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Carbon stocks and sequestration potential of Indian Mangroves

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Abstract: Mangrove forest patches and plantations with known age of plantation along both western and eastern coast of India were sampled for estimation of standing biomass and C stocks. A sample plot of 0.1 ha (1000 m^2) was laid in each patch depending on the contour of the patch. All woody stems >1 cm dbh were identified, measured for size and heights were estimated qualitatively. Standard vegetation parameters were estimated. Biomass was calculated using allometric equations based on diameter. *Rhizophora mucronata* was the most abundant species with 26.1% of total abundance. Mean biomass was 69.3 ± 49.7 t ha^{-1} (range 4.85–232.8) with wide variation. Mean AGB along the west coast was 72.6 ± 53.3 and along the east coast was 56.7 ± 30.5. They are not significantly different. The estimated biomass of Indian mangroves was found to be 41.2 million tons which is about 0.46% of total biomass of the Indian forests. Importance of mangrove forest along with carbon sequestration and other ecological services is discussed.

Key words: Above-ground biomass, C stocks, ecological service, Indian mangroves, *Rhizophora mucronata*.

Introduction

Mangrove is unique vegetation at the interface between saline and freshwater confluence zones along the coast. The ecology of mangroves is influenced by the environmental factors such as geomorphology of the coast, amplitude and duration of the tide, climate and fresh–water inflow (Selvam 2003). Of these factors flow of fresh water is the most important factor in determining species richness, structure and biomass of a mangrove forest patch. The ecological role of mangroves was realized as early as late 1880s (Lugo & Snedaker 1974). Mangroves have multiple uses for human kind. Some of the uses are: they act as natural barriers to cyclones and tsunami, prevents erosion of the coast, acts as a breeding ground for several fishes and provide minor subsistence for several communities along the coast. Mangroves have been utilized as fodder, fuel wood, timber, medicine and charcoal (Donato *et al.* 2011; Upadhyay *et al.* 2002).

Mangroves provide valuable ecological services throughout the tropics. However there are some negative impacts as seen in Hawaii (Cox & Allen 1999). Mangroves are known to be extremely productive ecosystems that store large amount of carbon especially in soils (Lugo & Snedaker 1974). The complex root systems that allow slow sedimentation and low oxygen content that allow accumulation of organic matter are the causes of carbon rich soils in mangroves. In fact, mangrove soils store five times more carbon than soils in terrestrial ecosystems (Donato *et al.* 2011). Though country wide estimates of biomass are available for India (Chhabra *et al.* 2002; Haripriya 2003; Ravindranath *et al.* 1997) the biomass and carbon estimates of mangroves are still lacking. In this study on Indian Mangroves, we are asking the following specific questions: (a) What is the standing biomass in a hectare of mangrove forest? (b) What is the C sequestration potential of a mangrove forest? and (c) What would be the

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enhancement in C sequestration with the given thrust on afforestation of degraded mangrove patches?

Mangroves in India

India has 7516.6 km long coast line along both east and west coasts including island territories (Mandal & Naskar 2008). Both east and west coast differ in the geological structure and provide a different environment for mangrove formations. There are several inventories and classification of mangrove wetlands of India (Gopal & Sah 1995; Selvam 2003). West coast mangroves are in the inter-tidal ones along the mouths of minor rivers and rivulets that drain the Arabian Sea. The vegetation is sparse, less extended and confined to patches due to scanty supply of upstream freshwater. Large amount of silt-clay deposition and relatively low tidal fluctuation characterizes west coast mangroves (Mandal & Naskar 2008). East coast mangroves are referred as deltaic mangrove forest along the mouths of major river flowing into the Bay of Bengal. They have more species than the west coast mangroves. According to FSI (2011) estimate India has 4662.56 km^2 of mangrove forests under different disturbance regimes. West Bengal has the largest area (46.21%) under mangrove formations that includes Sundarban Biosphere Reserve, followed by Gujarat (22.7%) and Andaman & Nicobar island (13.2%) complex. Area under mangroves in different coastal states is given in the Table 1. According to FSI (2011) area under mangrove has increased by 1.78% with considerable increase in Goa, Gujarat states and Union territory of Daman and Diu. Considerable decline in the area was noticed in Andaman & Nicobar Islands attributed mainly to Tsunami that hit the eastern coast of India (Table 1).

Methods

A 0.1 ha (1000 m^2) area was sampled in each mangrove forest patches in different states. Dimensions (50 m × 20 m, 250 m × 4 m, 100 m × 10 m) of the plot varied depending on the contour of the patch. Mangrove forest patches and sampling plots were selected randomly. All woody stems >1.0 cm dbh (diameter at breast height) were identified to species and measured for size. An ocular qualitative estimate of height was made for each individual. Notes were made on stem injury, if any, branching pattern and other interesting observations. We also sampled mangrove plantations to obtain annual growth assuming that growth is linear. Present stem size in the plantation by the age of the plantation would give us the annual increment (White 1998). The annual increment thus obtained was used to estimate the annual biomass gain estimated by allometric method and hence the carbon sequestration. Similar sampling strategy was followed with mangrove plantation. Year of plantation was obtained from forest department and age of the plantation was determined. Mangrove forest sampling was done in the summer months of 2007 and 2008 along the coast line of different states.

Standard indices that characterize vegetation such as Simpson's index (probability of picking up two different species), Shannon-Weiner's index (measure of heterogeneity) and Fisher's alpha (estimate of species diversity that is not influenced by plot dimensions) were calculated using standard protocols (Magurran 1988). Structural parameters such as density, basal area (calculated as area of a circle) and maximum diameter were estimated for each sample.

Aboveground biomass (AGB) for each sample was calculated using allometric equation based on diameter developed by Chave *et al.* (2005) for wet mangrove forest patches

AGB = ρ*exp (–1.349+1.980*ln D) + 0.207*(ln)) ^2–0.0281(ln (D))^3)

Where ρ = wood specific gravity (g cm^{-3}), ln = natural logarithm and D = dbh (cm).

There are several allometric equations developed for estimation of AGB (Brown *et al.* 1989; Chave *et al.* 2005; FSI 1996). The current equation is precise and also used in estimation of biomass by CTFS global network of permanent forest dynamics plots (Chave *et al.* 2005). A universal mean value of 0.6 was used as wood specific gravity as many mangrove species specific values are not available. Belowground biomass (BGB) was calculated as 26% of the AGB. Fifty percent of biomass is assumed as Carbon (World Bank 1998) and expressed as tons per hectare. Mean biomass value thus obtained from the samples was used to extrapolate to the national scale based on data published by the Forest Survey of India to estimate the standing biomass in mangrove forests and hence the carbon.

We employed the test of variability (ANOVA, single factor) to estimate the significance of variability in biomass stocking across different patches. We employed t test to characterize the significance of mean biomass in different states.

Table 1. Mangrove forest area & their change in various states (data source FSI 2011).

States	Area (ha)		
	2011	2005	% Change
Andhra Pradesh	35200	35400	–0.56
Goa	2200	1600	37.5
Gujarat	105800	99100	6.76
Karnataka	300	300	0
Maharastra	18600	18600	0
Orissa	22200	21700	2.30
Tamilnadu	3900	3600	8.33
West Bengal	215500	213600	0.89
Andaman & Nicobar	61700	63500	–2.83
Pondicherry	100	100	0
Kerala	600	500	0
Daman & Diu	156	100	56
Grand Total	**466256**	**458100**	**1.78**

Table 2. Biomass stocking in mangrove patches at several locations along the coast of India.

State	Region	Natural Patch (Biomass, t ha^{-1})	
		Aboveground (±SD)	Belowground (±SD)
Kerala	Central Kerala	50.66 ± 32.6	13.17 ± 8.4
	North Kerala	105.38 ± 77.4	27.45 ± 20.1
Karnataka	Mangalore	90.31 ± 59.1	23.45 ± 15.3
	Uttara Kannada	65.27 ± 40.2	16.97 ± 10.4
Goa	South Goa	117.69 ± 40.8	30.59 ± 10.6
Maharastra	Mumbai	4.85	1.26
West Bengal	Sundarbans	61.61 ± 29.7	16.01 ± 7.7
Orissa	Bitharkarnika	35.93 ± 29.2	9.34 ± 7.5

Results and Discussion

A total of seventy seven 0.1 ha sample plots were laid along both eastern and western coasts of India covering Maharastra, Goa, Karnataka, Kerala, Orissa and West Bengal. A total of 11070 individuals over 1.0 cm dbh (diameter at breast height) were enumerated belonging to 25 species of true mangroves. *Rhizophora mucronata* (26.1%) was most abundant species followed by *Avicennia marina* (25.5%) and *Avicennia officinalis* (10.5%). These three species together constitute 62.2% of total individuals. The floristic and structural aspects of mangrove patches would be discussed elsewhere.

Mean aboveground biomass in a hectare of mangrove forest stand was found to be 69.3 ± 49.7 t ha^{-1} (range 4.85–232.8, N = 77). There is a wide variation in the biomass stocking in a patch. CV (71.7%) was also high indicating very high variability in biomass stocking across different patches. Mean AGB along the west coast was 72.6 ± 53.3 t ha^{-1} (Range = 4.85–232.8, N = 61) and CV was 73.4%. Along the east coast mean AGB was 56.7 ± 30.5 t ha^{-1} (Range = 10.9–123.4, N = 16) and CV was 53.6%. Variability in mangrove forest biomass was significant (ANOVA, F = 2.75, df = 7 P <0.01), the variability in biomass was contributed by the patches on the western coast which showed significant variability among themselves (ANOVA, F = 2.96, df = 5, P<0.01). There was no significant variability among the eastern coast samples (ANOVA, NS). The variability in biomass distribution was high along the west coast when compared with east coast, however the mean AGB was not significantly different (t = 1.54, df = 42, P = 0.06). Mean AGB stocking in mangrove patches was significantly different between north and central Kerala (t = 2.05, P = 0.03, df = 9). Mean AGB within Karnataka (Mangalore and Uttara Kannada) patches was not different (t test, not significant) and AGB between patches in Karnataka and Kerala was also not significant (t test, NS). There was no significant difference in AGB among east coast patches (t test, not significant). Due to sample size constraints we did not compare other states and other pairs of comparison. Details of AGB in each region are given in the Table 2. A total of eight plantations were sampled with different ages of establishment. We could get the age for five plantations. Mean annual growth rate of individuals in different plantations was 7.88 ± 7.07 mm yr^{-1} with wide variation in growth rates (Table 3). It is observed that younger plantations showed relatively higher growth than the older plantations. The mean annual accumulation of the biomass was 0.936 ± 0.46 t ha^{-1}. There was not much variation in biomass accumulation rate between the older and the younger plantations. Among various species in plantations *Kandelia kandal* had lowest growth rate 2.57 ± 0.15 mm yr^{-1}. Highest growth rate was observed in *Avicennia marina* 11.1 ± 0.50 mm yr^{-1}. Most

Table 3. Growth rate and accumulation of biomass in mangrove plantations.

Location	Age of plantation	Annual Biomass increment ($t\ ha^{-1}\ yr^{-1}$)	Annual growth rate (C $mm\ yr^{-1}$)
Mumbai	3	0.872	11.5
Karnataka (Uttara Kannada)	21	1.367	3.1
Karnataka (Mangalore)	17	0.237	2.6
Karnataka (Mangalore)	35	1.376	3.5
Karnataka (Mangalore)	2	0.829	18.7

preferred species of the plantation *Rhizophora mucronata* had the mean growth rate of 2.80 ± 0.09 mm yr^{-1}. However, biomass accumulation was not proportional to growth rate. For example, *Avicennia marina* had biomass accumulation rate of 0.45 t ha^{-1}, while *Kandelia kandal* accumulated at the rate of 0.41 t ha^{-1}. Biomass accumulation and growth rate of different species in the plantations are given in the table 4. Estimated total biomass in mangrove forests in India was 41.2 million tons of which above ground biomass was 32.68 Mt and 8.49 Mt of belowground biomass. West Bengal with 19.03 Mt has high stocking of biomass followed by Gujarat (9.34 Mt) and Andaman & Nicobar islands (5.44 Mt). Chhabra *et al.* (2002) estimated that Indian forests have 8683.6 Mt of biomass including both aboveground and belowground biomass. Mangrove forests constitute 0.46% of total biomass of Indian forests. Growth rates from plantations of different ages indicate that *Avicennia officinalis* is the fastest growing species with mean growth rate of 8.06 ± 7.91 mm yr^{-1} (Table 4) with median diameter of 3.18 cm, followed by *Avicennia marina* 7.30 ± 5.93 mm yr^{-1} and median diameter of 8.11 cm. Species such as *Rhizophora mucronata*, *Kandelia kandal*, and *Sonnaratia alba* have relatively low growth rates, *Exocareya agallocha* a large shrub in mangroves has higher growth rate (Table 4)

Carbon stocks

According to FSI (2011) estimate, India has 6663 million tons of carbon in various forests.

Table 4. Species specific characteristics of annual biomass increment, growth and C stocks accumulation.

Species	Growth rate ($mm\ yr^{-1}$)	Annual biomass increment ($t\ ha^{-1}$)	Annual C sequestration ($t\ C\ ha^{-1}$)
Avicennia marina	7.30 ± 5.93	0.45 ± 0.59	0.226 ± 0.296
Avicennia officinalis	8.06 ± 7.91	0.466 ± 0.28	0.233 ± 0.14
Exocareya agallocha	11.3 ± 11.0	1.49 ± 0.15	0.748 ± 0.07
Kandelia kandel	2.57 ± 0.0	0.405 ± 0.00	0.202 ± 0.0
Rhizophora mucronata	2.95 ± 0.49	0.50 ± 0.02	0.25 ± 0.01
Sonnaratia alba	2.98 ± 1.71	0.195 ± 0.27	0.097 ± 0.13

Total C stocks in Indian mangrove forests are 20.59 Mt. Mangrove forests constitute 0.61% of total carbon pool which is not even one percent. West Bengal, Gujarat and Andaman & Nicobar Islands account for more than 80% of the C stocks of mangrove forests (Table 5). The mangrove plantations sequester carbon at a mean rate of 0.47 ± 0.23 t yr^{-1}. However, there was species specific variation in the sequestration rate (Table 4). Species such as *Rhizophora mucronata, Kandelia kandal* and *Avicennia marina* are among the slow carbon accumulators while *Exocareya agallocha* and *Avicennia officinalis* accumulates at a much faster rate (Table 4). According to the current rate of carbon sequestration raising of 0.1 mha plantations as envisaged in Green India Mission (Ravindranth & Murthy 2010) mangrove plantations sequester 468 tons of carbon per year. With the same sequestration rate, mangroves in India have the potential of sequestering 0.218 Mt C yr^{-1}. Mangrove area in the world is estimated to cover about 14 mha (Donato *et al.* 2011). India with 0.47 mha accounts for 3.3% mangrove forest in the world. It is estimated that at least 35% of mangrove forests have been lost and the loss of mangrove forests may even exceed the loss of threatened systems such as tropical rain forests and coral reefs (Valiela *et al.* 2001). Carbon stocks in Indian forests has shown considerable decline over the time. Biomass stocks in Indian forests were estimated to be 7940 Mt during 1880s and by

Table 5. Carbon stocks in mangrove forest patches in different states.

States	Area (ha)	Biomass (Mt)			C Stocks (Mt)
		Aboveground	Belowground	Total	
Andhra Pradesh	35200	2.46	0.64	3.10	1.55
Goa	2200	0.154	0.040	0.194	0.097
Gujarat	108500	7.41	1.92	9.34	4.67
Karnataka	300	0.021	0.005	0.026	0.013
Maharastra	18600	1.30	0.33	1.64	0.821
Orissa	22200	1.56	0.404	1.96	0.980
Tamilnadu	3900	0.273	0.071	0.314	0.1722
West Bengal	21500	15.10	3.92	19.03	9.51
Andaman & Nicobar	61700	4.32	1.12	5.44	2.72
Pondicherry	100	0.007	0.001	0.008	0.004
Kerala	600	0.042	0.010	0.052	0.026
Daman & Diu	156	0.010	0.002	0.013	0.006
Grand Total	**466256**	**32.68**	**8.49**	**41.18**	**20.59**

Table 6. AGB of mangrove patches from different countries across globe (Data from Komiyama *et al.* 2008).

Country (N)	Mean aboveground biomass (±SD) ($t\ ha^{-1}$)	Range ($t\ ha^{-1}$)	C Stock ($t\ ha^{-1}$)
Malaysia (3)	313.3 ± 129.8	460.0–211.8	156.6
Indonesia (13)	213.0 ± 134.3	436.4–40.7	106.5
Australia (3)	199.2 ± 123.7	341–112.3	99.6
Thailand (8)	212.2 ± 155.6	398.5–62.2	106.1
Japan (2)	102.8 ± 7.4	108.1–97.6	51.4
Srilanka (6)	136.3 ± 75.4	240–57	68.15
India (2) (Andaman & Nicobar)	169.0 ± 63.6	214–124	84.5
India (77) (Mainland)*	69.3 ± 49.7	4.85–232.8	34.6
Africa (3)	127.8 ± 108.3	249–40.1	63.9
America (13) (including USA, Central and South America)	129.4 ± 103.5	315–7.9	64.7

*present study

the end of 1980s it was reduced to 3426 Mt (Chaturvedi *et al.* 2008). There is a loss of more than 50% of C stocks in India over one hundred years. These estimates seems to be gross underestimate when compared with Ravindranath *et al.* (1997), who estimated the total C stocks in India in 1986 as 9585 Mt by adopting COPATH model. However, there was no estimate for mangrove forests. Mangrove patches in mainland India has the lowest carbon stocks in the world (Table 6). It can be estimated that carbon holdings of mangrove forests at global level is 1157.17 Mt. Though India has 3.3% of mangrove area, it accounts for 1.7% of C stocks. It is reported that over 33% of the Indian mangroves have been lost due to unchecked human mediated exploitation (Mandal & Naskar 2008). But FSI (2011) estimates that area under mangroves has increased by 616 km^2 from 4046 km^2 (1987) to 4662 km^2 (2011). Accordingly there is an increase of 2.15 Mt of C stocks in Indian mangroves leading to 15.2% increase C stocks. However, uncertainty still remains with respect to mangrove status in India. As per Greening India Mission objectives

(GIM) (Ravindranath & Murthy 2010) 0.1 mha mangroves are either to be restored or established leading to sequestration of 468 tons of carbon annually. Current C stock value of 44.2 t ha^{-1} is in the range of values of C stocks in Indian forests according to different estimates (Jana *et al.* 2009). According to FSI (2011) 70% of the area under mangrove forests is in various stages of degradation and has the scope for enhancing C stocks through either plantation activities or assisted natural regeneration activities. However, both activities require stringent measures for protection of these natural guards of the coastline. Nursery techniques for mangrove species are complex owing to their adaptation to halophytic environment. Among the species planted, forest departments of several states have developed propagation method for *Rhizophora mucronata*, other species are currently obtained from forest patches where there is a natural regeneration. It is now imperative that propagation techniques are developed for other species also so as to maximize the C sequestration potential of mangroves.

The ecological services of the mangrove are many and they could be the driving force behind the mangrove conservation. Though mangrove forests contribute to the carbon mitigation, their contribution is minimal. The ecological services of mangroves include shoreline protection and stabilization; mangrove patches are breeding grounds for many fishes and provide number of non-timber forest products Mangrove forest patches also provide fuel-wood to several communities along the coast. Given that 70% of Indian mangrove forests are in different stages of disturbance regimes, adequate protection and conservation of these forest patches would certainly enhance the carbon stockings of Indian mangroves that would significantly contribute to the global carbon pool. Indian mangroves could certainly be sinks of carbon.

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