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Evaluation of mangrove structure and condition in two trans-boundary areas in the Western Indian Ocean

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ABSTRACT

1. The structure, forest condition and regeneration status of nine mangrove forests in two trans-boundary areas of Mozambique bordering Tanzania and South Africa were studied. The main objective was to estimate the cutting intensity in the selected sites – Saco and Sangala in southern Mozambique; Mecúfi, Pemba, Ibo, Luchete, Ulo in northern Mozambique, and Mngoji 1 and Mngoji 2 in Tanzania.

2. A total of 135, 10 m × 10 m quadrats were set in the outer, middle and lower parts of the mangrove forests at all sampling sites. Measurements included stem diameter at breast height (DBH) and height of adult trees (i.e. all trees with stem diameter more than 2.5 cm). Young trees (with stem diameter of less than 2.5 cm) were classified as juveniles. To assess forest condition, trees within the quadrat were classified into intact, partially cut, coppiced, die back and stump. Pole quality was appraised through the classification of the lead stem into three categories–straight, semi-straight and crooked poles.

3. The results indicate different levels of exploitation with Mngoji 1 and Mngoji 2, the most degraded sites, having stump densities of 959 stumps ha^{-1} and 592 stumps ha^{-1}, respectively. Most sites had mostly poles of inferior quality (crooked poles), but high densities of straight and semi-straight poles were found in Mngoji 1 (742 stems ha^{-1}) and Saco (636 stems ha^{-1}).

4. Natural regeneration was observed in most sites but not for all species, with adequate regeneration in Saco (14 766 saplings ha^{-1}) and Mecúfi (14 706 saplings ha^{-1}), while low regeneration was recorded in Mngoji 1 and 2 (2212 saplings ha^{-1} and 4799 saplings ha^{-1}, respectively).

5. These results indicate the need for improved mangrove management and replanting especially in mangrove depleted conservation areas of southern Tanzania.

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KEY WORDS: mangrove forest structure; forest condition; pole morphology; Eastern Africa

INTRODUCTION

Mangrove forests occupy intertidal areas of tropical and subtropical coasts, between high water and low water mark of spring tides (Tomlinson, 1986). The forest provides timber and non timber products such as fuelwood, poles, fodder and fisheries resources to millions of people in the tropics (Saenger, 2002). They buffer land from storms and provide safe havens for humans (Spalding *et al*., 1997). Mangroves have the capacity to absorb heavy metals and other pollutants, thus controlling the quality of water reaching coral reef and seagrass ecosystems (Chu *et al*., 1998). In addition, mangrove forests provide nursery grounds for a number of commercially important fish species, prawn, crabs and other animals, and enhance fishery productivity of the nearby waters (Kathiresan and Bingham, 2001).

The widespread mangrove deforestation and subsequent loss of habitat is of global concern (Hogarth, 1999; Valiela *et al*., 2001; FAO, 2005). A number of case studies of mangrove

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degradation have been documented for Africa, Latin America and Asia (FAO, 2005). According to a recent assessment of global mangrove forests, the Western Indian Ocean (WIO) region has lost approximately 8% of its mangrove cover in the last 25 years (FAO, 2005), on average approximately 3000 ha $year^{-1}$. Direct causes of mangrove degradation in the WIO include over-exploitation of wood products, conversion of mangrove areas for aquaculture, solar salt works and urban development (Semesi, 1998; Barbosa *et al*., 2001; Beentje and Bandeira, 2007).

In Zanzibar (Tanzania), for instance, the area of mangroves dropped by 7% in 40 years prior to 1989 (Taylor *et al*., 2003), and demand for firewood has increased 100-fold since 1950 (Shunula, 2002). Madagascar, with its 330 000 ha of mangrove area, has experienced a reduction of mangrove area by at least 7500 ha in the period 1972 to 1995, mostly due to aquaculture development (Ranaivoson, 1998; Taylor *et al*., 2003). Degradation and transformations of mangroves in Kenya have been linked to over-harvesting of wood products, conversion of mangrove area for pond aquaculture and solar salt pans as well as pollution (Abuodha and Kairo, 2001). In Mozambique, an estimated 809 ha per year of mangrove were lost mainly to firewood and salt pan production between 1972 and 1990 (Saket and Matusse, 1994; Barbosa *et al*., 2001). This paper aimed to assess mangrove forest condition in two trans-boundary areas at the Tanzania–Mozambique and Mozambique–South Africa borders, through the estimation of cutting intensity in different mangrove areas.

METHODS

Study sites

The sampling was designed to assess the variation between south and north, and included a spatial approach, at each location. Two locations were chosen to compare two trans-boundary areas within the border region of Mozambique with South Africa (in the south) and Tanzania (in the north) – Inhaca Island sampling location is separated by around 2500 km from the other location, and is relatively close to the critical southern disappearance of mangrove forests on the eastern African coast. Sampling in South Africa was not carried out given the existence of only scattered small stands of mangroves and fewer mangrove tree species with an inconspicuous zonation pattern (Berjak *et al*., 1977; Beentje and Bandeira, 2007). Nine sampling sites (surveying mangrove stand) were chosen to assess mangrove condition: Saco and Sangala mangroves at Inhaca Island (southern Mozambique); Mecúfi, Pemba, Ibo Island, Luchete, and Ulo (in northern Mozambique). In Tanzania, mangroves were sampled at Mngoji 1 and Mngoji 2 (Figure 1).

The climate at the nine sites is characterized by having a rainy season between November and March and a cooler dryer season over the rest of the year. Species composition and zonation at all sites is similar. In both Tanzania and Mozambique, the upper zone is characterized by the presence of white mangrove (*Avicennia marina*); the middle zone is characterized by extensive cover of the red mangrove (*Rhizophora mucronata*); whereas the lower zone is dominated by apple mangrove (*Sonneratia alba*) in Tanzania, and northern Mozambique (Mecúfi, Pemba, Ibo, Luchete, Ulo) and by white mangrove (*Avicennia marina*) in southern Mozambique (Saco and Sangala) (Kalk, 1995; Semesi, 1998). The main economic activities in the area are agriculture and fisheries. Tourism is a growing industry, particularly in northern Mozambique. Some demographic data are: 5211 inhabitants in Inhaca Island (Saco and Sangala); 65 365 in Pemba-Metuge district (Mecúfi); 141 316 in Pemba City; 9509 inhabitants in Ibo; 94 197 in Mocimboa da Praia district (Ulo and Luchete) (www.ine.gov.mz.censo2007); and 1600 inhabitants in Mngoji (census of 2002, www.tanzania.go.tz/census/regions.htm).

Mangrove structure and condition analysis

A total of 135 quadrats $10 \times 10\,m^2$ were set, 30 of them in southern and 75 in northern Mozambique and 30 in Tanzania. Three zones were distinguished in each forest: the upper landward zone; the middle zone; and the lower seaward zone, following the species zonation pattern of the forest. In each zone, five random quadrats separated by not less than 20 m were sampled, giving a total of 15 quadrats per forest. Within each quadrat all trees greater than 2.5 cm diameter were identified and counted. Vegetation measurements included tree height (m) and stem diameter measured at 1.3 m above ground (DBH); from which were derived tree basal areas (m^2), species density (stems ha^{-1}) and frequency (Muller-Dombois and Ellenberg, 1974; Cintron and Schaeffer-Novelli, 1984). The ecological importance value (IV) of each species was calculated by summing the relative density, relative frequency and relative dominance (Cintron and Schaeffer-Novelli, 1984). The complexity index of each study site was obtained as the product of number of species, basal area ($m^2\,ha^{-1}$), maximum tree height (m) and number of stems $ha^{-1} \times 10^{-5}$ in a ha plot (Holdridge *et al*., 1971).

To assess mangrove forest status, individuals were counted and grouped into five categories. These were: intact; partially cut; coppiced, die back, and stumps; following the approach described in Cintron and Schaeffer-Novelli (1984), FAO (1994) and Kairo *et al*. (2002). Intact stands correspond to pristine stands with no signs of cutting, whereas, partially cut forests include plots whose trees have lateral branch cut or there is presence of past stumps. Coppicing of mangroves is known in the following species: *Avicennia marina*, *Sonneratia alba*, *Lumnitzera racemosa* and *Bruguiera gymnorhiza* (Tomlinson, 1986; Kairo and Kivyatu, 2000). Die back plants are those whose death was not caused directly by cutting.

The morphology of the sampled trees reflected the usage quality of available poles and was assessed based on the form of the lead stem, which was categorized either as Form 1, 2 or 3. Form 1 represents most straight poles suitable for building and Form 2 represents poles that need some modification prior to use in construction, while Form 3 represents crooked poles unsuitable for construction (Kairo *et al*., 2001).

Regeneration status of the forests was assessed by the identification and counting of young individuals (diameter at breast height less than 2.5 cm) within the quadrat, and their categorization into three groups, height less than 40.0 cm (RC I); height between 40.1 and 150.0 cm (RC II), and height greater than 150.0 cm but less than 3.0 m (RC III) (Kairo *et al*., 2002).

Data on mangrove condition (height, diameter at breast height, deforestation category, tree wood quality and regeneration) were subjected to normality and homogeneity of variances tests. As they did not meet all the ANOVA assumptions, the test performed was Kruskal–Wallis at 0.05 probability level to distinguish statistical differences. Comparisons

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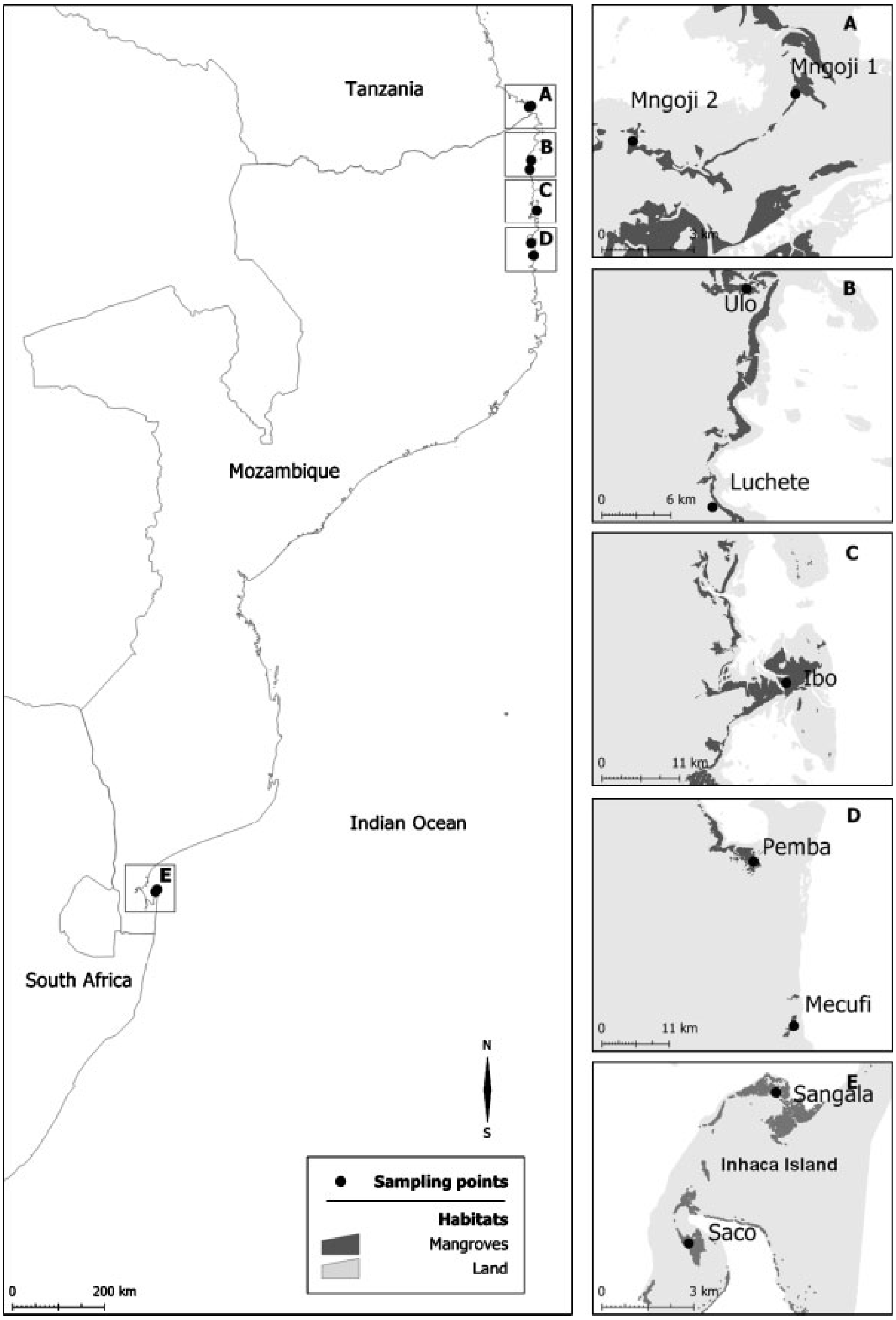

Figure 1. Geographical position of the sampling areas across the two trans-boundary locations in eastern Africa.

of stem density were made between sites and between species, the null hypothesis being that there is no difference in stem densities between sites and among species in a site.

RESULTS

Mangrove structure

A total of 3271 adult individuals were sampled, the commonest being *A. marina* and *R. mucronata*. The rarest species was *L. racemosa*, found only at Ulo (very few individuals and therefore not included in the statistical analysis). Overall stand stem density, DBH and tree height varied significantly between sites and between species at a site (Tables 1 and 2). For this study, the stem density appeared not to follow a specific pattern, but basal area and complexity index were markedly lower in both Mngoji forests. Most trees in the study area were small (Figure 2). In the Mozambican forests the modal diameter class was less than 5 cm, while in both Mngoji forests the commonest class was 5.1–15 cm. Mean heights ranged between 2.19 m (at Luchete) and 5.16 m (at Mngoji 1) and the tallest trees were found in Mngoji 1, Mngoji 2 and Saco with canopy heights of 5.16, 3.77 and 3.88 m, respectively. The tallest trees observed were *S. alba* (mean height 4.58 m), followed by *R. mucronata* (3.91 m). In terms of diameter distribution, there was a general trend of having more individuals with narrow stems (Figure 3(a), (b) and (c)), the correlation between diameter and height being statistically significant in all scatter plots of all three species (*A. marina*, *R. mucronata* and *S. alba*).

Table 1. Importance value (IV) of the mangroves in the study sites. All trees larger than 2.5 cm diameter at breast height (DBH) inside 0.01 ha plots were measured

		Relative values (%)			
Site	Species	Dominance	Stem density	Frequency	IV
Saco	*A. marina*	85.43	64.41	57.14	206.98
	B. gymnorhiza	0.004	0.34	4.76	5.10
	C. tagal	0.53	4.07	14.29	18.89
	R. mucronata	14.05	31.19	23.81	69.05
Sangala	*A. marina*	88.01	71.01	45.45	204.47
	B. gymnorhiza	1.17	5.80	13.64	20.61
	C. tagal	1.26	7.07	18.18	26.51
	R. mucronata	9.57	16.12	22.73	47.69
Mecúfi	*A. marina*	30.92	36.39	34.29	101.6
	B. gymnorhiza	0.2	2.75	8.57	11.52
	C. tagal	1.50	9.79	14.29	25.58
	R. mucronata	47.00	18.04	22.86	87.9
	S. alba	20.38	33.03	20.00	73.41
Pemba	*A. marina*	9.72	47.94	40.00	97.66
	B. gymnorhiza	0.02	0.24	3.33	3.59
	C. tagal	2.35	19.37	16.67	38.39
	R. mucronata	8.48	25.67	23.33	57.48
	S. alba	79.43	6.78	16.67	102.88
Ibo	*A. marina*	13.40	32.37	24.00	67.77
	C. tagal	1.10	11.86	20.00	32.96
	R. mucronata	7.81	31.40	20.00	59.22
	S. alba	77.69	24.36	36.00	138.05
Luchete	*A. marina*	17.98	53.10	35.29	106.37
	C. tagal	0.02	0.59	5.88	6.49
	R. mucronata	53.11	38.64	29.41	121.16
	S. alba	28.88	7.67	29.41	65.96
Ulo	*A. marina*	39.49	23.50	20.83	83.82
	B. gymnorhiza	0.01	0.21	4.17	4.39
	C. tagal	2.57	14.79	29.17	46.53
	R. mucronata	17.76	46.58	25.00	89.34
	S. alba	37.74	14.96	20.83	73.53
Mngoji 1	*A. marina*	10.86	30.63	26.32	67.81
	C. tagal	5.42	5.86	21.05	32.33
	R. mucronata	37.91	28.38	26.32	92.61
	S. alba	45.81	35.14	26.32	107.27
Mngoji 2	*A. marina*	14.01	41.98	33.33	89.32
	R. mucronata	34.07	26.82	33.33	94.22
	S. alba	51.92	31.20	33.33	116.45

Mangrove condition and wood quality

The sites studied all indicated different levels of mangrove degradation, as evidenced by the number of partially cut trees and stumps (Table 3). There were significant differences between sites in terms of stumps count ($P<0.001$), die back ($P<0.05$), coppicing ($P<0.05$), partially cut ($P<0.001$) and intact stands ($P<0.05$). Highest mean stump densities were found in both Mngoji forests (959 stumps ha^{-1} in Mngoji 1 and 592 stumps ha^{-1} in Mngoji 2). Mangroves at Mngoji have traditionally been used for firewood, building and sold to neighbouring villages in Tanzania. Partially cut trees were common all over Mozambican mangroves, with higher stem densities in Ulo (866 stems ha^{-1}), Luchete (713 stems ha^{-1}) and Saco (631 stems ha^{-1}). More intact individuals were found in Sangala (987 stems ha^{-1}) and Ulo (844 stems ha^{-1}). There were very few coppiced individuals at any sites, but where this occurred *A. marina* and *R. mucronata* were the preferred species for cutting. Overall, the highest stump density per species was recorded for *S. alba* at 989 stumps ha^{-1}. Significant differences were found when comparing (per species) stumps ($P<0.05$), coppicing ($P<0.05$), partially cut ($P<0.001$) and intact ($P<0.05$) but mean densities of die back were not significantly different ($P>0.05$).

Most poles in the study area were crooked (Table 4). High quality poles (straight and semi-straight poles) were found only in Ulo (618 stems ha^{-1}) and Mngoji 1 (742 stems ha^{-1}). Differences of poles quality among sites were statistically significant ($P<0.001$) for all pole categories. Crooked poles were more abundant in Mngoji 2, Luchete and Ibo (1287 stems ha^{-1}; 1212 stems ha^{-1} and 890 stems ha^{-1}, respectively). At species level, *R. mucronata* (504 stems ha^{-1}) and *S. alba* (436 stems ha^{-1}) had more poles suitable for construction (straight poles), whereas *A. marina* had most of the crooked poles (1360 stems ha^{-1}). There were statistical differences in wood quality between species ($P<0.001$ for straight poles; $P<0.05$ for semi-straight poles; $P<0.001$ for crooked poles).

Forest regeneration status

Natural regeneration was observed at all sites but with very high intra-site variance (Figure 4). There was very little

Table 2. Structural attributes of the mangroves in the study sites

Site	Mean diameter (cm) (1)	No. of species (2)	Stem density ha^{-1} (3)	Mean height (m) (4)	Basal area (m^2 ha^{-1}) (5)	Complexity index
Saco	16.83±1.46	4	1966±0.03	3.88±0.20	10.31	3.15
Sangala	7.84±0.38	4	3680±451	2.48±0.10	1.56	0.57
Mecúfi	10.72±0.64	5	2180±352	3.23±0.10	2.57	0.91
Pemba	11.76±1.13	5	2753±439	3.41±0.11	23.03	10.81
Ibo	10.62±1.01	4	2080±269	2.98±0.10	5.72	1.42
Luchete	11.46±0.9	4	2260±438	2.19±0.11	8.73	1.73
Ulo	7.73±0.43	5	3120±629	2.71±0.6	3.21	1.36
Mngoji 1	10.00±0.39	4	1480±136	5.16±0.26	1.16	0.35
Mngoji 2	8.17±0.26	3	2286±220	3.77±0.12	0.82	0.21

*Complexity index C.I. equals the product of (2), (3), (4) and (5) divided by 10^5 (Holdridge *et al.*, 1971).

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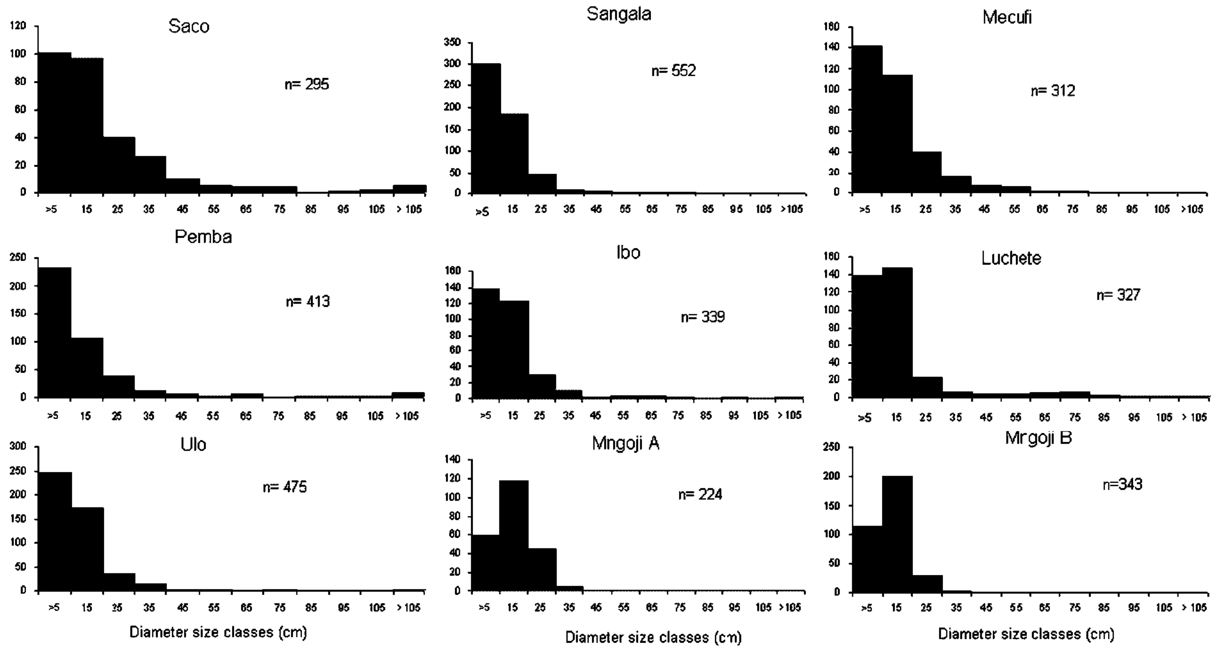

Figure 2. Diameter classes distribution of the mangroves in the study sites.

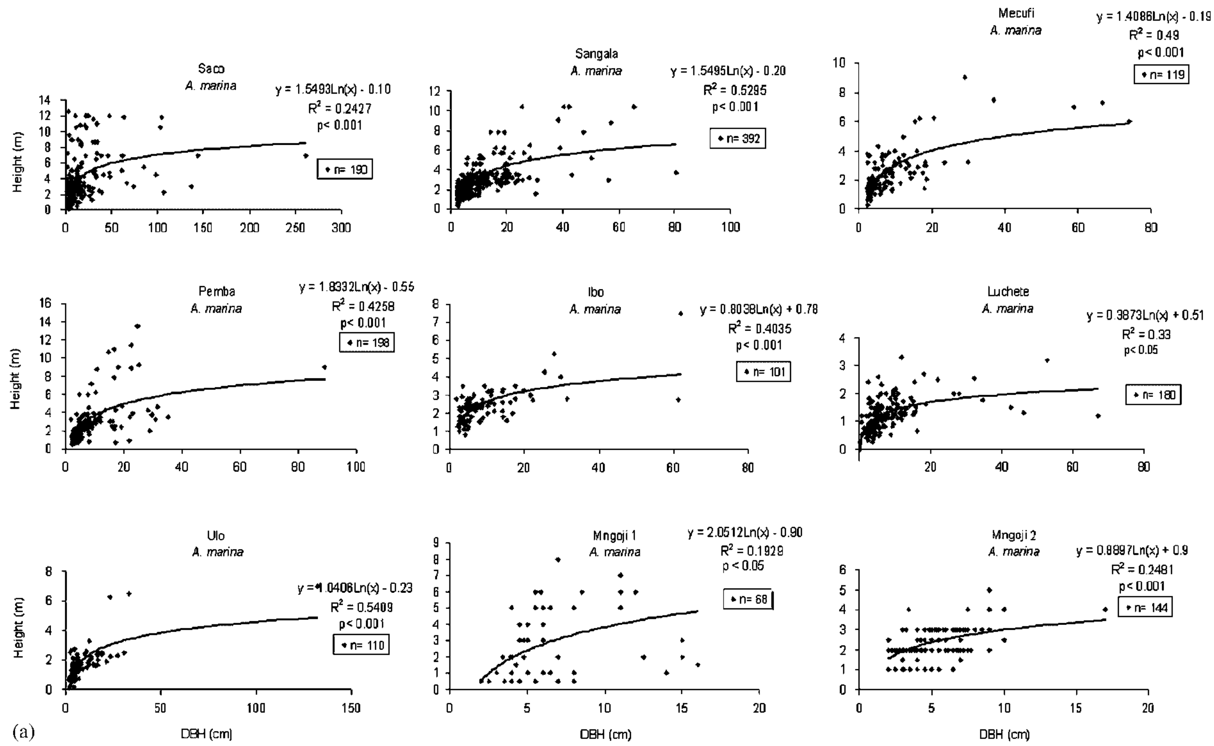

Figure 3. (a) Height–diameter distribution of *Avicennia marina* in studied mangrove forests; (b) height–diameter distribution of *Rhizophora mucronata* in studied mangrove forests; and (c) height–diameter distribution of *Sonneratia alba* in studied mangrove forests.

regeneration of *B. gymorhiza* at all sites. Most of the regenerating species tended to display a clumped dispersion pattern. There was significant difference in juvenile density among sites ($P < 0.001$), with higher densities recorded in Saco (14 766 ind ha^{-1}) and Mecúfi (14 706), and lowest densities in both Mngoji forests (2212 stems ha^{-1} in Mngoji 1 and 4799 stems ha^{-1} in Mngoji 2). There were more juveniles of RC I and II than of RC III at all sites visited and statistical difference only observed in RCIII ($P < 0.001$). Highest juvenile stem density was recorded for *R. mucronata* (with some 33 713 juvenile ha^{-1}), followed by *A. marina* (32 780 juvenile ha^{-1}), *C. tagal* (12 313 juvenile ha^{-1}), *S. alba* (2653 juvenile ha^{-1}) and *B. gymnorhyza* (1160 juvenile ha^{-1}). Differences between species were significant when comparing

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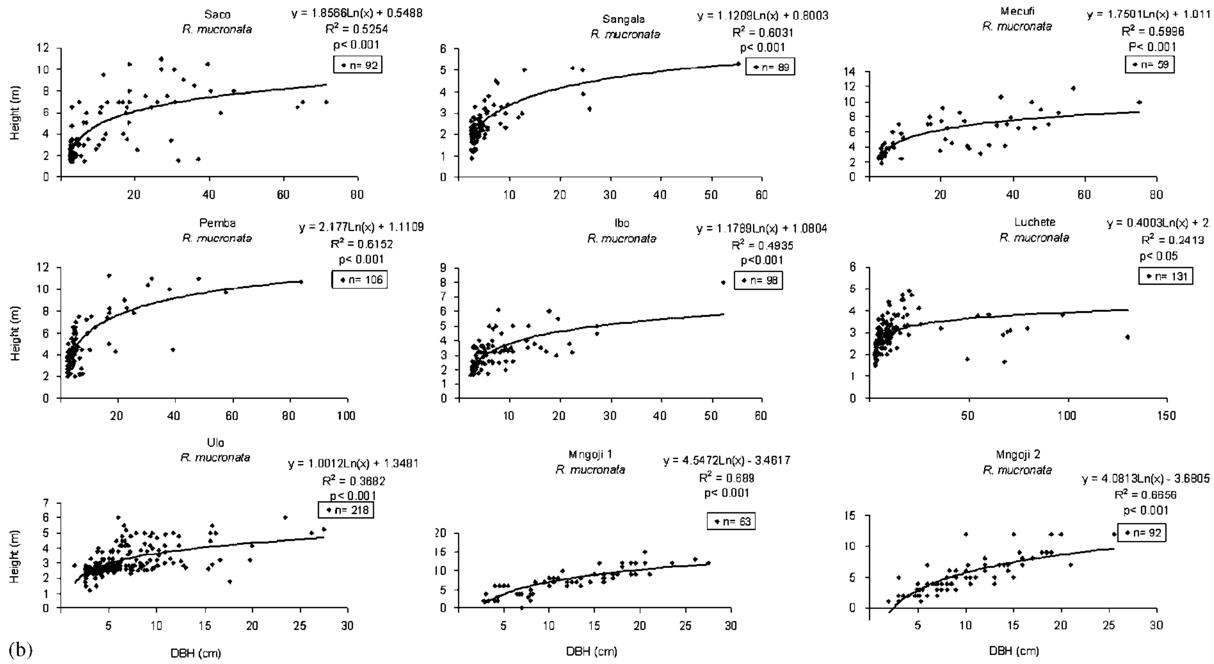

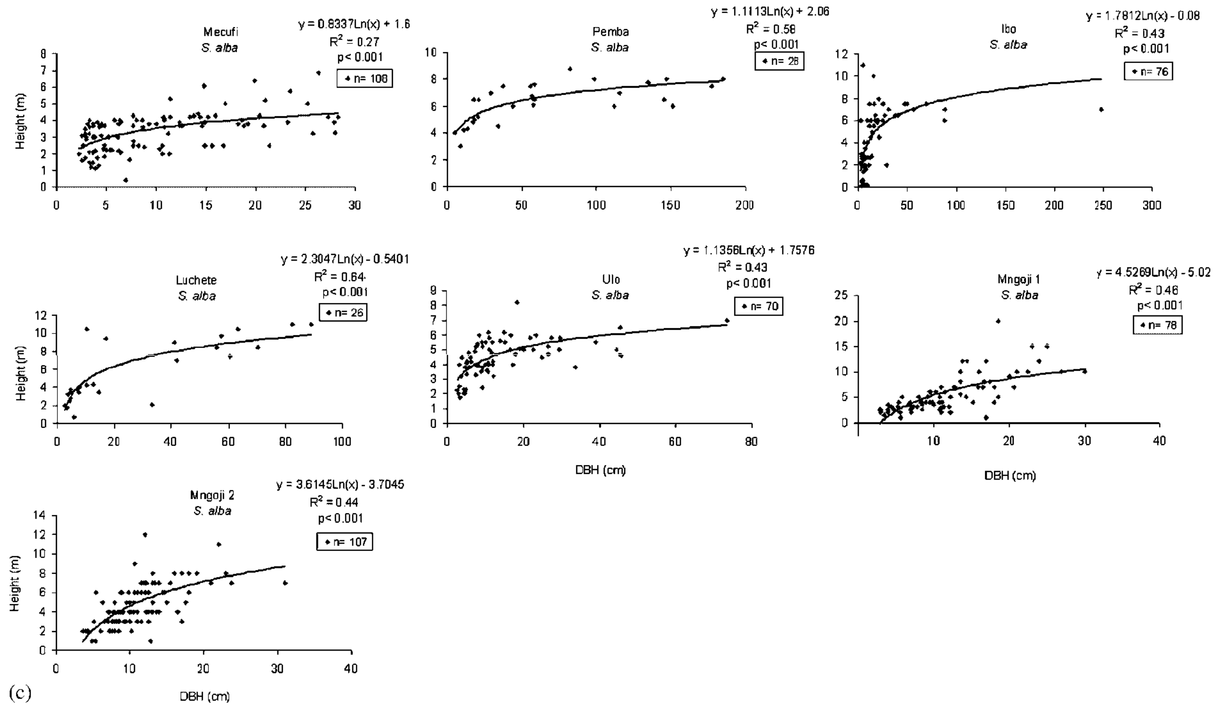

Figure 3. *Continued.*

stem density of individuals ($P<0.001$ for classes I and II; and $P<0.05$ for class II).

DISCUSSION

Mangrove forests in the study area showed evidence for usage at varying scales. Mangroves from Sangala, Ulo and Pemba in Mozambique were least degraded compared with Mngoji forests. The size-class structure (Figures 2, 3(a), (b) and (c)) in most localities of the study area showed the predominance of smaller trees, possibly indicating selective logging. Similar studies in Kenya have shown that selective harvesting of mangroves does not necessarily lead to loss in cover, but to changes in forest structures such that the superior stand containing preferred species is replaced by inferior unwanted species (Kairo *et al*., 2002). According to Walters (2005) and Kairo *et al*. (2002), stand stem density, basal area, and

Table 3. Mangrove forests conditions in the study sites

Site	Species	Intact		Partially cut		Coppicing		Die back		Stump	
		Mean density	S.E.	Mean density	S.E.	Mean density	S.E.	Mean density	S.E.	Mean density	S.E.
Saco	Am	408.3	132.3	1125.0	249.6	—	—	—	—	108.3	58.3
	Ct	333.3	145.3	66.7	33.3	—	—	—	—	—	—
	Bg	100.0	*	—	—	—	—	—	—	—	—
	Rm	1160.0	312.4	700.0	104.9	—	—	—	—	—	—
	Average	500.4		630.6		—		0.0		108.3	*
Sangala	Am	1340.0	437.0	1226.7	233.9	—	—	13.3	9.1	186.7	57.6
	Ct	640.0	254.2	140.0	87.2	—	—	—	—	120.0	37.4
	Bg	666.7	348.0	366.7	185.6	—	—	—	—	33.3	33.3
	Rm	1300.0	286.4	250.0	105.7	—	—	—	—	150.0	76.4
	Average	986.7		495.8		—		13.3	*	122.5	
Mecúfi	Am	361.5	98.4	523.1	149.4	23.1	12.2	—	—	115.4	52.9
	Ct	440.0	156.8	200.0	154.9	—	—	—	—	580.0	555.3
	Bg	200.0	200.0	100.0	*	—	—	—	—	33.3	33.3
	Rm	337.5	106.8	375.0	114.6	—	—	12.5	12.5	450.0	181.3
	Sa	942.9	541.1	514.3	143.8	57.1	42.9	28.6	18.4	28.6	18.4
	Average	465.4		342.5		40.1		20.5		241.5	
Pemba	Am	1191.7	439.9	433.3	115.0	16.7	11.2	—	—	66.7	18.8
	Ct	866.7	413.7	433.3	201.1	16.7	16.7	—	—	333.3	125.6
	Bg	100.0	*	—	—	—	—	—	—	—	—
	Rm	1300.0	504.7	200.0	57.7	—	—	28.6	28.6	342.9	179.8
	Sa	20.0	20.0	540.0	67.8	—	—	—	—	20.0	20.0
	Average	695.7		401.7		16.7		28.6	*	190.7	
Ibo	Am	633.3	289.4	966.7	224.6	33.3	33.3	16.7	16.7	1016.7	350.6
	Ct	500.0	197.6	42.9	29.7	—	—	—	—	757.1	369.6
	Rm	933.3	240.4	683.3	218.2	—	—	—	—	166.7	84.3
	Sa	400.0	132.3	266.7	70.7	155.6	86.8	—	—	22.2	14.7
	Average	616.7		489.9		94.4		16.7		490.7	
Luchete	Am	683.3	360.9	1633.3	530.2	716.7	464.3	—	—	33.3	21.1
	Ct	100.0	*	100.0	*	—	—	—	—	—	—
	Rm	1600.0	418.3	980.0	315.3	—	—	40.0	24.5	—	—
	Sa	340.0	188.7	140.0	87.2	40.0	24.5	—	—	—	—
	Average	680.8		713.3		378.3		40.0		33.3	
Ulo	Am	440.0	60.0	1460.0	404.5	220.0	102.0	120.0	97.0	300.0	137.8
	Ct	687.5	301.4	187.5	81.1	—	—	75.0	49.1	350.0	169.0
	Rm	2250.0	833.4	1400.0	371.5	616.7	616.7	16.7	16.7	800.0	330.7
	Sa	440.0	169.1	980.0	272.8	—	—	—	—	240.0	92.7
	Average	843.5		865.5		418.3		70.6		422.5	
Mngoji 1	Am	300.0	126.5	40.0	40.0	—	—	—	—	1380.0	265.3
	Ct	250.0	125.8	50.0	50.0	25.0	25.0	25.0	25.0	275.0	149.3
	Rm	480.0	153.0	20.0	20.0	—	—	—	—	1120.0	213.1
	Sa	20.0	20.0	20.0	20.0	320.0	66.3	420.0	58.3	1060.0	273.1
	Average	262.5		32.5		172.5		222.5		958.8	
Mngoji 2	Am	—	—	—	—	—	—	100.0	*	100.0	*
	Rm	100.0	100.0	25.0	25.0	—	—	—	—	950.0	330.4
	Sa	150.0	64.5	—	—	25.0	25.0	—	—	725.0	286.9
	Average	125.0		25		25		100		591.7	
All		**700.9**	**66.1**	**542.8**	**46.6**	**63.7**	**23.0**	**21.4**	**5.6**	**316.7**	**36.4**

Am denotes *Avicennia marina* etc. S.E. = standard error; *means only one sample (S.E. not calculated in this case); — means no individuals of the species were found in this condition.

complexity indices tend to be lower in disturbed forests. Low complexity index observed in both Mngoji forests indicated disturbed mangrove areas.

Small-scale logging may influence pattern and composition of natural regeneration in a mangrove stand (Ellison and Farnsworth, 1996; Krauss and Allen, 2003; Pinzón *et al.*, 2003; Walters, 2005; Bosire *et al.*, 2008). Gap creation during harvesting allows more light to reach the forest floor thus stimulating natural regeneration of the forest (Clark and Allaway, 1993; Sherman *et al.*, 2000). However, as canopy gaps in the forest become more abundant, species regeneration may also be selective, favouring those species more capable of surviving in gaps (Sherman *et al.*, 2000; Michinton, 2001; Walters, 2005). Results from this study indicate that all sites are being naturally regenerated, though at different rates. The Mngoji sites have the lowest juvenile stem density because of over-exploitation of the forests that has affected adult stocking densities. Among species, *A. marina* showed the highest generation capacity in all stands visited, and this could be due to its wide tolerance range to both salinity and shade

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Table 4. Quality of mangrove poles in the study sites

Site	Species	Straight poles		Semi-straight poles		Crooked poles	
		Mean density	S.E.	Mean density	S.E.	Mean density	S.E.
Saco	Am	8.3	8.3	575.0	171.5	950.0	232.7
	Ct	—	—	333.3	202.8	66.7	33.3
	Bg	—	—	—	—	100.0	*
	Rm	160.0	92.7	1000.0	223.6	700.0	327.1
	Average	84.2		636.1		454.2	
Sangala	Am	113.3	99.5	246.7	70.3	2246.7	530.2
	Ct	50.0	50.0	250.0	165.8	650.0	193.6
	Bg	33.3	33.3	833.3	441.0	166.7	33.3
	Rm	33.3	33.3	700.0	298.9	800.0	273.3
	Average	62.8		533.2		863.5	
Mecúfi	Am	15.4	10.4	400.0	94.7	476.9	152.0
	Ct	80.0	58.3	340.0	174.9	220.0	124.1
	Bg	66.7	66.7	233.3	133.3	—	—
	Rm	50.0	37.8	575.0	192.5	87.5	47.9
	Sa	328.6	174.2	971.4	420.7	185.7	101.0
	Average	108.1		504.0		242.5	
Pemba	Am	175.0	56.6	625.0	228.3	833.3	319.4
	Ct	450.0	168.8	300.0	131.7	566.7	430.2
	Bg	—	—	—	—	100.0	*
	Rm	1042.9	513.6	342.9	89.6	128.6	56.5
	Sa	220.0	66.3	320.0	37.4	20.0	20.0
	Average	472.0		397.0		378.1	
Ibo	Am	16.7	16.7	666.7	152.0	950.0	368.6
	Ct	—	—	—	—	760.0	250.2
	Rm	100.0	44.7	320.0	146.3	1560.0	186.0
	Sa	100.0	40.8	433.3	74.5	288.9	108.6
	Average	69.9		428.9		889.7	
Luchete	Am	33.3	21.1	66.7	49.4	2916.7	845.1
	Ct	—	—	100.0	*	100.0	*
	Rm	920.0	208.3	1060.0	522.1	620.0	97.0
	Sa	460.0	140.0	20.0	20.0	—	—
	Average	471.1		311.7		1212.2	
Ulo	Am	100.0	77.5	220.0	86.0	1860.0	481.2
	Ct	471.4	228.6	228.6	96.9	300.0	123.4
	Rm	800.0	235.2	2433.3	859.7	416.7	124.9
	Sa	1220.0	355.5	100.0	77.5	100.0	31.6
	Average	618.3		530.3		555.3	
Mngoji 1	Am	—	—	—	—	1550.0	263.0
	Ct	166.7	166.7	—	—	300.0	208.2
	Rm	1080.0	217.7	40.0	24.5	140.0	116.6
	Sa	980.0	66.3	480.0	205.9	440.0	196.5
	Average	742.2		260		607.5	
Mngoji 2	Am	—	—	—	—	—	380.1
	Rm	333.3	333.3	—	—	1333.3	176.4
	Sa	120.0	120.0	120.0	*	1240.0	220.5
	Average	226.7		120.0		1286.7	
Total		**269.2**	**34.6**	**448.1**	**48.5**	**749.5**	**74.8**

Am denotes *Avicennia marina* etc. S.E. = standard error; *means only one sample (S.E. not calculated in this case); — means no individuals of the species were found in this condition.

(Clark and Allaway, 1993). Many biotic and abiotic processes such as change in salinity, light penetration, temperature, sedimentation rates and sediment organic content, that are altered by tree cutting may also influence forest regeneration, predation of propagules by crabs and colonization of seedlings by insects (Krauss and Allen, 2003; Bosire *et al*., 2008; Granek and Ruttenberg, 2008).

The most utilized mangrove species at the study sites were *A. marina*, *R. mucronata* and *S. alba*, and this is similar to what has been reported in Kenya (Dahdouh-Guebas *et al*., 2000) and Tanzania (Semesi, 1998). In most parts of Eastern Africa, the wood from *A. marina* is used for many purposes, such as charcoal and firewood production, boat construction, handcraft handles, pounding poles, traditional drums and other small wood products (Dahdouh-Guebas *et al*., 2000; Taylor *et al*., 2003). *R. mucronata* on the other hand is mainly used for building and charcoal production; while *S. alba* wood is mostly used for boat construction and house ceilings (Taylor *et al*., 2003). The preferred size classes for construction poles are between 8.0 to 13 cm as documented by Kokwaro (1985) and Dahdough-Guebas *et al*. (2000). More resistant wood (to insect attack and rotting) is preferred for construction

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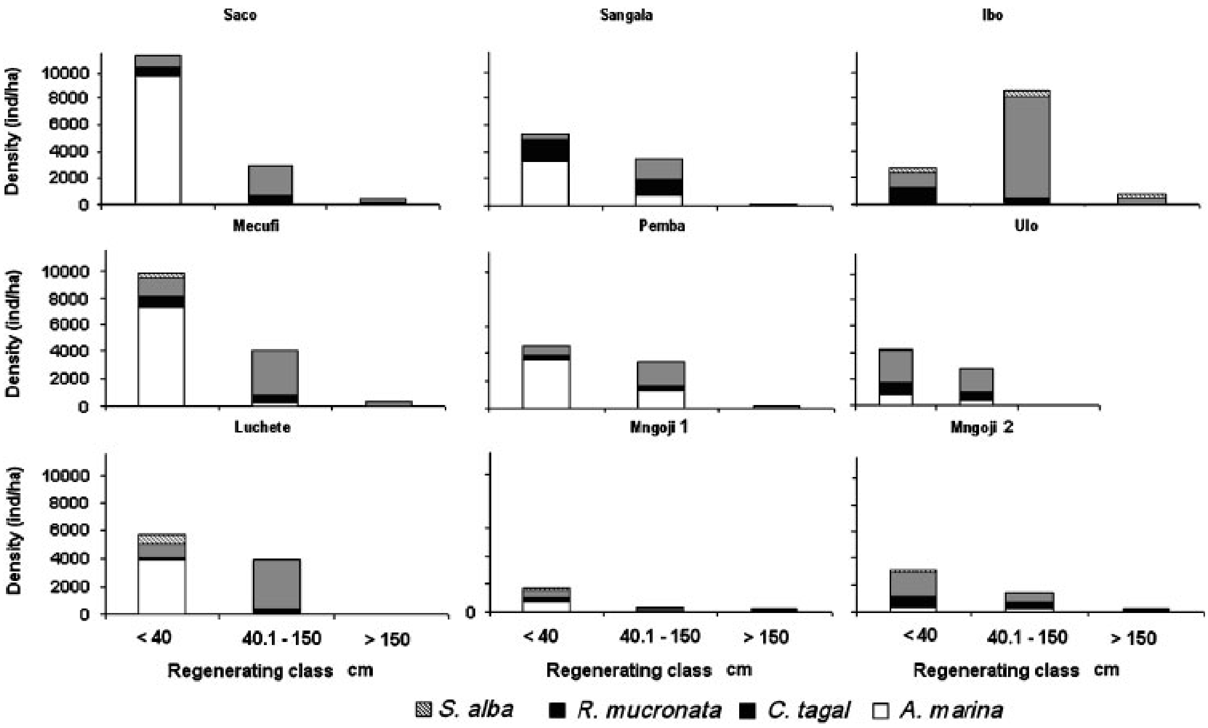

Figure 4. Juvenile density (saplings ha^{-1}) in the studied forests.

purposes such as *R. mucronata*, while for firewood production, the preference is for slow burning and smokeless species such as *A. marina* (Taylor *et al*., 2003).

Main drivers for mangrove destruction in Eastern Africa include overharvesting for fuelwood and charcoal supply, mangrove habitat conversion for salt works, as well as sedimentation associated with heavy river sediment discharge (Abuodha and Kairo, 2001; Kitheka *et al*., 2002). The loss of mangrove forests has been greatly increased by the growth of coastal towns such as Maputo and Beira in Mozambique (Barbosa *et al*., 2001). Further disturbance such as solid waste disposal, wastewater discharge and oil spills tend to occur in mangroves near to population centres (Semesi, 1998; Abuodha and Kairo, 2001). Infrastructure development associated with human density and poverty are important factors while analysing the root causes of mangrove degradation, all leading to ecological impacts such as loss of mangrove cover (Abuodha and Kairo, 2001; Beentje and Bandeira, 2007), increased shoreline erosion (Kitheka *et al*., 2003) and reduction in fisheries. The socio-economic consequences of this are loss of livelihood and increased poverty among the people who depend on mangroves. These activities have an accumulated effect on the current structure and regeneration of the forest (Dahdouh-Guebas *et al*., 2000).

CONCLUSION

Human activities have an accumulated effect on the current structure and conditions of the forest in the study area. The high CI values in Pemba, Saco, and Luchete compared to other sites could be due to differences in cutting intensity. The existence of significantly higher densities of stump at Mngoji than other sites may indicate the need for management intervention on the mangrove forests in this protected area of Tanzania. Mangrove reforestation as practised in Kenya and other parts of world has the potential of returning the lost forests, and thereby sustaining the supply of mangrove goods and services in the area. The replanted mangroves in Kenya have been shown to provide ecosystem services (e.g. coastal protection, biodiversity conservation, etc.) similar to natural stands (Bosire *et al*., 2005, 2008; Crona and Rönnbäck, 2005), and have also been shown to harbour higher quality poles than the degraded forests (Kairo *et al*., 2008). There is clear need to map degraded mangrove area in WIO region in order to initiate programmes for conservation, rehabilitation and sustainable utilization of mangrove resources. Such a programme has already started in the northern Mozambique in which UNEP is supporting mangrove reforestation in Nacala-Mossuril biodiversity hotspot (www.wiolab.org).

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