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SCOPE AND POTENTIAL OF COASTAL ECOSYSTEM TOWARDS MITIGATING CLIMATE CHANGE

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SCOPE AND POTENTIAL OF **COASTAL ECOSYSTEM TOWARDS MITIGATING CLIMATE CHANGE**

Introduction

Coastal ecosystems are some of the most productive natural systems on Earth and are home to a wealth of biodiversity. They provide us with essential ecosystem services, such as coastal protection from storms and nursery grounds for fish. Coastal and marine ecosystems encompass a wide range of important habitats, which include coral reefs, mangroves, seagrass meadows, tidal marshes, sand dune systems, and salt marshes. They are among the planet's greatest carbon storehouses, with CO_2 burial rates (i.e., rates at which carbon is converted into biomass through photosynthesis) 20 times greater than any other terrestrial ecosystem, including boreal and tropical forests (Hamilton 2018). Their role in sequestering and storing 'blue' carbon from the atmosphere and oceans is also increasingly being recognized by policymakers worldwide. The three types of coastal wetlands—mangroves, seagrasses, and tidal salt marshes–commonly referred to as blue carbon ecosystems–provide a full spectrum of mitigation, adaptation, and resilience benefits. These wetlands provide numerous benefits and services that contribute to people's ability to mitigate and adapt to the impact of climate change. Many of these services are essential for climate adaptation and resilience along coasts, including protection from storm surge and sea-level rise, prevention of erosion along shorelines, coastal water quality regulation, nutrient recycling, sediment trapping, habitat provision for numerous commercially important and endangered marine species, and food security for many coastal communities around the world (Kennedy 1984; Robertson and Alongi 1992; King and Lester 1995; Hogarth 1999; Beck, Heck, Able, *et al*. 2001; Kathiresan and Bingham 2001; Saenger 2002; Mumby 2006; Gedan, Silliman, and Bertness 2009; Barbier, Hacker, Kennedy, *et al*. 2011; Sousa, Lillebø, Risgaard-Petersen, *et al*. 2012; Cullen-Unsworth and Unsworth 2013). An estimated 151 countries around the world contain at least one of these coastal wetland ecosystems, and 71 countries contain all the three. Blue carbon is the carbon stored in mangroves, tidal salt marshes, and seagrass meadows within the soil, aboveground living biomass (leaves, branches, stems), belowground living biomass (roots), and non-living biomass. The carbon that is stored in the coastal ecosystems can be extensive and can remain trapped for very long periods (it can be centuries to millennia) and thus result in very large carbon stocks. Due to coastal development and land-use change, mangroves, tidal salt marshes, and seagrasses are under great pressure. The significant difference in the soil carbon accumulated in the terrestrial and the coastal ecosystems is that potential carbon storage in upland soil is limited by high availability of oxygen, allowing for aerobic microbial carbon oxidation and release back into the atmosphere (Schlesinger and Lichter 2001). However, in blue carbon ecosystems, the soil is saturated with water keeping it in anaerobic state (low to no oxygen), and it continually accretes vertically at high rates, resulting in continuous build-up of carbon over time (Chmura, Anisfeld, Cahoon, *et al*. 2003).

When vegetation is removed and the land is either drained or dredged for economic development, the sediments become exposed to the atmosphere or water column resulting in the carbon stored in the sediment bonding with oxygen in air to form CO_2 and other greenhouse gases (GHGs) that get released into the atmosphere and ocean. Not only such activities result in CO_2 emissions but they also lead to losses of biodiversity and critical ecosystem services.

The carbon found in the blue carbon ecosystem is categorized into two—autochthonous carbon and allochthonous carbon—which need to be assessed separately (Middelburg Nieuwenhuize, Lubberts, *et al.* 1997; Kennedy, Beggins, Duarte, *et al.* 2010). Autochthonous carbon is produced and deposited in the same location. Plants remove CO_2 from atmosphere/ocean through photosynthesis (primary production) and convert it for use by plant tissue (such as leaves, stems, roots/ rhizomes) to increase plant biomass. A large portion of plant biomass gets allocated to the roots where it decomposes very slowly in anaerobic conditions, thus storing the carbon within the sediments. Contrarily, allochthonous carbon is produced in one location and deposited in another. Blue carbon ecosystems exist in very hydro dynamically active settings; they are constantly battered by waves, tides, and coastal currents that transport sediments and associated organic carbon from adjacent ecosystems (offshore or terrestrial) to other places. The plants found in these systems have complex root structures and canopies that are efficient at trapping sediment moving through the system, adding to the local carbon stock as a result (Figure 1).

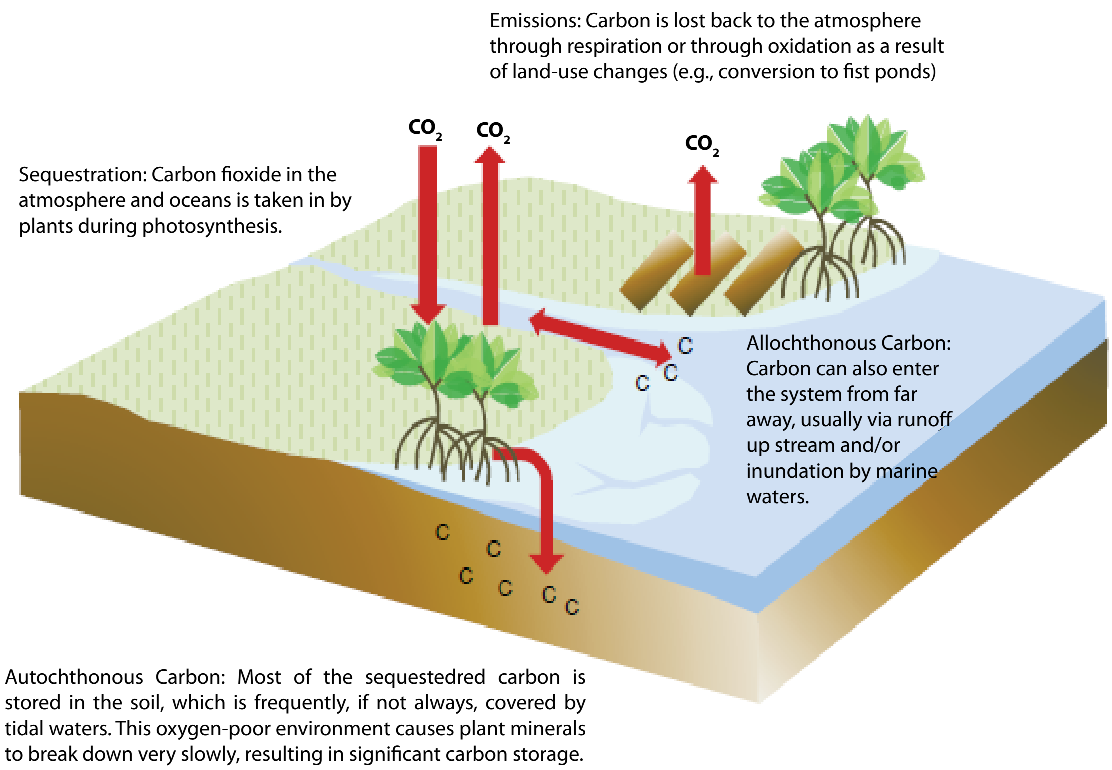

Figure 1: Allochthonous carbon and autochthonous carbon

Mangroves

Mangroves are defined as an association of halophytic trees, shrubs, and other plants growing in brackish to saline tidal waters of tropical and subtropical coastlines (Mitsch and Gosselink 2007). A mangrove is a tree, shrub, palm or ground fern, generally exceeding a half meter in height that normally grows above the mean sea level in the intertidal zone of marine coastal environments and estuarine margins. Mangroves are salt-tolerant plants and occur mainly between latitude 24°N and 38°S, and exhibit varied morphological and physiological evolutionary adaptations to survive the limiting factors imposed by lack of oxygen, high salinity, and diurnal tidal inundation. Succulent leaves, sunken stomata, pneumatophores, vivipary, stilt roots, buttresses, etc., are some of the adaptations exhibited by mangroves.

Mangrove Cover

The total mangrove cover in the world is 15 million hectare which is 1% of the total tropical forests. In India, according to the latest assessment by the Forest Survey of India (FSI), the mangrove cover is 4975 km^2, which is 0.15% of the country's total geographical area. The very dense mangrove comprises 1476 km^2 (29.66%) of the mangrove cover, moderately dense mangrove is 1479 km^2 (29.73%) while open mangroves constitute an area of 2020 km^2 (40.61%) in the country. West Bengal alone has 42.45% of India's mangrove cover, followed by Gujarat (23.66%), and Andaman and Nicobar Islands (12.39%). As per the assessment, Gujarat has shown maximum increase of 37 km^2 in mangrove cover. There has been a net increase of 54 km^2 in the mangrove cover as compared to the 2017 assessment in the country. The trend in mangrove cover from 2003 to 2019 is shown in Figure 2. The total mangrove cover has increased over the years.

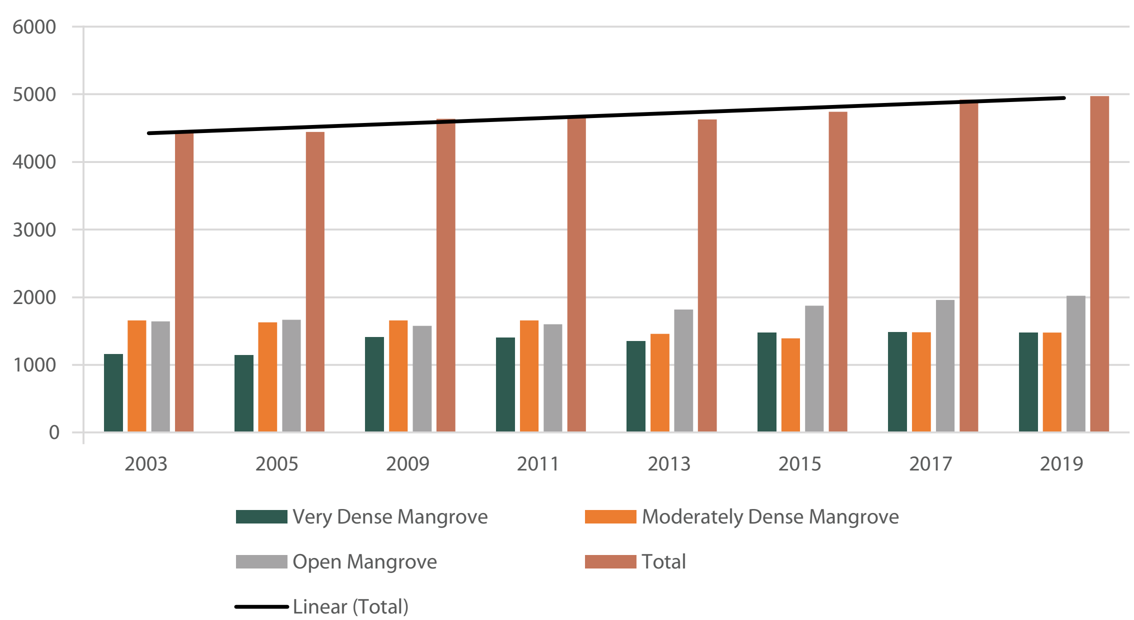

Figure 2: Status of mangrove cover since 2003–2019 in India

Conservation Measures for Mangroves in India

Mangrove ecosystems in India face continuous pressure due to increased human population in coastal areas and rising demand for small timber, fodder, fuelwood, and other non-wood forest products. Thus, there is a need to have appropriate management and conservation strategies for their conservation and sustainably generating the ecosystem's benefits along with the forest products to meet the needs of the local people. Realizing the same, mangrove-bearing states in the country are implementing different measures for conservation and management of the mangroves. For example, some of the important techniques adopted in Gujarat for restoring the degraded mangrove habitats include direct seed sowing, raised bed plantations, and fishbone channel plantation. In Andhra Pradesh, the Forest Department has formed Eco-development Committees and Van Samrakshan Samitis for joint implementation of projects in mangrove areas. Regular trainings are also being conducted for sustainable mangrove conservation. In Maharashtra, steps have been taken to conserve ecology and biodiversity of mangroves by protection, restoration, regeneration, and maintenance. Important species of mangrove ecosystems in India include *Avicennia officinalis, Morindacitrifolia, Rhizophora mucronata, Sonneratia alba, Avicennia alba, Bruguiera cylindrica, Heritieralittoralis, Phoenix paludosa,* and *Ceriops tagal.*

Current Status of Mangroves in India as per ISFR, 2019

In India, mangroves are spread over an area of 4740 km^2 which accounts for nearly 3% of the world's total mangrove vegetation. Sundarbans in West Bengal accounts for almost half of the total area under mangrove in the country. States-union territories (UTs)-wise mangrove cover as assessed by the FSI in different assessments is given Table 1.

Table 1: Mangrove cover assessment 2019

State/UT	Very Dense Mangrove	Moderately Dense Mangrove	Open Mangrove	Total Mangrove
Andhra Pradesh	0	213	191	404
Goa	0	20	6	26
Gujarat	0	169	1008	1177
Karnataka	0	2	8	10
Kerala	0	5	4	9
Maharashtra	0	88	232	320
Odisha	81	94	76	251
Tamil Nadu	1	27	17	45
West Bengal	996	692	424	2112
Andaman and Nicobar Islands	398	169	49	616
Daman and Diu	0	0	3	3
Puducherry	0	0	2	2
Total	**1476**	**1479**	**2020**	**4975**

The numbers in green represent increase in the area under the mangrove cover and the numbers in red represent the loss in area under the mangrove cover since the last assessment by the FSI (ISFR 2017). The total area under the mangrove cover has increased by 54 km^2 since the 2017 assessment by the FSI.

Seagrasses

Seagrasses are flowering plants belonging to four plant families (Posidoniaceae, Zosteraceae, Hydrocharitaceae, and Cymodoceaceae), all in the order Alismatales, which grow in marine, fully saline environments. There are 12 genera and 58 species known of seagrasses. These are found in coastal waters of all continents except Antarctica. Seagrass meadows store relatively small amounts of carbon in aboveground biomass. However, belowground biomass, in the form of large long-lived root structures, stores the majority of carbon stock below the ground. These root structures accumulate large stores of carbon through the formation of 'mattes' beneath seagrass meadows. These mattes accrete vertically over time, raising the seagrass meadow towards the surface of the water.

The present status of seagrass meadows in India has been surveyed by different researchers. Area covered by seagrass is represented in Table 2.

Table 2: Area covered by seagrass

Location	Seagrass Cover (ha)	Period	Reference
Lakshadweep (Agatti, kavaratti and Kalpeni)	53.9	1960	Jagtap (1996)
Lakshadweep (Kadmath, Minicoy, Amini, Kavaratti, Kalpeni and Agatti)	112.38	1986	Jagtap and Inamdar (1991)
Lakshadweep (Kavaratti, Agatti)	288	1988	Desai, *et al.* (1991)
Andaman	283.5	1996	Das (1996)
Gulf of Mannar	8571	1998	ICMAM PD (2001)
Lakshadweep (Bengaram and Thinnakara)	1200		Nayak and Bahuguna (2001)
Gulf of Mannar	2658.31	2004	Sridhar, *et al.* (2010)
Gulf of Mannar	5710.66	2005	Sridhar, *et al.* (2012)
Gulf of Mannar	1327.15	2007	Thangaradjou, *et al.* (2008)
Andaman	1223.9	2007	Nobi, *et al.* (2013)
Nicobar	1719.4	2007	Nobi, *et al.* (2013)
Lakshadweep	2590.2	2008	Nobi and Thangaradjou (2012)

Estimates are also available for change detection in a few areas covered by seagrass. The values are represented in Table 3.

Table 3: Estimates for detection in areas covered by seagrass

Site	Change Detection of Seagrass in Aerial Cover (ha)	Change (ha)	Reasons	Reference
Palk Bay (1996–2004)	2922.62–2658.31	(-) 264.31	Anthropogenic pressure	Shridhar, *et al.* (2010)
Gulf of Mannar (2000–2004)	1856.51–1327.15	(-) 56.08	Paper shell collection	Thangaradjou, *et al.* (2008)
Gulf of Mannar (1998–2005)	8571.0–5710.66	(-) 2860.34	Erosion and submergence of islands	ICMAM PD (2001); Susila, *et al.* (2012)
Lakshadweep (2000–2008)	1139.62–1066.59	(-) 73.03	Anthropogenic pressure	Nobi and Thangaradjou (2012)
Andaman (2004–2007)	1370.4–1223.9	(-) 146.5	After Tsunami seagrass was drastically reduced	Nobi, *et al.* (2013)
Nicobar (2004–2007)	3192.3–1719.4	(-) 1472.9	After Tsunami seagrass was drastically reduced	Nobi, *et al.* (2013)

Tidal Salt Marsh

A tidal salt marsh is a coastal ecosystem in the upper intertidal zone between land and open salt water or brackish water that is regularly flooded by the tides. It is dominated by dense stands of salt-tolerant plants such as herbs, grasses, or low shrubs. Salt marshes are intertidal ecosystems found on sheltered coastlines ranging geographically from the sub-arctic to the tropics and occurring most extensively in temperate zones. Salt marshes store carbon in anaerobic sediments where it is not oxidized to CO_2 and therefore is not released into the atmosphere. Intertidal ecosystems, such as salt marshes, are dependent on sediment accretion and rising elevation to compensate for sea-level rise. As the anaerobic sediments beneath salt marshes accumulate, so too does the total amount of carbon stored in them. Freshwater wetlands tend to be the sources of methane (Bridgham, Megonigal, Keller, *et al*. 2006), a GHG 25 times more potent than CO_2. But the saline environment of salt marshes inhibits the natural creation of methane, making for much lower releases of methane in these habitats.

Coral Reefs

Coral reefs provide various ecosystem services such as their contribution as a shield against storms and cyclones, protection to shorelines from erosion, and providing habitat for breeding grounds and nurseries for marine fishes. Coral reefs contribute to various ecosystem services annually worth over 100 million dollars globally and can get affected by climate change in numerous ways including mass bleaching of coral reefs due to rise in ocean temperature and ocean acidification. There is a rapid decline of coral reefs worldwide, resulting from anthropogenic activities, natural disturbances, and climate change. Coral reefs are assumed to be a carbon source instead of sink. It is important to restore coral reefs as they support habitation of various organisms which hold importance in various carbon cycles. Cycling of carbon through corals is a very complex system. Research is needed to find out whether coral reefs are carbon sink or carbon source. Currently, coral reefs are not included in the carbon budgets but their direct or indirect role and contribution to blue carbon cannot be ignored.

Sandy Beaches and Sand Dunes

India has a coastline of 7516.6 km, which consists of 6100 km of mainland coastline and a coastline of 1197 km of Indian Islands, touching 13 states and UTs. Around 2156 km (33%) of the country's surveyed coastline has faced erosion and around 1941 km (29%) has faced accretion (National Centre for Coastal Research 2018). These factors raise concerns regarding the health of the coastal ecosystems and therefore, immediate actions are required to improve the degrading ecosystems.

Coastal ecosystems play a significant role in mitigating the impact of climate change. Sandy beaches and sand dunes are one of the most powerful lines of defense against coastal storms and cyclones. The post-tsunami studies conclude that sand dunes are the best form of natural defence, even better than the shelter belts and mangroves. In the wake of the sea-level rise, it is therefore, critical that we strengthen the natural coastal defences rather than relying on artificial, human-made solutions. These ecosystems along with other benefits also have the potential to sequester carbon from the atmosphere. Dune vegetations, such as Ipomoea, Spinifex, and Palmyra, along with littoral forests have the potential to act as carbon sinks, thereby, binding carbon into sand.

Blue Carbon Inventories

To explicitly address the role of blue carbon ecosystems in climate change mitigation and human well-being through policy, regulatory, finance, or other mechanisms, the carbon stock in these ecosystems and the existing or potential carbon emissions resulting from changes to these ecosystems must be quantified. This process is referred to as creating a carbon inventory.

According to the Intergovernmental Panel on Climate Change (IPCC), carbon inventories can be established at various levels of details or certainty, often determined by the purpose of the inventory and the resources available (IPCC GPG 2003). The IPCC has identified the following three tiers of details in carbon inventories that reflect the degrees of certainty or accuracy of a carbon stock inventory (or assessment):

Tier 1: These assessments have the least accuracy. They are certainly based on simplified assumptions and published IPCC default values for activity data and emissions factors. Tier 1 assessments may have a large error range of +/-50% for aboveground pools and +/-90% for variable soil carbon pools.

Tier 2: These assessments include country- or site-specific data and hence have increased accuracy and resolution. For example, a country may know the mean carbon stock for different ecosystems within the country.

Tier 3: These assessments require highly specific data of carbon stocks in each component ecosystem or land-use area, and repeated measurements of key carbon stocks through time to provide estimates of change or flux of carbon into or out of the area. Estimates of carbon flux can be provided through direct field measurements or by modelling.

The IPCC recommends that countries should aspire for Tier 3 for the measurement of key carbon stocks/ sources/sinks. However, Tier 3 assessments are costlier to implement, require higher levels of technical resources and capacity, and are not always possible. When Tier 2 or 3 estimates are not possible, Tier 1 estimates can be performed. The globally averaged estimates, as shown in the Table 4, can be used to give a Tier 1 estimate of carbon stocks within any given area if site-specific data do not exist. They are based on globally averaged carbon stock estimates for mangroves, tidal marshes, and seagrass meadows according to the current literature. However, these estimates have a high degree of uncertainty.

Table 4: Global averaged estimates

Ecosystem	Carbon Stock (tonne/ha)	Range (tonne/ha)	tCO_2e/ ha
Mangrove	386	55–1376	1415
Tidal salt marsh	255	16–623	935
Seagrass	108	10–829	396

The benefit transfer method can be used to estimate the economic values for the ecosystem services by transferring available information from already done studies in other locations. A lower range is used for calculations in highly degraded or open vegetation; an average value is used where the vegetation is moderately dense; and an upper range is used in case of highly dense vegetation cover.

Measuring Blue Carbon

A carbon stock is the total amount of organic carbon (C_{org}) stored in a blue carbon ecosystem, typically reported as million tonnes of organic carbon per hectare (million tonnes of C_{org}/ha) over a specified soil depth. These stocks are determined by adding all relevant carbon pools within the investigated area.

Carbon Pools: Similar to most terrestrial forest ecosystems, mangroves can be roughly divided into four carbon pools: aboveground living biomass (trees, scrub trees, lianas, palms, pneumatophores), aboveground dead biomass (litter, downed wood, dead trees, belowground living biomass (roots and rhizomes), and soil carbon which includes the dead belowground biomass. For seagrasses, the following three major carbon pools can be considered: aboveground living biomass (seagrass leaves and epiphytes), belowground living biomass (roots and rhizomes), and soil carbon. Carbon pools that can be considered for tidal salt marshes are aboveground living biomass (shrubs, grasses, herbs, etc.), belowground living biomass (roots and rhizomes), and soil organic carbon.

Need to Conserve Coastal Ecosystems

Due to coastal development and land-use change, mangroves, tidal salt marshes, seagrasses, coral reefs, and sandy beaches and dunes are under great pressure (Alongi 2002; Gedan, Silliman, and Bertness 2009; Saintilan, Rogers, and Howe 2009; Waycott, Duarte, Carruthers, *et al.* 2009). When vegetation is removed and the land is either drained or dredged for economic development (e.g., mangrove forest clearing for shrimp ponds, draining of tidal marshes for agriculture, and dredging in seagrass beds – all common activities in the coastal zones of the world), the sediments get exposed to the atmosphere or water column. This results in the carbon stored in the sediment bond with the oxygen in the air to form CO_2 and other GHGs that get released into the atmosphere and ocean. Not only do these activities result in CO_2 emissions but they also result in the loss of biodiversity and critical ecosystem services. Thus, conserving mangrove forests, coral reefs, and seagrasses will add to climate change mitigation efforts globally. In May 2020, the cyclonic storm 'Amphan' caused widespread damage in eastern Indian, especially in West Bengal. The losses could have been minimized if effective mangrove conservation measures were taken along the coastline.

A marine conservation and climate protection programme can help in achieving the Nationally Determined Contribution (NDC) targets. This is a neglected area, where adequate information is not available and domain knowledge is limited to some large institutions. Marine protected areas fall under the state jurisdiction but may have international impacts. With the help of secondary research and stakeholder consultations we can propose increased conservation of key marine ecosystems to enhance carbon sequestration.

Importance of Coastal Ecosystems to Achieve NDC Targets

Coastal systems not only store massive amounts of carbon and offer additional CO_2 sequestration opportunities, but also deliver several adaptation and coastal protection benefits. The increased awareness of the importance of coastal systems for both adaptation and mitigation of climate change is reflected in the submissions of the NDCs, which are the national top-level policy and action plans meant to implement the Paris Agreement on the national level of the signatories. Among the 195 parties to the Paris Agreement, 28 countries included some kind of reference to coastal wetlands in their mitigation actions, while 59 countries included coastal ecosystems or coastal zones in their adaptation strategies and refer in their NDCs to at least one blue carbon ecosystem such as seagrass, salt marshes, and mangroves (Herr and Landis 2016).

Political awareness of the climate values of coastal wetlands and other nature-based solutions have developed considerably since the first NDCs were submitted. The specific motivations for the inclusion of coastal wetlands in the NDCs may vary between countries and may include:

- **High mitigation benefits:** Coastal wetlands sequester carbon at higher rates, per unit area, than terrestrial forests, storing carbon within both their biomass (leaves, roots, wood, and stems) and carbon-rich organic soil.
- **High adaptation benefits:** Coastal wetlands provide services essential for climate change adaptation, including protection from storm surges, flooding, sea-level rise, and coastal erosion. Investment in these forms of 'blue infrastructure', such as living coastlines, provides other essential ecosystem services, such as food security, local livelihoods (small-scale fisheries), and biodiversity, and is often more cost-effective than 'grey infrastructure', such as seawalls and breakwaters.
- **NDC progression:** The Paris Agreement encourages countries to move towards economy-wide mitigation targets, ultimately covering all the economic sectors and emissions sources. The integration of land sector emissions, including those from coastal wetlands, is a major milestone on this path.
- **High implementation value:** The inclusion of conservation, restoration, and/or sustainable management of coastal wetlands in an NDC serves as a strong signal of national importance, which in turn drives resources and actions that can result in better identified policy levers for the implementation.
- **Climate finance:** NDCs are one of many entry points for securing climate finance to support blue carbon-related actions. Under the provisions of the Katowice Climate Package concerning climate finance reporting, both the donor and the recipient countries must report how a particular financial support or flow contributes to the achievement of the recipient country's NDC. The inclusion of the protection of a coastal line within an NDC is therefore an important way for a variety of potential climate funds.

Sequestration Potential of Mangroves

Carbon sequestration is the process through which plant life removes CO_2 from the atmosphere and stores it as biomass. Mangrove forests play a major role in the carbon cycle in removing CO_2 from the atmosphere and storing it as carbon in plant materials. They also have important roles in sustaining tropical and subtropical coastal productivity and sequester large amounts of carbon below the ground. Mangroves are among the most carbon-rich forests in the tropics and their carbon sequestration potential is estimated to be up to 50 times greater than tropical terrestrial forests. India with a vast coastline of about 7516.6 km, including island territories, had a mangrove cover of about 6749 km^2, which is around 89% of the total coastline in India (Sahu, Suresh, Murthy, *et al*. 2015). With the total estimated mangrove cover of 495,842 ha in 2020 (66% of the total coastline of India) and the value of the carbon stock as **386 tonne/ha**, the total carbon sequestration potential of the mangroves has been estimated as **702.42 million tonne of CO_2e**. The potential of carbon sequestration will increase to **748.17 million tonne of CO_2e in 2030**. Upon conservation and protection of mangrove cover, it has been estimated that there can be an additional sequestration potential of **207.91 million tonne of CO_2e.** Figure 3 shows the trend in sequestration potential of mangroves in India over the years.

The total mapped area of seagrass is 25,378.4 ha, and with the carbon stock as 108 tonne/ha, the total carbon sequestration potential has been estimated to be 10.2 million tonnes of CO_2e.

The carbon sequestration potential for the tidal salt marshes can only be calculated once the area for the same is documented.

The study "Assessment for Designing REDD Plus Projects in India" was conducted by TERI in 2014. The mangrove forests in Sundarbans (West Bengal) are valued largely for their protective functions, and there is relatively limited direct dependency for fuelwood and minor forest produce. The economic value of the storm-protection services of the forest was estimated at one-third of the total cash incomes of the households. Damage cost avoided method was used to estimate the economic value of the storm-protection service of the forest, estimated to be ₹2,716, 389 over 3 years, or ₹7761 per household (one-third of the total cash incomes of the households). Using these data and benefit transfer approach, the economic valuation can be done for the entire mangrove cover in India. Therefore, mangroves in India can be considered as a potential site for implementing carbon finance projects and for trading carbon in the voluntary market.

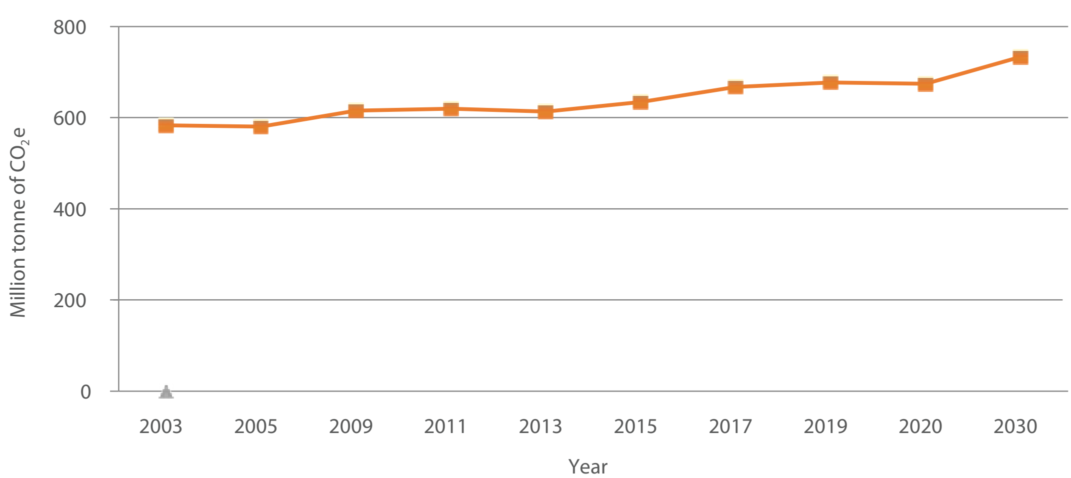

Figure 3: Sequestration potential of mangroves in India

Private Sector Finance to Accelerate Restoration of Coastal Ecosystems and Enhancement of Blue Carbon Stocks

The role of private sector finance is crucial for various conservation interventions pertinent to coastal ecosystems and to achieve the NDC targets effectively and efficiently. Blue carbon is a term coined to draw attention to the degradation of marine and coastal ecosystems and the need to conserve and restore them to mitigate climate change and other ecosystem services they provide. The multifaceted nature of blue carbon led to a vast and rich collaboration across disciplines where scientists, conservationists, economists, and policymakers interact intensely to share their advanced goals. Many of the existing finance mechanisms can be adapted and applied to coastal blue carbon ecosystems. However, most of these opportunities focus on carbon found in the aboveground vegetative biomass and do not currently account for carbon in the soil, which we completely intend to do. Such financial incentives for blue carbon might also offer a way to protect and capitalize on the other ecosystem services provided by these habitats, such as fisheries. Doing so will reap rewards beyond the immediate benefits of carbon sequestration. We believe that blue carbon meets all the three essential elements of sustainability—economic, environmental, and social—and should thus be framed as an essential component of the Blue Economy. Some of the types of private sector finance for coastal ecosystems are sustainable supply chain, payment for ecosystem services, and marine ecosystem insurance. These can help in providing additional income-generating opportunities for local communities, such as crab hatcheries, sustainable fisheries, etc. The development of the integrated mangrove and aquaculture systems results in good quality and high harvests with low external inputs, thereby directly benefiting the fishermen; providing engagement opportunities with small and medium enterprises to increase economic viability and security for the communities; and aid in strengthening governance systems of the village-level institutions formed for project implementation.

Importance of Nature-based Solutions

Nature-based solutions (NbS) are actions to protect, sustainably manage, and restore natural or modified ecosystems, and address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen Shacham, Walters, Janzen, *et al*. 2016). NbS have an important role in addressing both the causes and consequences of climate change.

Herr and Landis (2016) considered the prominence of conservation and restoration of coastal ecosystems, and assessed which NDCs included these ecosystems as part of the LULUCF (land use, land-use change, forestry) and other forest commitments (conservation and management, protection and reforestation as part of mitigation and adaptation plans). They also noted which NDCs make specific references to blue carbon, planning tools (e.g. ICZM), fisheries, synergies between mitigation and adaptation benefits of coastal ecosystems. There is a need to invest in all kinds of emission-reduction strategies and ensure that coastline services play their part in helping tackle climate change. Considering the management of coastal ecosystems as a whole for effectively addressing climate change mitigation and adaption can create opportunities for biodiversity and livelihoods as well. It is important for the climate change mitigation and adaption strategies for coastal ecosystem to consider the blue economy and promote sustainable development, as a sizeable amount of population reside near the coastline and is dependent on its resources, The strategies should focus on the ways to combine NbS for coastal development and urban development, as it can potentially bring positive social, economic, and financial impacts (Seddon, Sengupta, García-Espinosa, *et al*. 2019).

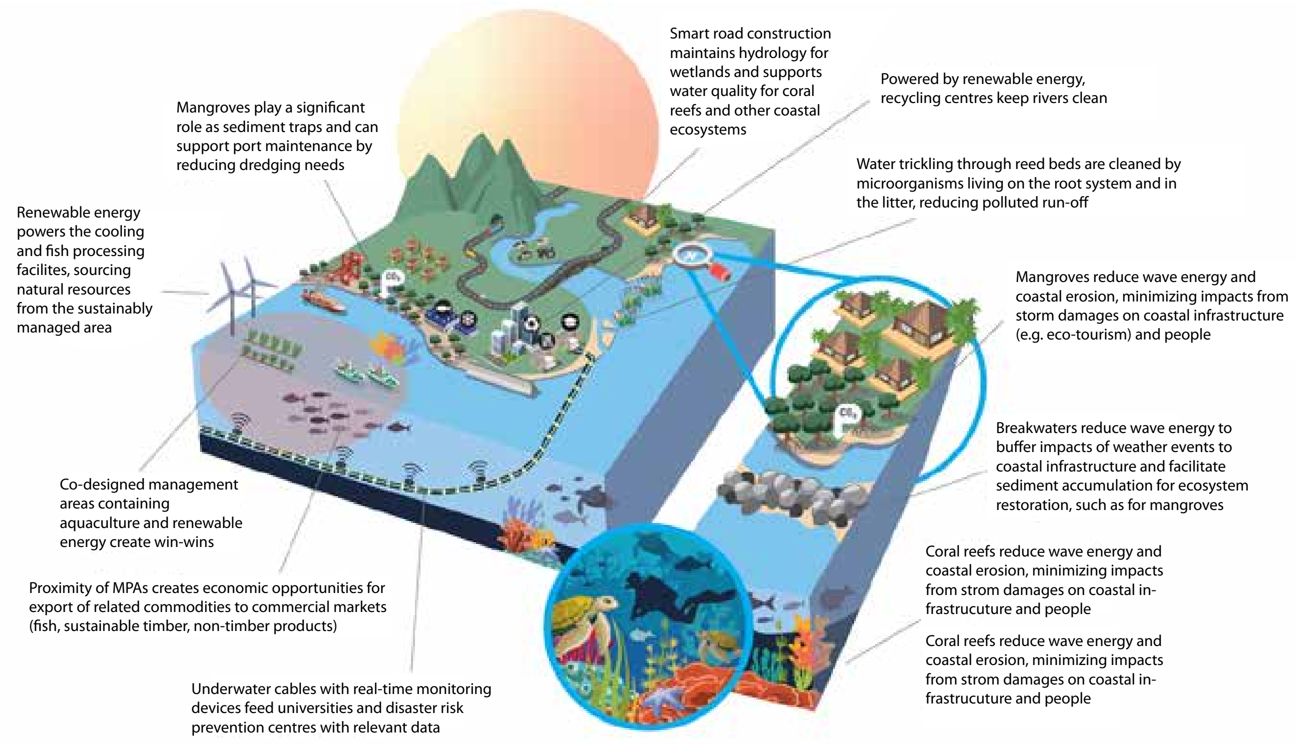

Figure 4: Role of nature-based solutions for coastal development

The role of mangroves and other coastal ecosystems has been recognized for adaptation which includes mangrove bio-shields, protection for coastal zones, and coastal zone management. The main aspect is to build national capacity for the implementation of comprehensive coastal management through ecological management, conservation and protection of critical habitats, coastal geomorphology and geology of coastal and marine areas, coastal engineering, socio-economic aspects, policy and legal issues, and other related fields in the area of coastal governance.

Discussions and Way Forward

Blue carbon has received international attention for its potential role in mitigating CO_2 emissions. With their value for both mitigation and adaptation, blue carbon ecosystems play a vital role in any climate change solution. The Government of India must negotiate with the United Nations Framework Convention on Climate Change (UNFCCC) for recognizing the carbon sequestered through coastal ecosystems at the national level in achieving India's NDC targets and mitigating climate change. India lacks in the mapping of seagrass whereas tidal salt marshes are not at all surveyed. These two carbon pools need to be surveyed and mapped. The Government of India should also take measures to conserve the existing mangrove cover and also to increase the cover which can lead to an additional sequestration potential of 207.91 million tonnes of CO_2e. Therefore, conserving blue carbon ecosystems can maintain carbon sequestration in future and prevent emissions from land-use change. However, severe data limitations need to be addressed if the role of blue carbon in meeting the targets of the Paris Agreement has to be robustly demonstrated.

As Sustainable Development Goal 14 (Life Below Water) outlines, the health of our ocean and coastal ecosystems is of fundamental importance for human well-being and sustainable development, while also playing a key role in both slowing climate warming and helping humans deal with climate change impact. These ecosystems should therefore feature prominently in the NDCs of the nations with major coastlines.

Recommendations

A stakeholder consultation was conducted under the chairmanship of Mrs BV Umadevi, Additional Secretary, Ministry of Environment, Forest and Climate Change. Other panellists present in the consultation were Dr JV Sharma, Director, Land Resources Division, TERI, Dr AL Ramanathan, Professor, School of Environmental Sciences, Jawaharlal Nehru University, Ms Dorothee Herr, Manager, Oceans and Climate Change, IUCN Global Marine and Polar Programme, Mr Sandeep Roy Choudhury, Director, VNV Advisory Services, Dr Naveen Namboothri, Director, Dakshin Foundation, Dr Alok Saxena, Former PCCF, Andaman and Nicobar Islands, and Dr Priyanka, Research Associate, Land Resources Division, TERI. The following recommendations were made during the discussion:

- Research and development activities need to be conducted to develop a methodology for carbon stock assessment of coastal ecosystems. For the mangrove areas we need a specialized methodology to estimate carbon stock, especially in the cases of soil organic carbon (SOC) and belowground biomass. The FSI should adopt the same for estimating SOC for mangrove forests.
- Beaches and sandy shore management is very important for the well-being of coastal ecosystems.
- Cycling of carbon through corals is a very complex system. Research is needed to find out whether coral reefs are carbon sink or carbon source. Corals are currently not involved in carbon budgets but the direct or indirect role of these species and their contribution for blue carbon cannot be ignored.
- The Government of India should adopt Carbon Neutrality Policy as a mandate of additional carbon finance for conservation of coastal ecosystems. Innovative financial mechanisms for coastal ecosystems such as the marine bonds, blue bonds, blue financing, involving industries such as shipping, oil refineries, cement works, chemical plants, meat and fish processing plants, power stations, pulp and paper mills, supporting port facilities, and other manufacturing plants, should be adopted.
- Monetary valuation of different ecosystem services of coastal ecosystems should also be considered along with carbon for obtaining finance under the umbrella of carbon market mechanism.
- Finance management and microfinance in particular should be embedded in coastal community management projects where coastal living communities can be encouraged to implement the conservation practices.
- NbS need to be adopted to protect and conserve coastal ecosystems.
- Involvement of private sector in financing various initiatives in the blue economy should be promoted.
- Ecosystem-based models need to be implemented for the conservation of coastal ecosystems and mitigating climate change.
- Drivers of degradation such as tropical cyclones, climate fluctuations, floods, etc., should be identified. There is a need to have additional technical and financial inputs as far as conserving blue carbon is concerned.
- Reduction in emission through adaptation and carbon sequestration should be considered for achieving the India's NDC target—2.5–3 billion tonnes of CO_2e. Also, the country needs to focus on the Blue Carbon Initiative of the International Union for Conservation of Nature to include blue carbon in achieving its NDC targets.
- Blue Flag certification programme is one of the world's most recognized voluntary eco-labels awarded to beaches and marinas for their conservation. In order to qualify for the Blue Flag, a series of stringent environmental, educational, safety, and accessibility criteria need to be met and maintained. The Ministry of Environment, Forest and Climate Change has shortlisted 12 beaches across India for the prestigious 'Blue Flag' certification.

References

Alongi, D.M. 2002. Present state and future of the world's mangrove forests. *Environmental Conservation* 29: 331–349

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. and Silliman, B.R. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81, 169–193.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M. et al. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience* 51, 633–641

Bridgham, S.D., Megonigal, J.P., Keller, J.K. *et al*.2006. The carbon balance of North American wetlands. *Wetlands* 26, 889–916

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R. and Lynch, J. C. 2003. Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles*, 17, Article 11

Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) 2016. *Nature-based Solutions to Address Global Societal Challenges*. Gland, Switzerland: IUCN.

Cullen-Unsworth, L. and Unsworth, R. 2013. Seagrass meadows, ecosystem services, and sustainability. *Environment: Science and Policy for Sustainable Development* 55, 14–28

Das, H.S. 1996. Status of seagrass habitats of the Andamcin and Nicobar coast. SACON technical report NO.4. Salim Ali Centre for Ornithology and Natural History. Coimbatore, India, 32.

Desai, P.S., Narain, A., Nayak, S., Manikam B., Adiga, S., and Nath, A.N. 1991. IRS-1A applications for coastal and marine resources. *Current Science* 61: 204–208

Duarte, C. M., Middelburg, J. J. and Caraco, N. 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2: 1–8

Forest Survey of India. 2003. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2005. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India.

Forest Survey of India. 2009. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2011. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2013. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2015. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2017. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Forest Survey of India. 2019. *India State of Forest Report*. New Delhi: Ministry of Environment and Forests, Government of India

Gedan, K. B., Silliman, B., and Bertness, M. 2009. Centuries of human-driven change in salt marsh ecosystems. *Marine Science* 1: 117–141

Hamilton, S. E., and Friess, D. A. 2018. Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. *Nature Climate Change* 8(3), 240-244.

Herr, D. and Landis, E. 2016. Coastal blue carbon ecosystems. Opportunities for Nationally Determined Contributions. *Policy Brief*. Gland, Switzerland: IUCN and Washington, DC, USA: TNC

Hogarth, P. 1999. *The Biology of Mangroves*. Oxford: Oxford University Press

ICMAM-PDA. 2001. Critical habitat information system for Gulf of Mannar (India). – *Technical Report*, ICMAM project Directorate, Department of Ocean Development, Chennai, pp. 1 – 88.

Jagtap, T.G. 1996. Some quantitative aspects of structural components of seagrass meadows from the southeast coast of India. *Botanica Marina* 39: 39-45.

Jagtap, T.G. and Inamdar, S.N. 1991. Mapping of seagrass meadows from Lakshadweep islands India, using aerial photographs. *J. Indian Soc. Remote Sens*. 19(2): 77-82

Kathiresan, K. and Bingham, B.L. 2001. Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* 40:81–251

Kennedy, H., Beggins, J., Duarte, C. M., Fourqurean, J. W., Holmer, M., Marbà, N., and Middelburg, J. J. 2010. Seagrass sediments as a global carbon sink: Isotopic constraints. *Global Biogeochemical Cycles* 24

King, S.E. and Lester, J.N. 1995. The value of salt marsh as a sea defence. *Marine Pollution Bulletin* 30:180–189

Lo Iacono, C., Mateo, M. A. Gràcia, E. Guasch, L. Carbonell, R., Serrano, L., Serrano, O., and Dañobeitia, J. 2008. Very high-resolution seismo-acoustic imaging ofseagrass meadows (Mediterranean Sea): Implications for carbon sink estimates. *Geophysical Research Letters* 35

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., and Silliman, B. R. 2011. A blueprint for blue carbon:

toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment* 9(10): 552–560

Middelburg, J., Nieuwenhuize, J., Lubberts, R., and Van de Plassche, O. 1997. Organic carbon isotope systematics of coastal marshes. *Estuarine, Coastal and Shelf Science* 45: 681–687

Mitsch, W. J. and Gosselink, J. G. 2007. *Wetlands*. New York: Wiley

Mumby, P.J. 2006. Connectivity of reef fish between mangroves and coral reefs: algorithms for the design of marine reserves at seascape scales. *Biological Conservation*, 128: 215–222

Nayak, S., and Bahuguna, A. 2001. Application of Remote Sensing data to monitor mangroves and other coastal vegetation of India. *Indian J. Mar. Sci*. 30(4): 195-213.

Nobi, E.P., DIlipan E., and Thangradjou, T. 2013. Integrating Indian Remote Sensing multi-spectral satellite and field data to estimate seagrass cover change in the Andaman and Nicobar Islands, India. *Ocean Sci. J* 48(2): 183–181

Nobi, E.P. and Thangradjou, T. 2012. Evaluation of the spatial changes in sea grass cover in the lagoons of Lakshadweep islands, Indiausing IRS LISS II satellite images. *Geocarto Int*. 27 (8): 647–660

Robertson, A.I. and Alongi, D.M. 1992. Tropical Mangrove Ecosystems. Washington DC: American Geophysical Union

Saenger, P. 2002. The value of mangroves. In *Mangrove Ecology, Silviculture and Conservation,* pp. 207–228. Berlin: Springer

Sahu S. C., Suresh, H. S. Murthy, I. K. and Ravindranath, N. H. 2015. Mangrove area assessment in India: Implications of loss of mangroves. *Journal of Earth Science and Climate Change* 6: 280

Saintilan, N., Rogers, K. and Howe, A. 2009. *Geomorphology and Habitat Dynamics,* pp. 58–60. Collingwood: CSIRO Publishing

Schlesinger, W. H. and Lichter, J. 2001. Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO_2. *Nature* 411: 466–469

Seddon, N., Sengupta, S., García-Espinosa, M., Hauler, I., Herr, D., and Rizvi, A. R. 2019. *Nature-based Solutions in Nationally Determined Contributions: Synthesis and recommendations for enhancing climate ambition and action by 2020*. Gland, Switzerland and Oxford, UK: IUCN and University of Oxford

Sousa, A.I., Lillebø, A.I., Risgaard-Petersen, N., Pardal, M.A. and Caçador, I. 201). Denitrification: an ecosystem service provided by salt marshes. *Mar Ecol Prog Ser* 448: 79–92

Sridhar, R., Thangradjou, T., Kannan, L., and Astalakshmi S., 2010. Assessment of coastal bioresources of the Palk Bay, India, using IRS-LISS-III data. *J. Indian Soc. Remote Sens*. 38: 565–575

Susila, S., Nobi E.P. Thangradjou, T., Sivakumar K., Anantharaman P., Kannan L., and Balasubramanian, T. 2012. *In situ Biomass Estimation of Seagrasses in the Gulf of Mannar (India) and their Aerial Coverage Using IRS P6 LISS III Images Aquatic Plants and Plant Diseases: types, characteristics and management*, pp. 209–226. New York: Nova Publishers

TERI. 2014. Assessment for Designing REDD Plus Projects in India. New Delhi: TERI

Thangradjou, T., Sridhar, R., Senthilkumar, S., and Kannan L. 2008. Seagrass resources assessment in the Mandapam coast of Gulf of Mannar biosphere reserve, India. *Appl. Ecol. Environ. Res*. 6(1): 139–146.

Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., and Kendrick, G. A. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106(30): 12377–12381

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