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Structural development and productivity of replanted mangrove plantations in Kenya

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Abstract

Forest structure and productivity was investigated in a 12-year-old *Rhizophora mucronata* Lam. plantation at Gazi Bay, Kenya. Sampling was carried out in 22, 10 m × 10 m quadrats laid along belt transects perpendicular to the waterline. Within each quadrat all trees with stem diameter greater than 2.5 cm were identified, position marked and counted. Vegetation measurements included tree height (m), canopy cover (%) and stem diameter measured at 1.3 m above the ground (D_{130}); from which were derived basal area (m^2/ha); stand density (stems/ha) and biomass (t/ha). Information regarding composition and distribution of juveniles was derived using linear regeneration sampling (LRS). The replanted forest had a stand density of 5132 stems/ha; with a mean canopy height and stem diameter of 8.4 ± 1.1 m (range: 3.0–11.0 m) and 6.2 ± 1.87 cm (range: 2.5–12.4 cm), respectively. The total juvenile density was 4886 saplings per hectare; 78.6% of which constituted the parental canopy. The standing biomass for the 12-year-old *R. mucronata* plantation was 106.7 ± 24.0 t/ha, giving a biomass accumulation rate of 8.9 t/(ha year).

Keywords: Mangrove reforestation; Silviculture; Yield tables; Gazi Bay; Kenya

1. Introduction

Around the world, mangroves are estimated to cover an area of between 180,000 and 200,000 km^2 (Spalding et al., 1997). In addition to providing a range of products that people need including building materials, firewood, tannins, fodder and herbal medicines (FAO, 1994; Dahdouh-Guebas et al., 2000), mangroves are of invaluable local and global ecologic, environmental and social importance. Mangroves serve as breeding grounds for many species of fish, molluscs, crustaceans and birds (Taylor et al., 2003; Nagelkerken et al., 2007). Being at the edge of the sea, mangroves protect shoreline from coastal erosion (Dahdouh-Guebas et al., 2005; Mazda et al., 2006). The world mangrove forests have been valued at approximately US $181 billions (Costanza et al., 1997). Despite their great value, mangroves have one of the highest rates of degradation of any global habitat—exceeding 1% of mangrove area per year (Valiela et al., 2001; FAO, 2005). Over-exploitation, clear-cutting and pollution are amongst the major causes for decline (Farnsworth and Ellison, 1997; Alongi, 2002), but also erroneous estimates of the 'health' or ecological condition of mangroves may prove detrimental and may undermine the functionality of mangrove forests in a hidden way (Dahdouh-Guebas et al., 2005). This has led to the realistic prospect of a world without mangroves (Duke et al., 2007). Hence, rehabilitation and sustainable utilization of mangrove resources is an international conservation priority.

Some 540 km^2 of mangroves occurs along the Kenyan coast, much of it in Lamu district (Kairo et al., 2002). This is only 3% of the forest area in Kenya, or 1% of the total area of the country; which makes mangroves a scarce and very valuable

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resource (Kokwaro, 1985; Dahdouh-Guebas et al., 2000). It is estimated that along the Kenyan coast, 70% of wood requirement is met by mangroves (Wass, 1995). Increased demand of mangrove wood products, particularly for firewood and building poles, has led to degradation of the forest in many areas along the coast (Dahdouh-Guebas et al., 2000; Abuodha and Kairo, 2001).

One of Kenya's forest development objectives for the year 2000 and beyond is: 'to increase the forest and tree cover in order to ensure an increasing supply of forest products and services to meet the basic needs of the present and future generations and for enhancing the role of forestry in socio-economic development' (MENR, 1994). This objective cannot be realized unless concerted efforts to reforest degraded forests are made.

From the viewpoint of rehabilitation of degraded mangrove areas in Kenya, a program of replanting mangroves was initiated at Gazi Bay in October 1991 (Kairo, 1995; Kairo et al., 2001). Since the date of planting is known, these plantations offer a rare opportunity to determine how stand structures develops with increasing age of mangrove forests.

For majority of mangrove studies worldwide, biomass and productivity has been estimated in natural stands (e.g. Komiyama et al., 1987; Saintilan, 1997; Komiyama et al., 2007). Only in Matang Mangrove Forest Reserve in Peninsular Malaysia do we find biomass and productivity estimates for replanted mangrove stands (Putz and Chan, 1986; Ong et al., 1995). To our knowledge and experience this is the first study in Africa to investigate tree growth and productivity in replanted mangrove plantations.

2. Materials and methods

2.1. Description of the study area

The study was carried out at Gazi Bay, Kenya, located about 55 km south of Mombasa in Kwale district (4°25′S and 39°30′E; Fig. 1). The Bay is characterized by two semi-permanent rivers—River Mkurumuji and Kidogoweni both originating from active agricultural hinterland. Ground water seepage is restricted to a few points in Gazi (Tack and Polk, 1999).

The climate along the Kenyan coast is characterized by a bimodal distribution of rainfall. A distinct dry season (January–February) is followed by a long (April–July) and a short rainy season. During the wet season, the rivers Mkurumuji and Kidogoweni provide an important freshwater source for the mangroves of Gazi Bay (Kitheka, 1997). The average temperature at the Kenyan coast ranges from 22 to 30 °C with a mean relative humidity of 65–81% (McClanahan, 1988).

All the nine true mangrove species (Tomlinson, 1986) described in Kenya are present at Gazi Bay; the dominant species being *R. mucronata* Lam, *Ceriops tagal* C.B. Robinson and *Avicennia marina* (Forssk.) Vierh. The total area of mangroves in Gazi is approximately 615 ha (Doute et al., 1981; Kairo, 2001).

Mangroves of Gazi are threatened by over-harvesting of wood products for firewood and building poles (Abuodha and Kairo, 2001). Recent surveys indicate that 70% of the mangroves of Gazi are degraded (Dahdouh-Guebas et al., 2004), with some of the affected areas requiring urgent attention.

A small scale mangrove reforestation program to rehabilitate degraded mangrove areas, restock denuded mudflats and transform disturbed forests into uniform stands of higher productivity was initiated at Gazi Bay in October 1991 (Kairo, 1995). Subsequent development of the reforested area has been studied by examining tree growth and biomass accumulation of above ground components (Kairo, 2001), floral and faunal secondary succession (Bosire et al., 2003, 2004, 2006); and nutrient dynamics (Bosire et al., 2005a).

Previous study by Kairo (2001) investigated structural characteristics of a 5-year-old *Rhizophora* plantation estab-

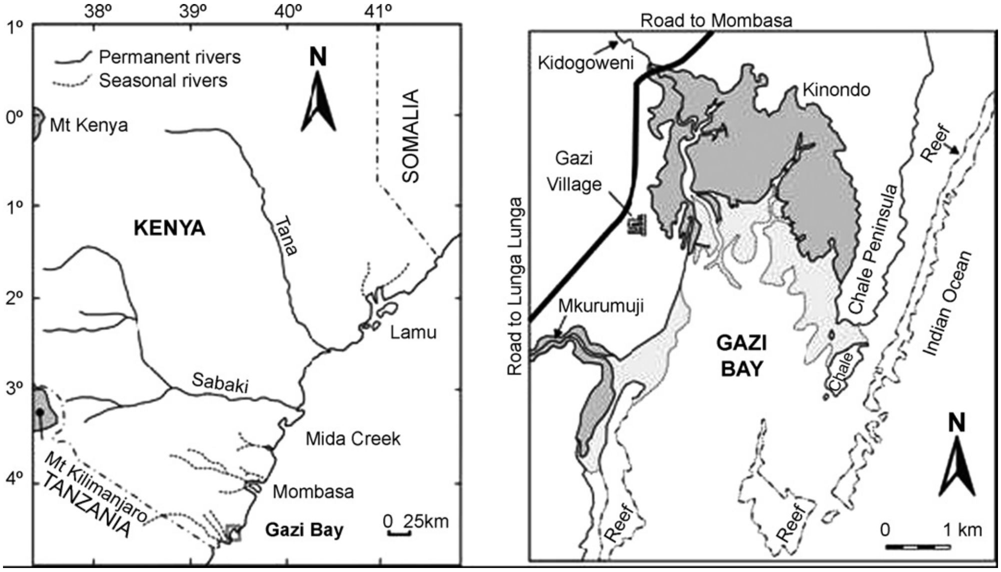

Fig. 1. Map of coastal Kenya showing the study area (Gazi Bay) (source: Bosire et al., 2003).

lished in April 1994. In the present study, we investigated structural development and biomass accumulation of the same plantation at 12-year-old. In addition to the above ground components the present study examined below-ground biomass for stems above 2.5 cm diameter.

2.2. Study design

In *ca*. 7.0 ha reforested *Rhizophora* stand at Gazi, six belt transects of 10 m wide were established perpendicular to the waterline. Along these transects, a total of 22 plots of 10 m × 10 m were marked. The distance from one transect to another was about 40 m. Along each transect, the distance from one plot to another ranged from 20 to 30 m depending on vegetation characteristics and landscape.

2.2.1. Measurement of soil characteristics

Soil samples were randomly collected in all 10 m × 10 m subplots using a 6 cm × 6 cm D-corer. An additional 40 soil samples were collected at random from a non-reforested site to serve as control. In the laboratory, the samples were weighed and oven-dried at 80 °C for 24 h, after which the soils were re-weighed to obtain the moisture content.

For grain size analysis, about 25 g of the dry soil of each sample was treated with 10 ml of aqueous sodium hexametaphosphate ($(NaPO_3)_6$) and subjected to a series of sieves; ranging from 63 to 500 μm mesh-size. Then, 10 g of the remaining sample were oxidized at 455 °C in a furnace for 8 h until only inorganic ash was left. What was lost during the oxidation process represents the soil organic matter (SOM). Soil organic matter generally contains approximately 56% organic carbon (Brady, 1990). The following equation was therefore used to estimate percentage soil organic carbon (SOC) from total soil organic matter (Brady, 1990):

$$\mathrm{SOC}\,(\%) = \mathrm{SOM}\,(\%) \times 0.56 \tag{2.1}$$

where SOC is soil organic carbon and SOM is soil organic matter.

2.2.2. Forest structure

Inside the 10 m × 10 m plots all trees with stem diameter greater than 2.5 cm were identified, counted and their position marked. Measurements included tree heights (m), stem diameters (cm), measured at 1.30 cm above ground (D_{130}), and canopy cover (%). For *Rhizophora* trees stem diameter was taken 30 cm above the highest prop root. From these data were derived basal area (m^2/ha), stand density (stems/ha), and frequency following the procedures described in Cintron and Schaeffer-Novelli (1984). The importance value (I.V.), which is a relative measure of the ecological contribution of a species, was calculated by summing the species' relative density, relative frequency and relative dominance (Muller-Dombois and Ellenberg, 1974; Cintron and Schaeffer-Novelli, 1984; Dahdouh-Guebas and Koedam, 2006).

Local stand tables and size class frequency diagrams were constructed for all trees with stem diameter ≥2.5 cm. All trees with stem diameter below 2.5 cm were grouped in juvenile category.

2.2.3. Estimation of plant biomass and vegetative carbon

2.2.3.1. Determination of above-ground biomass. Fifty trees with stem diameter >2.5 cm were randomly selected in the study plots and harvested at ground level using handsaws. Stem diameter at 30 cm above the highest prop root and heights of all harvested trees were measured. The above ground parts were separated into stem (trunk), branches, leaves, and stilt roots. Fresh weight of each component was measured in the field, and representative sub-samples oven-dried to constant weight at 85 °C in order to calculate wet-dry weight ratio. Allometric models were developed between above ground components and total above-ground biomass (Clough and Scott, 1989). The models were then applied to all the individuals in the quadrats to obtain the standing biomass in tons per hectare.

2.2.3.2. Determination of below-ground biomass. Below-ground biomass was estimated using a modified coring method described in Saintilan (1997). Nine cores (65 cm length and 15 cm diameter) were made at the parent root base, between and away from the stem as far as the roots from the tree can possibly extend. Four stems were randomly selected within 10 m × 10 m plot, making a total of 36 samples. Results obtained were pooled to obtain root biomass per unit ground area.

Total plant biomass (t/ha) was determined by summing the above-ground biomass (AGB) and below-ground biomass (BGB). Vegetative carbon (tC/ha) was calculated from total plant biomass, assuming 50% of vegetative biomass is carbon (MacDicken, 1997).

2.2.4. Composition and pattern of natural regeneration

Linear regeneration sampling (LRS) was used to assess composition and pattern of natural regeneration (Sukardjo, 1987; FAO, 1994; Kairo et al., 2002). Inside 5 m × 5 m subplots (of the 10 m × 10 m plots), occurrence of juveniles of different species was recorded and grouped according to their height classes and arbitrarily assigned regeneration classes (RC) I, II or III. The ratio of RCI:RCII:RCIII was used to assess the adequacy of natural regeneration (FAO, 1994).

2.2.5. Primary production

Leaf area index (LAI) was determined from 50 leaf samples collected randomly from the forest. Fresh weight of each leaf was accurately measured and its area was estimated by square grid method. Thereafter, the leaf area-weight relationship was determined and used to compute the leaf area index. Using the leaf area index and the average rate of photosynthesis the net canopy photosynthesis was estimated as (English et al., 1997)

$$P_N = A \times d \times \mathrm{LAI} \tag{2.2}$$

where A is the average rate of photosynthesis (gC/(m^2 h)); d is number of hours in a day; LAI is leaf area index.

The average rate of photosynthesis for *Rhizophora* species has been found to vary between dry ($A = 0.216$ gC/(m^2 h);

salinities >35 ppt) and wet seasons (A = 0.648 gC/(m^2 h); low salinities) for mangroves in Australia and Southeast Asia (Clough and Sim, 1989). Alongi et al. (2004) used A-values of 0.26, 0.38 and 0.43 gC/(m^2 h) for the 5-, 18-, and 85-year-old forests, respectively in Malaysia. Assuming that the average rate of photosynthesis for East African mangroves is similar to that of the mangroves of Southeast Asia and Australia, the empirical value of A used in this study was 0.32 gC/(m^2 h).

2.3. Data treatment

Data analyses were done using MINITAB 14.0 software package. Yield and volume tables and size class frequency distributions were constructed for the plantation using Microsoft® Excel spreadsheets. Single classification ANOVA was used to compare soil physico-chemical characteristics in the reforested and un-forested sites.

From the harvest data regression models for biomass were developed using the equation of the form

$$Y_i = aX_i^2 + bX_i + c \tag{2.3}$$

where Y_i is the above-ground biomass of the ith tree, X_i is D_{130} combined with height, and a, b and c are constants.

Local stand table were constructed for stem diameter ≥2.5 cm. Mean annual increment (MAI) in diameter (cm/year), height (m/year), and biomass (t/(ha year)) were obtained by dividing the value of each variable by the age of the stand.

3. Results and discussion

3.1. Soil characteristics

There were significant differences ($p < 0.05$) in soil moisture, grain sizes and organic matter content between soils in the reforested and non-reforested sites (Table 1). The lowest silt-clay content (15.52 ± 4.02%) was observed in non-reforested site. The proportions of fine and coarse sand were significantly higher in the non-reforested (58.85 ± 6.11 and 25.63 ± 3.92%) than in reforested site (41.01 ± 14.22 and 20.75 ± 6.24%). The high amounts of silt-clay compared to coarse sand in the reforested site could be attributed to enhanced accretion function of the replanted *Rhizophora* plantation. Earlier studies by Bosire et al. (2003) in the same plantation obtained organic matter content of 37.00 ± 8.00%; which is much similar to the present results (38 ± 13%). This shows that as mangrove plantation develops it assists in the build up of soil organic matter through accretion. Assuming that soil organic matter contains about 56% organic carbon (Brady, 1990), soils in the replanted *Rhizophora* plantation contained 17.39 ± 3.86% organic carbon compared to 12.41 ± 3.81% in the non-reforested control. The *Rhizophora* plantation has built up its soil carbon through accretion process with time.

Table 1
Soil physico-chemical characteristics for reforested and non-reforested areas at Gazi (values are percentage mean ± S.D.)

Factor	Reforested site	Non-reforested site
Relative grain sizes		
Silt-clay (<62 μm)	38.24 ± 13.09*	15.52 ± 4.02
Fine sand (62–500 μm)	41.01 ± 14.22	58.85 ± 6.11*
Coarse sand (>500 μm)	20.75 ± 6.24	25.63 ± 3.92*
Moisture content	54.55 ± 4.89*	8.20 ± 2.42
Soil organic matter	31.04 ± 6.89*	22.16 ± 6.80
Soil organic carbon	17.38 ± 3.86*	12.41 ± 3.81

* Significantly higher at $\alpha = 0.05$.

3.2. Forest structure

The structural attributes of the reforested mangrove stand at Gazi are given in Table 2. Based on importance value indices, *R. mucronata* was the principal species in the plantation followed by *C. tagal* (243.30 and 17.38, respectively). This was expected since the plantation was established as a monoculture (Kairo, 1995). With subsequent development, the plantation has promoted recolonization of the stand by non-planted species. Colonization of non-planted mangrove species into reforested stands has been confirmed at Gazi plantations by Bosire et al. (2003, 2006), which has enhanced the structural complexity of this stand.

Table 3 provides yield table data for replanted *Rhizophora* at Gazi. The density of *R. mucronata* was 4864 stems/ha, representing more than 95% of the total stand density. This is much higher than the 3330 and 3100 stems/ha that were recorded when the plantation was 5- and 8-year-old, respectively (Kairo, 2001; Bosire et al., 2003, 2006). The stocking rate for the 12-year-old plantation compares well with those reported for *Rhizophora apiculata* at similar age in Vietnam (FAO, 1993). However, compared to the stocking density of 2,077 stems/ha found in the 'pristine' mangrove stands in Kenya at Kiunga (Kairo et al., 2002), the current stocking rate in replanted forests can be said to be excellent.

Fig. 2 is a scattergram of height against D_{130} for replanted forest. 93% of the stems are distributed between 4 and 9 cm size classes (Table 3). The mean canopy height for the 12-year-old *Rhizophora* plantation was 8.4 ± 1.1 m (range: 3.0–11.0 m) with a mean stem diameter of 6.2 ± 1.9 cm (range: 2.5–12.4 cm). These values are within the range reported for *Rhizophora* plantations in South East Asia (see e.g. Srivasatava et al., 1988; FAO, 1993).

Fig. 3 shows histogram displays of diameter class distribution in Gazi plantation. The distribution of replanted *Rhizophora* followed a normal curve which is expected for an even-aged forest. Majority of the trees were in the 6.0–7.0 cm size class. The highest diameter class for the 12-year-old *Rhizophora* plantation was 11–13 cm.

The maximum annual height and diameter increment for the 12 years old plantation was 0.92 m/year and 1.02 cm/year, respectively. These figures are within the range of published mangrove growth rates (Srivasatava et al., 1988; Devoe and Cole, 1998; Saenger, 2002). In addition to environmental factors, growth in mangroves is influenced by stocking density, disturbances, and suppression by dominant species (Devoe and Cole, 1998).

Table 2
Structural attributes of a 12-year-old *Rhizophora* plantation at Gazi

Species	Mean height ($x \pm$ S.D.; m)	Basal area (m^2/ha)	Relative values (%)			I.V.
			Freq	Dom	Density	
Bruguiera gymnorrhiza	6.9 ± 1.7	0.07	13.64	0.39	0.97	15.00
Ceriops tagal	6.6 ± 0.9	0.17	13.64	1.00	2.75	17.38
Rhizophora mucronata	8.5 ± 1.0	16.53	50.00	96.53	94.77	241.30
Sonneratia alba	7.4 ± 1.8	0.16	11.36	0.93	0.71	13.01
Xylocarpus granatum	6.4 ± 1.8	0.20	11.36	1.14	0.80	13.31
Mean	8.37 ± 1.08					
Total		17.12	100	100	100	300

Table 3
Yield table data for 12-year-old *Rhizophora* plantation at Gazi: values in parenthesis are %; Fito, Pau, Mazio and Boriti are the local names for the corresponding utilization classes

Species	Utilization classes (D_{130} (cm))				Total
	<4 (Fito)	4.1–6.0 (Pau)	6.1–9.0 (Mazio)	9.1–13 (Boriti)	
R. mucronata	559	1586	2391	327	4864 (94.77)
C. tagal	91	50	0	0	141 (2.75)
B. gymnorrhiza	36	9	5	0	50 (0.97)
X. granatum	5	9	14	14	41 (0.80)
S. alba	5	5	18	9	36 (0.71)
Total	695 (14)	1659 (32)	2427 (47)	350 (7)	5132

3.2.1. Above-ground biomass

The above-ground biomass in replanted forests was best estimated by the equation

$$Y = 1.6E-05X^2 + 0.45X + 0.495; \quad (n = 35;\ r^2 = 0.98;\ p = 0.000) \tag{3.1}$$

where Y = above-ground biomass; $X = D_{130}{}^2H$.

Based on this equation the standing biomass of 12-year-old *Rhizophora* plantation was 106.7 ± 24.0 t/ha (Table 4), equivalent to 53.33 tC/ha. This represents a biomass accumulation rate of 8.89 t/(ha year). Stem and stilt roots accounted for 42.0% and 30.4% of the total above-ground biomass, respectively (Fig. 4). A similar productivity study for a 20-year-old *R. apiculata* plantation in Malaysia recorded total biomass (including below ground roots) of 117 tC/ha (equivalent to 234 t/ha) partitioned as; 74% in stems, 15% in below-

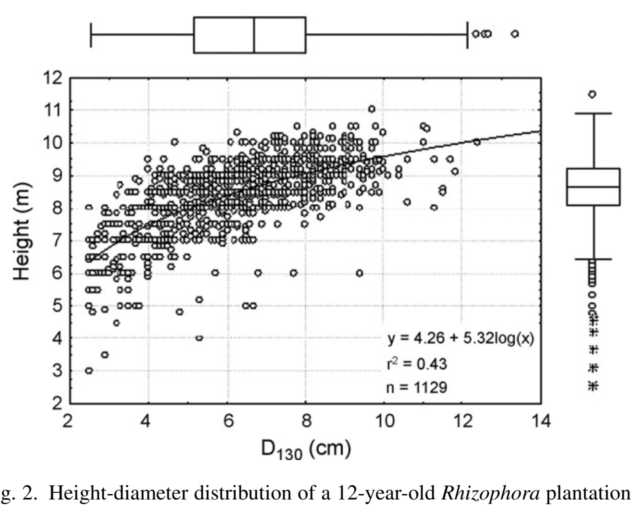

Fig. 2. Height-diameter distribution of a 12-year-old *Rhizophora* plantation at Gazi.

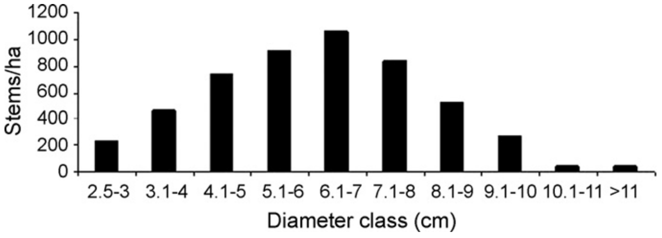

Fig. 3. Size class frequency distribution of trees ≥2.5 cm stem diameter in 12-year-old *Rhizophora* plantation at Gazi (n = 1129).

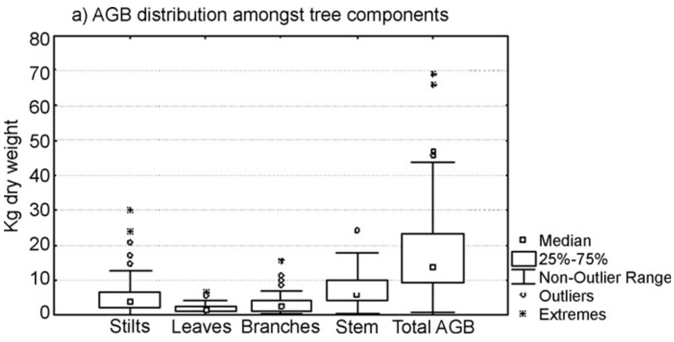

Fig. 4. Distribution of above-ground biomass amongst different plant components for *Rhizophora* plantation at Gazi.

Table 4
Stand table data for *R. mucronata* in 12-year-old mangrove plantation at Gazi

Variables	Utilization classes (D_{130} (cm))				Total
	<4.0 (Fito)	4.1–6.0 (Pau)	6.1–9.0 (Mazio)	9.1–13 (Boriti)	
Stems/ha	559	1586	2391	327	4864
Mean D_{130} (cm)	3.3 ± 0.5	5.1 ± 0.6	7.3 ± 0.8	9.8 ± 0.8	6.3 ± 1.8
Above-ground biomass (t ha^{-1})[a]	2.35	18.55	66.36	19.39	106.7 ± 24.0
Below-ground biomass (t ha^{-1})					24.9 ± 11.4

See Eq. (3.1).

[a] Equation used was: $y_i = 0.000016\,(D_{130}{}^2H_i)^2 + 0.0454\,D_{130}{}^2H_i + 0.495$; where y_i = biomass of the *i*th tree, D_{130} = diameter at 130 cm above the ground and H = height.

ground roots and stilts and 10.6% in leaves and branches (Ong et al., 1995). The latter results present higher productivity compared with the present study most likely due to age. It also appears that with age, trees invest more in the stem than other components.

3.2.2. Below-ground biomass

The root biomass value in replanted *R. mucronata* was 24.9 ± 11.4 t/ha. Together with the above-ground biomass, the total plant biomass of a 12-year *Rhizophora* plantation is 131.56 t/ha, or 65.78 tC/ha. Thus, what is buried below ground of a 12-year *Rhizophora* plantation represents 19% of the total plant biomass. A review of literature on biomass studies indicates that root biomass values vary from one study to another depending on the method used (e.g. Vogt et al., 1998). Our present estimate is in the 9–35% range observed for *Rhizophora* studies in Thailand (Alongi and Dixon, 2000).

The total biomass accumulation in the 12-year-old *Rhizophora* plantation was 11.0 t/(ha year) (equivalent to 5.48 tC/(ha year)). Biomass accumulation rates reported here for above ground components are higher than the 5.1 t/(ha year) reported for 80 years old natural plantation of *R. apiculata* in Malaysia (Putz and Chan, 1986). In Matang mangrove forest, Ong et al. (1995) reported above-ground biomass increment of 24.48 t/(ha year) (and 34.0 t/(ha year) when below-ground biomass was included) for 20-year-old plantation. It is logical to conclude that biomass accumulation rate is influenced by age, species, management system applied, as well the climate.

3.3. Composition and pattern of natural regeneration

The density and composition of natural regeneration in *Rhizophora* plantation is given in Table 5. Although majority of the juveniles were of the planted parental canopy, juveniles of non-planted species such as *Bruguiera*, *Ceriops*, *Xylocarpus* and *Sonneratia* were also present. Recruitment of non-planted species in monoculture stands of mangroves has been confirmed by Bosire et al. (2003). A possible explanation for this could be the creation of microhabitats by growing forests that allow other species to colonize. The regeneration ratio, RCI:RCII:RCIII, obtained in this study (i.e. 5:3:1) is lower than one would expect in a secondary forest undergoing rapid regeneration (see e.g. Kairo et al., 2002). Reason for this could be the shading effects created by parental canopy that prevent light from reaching the ground. Bosire et al. (2005b) also found propagule predation to be playing a crucial role in limiting seedling recruitment into this high-density stand.

3.4. Primary production

Leaf area for *Rhizophora* plantation was linearly correlated to leaf weight using a simple relation of $y = 1.7x$ (where y = leaf area; x = wet weight; $r^2 = 0.91$; $n = 50$). From this relation, the leaf area index (LAI) for the *Rhizophora* plantation was estimated as 3.99. If we assume the average rate of photosynthesis of Gazi mangroves is similar to that of mangroves in northern Australia and South East Asia (Clough and Sim, 1989; Alongi et al., 2004), we can estimate net canopy photosynthesis of Gazi plantation using LAI as follows (English et al., 1997).

Let the average rate of photosynthesis per unit leaf area (A) be 0.32 gC/(m^2 h)

Therefore, net canopy photosynthesis (P_{N})

$$= 0.32\,\mathrm{gC/(m^2\,h)} \times 3.99 \times 12\,\mathrm{h} = 15.4\,\mathrm{gC/(m^2\,h)}$$

$$= 56\,\mathrm{tC/(ha\,year)}$$

Productivity studies in Thailand reported canopy photosynthesis rates for *Rhizophora* ranging from 24.4 tC/(ha year) for 5-year-old stands to 76 tC/(ha year) for 25-year-old stands (Alongi and Dixon, 2000). Similarly, Alongi et al. (2004) reported day time photosynthetic production for 5-, 18-, and 85-year-old *R. apiculata* stands as 13, 21 and 35 gC/(m^2 day) which is equivalent to 47, 76 and 127 tC/(ha year), respectively.

Table 5
Juvenile densities in *Rhizophora* plantation at Gazi; values in parenthesis indicate percentages

Species	Regeneration classes			Total/ha
	I	II	III	
R. mucronata	2527 (89)	964 (62)	350 (66)	3841 (79)
B. gymnorrhiza	155 (6)	195 (13)	68 (13)	418 (9)
C. tagal	105 (4)	186 (12)	86 (16)	377 (8)
X. granatum	23 (1)	200 (13)	23(4)	245 (5)
S. alba	0 (0)	0 (0)	5(1)	5 (<1)
Total	2809 (57)	1545 (32)	532 (11)	4886

Table 6
Biomass table (kg) for replanted *Rhizophora* in Gazi[a]

D_{130} (cm)	Height (m)							
	4	5	6	7	8	9	10	11
3	2.72	4.01	5.63	7.60	9.95			
4	3.48	5.24	7.45	10.16	13.43	17.30		
5		6.48	9.32	12.82	17.07	22.16	28.20	
6		7.76	11.23	15.57	20.88	27.28	34.94	
7		9.05	13.21	18.42	24.85	32.67	42.08	53.30
8			15.23	21.37	28.98	38.31	49.62	63.18
9					33.28	44.22	57.56	73.65
10					37.74	50.39	65.90	84.71
11					42.37	56.82	74.64	96.35
12						63.52	83.78	108.58
13							93.32	121.40

[a] Equation used was: $\text{biomass} = 0.000016\ (D_{130}^2\text{H})^2 + 0.0454 D_{130}^2\text{H} + 0.495$.

4. Conclusion

Recent estimates indicate that about 50% of the mangroves in Kenya have been lost in the last 50 years (FAO, 2005) and many mangroves worldwide risk to disappear in the following decades (Duke et al., 2007). Loss of mangroves has affected the local and national economy as indicated by shortage of firewood and building poles, increased coastal erosion and reduction in fishery (Dahdouh-Guebas et al., 2000; Abuodha and Kairo, 2001). Conservation alone is not enough to reverse these problems. Concerted efforts have to be made to reforest degraded mangrove areas in order to achieve the objectives of sustainable forest management. The quantitative findings from this study, among the first to be reported for Eastern African mangroves, demonstrate the potential use of reforestation as tool in returning the lost forests and thereby sustain supply of mangrove goods and services. Allometric equations for above ground components allow us develop biomass table for replanted mangrove stands (Table 6). This table provides a quick estimate of above-ground biomass using D_{130} and height only. Biomass tables have direct application in forest management as foresters and managers can easily predict yields of replanted forests and hence aid the formulation of mangrove management plans in their areas (Semesi, 1992). Estimates of stand biomass provided here give an indication of how carbon is allocated to plant tissues, which is vital information with regard to local as well as regional carbon accounting. Therefore, the results achieved in this study have wide applications in the improvement of the science of mangrove management in general and Kenya in particular.

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