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Salt Marsh: Ecologically Important, Yet Least Studied Blue Carbon Ecosystems in India

Kakolee Banerjee, Swati Mohan Sappal, Purvaja Ramachandran and R. Ramesh*

National Centre for Sustainable Coastal Management (NCSCM), Anna University Campus
Chennai – 600 025, Tamil Nadu, India
✉ rramesh_au@yahoo.com

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Abstract: Salt marshes are intertidal halophytic vegetations, distributed in mid to lower latitudes. They provide important ecosystem services, including transportation and remineralization of nutrients, habitat for coastal biota, coastal bioshield, biofilters and recreation and cultural benefits. In India, 15 salt marsh species so far have been reported, spread over 1600 km^2. Salt marshes are known to adapt themselves to the changing environmental conditions fairly quickly by maintaining a balance between the existing pressures and the prevailing state. Thus, they tend to retain a long-term ecosystem sustainability under changing environmental conditions. Recent studies have recognized them for their extraordinary capacity of carbon sequestration, which gives them edge amongst the coastal ecosystems, but the carbon stock is comparatively low due to their alarming decline in global areal extent.

In the Indian context, salt marshes occupy a significant share of the coastline along with the other blue carbon ecosystems like mangroves and seagrasses. This provides India with a very promising alternative for achieving its Intended Nationally Determined Contribution towards climate change mitigation through enhancing additional carbon sinks (INDC goal # 5). But, despite its rich salt marsh diversity and distribution along the entire coastline, Indian salt marshes are one of the most overlooked coastal ecosystems. The documented studies on the Indian marshes are relatively scarce and studies addressing their carbon storage and climate change mitigation potential are totally non-existent. There is an urgent need for targeted scientific studies to be taken up on the Indian salt marsh ecosystems to develop a holistic and updated database, which can support resource management, decision-making and facilitate to estimate Blue carbon economy of India.

Keywords: Salt marshes; Ecosystem services; Dynamics; Climate change; Blue carbon, India.

Introduction

Salt marshes are salt tolerant rooted vegetation and present in a low-energy transition zone between submerged and emerged environments, occupying the upper margins of the inter-tidal landscape. These plants are able to withstand high salinity and regular submersion due to regular or occasional immersion by the tides (Siikamäki et al., 2013). They are the major blue carbon ecosystems, with a greater latitudinal extent than mangroves, and are dominated by herbaceous and halophytic shrubs rather than trees. However, there are confusions in defining halophytes regarding which species should be considered as a true salt marsh species among the coastal vegetations (Grigore et al., 2010). Salt marshes provide a unique habitat for a large number of species that cannot survive in other habitats. Therefore, they are an essential element in our ecological structure.

*Corresponding Author

Global Distribution

The distribution of salt marsh species is linked to variations in soil, elevation, hydro-period or inundation frequency (Morris et al., 2002; Townend et al., 2011). Salt marshes occur worldwide, particularly distributed in temperate and arctic latitudes from 30° to 80° (Chapman, 1977), and are usually restricted to comparatively sheltered locations. Salt marshes are estimated to cover roughly 54,951 km^2 worldwide (Mcowen et al., 2017), spreading over 43 countries and territories (Figure 1). A recent study shows that the most extensive salt marsh worldwide is found outside the tropics, especially in the low-lying, ice-free coasts, bays and estuaries of the North America and Canada (41%), followed by Oceania (24%), Russian Federation (13%), China (10) and Europe (8%) (Mcowen et al. 2017).

Indian Distribution and Species

In India salt marshes are distributed in seven coastal districts/UTs, viz. Gujarat, Daman and Diu, Maharashtra, Tamil Nadu, Puducherry, Andhra Pradesh and Andaman & Nicobar Islands, covering an approximate area of 1600 km^2. Gujarat has the highest area cover of 89.5% of total cover, followed by Tamil Nadu (3.8%), Andaman & Nicobar Islands (3.7%), Andhra Pradesh (2.5%), Maharashtra (0.4%), Puducherry (0.04%) and Daman and Diu (0.04%) (SAC, 2011; Patro et al., 2017).

There is hardly any species level mapping in India, 15 major salt marsh species have been reported so far from general biodiversity studies. Common species are *Arthrocnemum indicum*, *Cressa cretica*, *Fimbristylis ferruginea*, *Heliotropium curassavicum*, *Myriostachya wightiana*, *Porteresia coarctata*, *Phragmites karka*, *Salicornia brachiate*, *Scirpus littoralis*, *Sesuvium portulacastrum*, *Suaeda maritime*, *Suaeda nudiflora*, *Suaeda monoica*, *Suaeda fruticosa* and *Urochondra setulosa* (Nayak and Bahugune, 2001; Kathiresan and Ramanathan, 2004; Patro et al., 2017).

Ecosystem Services of Salt Marsh

Ecosystem services are the benefits that humans derive from ecological systems and are generated directly from the processes that sustain ecosystems, or ecosystem functions (UNEP, 2006). Salt marshes provide some of the highest and most valuable ecosystem services among other natural ecosystems (Costanza et al., 2007; Gedan et al., 2009) which lead to one of the primary needs for protecting salt marshes (Figure 2).

Provide raw material and food: Direct provisioning of raw materials and food from salt marshes are known (Davy et al., 2009) as in different parts of the world's marsh lands are used as pasture land (Bromberg-Gedan et al., 2009).

Providing a buffer against wave and storm surges: Marsh vegetations help to stabilize the coast by trapping sediment from the runoff. In due course, increased intertidal height and vertical leaf blades provide a form of sea defense by reducing wave energy, velocity, height and duration (Morgan et al., 2009; Moller et al., 2014; Roner et al., 2015). At times, marshes support to reduce the storm surge duration and height by providing extra water uptake (Barbier et al., 2011).

Nursery areas for coastal biota: Salt marsh ecosystems play a major role in maintaining fisheries by providing nursery ground (MacKenzie and Dionne, 2008). The complex and dense plant structure of marshes provide safe habitat for commercially important young fishes, shrimp and shellfish, as this area is mostly inaccessible to large fishes. Sometimes, they act as high tide refuges for birds feeding on adjacent mudflats and acts as a source of food for marsh dependant birds (Greenberg et al., 2014).

Filters for nutrients and pollutants: Marshes are called natural filters as they effectively purify water entering the estuary (Mitsch and Gosselink, 2008). As water from upstream passes through marshland, it looses its velocity due to friction with marsh vegetation and suspended particles slowly get deposited on the marsh surface. This natural filtration mechanism facilitates nutrient and pollutant uptake and recycling process.

Facilitates carbon sequestration: Salt marshes are known as one of the most productive ecosystems in the world, as they effectively sequester atmospheric carbon and serve as an organic carbon sink (sequester millions of tons of carbon annually) (Mitsch and Gosselink, 2008).

Enhances cultural values: The aesthetics of salt marsh and high diversity of migratory and passerine birds found within marshes draws attention to many tourists and bird watchers, giving a scope for recreational activities. Salt marsh and other associated ecosystems provide wide possibilities for research.

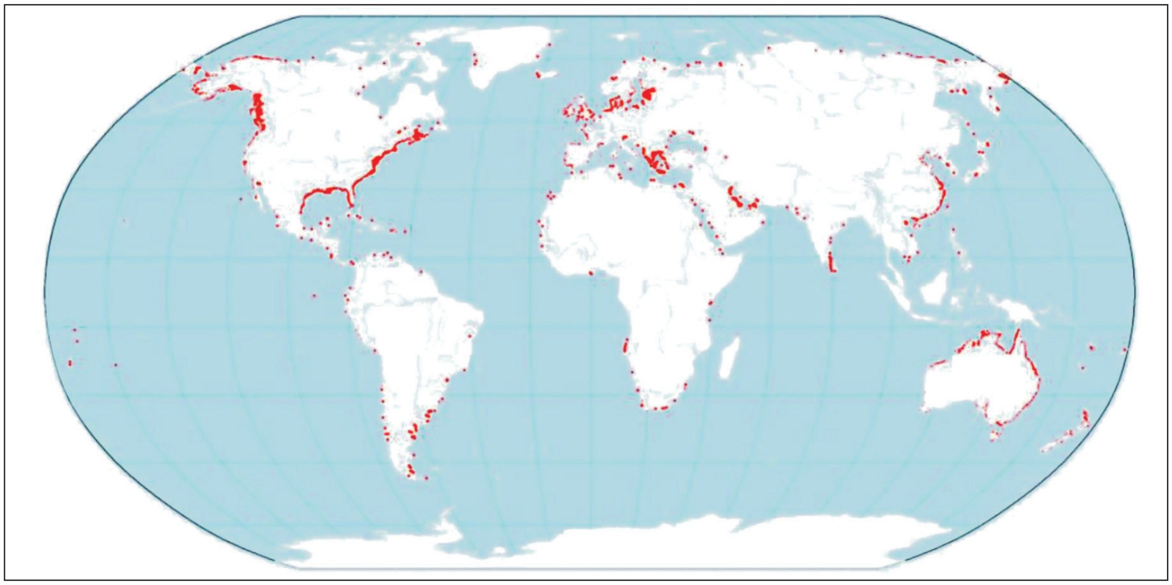

Figure 1: Global distribution of salt marshes based on current data available.
Source: **UNEP-WCMC, 2016; Mcowen et al., 2017**

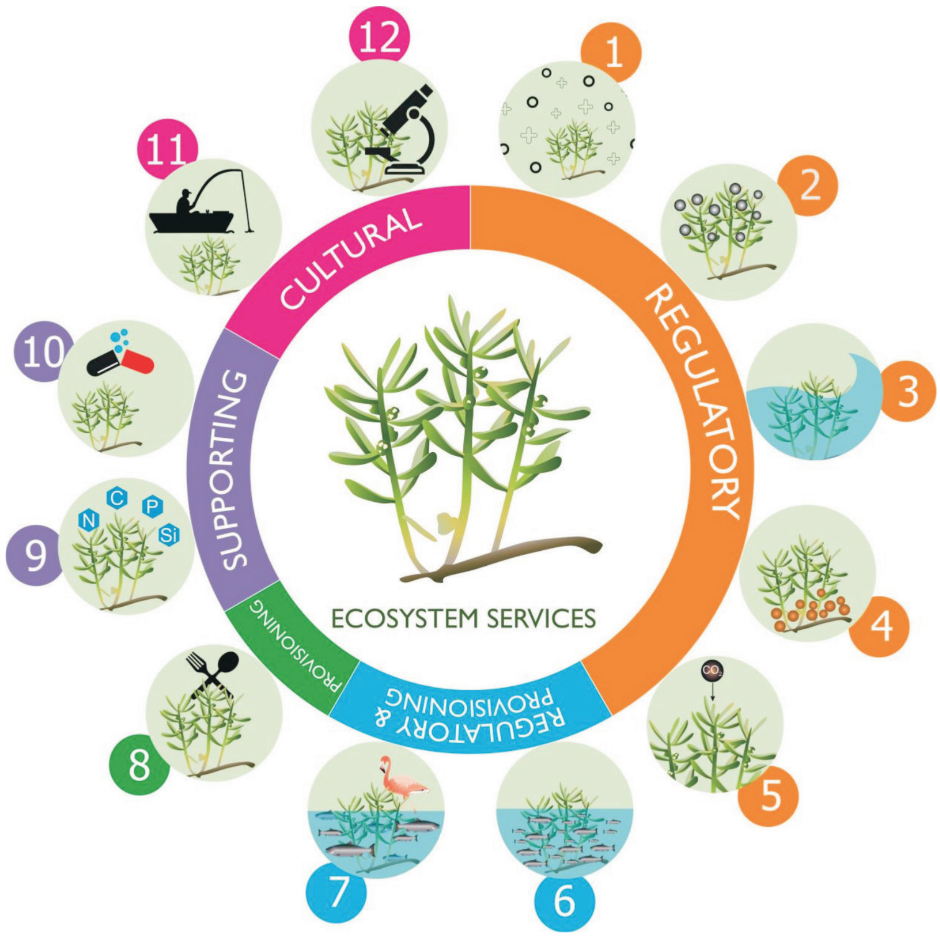

Figure 2: Ecosystem services of salt marshes: 1. Bio-filter for nutrients; 2. Trap for pollutants; 3. Buffer against waves and storms; 4. Sediment trapping and shoreline stabilization; 5. Carbon sequestration; 6. Nursery for fishes; 7. Breeding and feeding grounds; 8. Raw material and food; 9. Nutrient source for biota; 10. Medicinal use; 11. Recreation; 12. Research.

Salt Marsh Vulnerability

Coastal ecosystems are some of the most heavily exploited and threatened natural systems globally (Barbier et al., 2011), as 40% of the world's population resides on the world's coasts, which account for just 4% of the land surface (UNEP, 2006). The future of these valuable coastal ecosystems is today at risk, as they are exposed to possibly irreversible transformations due to the effects of climate changes and human interferences. Globally, 25-50% of salt marshes are either lost or degraded due to intense human activities (Crooks et al., 2011; Barbier et al., 2011). Major threats to salt marshes include biological invasions, eutrophication, climate change and sea level rise, increasing air and sea surface temperatures, increasing CO_2 concentrations, altered hydrologic regimes, marsh reclamation, vegetation disturbance, and pollution (Neubauer, 2009; Silliman et al., 2009).

- Any alteration that influences the sediment supply to the marsh is likely to have some influence on marsh development. Dredging or trawling can trigger the influx of sediment into the system or removal from the system to the nearby wetlands. This alteration in sediment load disturbs the marsh stability.

  Land reclamations and construction of sea walls can also constrain a marsh and limit the potential for marine transgression.

  Grazing on the marsh can be both beneficial or detrimental, depending on the grazing intensity.
- Nutrients, such as nitrogen and phosphorus, from several points and non-point sources like fertilizers, septic systems and farm wastes are common pollutants that in high enough concentrations can change the structure and function of any natural ecosystems. These excess nutrients are a particular problem in salt marshes because they lead to eutrophication.
- Salt marshes are also prone to trace metal pollution with possibility of its biological uptake. Metal accumulates majorly in the plant roots rather than the aerial portions. Salt marsh species like *Zostera marina* are efficiently used as biomonitors to assess the possible pollution effects as they are able to reflect metal concentrations in the surrounding water and sediments (Williams et al., 1994).
- Introduction of salt marsh species for coastal defense has led to large-scale invasions of many grasses, mostly Spartina (Daehler and Strong, 1996). Apart from that, exotic plants and animals introduced by humans can also change community composition and disrupt the food webs and ecological functions.
- Severe environmental stress from temperature fluctuations, high soil salinity and low oxygen availability has limited salt marsh plant diversity to a handful of stress-tolerant, halophytic genera (Chapman, 1977; Gedan et al., 2009).

Salt Marsh Dynamics

Salt marshes are known to form in low energy environments where there is shelter from the wind and waves and require a large input of sediment which arrive from the sea via tides, storms, etc. and from the rivers. The low gradient of the tidal flats provides a substratum for the deposition of the sediments transported by the flowing rivers. At the same time, the periodic flooding of the tidal flat by the tides deposits even more sediments. The geomorphology of the salt marshes has been studied to be in close equilibrium over time scales ranging from a few decades to centuries (Reed, 1988; Allen, 2000b; French, 2006). Salt marshes are known to adapt themselves to the changing environmental conditions fairly quickly, thus, creating a dynamic balance between the forcing conditions like winds, tides, surges and the prevailing state (Friedrichs and Perry, 2001). It is this short-term adaptability of these coastal ecosystems that helps them to cope up with the adverse coastal environment and sustain long-term stability.

The development of a salt marsh depends on a host of variables, of which estuarine accommodation space (EAS) is a key governing factor. EAS refers to the volume freely available for the storage of water and sediments in a coastal space have been found to control channel dynamics and thus salt marsh formation (Townend et al., 2011). The EAS tends to vary in time and space and is regulated by changes in the sea level, basin hypsometry, and supply of sediments. Any change in the EAS tends to change the salt marsh characteristics via land build-up or erosion, leading to the lateral migration of these ecosystems.

In case of small or limited space, erosional episodes become dominant and thus there will be prevalence of extensive sand and mud flats. On the other hand, when the EAS is large, there will be increased sedimentation leading to stabilisation of the channel and formation of abundant salt marshes. The influence of EAS on the channel stabilisation and salt marsh development has been well studied in the temperate salt marshes (Rees et al., 2000; Long et al., 2000; Townend et al., 2007). Many authors have studied that the salt marsh development/EAS is also affected by sea level changes and marine transgression (Allen, 1990b; Pethick, 1996; Long et al., 2000). As the sea level rises, landward migration/expansion is pronounced; salt marsh in order to keep pace with the sea level also migrates inland in relation to the hinterland topography (Morris, 2007). Thus, salt marshes quickly adjust to the changing hydrodynamic conditions (Pethick, 1992; Day et al., 1999; Morris, 2000; Morris et al., 2002; Kirwan and Murray, 2007; Morris, 2007; Knaapen et al., 2009).

Furthermore, seasonal changes also affect the salt marsh development viz changes in tidal regimes, freshwater inflow, etc., which regulate the sediment delivery, soil salinity, nutrient availability and other such factors (Morris et al., 2002; Mudd et al., 2013; French, 2006; Townend et al., 2011). In addition to this, the waves have been found to influence salt marsh formation and their impact has been studied via two perspectives. Firstly, salt marshes act as a first line of defense against the fury of storms and waves by dissipating their energy (Pethick, 1998; Moeller et al., 2001) and secondly, they get adversely impacted by their exposure (Gray, 1992; Carniello et al., 2007). The geomorphology and the response of salt marsh is greatly transformed by the combined effect of tidal range and wave/storms.

Studies have found that there is a significant difference in the behaviour of marshes developing in the micro tidal and macro/meso tidal estuaries. In microtidal estuaries, the tidal range is small and the marshes are majorly dependent on the storm surges for the supply of sediments. Due to this, such marshes are found to show a rapid response by accreting vertically and expanding horizontally over a short time span. Whereas, marshes developing in the macro and meso-tidal estuaries are largely dependent on the tidal delivery of the sediments which is slow, gradual and continuous (Stumpf, 1983; French and Spencer, 1993), as a consequence, these marshes are better able to keep pace with rising sea-levels (Friedrichs and Perry, 2001).

The hydroperiod is another factor which affects the salt marsh formation and sedimentation. Hydroperiod is found to largely govern the sedimentation patterns (Reed, 1990) and biological productivity in contrasting ways. Greater hydroperiod leads to greater sedimentation and substrate development; however, this also induces a stress on the growing salt marsh plants, thus, inhibiting the biological productivity. Hence, the net impact of the hydroperiod varies spatially with lower marshes being stunted with dominant inorganic sedimentation and higher marshes with dominant organic sedimentation.

The nature and source of the deposited sediment also are an important parameter to quantify in order to delineate the salt marsh characteristics. Like in other coastal ecosystems, sediment deposition in salt marshes can also be contributed by a host of sources which may be both organic autochthonous and inorganic allochthonous (Sappal et al., 2016). Salt marsh formation and persistence are dependent on the net flux of sediment onto the marsh platform (Kirwan et al., 2010; Fagherazzi et al., 2012) and loss of salt marsh during storms (Mariotti and Fagherazzi, 2010; Tonelli et al. 2010). Sediment deposition, along with accumulation of autochthonous organic material, contributes to the health of the salt marsh ecosystem by providing vertical accretion necessary for a marsh surface to maintain its elevation above mean sea level as sea level rises (Reed, 1989; Morris et al., 2002; Mudd et al., 2009). Overall, the healthy salt marshes need to be net sediment sinks with organic rich sediments.

Additionally, the sedimentation in the marshes has been found to be governed by the presence of vegetation. Many attempts have been made to specifically study the sediment deposition and their distribution patterns influenced by the presence of marsh vegetation (Ranwell, 1964; Friedrichs and Perry, 2001; Morris et al., 2002; Mudd et al., 2004; Temmerman et al., 2004; Marani et al., 2007; Knaapen et al., 2009). Plant canopy has been found to trap sediment in a number of ways, but there is still a dearth of studies addressing the subsequent modification of the deposited sediments by the marsh vegetation.

Nutrient Cycling in Salt Marshes

Nutrients are an important component required for the functioning of the salt marsh ecosystems. Being primarily partitioned between the dissolved and the particulate phases, the nutrients (viz. organic carbon, inorganic compounds/elements like nitrates, nitrites, phosphates, silicates, heavy metals, etc.) are mainly derived from the hinterland sources, brought down to the marsh ecosystems through river runoff, storm water, groundwater discharge and also by oceanic systems via tides and waves. However, the input through the terrestrial sources outweighs the oceanic inputs in most of the cases (Correll et al., 1992; Taylor, 1992; Valiela et al., 1993). Besides, advective fluxes between the sediment water and overlying water additionally modify the nutrient concentrations within the salt marsh ecosystems (Whiting and Childers, 1989). These wetlands have been found to be a statistically significant sink of nutrients (like nitrates and phosphates) (Spurrier and Kjerfve, 1988, Wolaver and Spurrier, 1988; Dame et al., 1990, De-Laune and Patrick, 1990), thus validating their role as a nutrient trap and water filters. With the growing concern of the anthropogenic interventions in the coastal ecosystems, nutrient cycling in the salt marshes has received considerable interest. These ecosystems have been comprehensively reviewed in context of biogeochemical cycling of nitrogen, phosphorous, silica and heavy metals (Vernberg, 1993; Williams et al, 1994; Fagherazzi et al., 2013). But the studies targeting on carbon cycling and storage in salt marshes only recently gathered attention (Neubauer et al., 2000; Chmura et al., 2003; Mudd et al., 2009; Murray et al., 2011; Livesly and Andrusiak, 2012; Kirwan and Mudd, 2012; Macreadie et al., 2013; Siikamaeki et al., 2013; Ouyang and Lee, 2014; Coverdale et al., 2014).

Salt marshes like other coastal ecosystems are thought to store significant amounts of organic carbon in their biomass and sedimentary reserves, with sediments being comparatively larger storehouses in view of their ability to preserve carbon under constantly flooded conditions (Murray et al., 2011; Sappal et al., 2016). The amount of this carbon stored is usually a consequence of competition between mineral sediment deposition and organic matter accumulation (Mudd et al., 2009). Furthermore, warm conditions and increased sea level, which is a result of the changing climate, have also been found to affect the carbon storage and cycling in salt marsh ecosystems (Kirwan and Mudd, 2012). There exist a few studies which focus on the sedimentary carbon storage and emissions in salt marsh ecosystems and the processes affecting them (Chmura et al., 2003, Murray et al., 2011; Livesly and Andrusiak, 2012; Macreadie et al., 2013; Siikamaeki et al., 2013). However, very little is yet understood about the carbon dynamics in dissolved and particulate fractions in salt marsh ecosystems which can drastically affect their carbon budgets and storage. Apart from the ability of salt marshes to store carbon, they have also been found to export/out well a significant portion of it to the oceans and seas (Alongi, 1998; Childers et al., 2000; Odum, 2000; Valiela et al., 2000). This out welling is mainly controlled by the salt marsh hydrology and geomorphology (Bianchi, 2007). Some studies show that the out welling via the dissolved fractions outcompetes the out welling via the particulate fractions (Eldridge and Cifuentes, 2000).

Capacity of Salt Marshes to Act as Carbon Sinks

Only a very insignificant amount of the planet's active carbon is present in the atmosphere, but much of it is stored in coastal wetlands as blue carbon. It is estimated that ~450 Pg of carbon is stored in coastal wetland soils, which accounts for almost one third of the global carbon stock (~1550 Pg) (Mitsch and Gosselink, 2007; Lal, 2008; Zhao et al., 2016). The capacity of coastal ecosystems to sequester carbon is dependent upon three broad ecosystem factors: (1) high productivity in converting CO_2 into plant biomass C- (assimilation of carbon) (Alongi, 2002); (2) effective trapping of particulate organic C originating from within the ecosystem (autochthonous C) and/or from external sources (allochthonous C) (Kennedy et al., 2010); and (3) biogeochemical conditions within sediments which slow the decay of organic material and facilitate long-term storage (carbon sequestration) (Fourqurean et al., 2012; Kristensen et al., 2008; McLeod et al., 2011; Kelleway et al., 2017). Salt marshes provide short-term storage of C through biomass of vegetation, and provide long-term storage through their capacity to store C in anaerobic sediments (Mcloed, 2011). Exceptionally high primary productivity rate in marshes actively removes carbon from the atmosphere by photosynthesis (Duarte, 2005). Apart from that, sediment trapping efficiency of marshes depends on the vegetation type which controls particle settling velocity by reducing the kinetic energy or by directly capturing sediment particles (Leonard and Croft, 2006; Li and Yang, 2009; Mudd et al., 2010). Another way of organic matter settlement takes place via direct deposition due to root growth and litter deposition (Nyman et al., 2006; Neubauer, 2008; Mudd et al., 2009). Salt marshes have some of the highest rates of carbon storage capacity among other coastal vegetative ecosystems (Figure 3) and globally the average C accumulation rate in salt marsh soils is estimated to be ~245 g cm^{-2} yr^{-1} (Ouyang and Lee, 2014; Roner et al, 2015).

The largest flux of CO_2 in the global C cycle is driven by the greenhouse gas exchange between coastal wetlands and the atmosphere, which is again governed by metabolic activities like photosynthesis and respiration (Schlesinger, 1991). Biogeochemical and microbial processes largely control the emissions of both CH_4 and CO_2 in salt marshes. However, although salt marshes are net carbon sinks, they act as a source of carbon to the atmosphere as CO_2 and CH_4 (Chmura et al., 2003; Kristensen et al., 2008), but their emission magnitude is relatively lower than other coastal ecosystems (Livesley and Andrusiak, 2012). High saline conditions in marshland restricts emissions of methane as the system is having abundant sulphate electron acceptors which suppresses methanogenesis. However, there are recent studies which show a large amount of CH_4 emissions even though the sulphate reduction is dominant (Lee et al., 2008; Alongi, 2009). Also, periodic oxidation of sediment allows aerobic decomposition of organic material (Moseman-Valtierra, 2011).

Siikamäki et al. (2012) compiled data on carbon storage and emissions from different coastal ecosystems (Table 1), which distinctly shows that emissions from marsh ecosystems are 2-10 times lower than mangroves.

Table 1: Comparison between carbon storage and emissions among the blue carbon ecosystems

Storage (Pg C)	*Mangroves*	*Salt marsh*	*Seagrass*
Biomass	2.05	0.02	0.06
Soil (up to 1 m depth)	4.45	1.99	2.23
Total stock	6.51	2.01	2.29
Burial	0.02	0.01	0.03
Emissions (Pg C)			
Biomass	0.011	<0.001	<0.001
Soil	0.019	0.009	0.010

Source: Siikamäki et al., 2012

Climate Change and Salt Marshes – Probable Impacts

Climate change is a global and unintended force caused by human abuse on nature. Salt marshes are experiencing simultaneous changes in climate and food web structure owing to direct and indirect effects of human activities. Ambiguity is still there on the specific response of marshes towards the shifting climate, though it is expected that the ultimate response of marsh ecosystems will be dependent on the degree of climate change and ecosystem resilience (Figure 4).

Anthropogenic CO_2 release into the atmosphere is a major driving force for climate change, which affects salt marshes in varied ways. Several studies showed that C_3 marsh plants grow more in elevated CO_2 conditions, whereas growth ceases in C_4 marsh species. This composition specific response of salt marshes to elevated CO_2 speculate that there is a chance of compositional shifts toward C_3 plants, as C_4 plants will be gradually outproduced and outcompeted (Lenssen et al., 1993; Ainsworth and Long, 2005; Erickson et al., 2007; Gedan et al., 2009).

Effect of global warming is multi dimensional. Predicted increase in atmospheric temperature, due to elevated CO_2 level, will cause increased soil evaporation, which could elevate soil salinities in marshes, leading to decreased plant productivity and increase the size, extent and latitudinal range where soil salinities are too stressful for most plants to live (Bertness et al., 2004).

Another consequence of global warming is rise in sea level due to thermal expansion of water and melting of land-based ice sheets. Mid 20^{th} century onwards increase in sea level has already gradually shifted the distribution of marsh plants to higher elevations, towards landward. Landward migration of marshes could eventually bring a shift in species or sometimes replacement of salt marsh by mangroves (Rogers et al., 2005). If salt marshes are unable to keep pace with continued sea level rise and swift moving inland, they will be submerged. This could lead to the loss of large areas of coastal marshes, ultimately invite catastrophic consequences on coastal systems with increased rates of shoreline erosion, increased nutrients and pollutants from runoff entering estuaries, decreased nursery habitat (Morris et al., 2002; Bertness et al., 2004).

As an effect of climate change, extreme events like storm-surges could affect the first line of coastal defense, salt marshes. Magnitude of ecological disturbance caused by storms on the marshes is less than in terrestrial habitats (Michener et al., 1997). However, intense storms will likely increase inter-annual and inter-marsh variability in sedimentation rates (Cahoon, 2006).

Research Status in the Indian Context

Salt marshes have been one of the most overlooked coastal ecosystems in India with only a small number of studies documented so far. In the available literature on the Indian coastline, the research focus is mainly oriented towards the ecological and biological aspects of the salt marsh ecosystems and there is a dearth of literature exploring their hydrological, biogeochemical and climate change mitigation aspects.

In a recent study by Patro et al. (2017), they presented a checklist of true salt marsh species existing in the Indian coastline. The challenge with the salt marsh species identification is that it is difficult to distinguish between the true salt marsh species from other coastal vegetation due to the large ambiguity in the available literature. Out of the 45 species of salt marshes and other coastal vegetation documented in India by Kathiresan and Ramanathan (2004), the study by Patro et al. (2017) concluded that only 15 of them

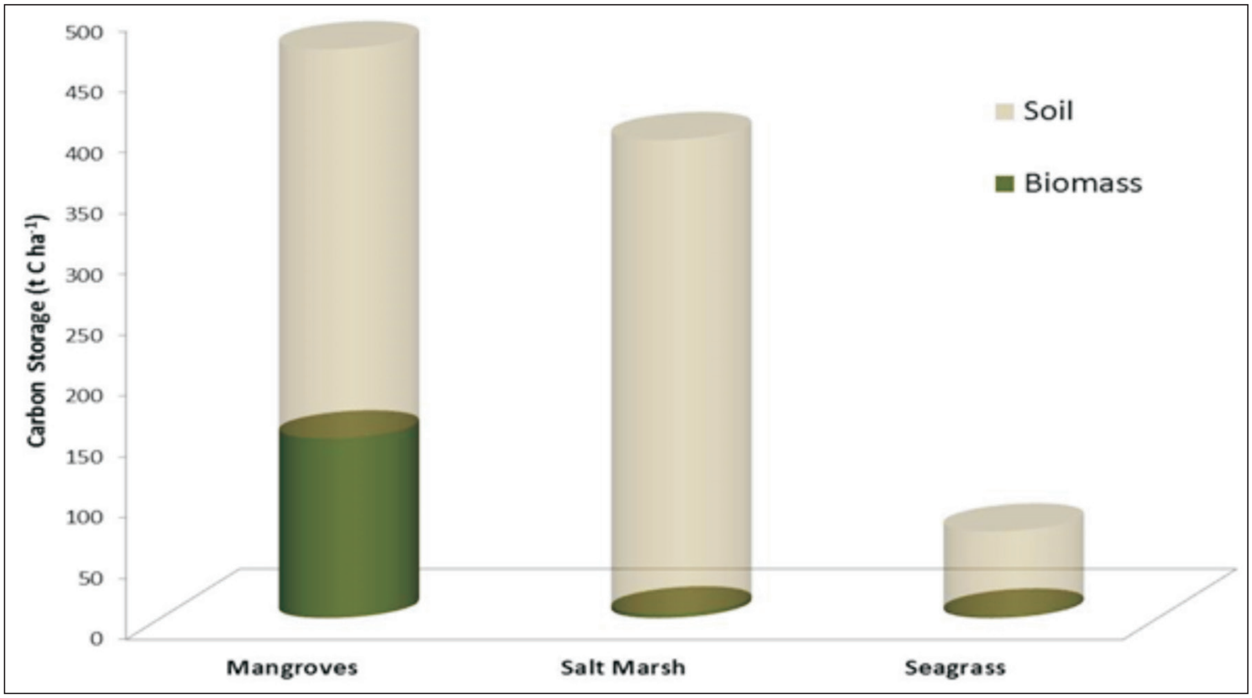

Figure 3: Carbon storage capacity of blue carbon ecosystems (data from Siikamäki et al., 2012).

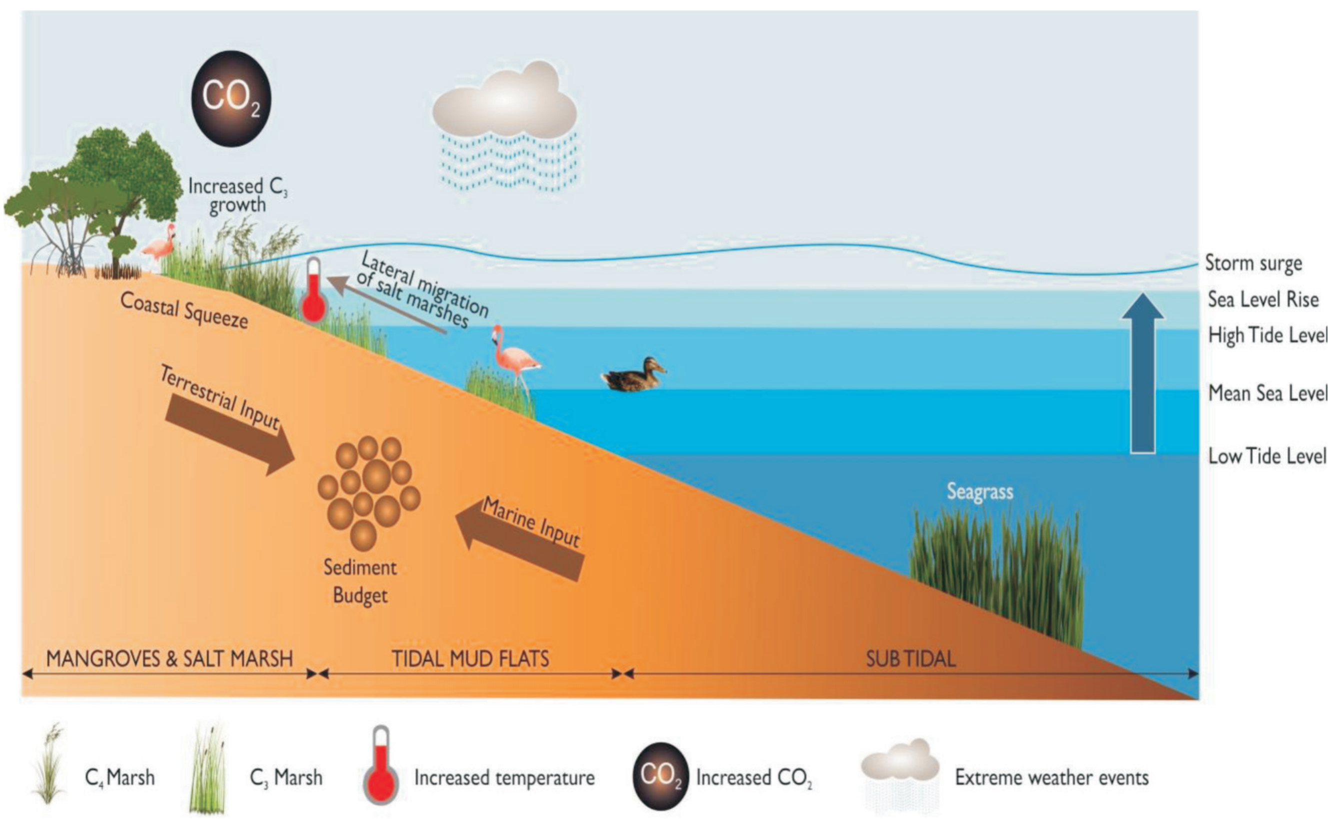

Figure 4: Conceptual representation of effect of climate change on salt marshes.

are truly salt marsh species in view of their classical definition and qualifying characteristics. Apart from this, there also exist a few studies along the Indian coastline that demarcate the distribution of these species (Nayak and Bahuguna, 2001; SAC, 2011; Ayyappan and Ravindran, 2014).

A few studies from the Indian subcontinent have highlighted the therapeutic properties of salt marsh plants. A study conducted by Chandrasekaran et al. (2009) concludes that the salt marsh halophytes show antibacterial action against isolates of *staphylococcus aureus*. In another study by Ravikumar et al. (2010), it was found that the leaf extracts of marsh species like *Suaeda monoica* seem to possess hepato-protective activity. In the work by Gayathri et al. (2010), bioprospecting potential of the endophytic fungi isolated from the leaves of salt marsh and mangrove species has been assessed. It was found that out of the total 36 isolates of bacteria, more than 20 isolates were sensitive to antibiotics like streptomycin and trimethoprim, while 31 isolates were resistant to vancomycin and bacitracin. Almost 85-95% of the strains were found to promote growth. The study established that salt marshes are sources of endophytic bacteria that produce substances of potential antimicrobial, enzymatic, plant growth promoting and biodegrading activities.

A few more biological studies, like Ingole et al. (1987), assessed the benthic meiofauna in the Saphala salt marsh in the west coast of India. Their study showed that the meiofaunal distribution was generally abundant in to the top 5 cm of the sediment layer and was found to be influenced by soil salinity, dissolved oxygen contents and the availability of the food. Benthic fauna was dominated by nematodes, harpacticoids, turbellaria, crustacean nauplii and polychaetes. Also, it has been reported that the rhizosphere soils of the pioneer salt marsh plants in the Ganges river delta are associated with vesicular arbuscular mycorrhizal colonization (Sengupta and Chaudhuri, 1990). These fungi are scientifically well known for their ability to uptake and transport mineral nutrients from the soil directly into host plant roots thus exhibiting mutually beneficial partnership.

In another study by Ravindran et al. (2007), the authors identified the salt marsh species with high potential for salt accumulation to assess the applicability of salt bioaccumulation via salt marsh plants. Their study concluded that among studied species, *Suaeda maritima* and *Sesuvium portulacastrum* exhibited greater accumulation of salts in their tissues as well as higher reduction of salts in the soil medium. These species could therefore be used successfully to remediate saline soils which can then be used for crop production after a few repeated cultivation and harvest. Ayyappan and Ravindran (2014) evaluated the tolerance and bioaccumulation potential of *Suaeda monoica* of heavy metals from tannery effluent. Their results showed that 1 kg dry weight of *Suaeda Monoica* can accumulate as much as 40.89 mg kg^{-1} Cr, 17.50 mg kg^{-1} Cd, 29.2 mg kg^{-1} Cu, 60.20 mg kg^{-1} Zn, and 194.83 mg kg^{-1} NaCl from the soil treated with tannery effluent.

Existing Knowledge Gaps and Future Recommendation

Salt marshes like the other coastal ecosystems (mangroves and seagrass) have been recognized to be of immense ecological importance. They provide a variety of ecosystem services, of which, their ability to sequester and store carbon under adverse environmental conditions is a comparatively newly acknowledged aspect. Current research developments show that the salt marshes have recently gathered the interest of the scientific community in terms of its carbon sequestration potential, but there is still lack of such studies in terms of their global coverage. In the context of Indian salt marshes, such studies are non-existent. Considering the increased recognition of salt marshes as 'blue carbon' (C) sinks, studies on carbon storage capacity from salt marshes and climate change mitigation potential will help to achieve India's Intended Nationally Determined Contribuion #5 (INDC goals), as India has already committed to create an additional sink of 2.5-3 billion tonnes of CO_2 equivalent. India is bestowed with a vast coastline with salt marshes covering as much as 1600 km^2 of area (SAC, 2011) but these ecosystems are also under tremendous pressure owing to the increasing habitat loss.

Despite their importance, knowledge of the current spatial distribution (occurrence and extent) of salt marshes is incomplete. There is a need to correctly map and monitor these threatened ecosystems and update the existing data. More work is needed to be carried out to determine the shifts in the regulating mechanisms of salt marshes and to identify the drivers responsible for the change. There is also a need to estimate the possible emissions of greenhouse gases from natural and degraded Indian salt marshes. Furthermore, the biogeochemical controls on the carbon storage need to be studied in order to better understand the carbon dynamics in these ecosystems. Such data can support resource management, carbon stock estimation, strengthen decision-making and facilitate to estimate Blue economy of India. In a much larger context, management of salt marshes needs to be integrated into coastal zone development and climate change adaptation policies.

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