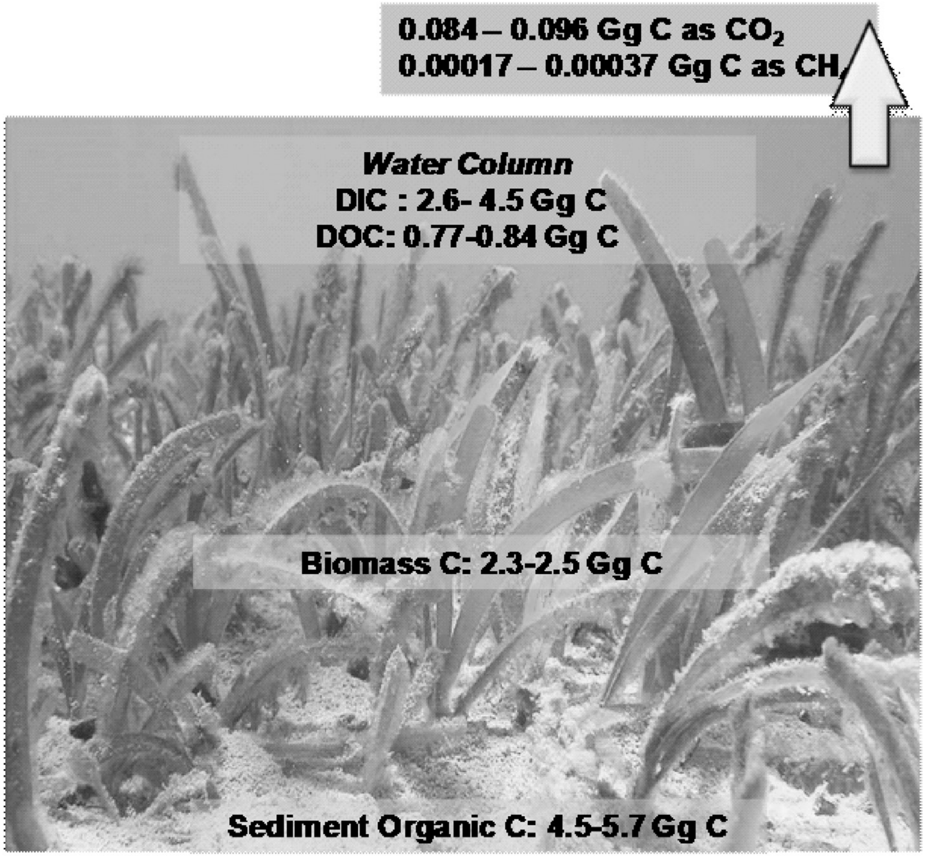


Figure 4: Significant carbon pools in Chilika ecosystem.

local inhabitants due to lack of awareness. The loss of seagrass area in India due to anthropogenic activities has been rarely mapped.

Seagrass are sentinels of change in the environmental condition such as water quality, sediment loading, and human induced modifications. They give early indication of detoriating water quality with growth plant competitors like macroalgae and microalgae. Additionally, degradation of seagrass bed can change the sediment character from anoxic to oxic condition which in turn may stimulate the decomposition of stored carbon and corresponding GHG emission from the degraded bed. Efforts have been made for the first time by NCSCM to quantify the net CH_4 exchange from Indian seagrass bed (unpublished results). Initial results indicated that degraded seagrass bed and coastal water has 3-8 times higher dissolved GHG concentration as compared to healthy seagrass bed.

Seagrass Ecosystem and Blue Economy

There exists an intricate relationship between societies and nature, and seagrass ecosystem is no exception. Seagrass ecosystems are observed to play an important role in ecological functions and ecosystem services such as food web dynamics, seascape interactions and ecological resilience potential. Irrespective of the geographic location i.e., tropical or temperate, they have shown to stabilize the sea floor, sequester carbon and create supportive conditions for fisheries and other marine habitats (Table 2).

Inclusion of Blue Carbon economy in market-based climate policy mechanisms could result in significant funding for coastal ecosystem protection and restoration. However, several factors should be carefully considered (country specific and ecosystem specific) and several preconditions should be met before Blue Carbon can be included in many of these policy mechanisms. The services (social, financial, ecosystem level, environmental) which an ecosystem is providing to the society need to be evaluated accurately. Evaluation made by Luisetti et al. (2013) showed that the extent of European coastal blue carbon has an accounting stock value of about US $180 million. No such effort has been initiated in the Indian sub-continent to evaluate the value of the coastal blue carbon. Critical evaluation

Table 2: Ecosystem services of seagrass ecosystem of India

Regulating	*Supporting*	*Provisioning*	*Cultural*
• Climate regulation	• Photosynthesis	• Food, raw materials	• Cultural diversity
• Erosion regulation	• Primary production	• Biodiversity	• Spiritual and religious values
• Water purification	• Nutrient cycle	• Aquaculture	• Knowledge systems
• Carbon sequestration	• Water cycle	• Biochemicals/Pharmaceuticals	• Educational values
• Fresh-water storage and retention		• Natural medicines	• Employment
• Natural hazard regulation		• Genetic resources	• Aesthetic values
• Pollination		• Energy (human use)	• Social relations
• Biological regulation		• Ornamental resources	• Cultural heritage
• Soil fertility		• Traditional and bio-physical products	• Recreation and eco-tourism
• Air quality regulation			

of these direct and several other indirect services can lead to the successful estimation of the economic value of the ecosystem.

Summary

Lack of a comprehensive database of blue carbon from the ecologically important coastal ecosystems of India is an established fact. The present review, hence thereby, throws light on the potential of the carbon storage, sequestration and release potential of seagrass and associated ecosystems along the Indian coast. It further highlights the need of standard protocol to study the geography, biology and economic value of all major seagrass ecosystems in India. A brief outlook of the role of seagrass ecosystem in blue carbon sequestration was elucidated in the present study which depicted that these unique ecosystems are a huge sink of carbon, yet to be explored. The study showed that the seagrass develop intricate supportive environment to ambient ecosystems by increasing the oxygenation as well as facilitating calcification rates. The present study also depicted the impact of natural variables (salinity, temperature and carbon dioxide) as well as stresses (degradation and pollution) and on the biogeochemistry of these ecosystems.

The impact on the regional/global scale climate change could be determined through detailed and in-depth study of all major seagrass ecosystems in India. In depth studies are needed for understanding the actual role of these unique ecosystems towards the release of GHGs vs. their carbon sequestration potential. Some of the thematic areas for future research include: mapping of seagrass bed along Indian coast; GHG inventory; estimation of carbon stocks and budgets and estimation of its socio-economic values. Additionally, understanding the importance of these ecosystems as coupled social-ecological system is needed, particularly in developing countries in order to preserve them for a sustainable future in the current scenario of global environmental change.

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