Carbon stocks in natural and planted mangrove forests of Mahanadi Mangrove Wetland, East Coast of India

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Mangrove forest ecosystem is one of the important carbon sinks in the tropics. The role of mangrove forests in mitigating climate change through reduced deforestation is well recognized. The present field study aimed to estimate the carbon stocks of Mahanadi Mangrove Wetland (MMW), east coast of India. Carbon stocks were estimated in vegetation and soil of natural mangrove forest stands and new mangrove plantation stands. The mean of carbon stock in natural stands was 143.4 ± 8.2 Mg C ha^{-1} (vegetation 89.1 ± 8.9 and soil 54.3 ± 3.0 Mg C ha^{-1}) and plantation at 151.5 ± 7.9 Mg C ha^{-1} (vegetation 90.6 ± 16.2 and soil 60.9 ± 5.6 Mg C ha^{-1}). The mean overall C-stock of natural stands and plantations was 147.0 ± 8.1 Mg C ha^{-1} (vegetation 89.4 ± 7.6 and soil 57.6 ± 3.2 Mg C ha^{-1}), which is 1.6 times higher than that in forests of Odisha. A positive correlation (*r* = 0.87) was found between vegetation biomass and soil organic carbon in the surface soil (0–30 cm), indicating the role of vegetation in building surface soil/sediment organic carbon. The 6651 ha of mangrove forests in the MMW is estimated to store 0.98 Mt of C, which is equivalent to 3.59 Mt of CO_2e. The present study reveals that MMW stores substantial amount of atmospheric carbon and therefore needs to be conserved and sustainably managed to maintain as well as increase carbon storage. Further, mangrove plantations, on a per unit area basis, can sequester as much carbon as natural stands.

Keywords: Carbon stocks, mangroves, natural stands, plantations.

PLANT communities sequester carbon during photosynthesis and store it as biomass. Carbon is stored in five pools, namely above-ground biomass (AGB), below-ground biomass (BGB), leaf litter, dead wood and soil carbon stock in forest ecosystems. Forests act as both sink and source of CO_2 when it is conserved and destroyed respectively. Further, forests play an important role in carbon sequestration from the atmosphere and in particular, mangroves sequester four times carbon per unit area compared to terrestrial forests in the tropics[1,2]. Despite mangrove accounting for only 0.7% of tropical forest area, it generates emissions up to 10% from total global deforestation[3,4]. Hence, mangroves are considered as an important component in climate change mitigation and reducing emissions from deforestation and degradation (REDD+) schemes[5]. In terms of biodiversity, mangrove forests are highly productive and biologically complex ecosystems. They provide several important ecosystem services, including maintenance of coastal water quality, reduction in severity of storm, wave and flood damage, and as a breeding ground for commercial fishery species[6,7].

India has a total mangrove cover of 4627.63 sq. km (ref. 8), or 0.15% of the country's land area, 3% of the global mangrove area, and 8% of Asia's mangroves. Recent assessment of mangrove area in India (1987–2013) reveals that the mean annual change during the period is 24.25 ± 82.57 sq. km. Most of the states are experiencing an increase in area under mangroves, except Andhra Pradesh (–5.95 ± 15.70 sq. km) and Andaman and Nicobar Islands (–3.41 ± 52.32 sq. km)[9]. Mangroves in India are unique in terms of their extent, variability and biodiversity. A total of 4011 species, including 920 plant (23%) and 3091 animal (77%) species have been recorded from Indian mangrove ecosystems, which is highest in the world[10]. However, there has been an overall continuous decline in mangrove forests caused by conversion to agriculture, aquaculture, tourism and urban development[11,12].

The M.S. Swaminathan Research Foundation (MSSRF), Chennai launched a major programme in 1996 on the restoration of the mangrove wetlands on the east coast of India, in collaboration with the Ministry of Environment and Forests, Government of India. In this programme, 1565 ha area was planted in Mahanadi Mangrove Wetland (MMW), Odisha, with participation of local people as well as the Odisha Forest Department. Considering the importance of mangroves in carbon sequestration and climate change mitigation, the present study was undertaken to assess biomass and soil carbon stock in natural as well as plantation stands in MMW. Comparison of C-stock in natural stands with plantations is rare[13],

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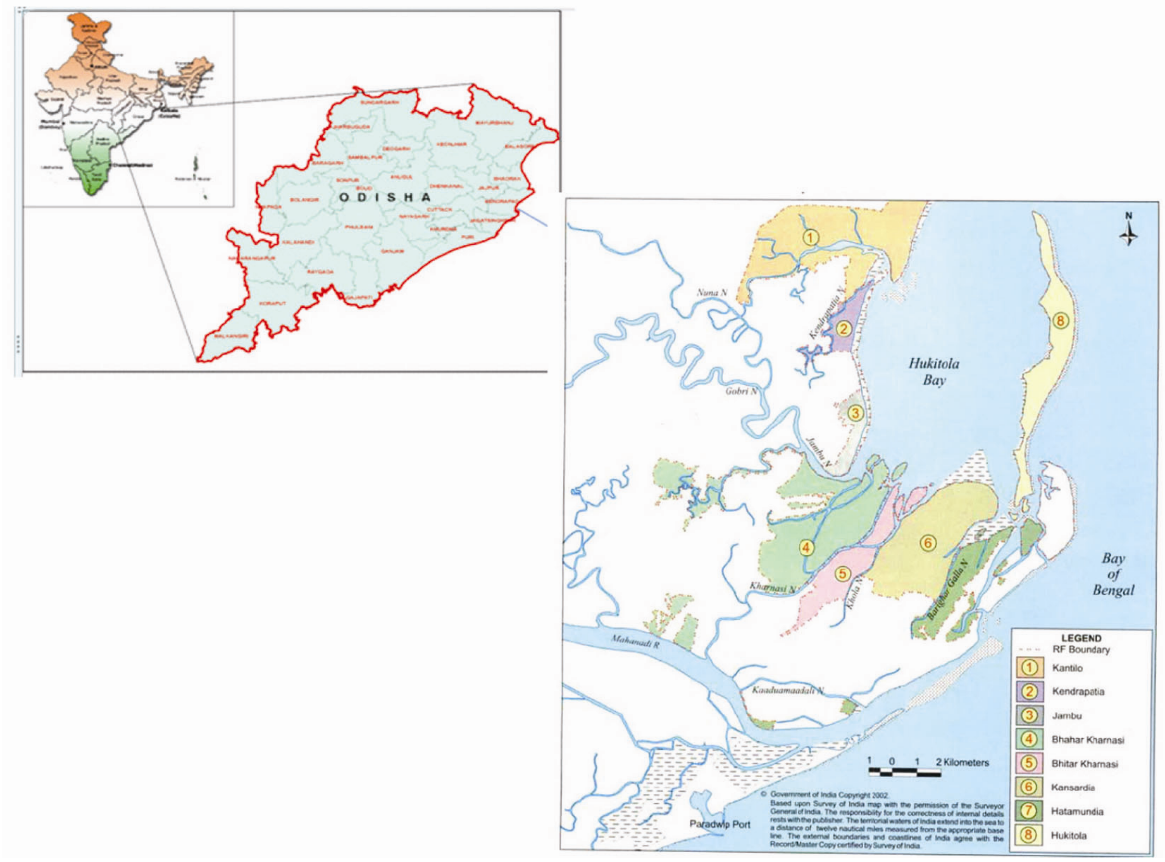

Figure 1. Study area showing forest blocks of Mahanadi Mangrove Wetland. (Adapted from *Atlas of Mangrove Wetlands of India, Part-3, Orissa.*)

which would provide baseline information for carbon stock enhancement programmes. Here an attempt is made to estimate the ecosystem carbon stock in a mangrove forest ecosystem. Further, little information is available on carbon stocks, biomass and carbon sequestration rates of mangrove forests in India in general[14–19] and for MMW in particular, although it is one of the most important mangrove ecosystems of India possessing two globally threatened mangrove species (*Heritiera fomes* and *Sonneratia griffith*). Further, quantification of carbon stocks and sequestration rates in mangrove forests is a prerequisite for implementing future climate change mitigation strategies and REDD+ schemes in wetlands. Hence, this study aims to assess biomass and soil carbon stock of MMW.

Materials and methods

Study area

MMW is located in Kendrapara district, Odisha, east coast of India between 20°18′–20°32′N lat. and 86°41′–86°48′E long. Dense mangroves extend from Hukitola Bay in the north to Mahanadi river mouth near Paradip port in the south. MMW enjoys tropical monsoon climate. Its annual rainfall is about 2000 mm. Cyclonic storms are common during the monsoon season and there are two cyclonic peaks, one during May–July and other during October–November. Seasonal variations in tidal amplitudes are within a range of 6 and 1.2 m in monsoon and dry seasons respectively. The inter-zone combination of freshwater and tidal water, presence of numerous creeks and channels constitute a suitable habitat for luxuriant mangroves in the Mahanadi mouth region. Water salinity shows considerable variation between monsoon and summer season along with distance from sea to the rivers and creeks. Higher values of salinity were observed near the sea (11.5–19.9 pptv; parts per trillion volume), whereas it decreased in the interior mangrove region (0.3–0.7 pptv)[20]. MMW consists of eight forest blocks, namely Kantilo, Kendrapatia, Jambu, Bhitar Kharnasi, Bhahar Kharnasi, Kansaridia, Hatamundia and Hukitola. According to the records of Odisha Forest Department, the total mangrove area of MMW is 6651 ha including plantations.

Field sampling

Twenty sampling plots of size 25 m × 20 m were laid through stratified random quadrat sampling technique to determine the structure, composition and C-stock of the wetland covering a total area of 1 ha. Sixteen of the sampling plots were located in natural mangroves and four plots were laid in plantation area considering species composition, density and environmental conditions. Random number table was used to specify the geographical coordinates of these sites. To know the exact location of the sites, a Global Positioning System (GPS-Garmin Oregon-600) was used. The spatial location (latitude, longitude and altitude) of each quadrat was also collected. The age of the plantation forest stands was 15 years. All the woody plants greater than or equal to 10 cm girth at breast height (GBH) were measured[21,22], and individuals with less than 10 cm GBH (≥4.77 cm diameter at breast height (DBH)) were categorized as saplings. For *Rhizophora apiculata*, DBH was measured above the highest prop roots. Information on elevation, slope, rainfall and temperature was also gathered during the study period.

Plant diversity indices such as Shannon–Weiner's index (H') based on natural log, Simpson's index (D), evenness value and Menhinick's species richness were calculated following Magurran[23]. Dominance is defined as maximum relative contribution of a particular species to the total stand. Important value index (IVI) of each species was calculated by the summation of relative frequency, relative density and relative dominance.

Three pools of carbon were considered to measure the carbon stored in mangrove ecosystems. They were: (1) above-ground biomass, (2) below-ground biomass/root and (3) sediment/soil. Above-ground biomass (W_{top}) and root biomass (W_{R}) were estimated using the allometric equations for mangroves developed by Komiyama *et al.*[24] for Southeast Asia. These allometric equations use diameter and wood density as predictive variables and have a coefficient of determination (R^2) of 0.979 and 0.954 respectively. The allometric equations used are

$$W_{\mathrm{top}} = 0.251\rho D^{2.46},$$

$$W_{\mathrm{R}} = 0.199\rho^{0.899}D^{2.22},$$

where W_{top} is the above-ground biomass (kg), W_{R} is the root biomass (kg), ρ the wood density of the species, and D is the diameter at breast height.

The value of total biomass (above-ground and root) per plot was summed for all plots and averaged to get the mean total biomass, which was then converted to tonnes per hectare. Conversion from biomass to carbon was achieved through use of carbon fraction value of 50% (ref. 25).

Soil analysis: Soil samples (0–30 cm) were collected in polythene bags with auger (coleparmer WW-99026-00, $r = 3.5$ cm, $h = 30$ cm) from different sites of mangrove forest of MMW. Soil samples were analysed for pH, bulk density (BD), electrical conductivity (EC), moisture content, organic carbon (OC), available nitrogen and available phosphorus. Soil pH and EC were measured by dipping digital pH and EC meter (OKATON) probe in supernatant saturated suspension (w/w soil : water : 1 : 2.5) respectively. Soil moisture content was estimated by oven-drying method (105°C for 48 h). Bulk density was calculated using oven-dried weight of soil divided by augur volume ($\pi r^2 h$). Plant debris was handpicked and sieved from air-dried soil for estimation of organic carbon, available nitrogen and available phosphorus. Soil organic carbon (SOC), available nitrogen and available phosphorus were estimated by Walkley and Black method[26], Kjeldahl and Olsen methods respectively. Finally, soil organic carbon per hectare was determined using the following formula[2]

$$\text{Soil organic carbon (t/ha)} = \text{bulk density (g/cm}^3) * \text{soil depth (cm)} * \text{organic carbon (\%)}.$$

Total ecosystem carbon storage: Ecosystem carbon storage (Mg C ha^{-1}) was calculated by summing up the above- and below-ground biomass and soil C-stocks. The total carbon stock of mangrove forests of MMW was scaled up by multiplying the mean ecosystem carbon stock (Mg C ha^{-1}) with the total area of mangrove forest (6651 ha) and converting to carbon dioxide equivalents (CO_2e) using a factor of 3.67 (ref. 27).

Statistical analysis: Data on plant biomass, C-stock and SOC density were statistically analysed using the software SPSS 13.0. Means ± standard error are presented. A Pearson's correlation study was carried out between vegetation biomass and different physico-chemical parameters to determine the sensitivity of SOC response to the change of vegetation biomass among different mangrove communities in different locations.

Results and discussion

Floristic composition

A total of 1963 individual stems were recorded from 1 ha sampling area under natural and plantation stands. There are 16 species belonging to 14 genera and 12 families. Apart from tree species like *Avicennia*, *Rhizophora*, *Lumintzera*, *Excoecaria*, etc., *Merope angulata* (shrubs), *Ipomoea pes-caprae*, *Derris trifoliata* (climbers), *Acanthus ilicifolius* (herbs) and *Porteresia coarctata*, *Myriostachya wightiana* (grasses) were also reported. *Acrostichum aureum* was the only fern recorded from the study area. Plantation vegetation was represented by the species such as *Avicennia marina*, *A. officinalis*, *A. alba*, *R. apiculata* and *Sonneratia apetala*. *Acanthus ilicifolius* was common in both plantation and natural mangroves. DBH of mangrove trees ranged from 3.18 to 33.74 cm. *A. officinalis* had the highest DBH of 33.74 cm and

Table 1. Floristic composition of mangroves in the Mahanadi Mangrove Wetland (MMW), East Coast of India

Species	Important value index	Density (trees/ha)	DBH (cm) mean ± SD	Basal area (cm^2/ha)	Biomass (t/ha)
Aegiceras corniculatum	0.120	2	10.8 ± 0.6	27.90	0.01
Avicennia alba	21.892	123	35.49 ± 15.2	24046.69	23.96
Avicennia marina	105.328	1060	24.42 ± 12.7	78987.18	71.34
Avicennia officinalis	22.016	90	48.42 ± 23.7	26824.58	30.58
Briguiera cylindrica	0.801	10	20.80 ± 6.3	448.78	0.34
Ceriops decandra	2.756	45	13.38 ± 2.83	713.93	0.45
Clerodenron inerme	0.123	2	14.35 ± 3.0	33.50	0.02
Excoecaria agallocha	33.788	253	25.11 ± 13.5	32161.02	29.42
Heritiera fomes	7.279	100	17.39 ± 8.2	3362.35	2.61
Lumnitzera racemosa	12.676	142	22.41 ± 7.9	8375.94	6.76
Phoenix palludosa	0.127	1	12.58 ± 2.4	117.42	0.07
Rhizophora apiculata	13.279	104	24.69 ± 9.9	12281.99	10.40
Salvadora persica	0.179	1	28.56 ± 4.8	198.53	0.16
Sonneratia apetala	0.719	2	45.54 ± 19.8	950.94	1.01
Thespecia populnea	2.543	27	22.77 ± 9.6	1796.69	1.49
Xylocarpus granatum	0.151	1	44	154.06	0.14

E. agallocha had the lowest DBH of 3.18 cm. The dominant tree species (according to IVI) in the study site were *A. marina* (105.32), *E. agallocha* (33.78), *A. officinalis* (22.01), *A. alba* (21.89) and *R. apiculata* (13.27) (Table 1). Family-wise distribution revealed that Rhizophoraceae and Avicenniaceae had three species each, and others had a single species. The Shannon–Weiner index (H') was estimated to be 0.79 ± 0.38 with Simpson's value at 0.42 ± 0.22, evenness value at 0.48 ± 0.15 and Menhinick's species richness at 0.38 ± 0.11. Several studies have also concluded that the mangroves have very low diversity indices in contrast to other tropical forest ecosystems[14,28–30].

Biomass C-stock

Table 2 provides the summary of biomass and carbon stocks of plantation and natural stands. Plantation stands have a total mean biomass of 181.2 ± 32.5 t/ha (C-stock of 90.6 ± 16.2 t-C/ha), while natural stands it is 178.3 ± 17.9 t/ha (C-stock of 89.1 ± 8.9 t-C/ha). The overall mean biomass considering both natural and plantation stands is 178.8 ± 15.3 t/ha, with carbon stock of 89.4 ± 7.6 t-C/ha. The highest biomass and carbon stock can be attributed to dense stem density of 3500 individuals/ha in the natural stands (Plot-16) and 2050 individuals/ha in the plantations (Plot-3).

Figure 2 shows a comparison of mean AGB in different Asian countries, including the present study. The overall mean AGB is 125.0 ± 10.9 t/ha, while plantation stands is 125.5 ± 22.6 t/ha and natural stands is 124.9 ± 12.8 t/ha. The range of overall AGB in the present study (67.8–236.9 t/ha) is comparable with that in the Sundarbans[14,31], Japan[32], Australia[33], Senegal[34], Guadeloupe[35], Puerto Rico[36], Thailand[37], Florida[38] and estuarine complex along the Bay of Bengal (India)[18]. Estimates in this study are lower than those for Indonesia[39], Malaysia[40], Sri Lanka[41], Andaman Islands (India)[17] and the Philippines[13]. The BGB carbon pool contributes about 18% of the total carbon pool. The overall mean BGB biomass is 53.8 ± 4.5 t/ha (C-stock of 26.9 ± 2.2 t-C/ha), while plantation stands is 55.7 ± 9.8 t/ha (C-stock of 27.98 ± 4.9 t/ha) and natural stands is 53.3 ± 5.2 t/ha (C-stock of 26.6 ± 2.6 t-C/ha). The values of mean BGB and carbon stock (53.8 ± 4.5 t-C/ha and 26.9 ± 2.2 t-C/ha respectively) in MMW show comparatively higher C-stock than mangrove forests in Northern Vietnam[42], southern China[43] and Tamil Nadu (India)[13]. But, in the present study C-stock value is much lower than that in mangrove forests in Bahile (Philippines)[44], Bohol (Philippines)[13] and Yap[45]. The above-ground and below-ground biomass ratio (T/R ratio) for the present study ranged from 2.0 to 2.6, or an average of 2.3. The result is consistent with the value given in Komiyama *et al.*[46], which varies from 1.1 to 4.4. It is a general feature of mangrove forests to have lower T/R ratio than upland forests for better adaptation to stand upright in wet and soft mud conditions. In terms of biomass allocation of MMW, AGB represents 71% of the total and root accounts for 29%. Biomass varies along latitude and is also determined by different factors such as species diversity, tree height and density. Further, biomass is also related to species composition, community structure, growth forms, and age of the plant community[17,33,38,47]. AGB and BGB differ greatly among species, depending upon the geographical location, plant density and ecology.

Tree biomass allocation by different species

Among tree species, the top five that contribute the most to AGB are *A. marina* (71.3 t/ha), *A. officinalis* (30.5 t/ha),

Table 2. Biomass and carbon stock of plantation and natural stands (plot-wise) in MMW

Stand	Above ground		Below ground		Total	
	Biomass (tonne ha^{-1})	Carbon (tonne ha^{-1})	Biomass (tonne ha^{-1})	Carbon (tonne ha^{-1})	Biomass (tonne ha^{-1})	Carbon (tonne ha^{-1})
Plantations						
Plot-1	166.10	83.05	72.36	36.18	238.46	119.23
Plot-2	162.39	81.19	72.83	36.41	235.22	117.61
Plot-3	77.53	38.76	34.93	17.46	112.47	56.23
Plot-4	96.19	48.09	42.75	21.37	138.94	69.47
Mean	125.55	62.77	55.72	27.86	181.27	90.63
Standard error	22.6	11.3	9.8	4.9	32.5	16.2
Natural stands						
Plot-1	130.22	65.11	59.02	29.51	189.24	94.62
Plot-2	111.25	55.62	50.90	25.45	162.16	81.08
Plot-3	111.77	55.88	43.60	21.80	155.38	77.69
Plot-4	106.46	53.23	40.62	20.31	147.08	73.54
Plot-5	90.69	45.34	42.69	21.34	133.38	66.69
Plot-6	78.33	39.16	37.03	18.51	115.37	57.68
Plot-7	129.95	64.97	52.36	26.18	182.31	91.15
Plot-8	105.89	52.94	43.53	21.76	149.43	74.71
Plot-9	135.96	67.98	58.67	29.33	194.64	97.32
Plot-10	92.93	46.46	41.29	20.64	134.23	67.11
Plot-11	67.80	33.90	32.95	16.47	100.75	50.37
Plot-12	68.74	34.37	32.89	16.44	101.64	50.82
Plot-13	111.57	55.78	43.67	21.83	155.24	77.62
Plot-14	217.49	108.74	81.69	40.84	299.19	149.59
Plot-15	202.52	101.26	89.87	44.93	292.40	146.20
Plot-16	236.95	118.47	103.39	51.69	340.35	170.17
Mean	124.91	62.45	53.3	26.69	178.30	89.15
Standard error	12.8	6.4	5.2	2.6	17.9	8.9

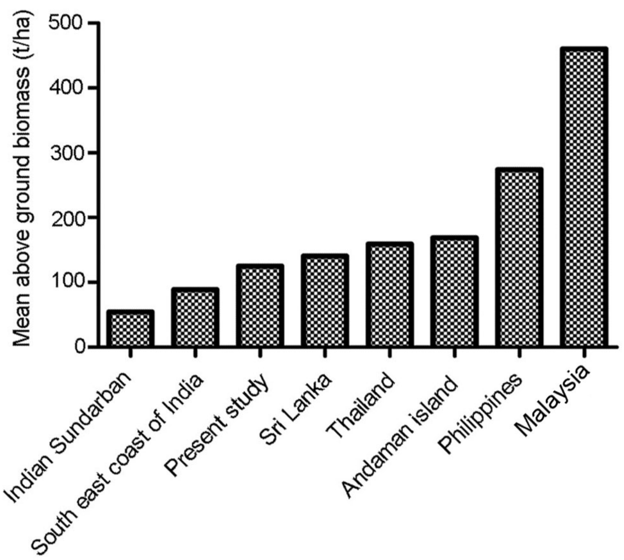

Figure 2. Comparison of above-ground biomass of mangrove forests in different Asian countries, including the present study.

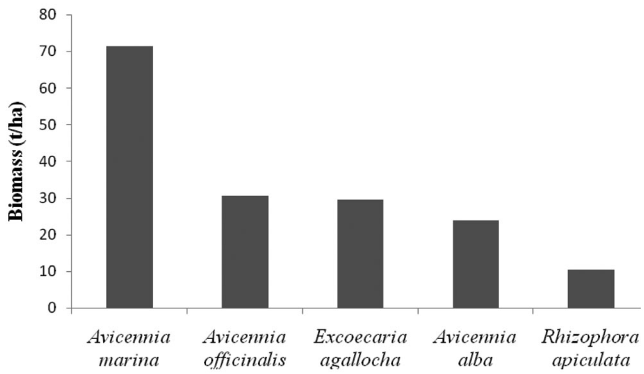

Figure 3. Top five potential C-accumulating tree species.

E. agallocha (29.4 t/ha), *Avicennia alba* (23.9 t/ha) and *R. apiculata* (10.4 t/ha; Figure 3). At Kagekanu plot (Karnataka), *A. officinalis* contributes >70% of total biomass, *Sonnaratia alba* about 8% biomass, while *S. apetala* has significant amount of biomass in the Sundarban mangroves[16]. This is an indication of the dominance of a single species contributing more in the forest ecosystem and warrants prioritization of *A. marina* for conservation to achieve significant biomass and carbon stocks in MMW.

Soil carbon stock: Table 3 provides results of different soil parameters in MMW. SOC stored in the upper 30 cm depth of the sediment as estimated in this study is in the range 43.8–79.2 t C ha^{-1}, with an average of 57.6 ± 11.1 t C ha^{-1} (Table 3). Natural stands had mean

SOC of 54.3 ± 7.4 t C ha^{-1}, whereas plantations had 60.9 ± 13.9 t C ha^{-1}. The upper 30 cm depth showed significant amount of carbon in the present study. The estimated mean soil C-stock (57.6 ± 11.1 t C ha^{-1}) is comparable to SOC in 1 m sediment depth in Okinawa, Japan[1], and northern Vietnam[42], and 20 cm depth in southeast Australia[48]. However, SOC value in the present study is less in comparison to that reported at 30 cm depth in the Philippines[44]. Many studies have shown that there is a decrease in density of carbon with increasing soil depth[42]. Further studies are needed to account for SOC in the total depth of sediment deposits.

Correlation study between different physico-chemical parameters and plant biomass

In the correlation study, SOC ($r = 0.87$) and BD ($r = 0.67$) were significantly correlated to total plant biomass (TPB; AGB + BGB) (Table 4), whereas available nitrogen ($r = -0.74$) had negative correlation with TPB. However, SOC had negative correlation with available nitrogen ($r = -0.80$).

In this study, SOC density and TPB increased from 43.8 t ha^{-1} and 100.7 t ha^{-1} to 79.2 t ha^{-1} and 340.3 t ha^{-1}, considering both plantation and natural forest stands respectively. This may be attributed to the larger vegetation biomass and increased net primary production, which resulted in higher input of dead roots over time, as well as the higher rate of litterfall[49]. Increase in SOC density along with biomass growth has been demonstrated in a study at the Leizhou Bay mangrove forest of South China[49]. Gleason and Ewel[50] found that standing living root biomass is positively correlated with soil carbon in a Micronesian mangrove forest. As shown in Table 4, a significantly positive correlation is found between biomass and SOC concentration on the surface layer of 0–30 cm depth ($r = 0.87$). Wang *et al.*[51] concluded that SOC density increases across the tidal gradient from the low to the high intertidal zone.

Table 3. Soil parameters in MMW (mean ± SD)

Parameters	Plantation	Natural
pH (1 : 2.5)	7.1 ± 0.2	6.98 ± 0.37
Electrical conductivity (dSm^{-1})	5.7 ± 0.8	5.2 ± 0.3
Bulk density (g/cc)	0.8 ± 0.05	0.8 ± 0.1
Available N (kg/ha)	150.0 ± 11.5	149.6 ± 23.8
Available P (kg/ha)	36.8 ± 4.6	35.1 ± 3.0
Soil organic carbon (t/ha)	60.9 ± 13.9	54.3 ± 7.4

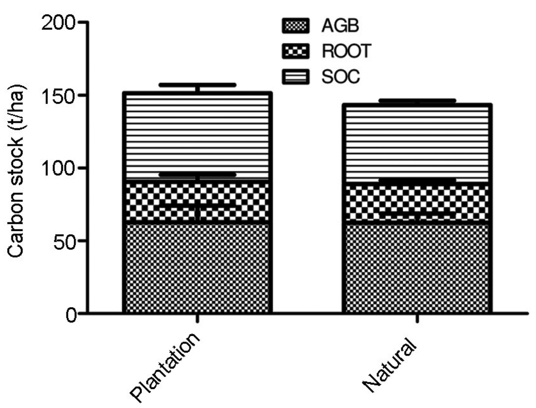

Figure 4. Carbon stocks of plantation and natural forest stands in MMW. SOC pools are up to 30 cm depth and vertical bars denote standard error.

Total C-stock: The overall total mean C-stock, including biomass and soil carbon stock of MMW is estimated to be 147.0 ± 8.1 Mg C ha^{-1} (Figure 4), which is equivalent to 539.5 Mg CO_2 ha^{-1}. The mean of carbon stock in natural stands is 143.4 ± 8.2 Mg C ha^{-1} (vegetation 89.1 ± 8.9 Mg C ha^{-1} and soil 54.3 ± 3.0 Mg C ha^{-1}), and for plantations it is 151.5 ± 7.9 Mg C ha^{-1} (vegetation 90.6 ± 16.2 Mg C ha^{-1} and soil 60.9 ± 5.6 Mg C ha^{-1}). The mean C-stock in plantation stands is higher than that in natural stands due to high tree density, with the area well protected by the Forest Department. Another reason may be that in plantation stands, silvicultural activities are going on regularly to properly allow tidal water to each stand. So the nutrient cycling in plantation stands is good, favouring visual growth. The distribution of C-stock in above-ground biomass is 43%, soil (39%) and below-ground biomass (18%). The total area of mangrove forest cover in MMW is 6651 ha (Odisha Forest Department). We extrapolated the mean C-stock value for total area of mangroves and estimated a substantial sink of 0.98 Mt of C, which is equivalent to 3.59 Mt of CO_2e. These estimates suggest a high carbon storage and carbon sequestration potential of MMW, besides providing an array of other ecosystem services, such as fuel wood, fishing, non-timber forest products, soil conservation, cleaning and protecting coastal areas from cyclones and storms and providing livelihoods to local people. In our study, SOC density may have been underestimated because it is based on the upper 30 cm layer. However, several studies have reported that SOC may extend up to several metres in depth[45,52]. Thus, actual mangrove ecosystem carbon stock may be much higher than the value estimated in the present study. The mean overall C-stock considering both natural stands and plantations is 147.0 ± 8.1 Mg C ha^{-1}. This is 1.6 times higher than carbon reported for the forests of Odisha (88 Mg C ha^{-1})[8]. Thus, there is potential for large sink benefit by expanding mangrove plantation in degraded areas of 212,100 ha lost since the last 30 years in India.

Conclusions

Estimation of C-stocks in MMW revealed the high potential of mangroves for sequestering carbon. The plantations can

Table 4. Pearson's correlation between different physico-chemical parameters and plant biomass

Parameters	Bulk density	Available nitrogen	Available phosphorus	Total plant biomass	Soil organic carbon
Bulk density	1.00				
Available nitrogen	–0.53	1.00			
Available phosphorus	–0.40	–0.17	1.00		
Total plant biomass	0.67*	–0.74*	0.03	1.00	
Soil organic carbon	0.70*	–0.80**	0.10	0.87**	1.00

*Correlation is significant at 0.05 level (two-tailed). **Correlation is significant at 0.01 level (two-tailed).

store as much carbon as natural mangrove forests. This highlights the need for expanding mangrove plantations as well as reclaiming degraded land in the past 30 years, which is about 212,100 ha in India. Although mangrove forests in MMW are protected by the Forest Department of Odisha, they have been continuously facing illegal practices of prawn farming, encroachment, firewood collection, coastal erosion and tropical cyclones. The present study suggests participatory incentivized plantation and restoration of mangrove forests with local people for climate change mitigation programmes.

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