

Diversity, Structure and Dynamics of a Mangrove Forest: a Case Study

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Abstract

The intertidal vegetation along tropical and subtropical coast is defined as mangrove vegetation. India has a long coast line measuring 7516 km. The ecology of mangrove forest is relatively less studied. Mangrove systems are known to be one of the most productive systems in the world. The study aimed to estimate the carbon sequestration potential of a relatively protected sacred grove along the western coast of India, in Kagekanu, Kumta, Karnataka. One hectare permanent plot was established, with all woody stems > 1 cm dbh (diameter at breast height), which were marked and identified. Repeated measurements were made to register the growth and other parameters. Allometric equation was used to estimate the biomass, out of which 50% was considered as carbon content. A total of 1100 stems > 1 cm dbh, belonging to 4 species, were enumerated. There was an overall decline of 13.9% stems during the study period. Mean mortality rate was found to be $5.83 \pm 1.85\%$ and there was no recruitment. The biomass increased from 155.53 tons/ha to 164.28 tons/ha. There was a net gain of 4.38 tons. *Avicinnia officinalis* was found to contribute significantly to carbon sequestration.

Keywords: *Avicinnia officinalis*, biomass, carbon sequestration, growth, mortality, recruitment, *Rhizophora mucronata*

Introduction

Mangrove forests have attracted attention of humans historically by their special adaptation for surroundings, their economical utilities and their ecology (Lugo and Snedekar, 1974). The intertidal forested vegetation in tropical estuarine zones is defined as “mangrove” (Mooney *et al.*, 1995; Valiela *et al.*, 2001); they consist of salt tolerant species with complex dynamics (Lugo and Snedekar, 1974; Tomlinson, 1986; Duke *et al.* 1998) and are estimated to cover about 240 x 103 km² area (Lugo *et al.*, 1990; Mandal and Naskar, 2008). Valiela *et al.* (2001) found that at least 35% of the mangrove habitats were lost during the last two decades. Giri *et al.* (2008) opine that mangrove forests in India and Bangladesh have remained largely unchanged during 1975-2005, and even more, it gained a small percentage area. Although mangrove forests cover small geographical area, they have a unique and significant contribution to the carbon geochemistry (Mitra *et al.*, 2011) and provide a wide range of ecosystem services (Badola and Hussain, 2005; Donato *et al.*, 2011). The floristics of mangrove forests has been reviewed globally (Duke *et al.*,

1998) and at local scale, for example Sundarbans (Gopal and Chauhan, 2006), but the studies on the patterns of diversity, structure and dynamics of mangrove are scarce. The land forests including tropical aseasonal (Lee *et al.* 2002), seasonal dry (Mc Shea *et al.* 2011), and temperate forests, have been extensively studied for several ecological aspects. The large consortium of large plots network coordinated by Center for Tropical Forest Science (CTFS) has been monitoring tropical forests for a long time (Condit, 1998). There are other networks, such as “rainfor”, that monitor forests. But with all this, there is no such organized effort to monitor mangrove forests.

India has a long coast line of 7516 km, including island territories. Recent estimation of mangrove forest cover is of 4639 km², which is about 3% of the global mangrove forest area (FSI, 2011), including in this surface also Sundarbans, the land shared between India and Bangladesh, which is probably the largest wet land in the world (Gopal and Chauhan, 2006). Indian mangroves have been classified as “tidal wetlands, woody vegetation”, under a hierarchical system of classification that considers factors such as location, salinity, physiognomy and duration of flooding (Gopal and Sah, 1995). Indian mangrove vegetation has

three distinct zones: 1. East coast habitats, having a coast line of 2700 km, facing the Bay of Bengal; 2. West coast habitats, having a coast line of 3000 km, facing the Arabian sea; 3. Island territories with 1816 km of coast line (Mandal and Naskar, 2008). Mandal and Naskar (2008) also recognized three habitat types with the Indian mangroves, which include: a. Deltaic mangrove habitat (east coast mangrove and gulfs of Gujarat), b. Coastal mangrove habitat (west coast mangroves) and c. Island mangrove habitat (Lakshadweep, Andaman and Nicobar islands). Characteristics and status of mangroves along the Indian coast have been reviewed by Selvam (2003). Studies in Indian mangroves have been along the lines of documenting biodiversity (Gopal and Chauhan, 2006), biomass (Mitra *et al.*, 2011), nutrient dynamics (Kumar *et al.*, 2011) and other conservation aspects, such as review of status (Jagtap *et al.*, 1993; Gopal and Chouhan, 2006). Biodiversity studies in mangrove forests have focused on describing different species of both true mangrove and associates of mangrove formations in Sundarbans (Joshi and Ghose, 2003; Gopal and Chouhan, 2006), Godavari delta (Azariah *et al.*, 1992), Bidarkarnika (Upadhyay and Mishra, 2008) or Andamans (Singh *et al.*, 1987). There are hardly any studies on the quantitative aspects of vegetation diversity and growth rates on mangrove species, based on repeated stem measurements.

This paper describes the diversity and structure in a one-hectare permanent vegetation plot of a mature mangrove sacred grove along the western coast of Karnataka. The present study describes the dynamics of the forest, including population changes, demographical changes based on size class distribution, patterns of mortality, growth and carbon sequestration over a period of three years. This is probably the first permanent plot based systematic and an innovative and elaborate study on the mangrove forest in India.

Study area

This study was undertaken in Uttara Kannada district (14° 63' N Lat and 74° 81' E Long) of Karnataka state,

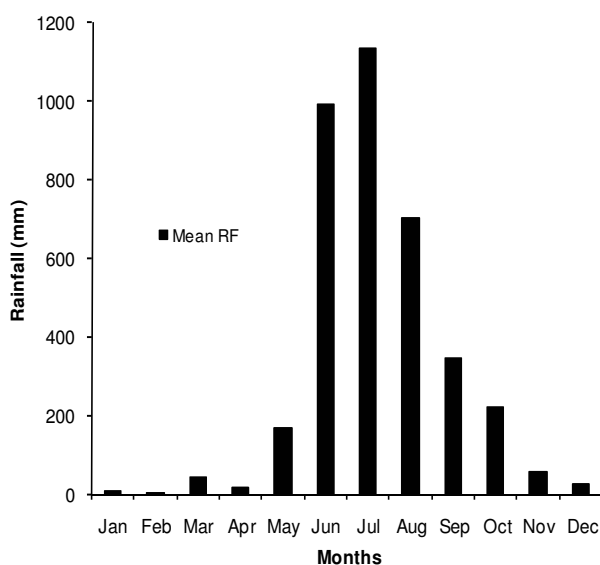


Fig. 1. Rainfall pattern in the study area (Kumta). Data from District met office, Karwar, for the period of 1990-2010

south India. Uttara Kannada is characterized by undulating terrain with fertile valleys. There is a considerable variation in the altitude, ranging from sea level to as high as 1000 meters ASL. Rainfall is mainly from the southwest monsoon, which is active from June to September. Mean annual rainfall during 1990-2010 is 3629.6 ± 521 mm, with June and July being the rainiest months (Fig. 1). The vegetation varies from tropical seasonal evergreen forests and its variants towards the west to moist deciduous forests on the eastern part (Pascal, 1986). Administratively, the forests in the district are classified into the following categories: a. Reserve forest (exclusively under state control and highly regulated), b. Minor forests (extraction of biomass and fuel wood is allowed to meet the demands of people) and c. Leaf manure forests, or locally called "Soppina betas" (forest area allotted to areca nut farmers under certain privileges for extraction of leaf and dry wood). Further, detailed description of the study area can be found in Daniels (1989) and Bhat *et al.* (2011). In Uttara Kannada district mangrove patches are seen in estuarine zones of important westward flowing rivers such as Kali, Bedthi, Aghanashini, Sharavathi and Vektapura. Mangroves are also present along the estuaries of small creeks and rivulets. Among these, Kali and Aghanashini estuaries support larger isolated mangrove patches. River Aghanashini runs in thick forests and amid cultivated lands, mainly paddy and Areca orchards, forms two waterfalls, covers a total distance of about 121 km before joining Arabian sea at Tadri and Aghanashini villages. The estuary is 13 km long and 2-6 km broad. This is the only river in Uttara Kannada district so far not dammed and with no major townships and industries polluting the water (Gadgil *et al.* 1993). Therefore, it is supposed to be least polluted. Before joining the sea, it forms many islands in the estuarine zone, varying in area. These islands are locally called by names such as Masurkurve, Gunda, Kekanakodi, Keppekuve, Tanneerahonda, Chowlihonda. Among these, Masurkurve is the largest, comprising about 32 ha. Though part of the land area of the island is cultivated by the local farmers, there is a good mangrove patch along the fringe. This patch is conserved and protected over many years in the name of a deity 'Bobbrudevaru', which is housed in a temple in the island. On the account of this, local community considers the patch as sacred and do not extract from this mangrove patch for personal use. However, collection and use of dead and fallen wood is allowed for performing religious rituals for the deity. This particular forest patch is called Kagekanu (14° 42' N Lat and 74° 40' E Long). Majority of the islands are used for prawn culture after the harvest of the paddy crop.

Material and Methods

We established one-hectare (100 x 100 meters) permanent plot in the sacred grove. Caution was taken in laying the plot to avoid edge effect. For easy enumeration we temporarily divided this plot into smaller blocks of 20 X 20 meters, by laying ropes. Within these smaller blocks, all woody individuals > 1.0 cm DBH (diameter at breast height) were enumerated for species, measured for size and marked with a unique tag number. Point of measurement was marked with paint for successive measurements. Multiple stems were given the same number and measured

for size. Any deformity on the stems, such as stem breakage, bark stripped, top broken and branches pulled, were noted.

Sizes of surviving stems were measured annually at the same point of measurement. Dead stems were noted, and recruitment of new stems of 1.0 cm DBH was also marked. Sizes of the largest stems were considered for growth analysis for individuals with multiple stems. All stems were included in basal area estimation. Mortality rate was estimated as the proportion of dead stems with respect to surviving stems and expressed as percentage. Recruitment was defined as appearance of new stems >1 cm DBH in accordance with CTFS protocols (Condit, 1998). Growth rate was calculated as difference in size between census periods over time elapsed between census period.

Above ground biomass (AGB) was calculated using allometric equation based on diameter, developed by Chave et al. (2005) for wet mangrove forest patches:

$$AGB = \rho * \exp(-1.349 + 1.980 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$$

where ρ = wood specific gravity (grams/cm³), ln = natural logarithm and D = dbh (cm).

There are several allometric equations developed for the estimation of AGB (Chave et al., 2005; Brown et al., 1989; FRI, 1970). 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. 50% of AGB was considered as C stocks, according to IPCC standards.

Results

One-hectare permanent plot at Kagekanu had 1100 individuals >1.0 cm dbh (diameter at breast height) belonging to 4 species. *Rhizophora mucronata* (Rhizophoraceae) was the dominant specie, with 368 individuals, followed by *Avicinnia officinalis* (Verbenaceae, 273 individuals), *Sonneratia alba* (Sonneratiaceae, 233 individuals) and *Kandelia kandel* (Rhizophoraceae, 233 individuals). *Rhizophora mucronata* and *Avicinnia officinalis* accounts for more than 58% of the stand composition (Tab. 1). Vegetation diversity of the plot was low. The probability

Tab. 1. Abundances of different species in the Kagekanu permanent vegetation plot

Species (Family)	Number of Individuals	Rel. Abundance (%)	Cum. Abundance (%)
<i>Rhizophora mucronata</i> (Rhizophoraceae)	368	33.45	33.45
<i>Avicinnia officinalis</i> (Verbenaceae)	273	24.81	58.27
<i>Sonneratia alba</i> (Sonneratiaceae)	233	21.18	79.45
<i>Kandelia kandel</i> (Rhizophoraceae)	226	20.54	100

of picking two individuals (Simpson's index) though was relatively high (0.73), while the heterogeneity index (Shannon-Weiner's H) was low (1.36). Non-parametric

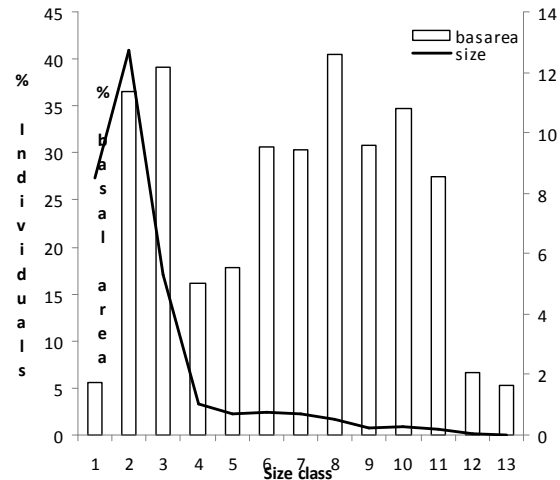


Fig. 2. Size class distribution of individuals and basal area in Kagekanu permanent vegetation plot

estimation of species diversity, Fisher's alpha, was also very low (0.52). The distribution of individuals among various species was uniform, as shown by the high evenness index (0.98).

Size class distribution of individuals followed the typical inverted "J" shape (Fig. 2). There was a large concentration of individuals in 5-10 cm size class. Over 62% of the individuals were in 0-10 cm size class (Fig. 2). Among species, *Avicinnia* had more or less a uniform distribution of individuals in each size class (Fig. 3) and was significantly

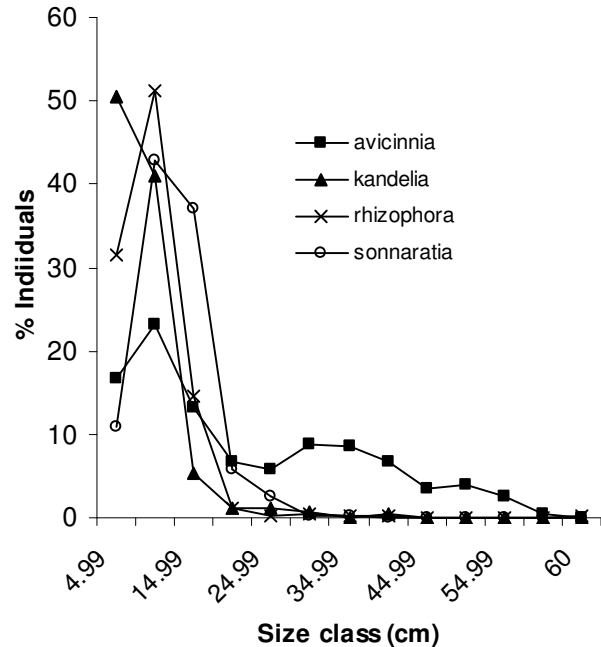


Fig. 3. Distribution of individuals in various size classes

different from all species (KS test, p>0.05). Other species did not show significant difference among themselves (KS test NS). There were 339 stems (30.9%) that had multiple stems. Population of *Avicinnia officinalis* had much larger stems with mean dbh of 21.4±15 cm, followed by

Sonneratia alba (10.6±4.3 cm), *Rhizophora mucronata* (7.1±4.4 cm) and *Kandelia kandel* (6.1±4.5 cm).

Total basal area of the one hectare plot was 24.4 m². *Avicinnia officinalis* accounts for 69.5% (16.9 m²) of the total basal area, followed by *Rhizophora mucronata* (14.1%, 3.4 m²), *Sonneratia alba* (11.5%, 2.8 m²) and *Kandelia kandel* (4.7%, 1.1 m²). Basal area was more or less uniformly distributed across size classes and did not show concentration in higher size class as observed with several other mature forests (Fig. 2). Total biomass of the plot was 155.53 tons. *Avicinnia officinalis* accounted for 77.4% of total biomass, followed by *Rhizophora mucronata* (10.8%), *Sonneratia alba* (8.3%) and *Kandelia kandel* (4.1%).

Dynamics of the forest

Population change

There was a decline of the population from 1100 individuals in 2008 to 971 in 2011, resulting in an overall decline of 13.9%. All species have shown decline, but *Kandelia kandel* had the maximum decline of 16.5% (Tab. 2). Mean decline observed in all species was in the range of 4.27% to 5.73% (Tab. 2). There was a major decline in the lower size classes (Tab. 3). However, there is a positive trend in higher size classes, as a result of growth from smaller size class.

Mortality and recruitment

Mean mortality rate of the community was 5.83±1.85% (range =4.27% - 7.88%, N =3). Among the different species, *Avicinnia officinalis* had a mean rate of 4.95±1.62%, *Kandelia kandel* had 6.79±3.06%, *Rhizophora mucronata* had 5.13±2.33% and *Sonneratia alba* had 7.10±2.02% mortality rates. There was no significant difference in

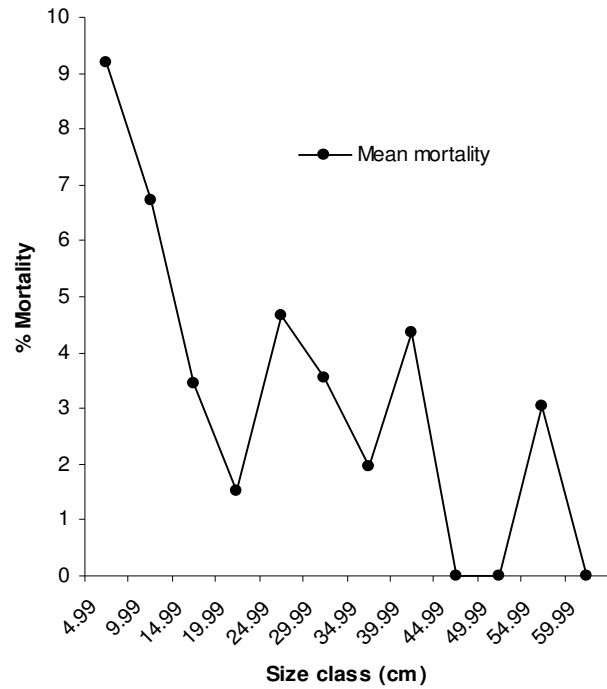


Fig. 4. Size class specific mortality observed in Kagekanu permanent plot

mortality rates between species (t test, NS).

There was a declining trend in mortality rates with increasing sizes (Fig. 4); however, there were elevated mortality rates in the size classes of 20-25 cm, 35-40 cm, 50-55 cm dbh (Fig. 4). Mean mortality rate for stems <30 cm

Tab. 2. Population changes observed in Kagekanu permanent vegetation plot

Species (Family)	Percent change (2008-2009) (N 2008)	Percent change (2009-2010) (N 2009)	Percent change (2010-2011) (N 2010)	Percent change (2009-2011)(N 2011)
<i>Rhizophora mucronata</i> (Rhizophoraceae)	-5.70 (368)	-4.32 (347)	-3.01 (332)	-12.5 (322)
<i>Avicinnia officinalis</i> (Verbenaceae)	2.56 (273)	-12.5 (280)	-2.85 (245)	-12.8 (238)
<i>Sonneratia alba</i> (Sonneratiaceae)	-8.58 (233)	-6.10 (213)	-1.00 (200)	-15.02 (198)
<i>Kandlia kandel</i> (Rhizophoraceae)	-5.75 (226)	9.39 (213)	2.07 (193)	-16.3 (189)
Total population	-4.27 (1100)	-7.88 (1053)	-2.37 (970)	-13.9 (947)

Tab. 3. Size class specific population changes in Kagekanu permanent vegetation plot

Size	Pop 2008	Pop 2009	Pop 2010	Pop 2011	Change 08-09	Change 09-10	Change 10-11	Change 08-11
4.99	293	236	182	142	-19.45	-22.88	-21.97	-51.53
9.99	397	382	346	331	-3.77	-9.42	-4.33	-16.62
14.99	215	225	223	242	4.65	-0.88	8.52	12.55
19.99	43	60	69	71	39.53	15.0	2.89	65.11
24.99	29	27	32	36	-6.89	18.51	12.5	24.13
29.99	31	24	20	28	-22.58	-16.66	40.0	-9.67
34.99	32	36	32	31	12.5	-11.11	-3.12	-3.12
39.99	22	23	23	22	4.54	0.0	-4.34	0.0
44.99	12	13	15	13	8.33	15.38	-13.33	8.33
49.99	15	14	12	15	-6.66	-14.28	25.0	0.0
54.99	9	11	14	14	22.22	27.27	0	55.55
59.99	2	2	2	2	0	0	0	0

dbh was 6.06±2.02% and for the stems >30 cm it was 2.05±2.06%. There was no recruitment observed during the study period into 1 cm dbh class.

Growth and carbon sequestration

Mean growth rate in *Avicinnia officinalis* was found to be 0.6±1.08 cm per annum, with maximum growth of 3.71 cm and shrinkage of 3.2 cm. It was 0.43±0.44 cm in *Kandelia kandel*, which had the maximum growth of 6.5 cm and shrinkage of 0.9 cm. Mean growth rate in *Rhizophora mucronata* was 0.49±0.76 cm, with growth as high as 9.1 cm and shrinkage of 1.2 cm. *Sonneratia alba* recorded a mean growth of 0.45±0.62 cm, with maximum growth of 2.8 cm and shrinkage of 3 cm. There was high variability in growth rates among species.

There was no pattern in growth rates in each species across different size classes (Tab. 4). However, there was high variability in mean growth rates in each size class (Tab. 4). The mean growth rates among different species in the size class 0-5 cm dbh were not significant (t test, p>0.05, NS). Mean growth rate of *Avicinnia officinalis* with other species in the size 5-10 cm dbh was significantly different (t test, p<0.05) and also between *Kandelia kandel* and *Rhizophora mucronata* (t test, p<0.05). Growth rate of *Sonneratia alba* with *Kandelia kandel* and *Rhizophora mucronata* was not different (t test, p>0.05, NS). Among the stems of 10 -15 cm dbh, *Kandelia kandel* had significant difference with *Rhizophora mucronata* and *Avicinnia officinalis* (t test, p<0.05), but rest of the combinations were not significant (t test, p>0.05, NS).

There was a net gain of 1.36 m² (5.57%) of basal area during the study period of three years. However, the gain was not uniform. During the first year, it was 0.56 m² (2.31%), in the second year it was negligible (0.0014 m², 0.005%) and in the third year there was a significant gain of 0.79 m² (3.18%) (Tab. 5). *Kandelia kandel* lost 12.7% basal area during the study period, while other species gained basal area in the range of 5-6%.

During the study period, in all censuses *Avicinnia officinalis* contributed with over 75% to the AGB pool,

followed by *Rhizophora mucronata* (10%), *Sonneratia alba* (8%) and *Kandelia kandel* (2%). AGB changed from 155.53 tons/ha to 164.28 tons/ha, resulting in a net accumulation of 8.76 tons. *Avicinnia officinalis* (8.61 tons) and *Sonneratia alba* (1.41 tons) gained biomass, while both *Kandelia kandel* (1.25 tons) and *Rhizophora mucronata* (0.01 tons) lost biomass.

The carbon stock of the plot ranged from 77.7 to 82.1 tons of C. There was a net gain of 4.38 tons during the study period. The mean annual increment in C stocks over three years was 1.46±1.02 tons. However, there is a great variability for this parameter. In the Kagekanu plot, large amount of carbon has been locked up in *Avicinnia officinalis* and accounts for more than 70% of total C stocks. *Avicinnia officinalis* also contributes significantly for the sequestration of C.

Discussion and conclusions

Mangroves are unique ecosystems of the world with adaptations to halophytic conditions. Mangrove ecosystems are known to provide great services to both human beings and others organisms, including fishes and water birds (Ewel et al., 1998; Bridgewater and Cresswell, 1999; Badola and Hussain, 2005; Donato et al., 2011). But mangrove forests are facing serious threat as a consequence of human activity (Valiela et al., 2001; Upadhyay et al., 2002).

Mangrove forests across the globe consists of species poor compared to either aseasonal rain forests or tropical dry forests (Condit, 1998). Mangrove forest of Kagekanu is also species poor. Pattern is similar to species richness reported from other mangrove patches along the western coast of India (Suresh et al., 2010). Less number of species was observed in pure mangrove stands off the coast of French Guiana (Fromard et al., 1998). *Avicinnia officinalis* dominates the floristics of Kagekanu plot. Similar pattern of dominance of *Avicinnia* sp. was also observed in Sundarbans (Joshi and Ghose, 2003), but domination of different species of *Avicinnia* was determined by salinity (Joshi and Ghose, 2003). Dominance of *Avicinnia* was also seen in pure stands of French Guiana (Fromard et al., 1998).

Tab. 4. Mean growth rates (± SD) (cm) in various size classes for different species in Kagekanu permanent vegetation plot

Size class (dbh cm)	<i>Avicinnia officinalis</i>	<i>Kandelia kandel</i>	<i>Rhizophora mucronata</i>	<i>Sonneratia alba</i>
0-4.99	0.49±0.44	0.54±0.70	0.52±0.84	0.53±0.49
5-9.99	0.80±0.70	0.32±0.39	0.43±0.44	0.41±0.52
10-14.99	0.86±1.07	0.28±0.33	0.55±0.58	0.49±0.31
15-19.99	0.68±1.19	1.43±2.24	0.66±0.79	0.52±0.65
20-24.99	0.66±0.74	0.26±1.53	1.64±4.36	0.34±0.34
25-29.99	0.40±0.57	NA	0.04±0.03	-3.77±5.72
30-34.99	0.3±0.41	NA	0.70±0.43	1.36±1.84
35-39.99	0.52±0.58	NA	0.40±0.21	NA
40-44.99	0.86±0.95	NA	NA	NA
45-49.99	0.50±0.71	NA	NA	NA
50-54.99	0.31±0.84	NA	NA	NA
55-59.99	0.29±0.03	NA	NA	NA

Tab. 5. Basal area changes (%) in the Kagekanu permanent vegetation plot

Year	Size 0-10 cm dbh	Size 10-20 cm dbh	Size 20-30 cm dbh	Size >30 cm dbh	Total
2008-2009	-4.98	19.09	-14.44	8.91	5.22
2009-2010	-9.83	4.60	4.14	-0.57	-0.08
2010-2011	-5.81	4.21	13.76	1.38	2.80

However, Jayatissa *et al.* (2002) reported 8-16 true mangrove species from different patches at Sri Lanka. The complexity index of Kagekanu plot (6) is considerably low compared to mature mangrove stands of French Guiana (18, Fromard *et al.*, 1998), which could be attributed to the height of the forest. Mean height of Kagekanu plot was 5.58 meters, while in French Guiana it was 19.6 meters. Total number of species recorded in Indian mangroves is 33 (Selvam, 2003). Region-wise diversity of mangrove species, which include both true and associated species in India, is given in Mandal and Naskar (2008). A total of 13 species was reported from mangrove forests of Godavari region (Azariah *et al.*, 1992).

Azariah *et al.* (1992) also reported a gradient in species diversity, with inland mangroves being highly diverse. Relative mangrove diversity of Kagekanu region, as estimated by Mandal and Naskar (2008), is also low compared with other mangrove regions in India. Kagekanu plot, being a shoreline mangrove, is having a low species diversity, which could be attributed to high salinity.

Size class distribution of individuals followed the typical inverted "J" shaped curve, which is seen in most tropical (Sukumar *et al.*, 1992) and other mangrove forest patches (Jimenez *et al.*, 1991; Cox and Allen, 1999; Khan *et al.*, 2009). A bell shaped curve is reported for *Rhizophora* plantation from Kenya (Kairo *et al.*, 2008) and for natural *Rhizophora* forest of Malaysia (Eong *et al.*, 1995). Density of stems at Kagekanu plot was considerably low compared to stands in Odisha (Upadhyay and Mishra, 2008). Kairo *et al.*, (2008) reports a density of 5132 individuals in a hectare of 12 year old *Rhizophora* plantation. Similarly, Engo *et al.* (1991) reports a stand density of little over 4000 stems from Malaysia. Exceptionally high density of 47000 stems over 2.5 cm dbh was recorded in mangrove stands of Puerto Rico (Pool *et al.*, 1977).

There is a great variation in basal area reported for mangrove forests across tropics. Pool *et al.* (1977) reports an area as high as 96.4 m²/ha to as low as 6.0 m²/ha from Central America. Komiyama *et al.* (2008) reports values ranging from 2.5 m²/ha to 43.8 m²/ha for mangrove forest patches across globe. Basal area of Kagekanu plot is in the range of values reported for tropical dry forest (Sukumar *et al.*, 1998) and is higher than the values reported from Sundarbans (Joshi and Ghosh, 2003).

Mangrove forests are dynamic systems. The dynamism in these forests is influenced both by extreme natural events such as hurricane, cyclone and tsunami, as well as normal processes including diseases and pests, resulting in natural mortality and recruitment (Jamenez *et al.*, 1985).

Other human mediated factors, such as erosion and flooding, could also result in mangrove tree mortality (Jamenez *et al.*, 1985). Kagekanu plot is not exposed to any of the natural extreme events. Our results indicate the decline in total population as shown in dry forests of Mudumalai initially (Sukumar *et al.*, 2005). However, long-term data is required to understand the dynamics of a forest. Mortality rates reported in the literature (Jamenez *et al.*, 1985) include small seedlings. Hence, the rates observed in Kagekanu are not comparable. There are hardly any studies on the dynamics of mangrove forest as they are done in either dry or moist land forests (Losos and Leigh, 2004).

Carbon sequestration potential

Mangrove forests are one of the carbon rich forests in the tropics (Donato *et al.*, 2011), however most carbon is locked up in the soil. There is a great variation in AGB across different geographical areas. AGB of mangrove forest at a global scale varies from as low as 7.9 tons/ha to as high as 460 tons/ha (Fromard *et al.*, 1998; Komiyama *et al.*, 2008; Khan *et al.*, 2009). One hectare of mangrove forest in Kagekanu plot has 155.53 tons, which is in the range of values reported for other forests, such as tropical dry forests (Sukumar *et al.* unpublished results), mangrove forest patches in Andaman islands (Mall *et al.*, 1991), *Rhizophora* plantations in Kenya (Kairo *et al.*, 2008) and mangrove patches in French Guiana (Fromard *et al.*, 1998). There is also a considerable variation in biomass storage across species, along with total biomass. At Kagekanu plot, *Avicinnia officinalis* accounts for >70% of total biomass. *Sonneratia alba* in Kagekanu plot accounts for 8% of biomass, while *Sonneratia apetala* has significant amount of biomass in Sundarban mangroves (Mitra *et al.*, 2011). A detailed analysis of carbon content in different forests across different districts in India has been carried out (Chhabra *et al.*, 2002). According to them, India had a total phytomass C pool of 3874.3 TgC in 1994. According to Ravindrath *et al.* (2008) total forest carbon stocks in India was 10.01 GtC. Chhabra and Dadhwal (2004) based on growing stock-volume approach, estimated the Indian forest phytomass in the range of 3.8-4.3 PgC. A hectare of mature forest such as Kagekanu is estimated to sequester 1.46 tons of carbon per annum, which is higher than the reported value of 0.535 tons/ha (Lal and Singh, 2000). The above ground carbon sequestration rate is comparatively lower than most forest types in the world; most forest are reported to sequester carbon in the range of 1.40 to 8 tons/ha (Jina *et al.* 2008). A hectare of *Rhizophora* plantation is estimated to accumulate 11.0 tons (equivalent to 5.5 tC) (Kairo *et al.* 2008). Putz and Chan (1986) record mean increment of 6.7 tons/ha/year of biomass in mangrove forest of Malaysia. India has 306400 hectares of mature (dense) and moderately dense mangrove stand (FSI, 2011). Assuming the above values, mature stands of Indian mangroves sequester 447,344 tons of C per annum. These values are comparatively low with other mangrove stands across the globe. Dense mangroves form 0.44% of total forest cover. Degraded mangroves cover an area of 157500 hectares. Reclamation of these mangroves and development into dense mangroves would result in additional 229,950 tons of carbon per annum. Total carbon sequestered by above ground mangrove vegetation would be 677,294 tons per annum. Contribution of mangrove forests to the total carbon pool of the country is on the lower side, as mangrove forests cover relatively less geographical area. But we need to have a pragmatic approach to conservation and development of mangrove forests, as they store very high levels of soil carbon, and also offer immense ecosystem services. Therefore, there is an urgent need to make a proper assessment of potential area available for the development of mangrove vegetation through assisted propagation and planting of mangrove species along traditional coastal agricultural bunds, which would help in not only mitigation of impacts of climate change, but also provide several

ecosystem services to communities that are traditionally dependent on mangroves.

Acknowledgements

We thank Ministry of Environment and Forests, Government of India for funding this research. We thank Forest department, Karnataka State for their help during the research. We thank Sridhar Patagar, M. Govinda Praveen Dube, Mr. Deepak Shetty, Mr. G.T. Hegde and other for their help during the field survey. We thank the Kagekanu temple authorities for their help and cooperation.

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