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An update on the status of mangrove forests in the western coast of Unguja Island, Tanzania: a rural *vs* peri-urban comparison

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Abstract: The status of mangrove forests was assessed in the western coast of Unguja Island, Tanzania along a rural-peri-urban gradient. Employing a systematic random sampling, we specifically compared the structural composition and rates of deforestation and forest regeneration. Sampling was carried out within 179 sample plots (10 × 10 m) established along line transects set across the shores. A total of six mangrove species were encountered. Tree density averaged 2134 trees ha^{-1}. Spatial variation in species composition, stand density, species importance, and forest structural complexities were observed among the mangrove forests. High levels of forest degradation and deforestation were also observed, with averages of 854.0 and 314.4 stumps and partially-cut trees per hectare, respectively. Although the rate of regeneration was high (37,600 juveniles ha^{-1}) and far above the recommended minimum for natural forest re-stocking, the actual regeneration potential is questionable, as the majority (> 60%) of the juveniles were of the lowest regeneration class (RCI), with little or no chance to recruit into higher classes and eventually adulthood under the current levels of exploitative pressure. This study has revealed higher intensity of anthropogenic pressure within the peri-urban mangroves, compared to their rural counterparts. Unless appropriate measures are undertaken, within the framework of the newly established Marine Conservation Areas (MCAs) in the western coast of the Island, this trend may irreversibly impair the capacity of these vital habitats to offer the ecological services upon which coastal livelihoods are dependent.

Key words: Deforestation, mangroves, recruitment, regeneration, structural composition, Unguja Island, Zanzibar.

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Introduction

Mangrove forests are critical habitats valued for their unique ecological functions and the vital socio-economic benefits they offer to coastal communities. They are among the keystone coastal ecosystems characterized by high ecological productivity (Alongi 2009; Boto & Bunt 1981; Mann 1982), thus forming an important energy base within the coastal and marine biotopes. Due to significant connectivity among marine habitats, much of the organic matter produced by the mangroves is exported to other marine ecosystems, consequently contributing significantly to the productivity of such recipient ecosystems (e.g. Menge *et al.* 1997). Moreover, mangroves offer a plethora of other ecosystem goods and services. For instance, they play a crucial role in coastal protection and stabilization; pollutant filtration and waste assimilation; as fish nurseries and refugia; as well as being an important source of fuel wood and building materials (Dahdouh-

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Guebas *et al.,* 2005; Hussain & Badola 2010; Joshi & Ghose 2014).

Mangroves form one of the most important coastal habitats in Zanzibar, being the second largest natural forest vegetation after coral rag thicket (Jumah *et al.* 2009). With approximately 20,000 ha, mangrove vegetation is estimated to cover nearly nine percent of the total land area (Leskinen & Ali 1997), with about 35% of that being found on the Island of Unguja (Ngoile & Shunula 1992; Shunula 1990). All of the 10 regional species of mangroves are reported to occur on the Island (Oliveira *et al.* 2003), being generally found in protected bays, but best established in estuaries. These include: *Avicennia marina* (Forsk.) Vierh; *Bruguiera gymnorrhiza* (L.) Lam.; *Ceriops tagal* (Perr.) CB. Rob.; *Heritiera littoralis* (Aiton); *Lumnitzera racemosa* (Willd.); *Rhizophora mucronata* (Lam.); *Sonneratia alba* (Sm.); *Xylocarpus granatum* (J. König); *Xylocarpus moluccensis* (Lam.) M. Roem and *Pemphis acidula* (J. R. Forst & G. Forst)

Despite the enormity of the socio-ecological importance of mangrove ecosystems, threats to such habitats are still prevalent. Although natural forces may play a major role in determining the health of such ecosystems, anthropogenic stress has largely been responsible for their deterioration (Upadhyay & Mishra 2008). Land clearing for saltpans, prawn culture, agriculture, and cutting of mangrove trees for poles, fuel wood and charcoal production are all to blame for mangrove deforestation (Semesi *et al.* 1999). Although several measures have been undertaken to arrest or even reverse the rate of mangrove deforestation in Zanzibar, including the institution of strict management regimes, illegal exploitation of mangroves has continued unabated (Jumah *et al.* 2009), threatening both the quantity and quality of the services these vital ecosystems provide. Increased population growth, expansion of urban areas, high degree of dependency of coastal residents on mangroves, scarcity of alternative sources of fuel and income, as well as inadequate law enforcement have been some of the underlying causes of such a negative trend.

Until recently, efforts to conserve mangrove resources on the Island of Unguja have been mainly concentrated in the eastern and southern mangrove forests of Chwaka and Menai bays, with little attention being paid to other forests, including those in the western coast (Jumah *et al.* 2009). Although the mangroves within those two bays form a significant portion of the total mangrove area on the Island, ignoring other areas may have rendered such resources largely open-access and, thus, unprotected. This is despite the fact that all the mangrove forests on the Island have long been legally recognized as forest reserves under the Zanzibar Forest Reserve Decree of 1965 (Jambiya *et al.* 2004). However, additional steps have recently been taken for serious conservation of the mangrove forests in the western coast of the Island. These include the establishment of two marine conservation areas namely, Changuu-Bawe Marine Conservation Area (CHABAMCA) and the Tumbatu Marine Conservation Area (TUMCA) to cover the mid- and north-western parts, respectively. This has necessitated an urgent need for an update on the status of the mangrove forests along the western coast. Baseline information on mangrove floral structures, levels of deforestation and degradation, as well as their regeneration potentials is vital for future monitoring of ecological changes within the mangrove ecosystems. The assessment of the structural composition of mangrove forests would also assist in the development of sustainable management strategies for the forests (Holdridge *et al.* 1971), by guiding important decisions on such measures as the designation of specific areas for harvesting and the setting of annual allowable harvesting limits (FAO 1994).

Increased urbanization has been a major cause of deforestation and degradation of mangrove ecosystems worldwide (Ehrenfeld 2000; Kathiresan 2008). Either through the modification of hydrological and sedimentation regimes and nutrient and pollutants dynamics or direct habitat alterations, urbanization has had significant influence on the structure and function of coastal wetlands such as mangroves (Costanza & Greer 1998; Faulkner 2004; Lee *et al.* 2004). In order to assess the possible impact of rapid urbanization on the integrity of mangrove forests, the present study compared the forest structures and extent of deforestation between stands of peri-urban and rural mangrove forests along the western coast of Unguja Island. The existence of a rural-peri-urban continuum among the mangrove forests, offered an opportunity for the assessment of the possible impact of urbanization on mangrove ecosystems. For instance, higher prevalence of sewage pollution observed within the peri-urban mangroves of Kinazini-Maruhubi, being mainly a result of direct pouring of sewage effluents into the mangrove stands or sewage reception from a nearby outfall (Abbu & Lymo 2007), could potentially have a greater effect on the mangrove ecosystem than in the more northerly rural stands, devoid of such large scale urban sources of pollution. Several authors have linked prevalence of mangrove degradation to increased urbanization. For instance, Bosire *et al.* (2013) found that the peri-urban mangroves in Mombasa, Kenya were more affected by degradation than the global average, linking such a trend to the response of the mangrove ecosystems to man-induced stressors, in combination with indirect impact of climate change and variability. Similarly, Nfotabong-Atheull *et al.* (2011) when comparing levels of degradation between urban and rural mangrove forests in Cameroon found an overall impact of urbanization on the forests. They mainly attributed the observed deforestation to a stronger preference by the surrounding urban communities for mangrove forests' products than in the rural settings. However, generalizations are far from being simple, as some studies have found the opposite to be true. Jumah *et al.* (2009) for instance, attributed the relative intactness of some peri-urban mangroves in Zanzibar to the relative economic stability of the surrounding urban communities, who attach less value to the mangrove resources compared to their rural counterparts. This study, was therefore, aimed at assessing the status of mangrove forests in the western coast of Unguja in relation to the extent of urbanisation. Specifically the study intended to: (i) determine the structural composition of the mangrove forests, (ii) compare levels of deforestation between selected mangrove forests, and (iii) describe and compare their regeneration potentials.

Study sites

The study was carried out within the mangrove forests located in the western coast of Unguja, which is one of the two major islands of the Zanzibar Archipelago. Sampling was conducted in four major mangrove forests located on the 1) Kinazini-Maruhubi coast (hereafter, Maruhubi) (39.20ºE, 6.15ºS); 2) Makoba (39.21ºE, 5.91ºS); 3) Mkokotoni-Muwanda coast (hereafter, Mkokotoni) (39.25ºE, 5.88ºS); and 4) Tumbatu (39.23ºE, 5.81ºS) (Fig. 1), representing a rural-urban gradient of the mangrove forests in the western coast of the Island. The Maruhubi forests are the most peri-urban, being located close to Zanzibar Town, the main urban centre on the Island. They are mostly sorrounded by human settlements, but are also flanked by recreational and industrial installations, fish landing sites and a sea port. The Tumbatu mangroves in contrast, were the farthest from Zanzibar Town. Being a small, relatively remote islet, Tumbatu was the most rural of all the study sites. It is predominanly a fishing village with limited agricultural activities. Makoba and Mkokotoni forests are located within a major embayment in the northwestern part of the Island. Besides being sorrounded by a number of fishing communities, the main activity in these areas is agriculture.

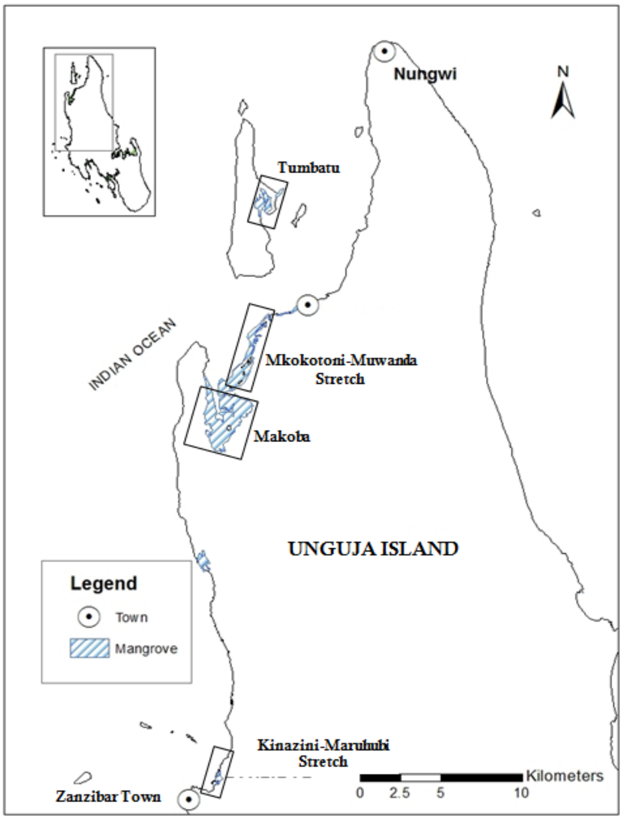

Fig. 1. Map showing the study sites.

Materials and methods

Sampling strategy

Using stratified random sampling, assessments for mangrove floral structure; degradation, and forest regeneration potentials were carried out once per site between September 2009 and March 2010 as per the following schedule: (Maruhubi: 9–14 September 2009, Makoba: 3–9 October 2009, Mkokotoni: 13–17 January 2010, and Tumbatu: 16–18 March 2010). Transects were established across the shores from the seaward to landward limits of the forests. Along each transect, 15 plots (10 × 10 m) were randomly set to include five each in the lower, middle and upper zones of the forest. Smaller plots (5 × 5 m) were used for practical reasons wherever the tree densities were deemed too high. A total of 179 quadrats were studied to include 59, 45, 45, and 30 in Maruhubi, Makoba, Mkokotoni and Tumbatu, respectively.

Assessment of tree stand density, degradation and regeneration potentials

Within each sampling plot all trees were identified to species level. All established trees (girth: > 2.5 cm) were then counted and their heights and diameters at breast height (DBH) measured and recorded. DBH was considered diameter of a tree at 130 cm aboveground (Brokaw & Thompson 2000). In the case of *Rhizophora mucronata*, the girth was measured just above the top prop root (Amarasinghe & Balasubramaniam 1992). The condition of each tree was also recorded as intact, partially cut, coppicing, or dying back. The extent of deforestation was assessed by counting and recording all cut remains (stumps). To establish levels of natural regeneration, all juvenile mangroves (girth: ≤ 2.5 cm) were enumerated for each species (Kairo *et al*. 2002).

Data treatment and statistical analysis

In order to determine the condition of the mangrove forests, characteristics such as tree density, tree basal area, species dominance, relative frequency, relative density and relative dominance were computed (Cintrón & Schaeffer-Novelli 1984). Species importance value index (IV), describing the structural role of individual tree species in the four forests, was calculated following Husch *et al*. (2003). Complexity indices (I_c) for the mangrove forests were calculated following Holdridge *et al*. (1971). Extent of forest degradation and deforestation was assessed by determining the density of stumps, partially-cut trees, and die-backs, computed as their respective average abundance per hectare. Rates of natural regeneration for each forest stand were computed as the the average percentage of the juvenile mangroves (DBH: ≤ 2.5 cm) out of the total mangrove trees recorded. The juveniles were analyzed based on three categories (recruitment classes) grouped in accordance to height classes, whereby seedlings less than 40 cm in height were classified as recruitment class 1 (RC1); saplings between 40 and 150 cm as recruitment class 2 (RC2), and small trees with heights greater than 1.5 m but less than 3 m as recruitment class 3 (RC3) (Mohamed *et al*. 2009). Species diversity (Shannon & Weaver 1963) and evenness (Pielou 1966) were determined for each forest separately using all the species present. Using SPSS software (IBM Corporation USA) data were tested for homogeneity of variance using Levene's test (α = 0.05). With homoscedasticity assured, one way Analysis of Variance (ANOVA) was applied to test for the spatial differences in densities at a level of significance of 5%, and Hochberg HSD test (Hochberg & Tamhane 2008) was used for posthoc comparison. Multivariate patterns of species composition were compared among the mangrove forests using non-Metric Multidimensional Scaling (nMDS) ordination (PRIMER 6, Primer Ltd, UK), based on Bray-Curtis similarity coeffiecients of 4th root-transformed abundance data.

Results

Floristic composition and species diversity

A total of six species of mangroves were encountered in the mangrove forests in the western coast of Unguja Island, to include *Avicennia marina, Ceriops tagal, Sonneratia alba, Bruguiera gymnorrhiza, Rhizophora mucronata* and *Xylocarpus moluccensis*. The number of species encountered in the mangrove forests were as follows: Maruhubi (5), Makoba (5), Mkokotoni (5) and Tumbatu (6). Shannon species diversity was highest in the most rural forest stands of Tumbatu (Mean ± SE = 0.58 ± 0.07, N = 30) and lowest in Makoba (Mean ± SE = 0.19 ± 0.05, N = 45). Statistical comparison showed significant differences in diversity among the mangrove forests ($F_{3,175}$ = 7.52, P < 0.0001). Subsequent pairwise comparison found differences between the rural forests of Tumbatu and Maruhubi, the most urban mangrove stands (P = 0.01); also between Tumbatu and Makoba (P < 0.0001) and Mkokotoni and Makoba (P = 0.04). There were no significant differences in species evenness among the four mangrove forests ($F_{3,97}$ = 0.81, P = 0.487), reflecting similarity in the levels of species dominance among the forest stands. Multivariate comparison of species assemblages showed closer resemblance in species composition between Makoba and Mkokotoni forests, which together, were relatively more distinct from the most urban

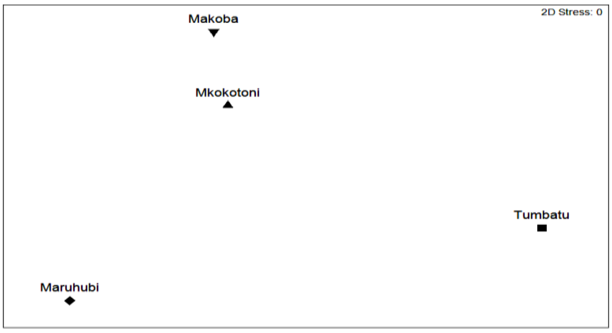

Fig. 2. Species resemblance patterns (nMDS ordination) among the four mangrove forests in the western coast of Unguja Island.

and most rural forests of Maruhubi and Tumbatu, respectively (Fig. 2).

Mangrove community structures

The structural attributes of the mangrove forests in the western coast of Unguja Island are summarized in table 1. In all the surveyed plots (N = 179), established tree density ranged from 0–14400 trees ha^{-1}, with an average of 2134 ± 147.8 trees ha^{-1}. Significant variation in density was observed along the rural-peri-urban gradient ($F_{3,175}$ = 4.47, P = 0.005), with the peri-urban mangroves of Maruhubi having the highest abundance (Mean ± SE = 2717 ± 275 trees ha^{-1}, N = 59). The lowest abundance was found in Makoba (1427 ± 361 trees ha^{-1}, N = 45). Posthoc analysis found significant difference only between the peri-urban stands of Maruhubi and Makoba (P < 0.05). Species-wise, *Rhizophora mucronata* was found to have the highest abundance (Mean ± SE = 725.14 ± 117.04 trees ha^{-1}, N = 179), while *Xylocarpus moluccensis* was the least abundant (1.12 ± 0.79 trees ha^{-1}, N = 179). Differences in the relative abundances among species in the four mangrove forests are depicted in Fig. 3. Variations in species importance (IV) were also observed among the mangrove forests. For instance *Avicennia marina* was the most important species in the urban mangroves of Maruhubi, while *Rhizophora mucronata* was the most important in the more rural forests of Makoba and Tumbatu. *Ceriops tagal* was the least important species in both Makoba and Mkokotoni, while *Sonneratia alba* was the least important in Tumbatu. In terms of structural complexity the rural forests were found to be more complex compared to the peri-urban mangroves, with the mangrove stands of the most rural Tumbatu exhibiting the highest level of complexity (Table 1).

Table 1: Structural attributes of the mangrove forests in western coast of Unguja Island (RD = Relative density, RF = Relative frequency, RDo = Relative dominance, IV = Importance value, Ic = Complexity index).

Mangrove forest	Species	Height (m)	Basal area (m^2 ha^{-1})	RD (%)	RF (%)	RDo (%)	IV	Rank	Ic
Maruhubi	*Avicennia marina*	4.26±0.11	10.94±2.74	42.70	44.55	50.67	137.92	1	2.37
	Sonneratia alba	5.71±0.13	9.99±2.86	33.43	30.69	48.33	112.45	2	
	Ceriops tagal	2.76±0.12	0.09±0.03	11.42	12.87	0.21	24.5	3	
	Bruguiera gymnorrhiza	3.14±0.13	0.44±0.39	9.48	7.92	0.62	18.02	4	
	Rhizophora mucronata	4.34±0.45	0.10±0.06	2.93	2.97	0.15	6.05	5	
Makoba	*Avicennia marina*	2.72±0.09	0.71±0.22	16.40	17.05	15.02	48.47	3	1.22
	Sonneratia alba	5.63±0.25	2.61±1.06	22.58	26.14	54.98	103.7	2	
	Ceriops tagal	2.59±0.34	0.02±0.01	7.16	12.50	0.54	20.2	5	
	Bruguiera gymnorrhiza	0.26±2.59	0.29±0.18	6.23	10.23	6.10	22.56	4	
	Rhizophora mucronata	3.90±0.14	1.11±0.32	47.66	34.09	23.34	105.09	1	
Mkokotoni	*Avicennia marina*	5.53±0.12	0.82±0.29	9.36	24.70	6.18	40.54	3	2.15
	Sonneratia alba	7.14±0.28	9.47±2.55	23.64	20.59	70.98	115.21	1	
	Ceriops tagal	4.31±0.30	0.21±0.11	4.68	10.29	1.63	16.6	5	
	Bruguiera gymnorrhiza	4.10±0.26	0.17±0.09	3.96	14.60	1.30	19.97	4	
	Rhizophora mucronata	4.70±0.12	2.63±0.43	58.34	28.41	19.77	107.52	2	
	Xylocarpus moluccencis	3.00±0.00	0.01±0.01	0.02	1.41	0.10	1.61	6	
Tumbatu	*Avicennia marina*	3.48±0.20	0.92±0.05	1.35	4.29	0.17	5.81	4	2.99
	Sonneratia alba	4.74±0.98	3.52±0.67	0.53	4.29	0.29	4.82	5	
	Ceriops tagal	3.58±0.19	0.69±0.20	23.58	28.57	7.00	59.32	3	
	Bruguiera gymnorrhiza	5.36±0.33	1.66±0.56	12.40	28.57	22.17	63.14	2	
	Rhizophora mucronata	5.48±0.22	8.45±2.37	61.86	34.29	69.38	165.82	1	
	Xylocarpus molucencis	3.50±0.59	0.18±0.12	0.27	2.90	0.98	4.15	6	

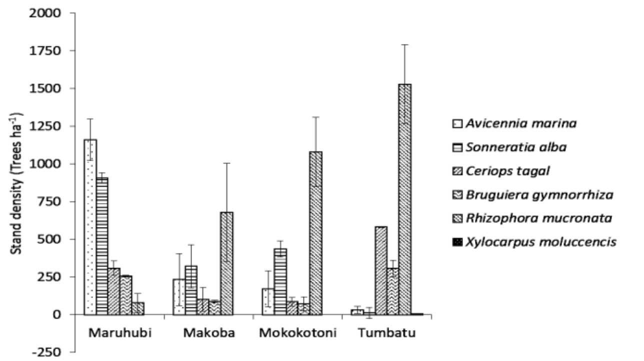

Fig. 3. Density of established trees within the mangrove stands in the western coast of Unguja Island.

Levels of degradation and deforestation

Completely cut trees (stumps)

Considerable levels of deforestation were observed along the rural-peri-urban gradient in the western coastal of Unguja Island, with an overall average of 854 stumps ha^{-1} being recorded within the mangrove forests. The highest density was recorded within the Makoba forests (Mean ± SE = 1257.7 ± 395.33 stumps ha^{-1}, N = 45), while the most rural stands of Tumbatu had the lowest (Mean ± SE = 326.6 ± 61.7 stumps ha^{-1}, N = 30) (Fig. 4). However, statistical comparisons did not reveal any significant difference in the abundances of stumps ($F_{3,175}$ = 1.74, P = 0.15).

Partially-cut trees

There was an overall average of 314.4 partially-cut trees ha^{-1} in the studied forests, representing approximately 8% of all the established trees. A clear rural-peri-urban trend in the rate of forest exploitation was observed along the coast, with significant differences in the density of partially-cut tree recorded ($F_{3,175}$ = 7.41, P < 0.05). The highest abundance of cut trees was recorded in the peri-urban mangroves of Maruhubi (Mean ± SE = 771.1 ± 180.4 trees ha^{-1}, N = 59), and lowest (Mean ± SE = 76.6 ± 26.4 trees ha^{-1}) in the most rural forests of Tumbatu (Fig. 4). Pairwise comparison revealed differences between the peri-urban forests of Maruhubi and Makoba (P = 0.001); Maruhubi and Mkokotoni (P = 0.01) and Maruhubi and Tumbatu (P = 0.001). Some differences in the extent of degradation were noticed among the different species. Generally, *Avicennia marina* and *Sonneratia alba* were the most exploited species. For instance, they accounted for nearly all (98.9%) of the partially cut trees in the most exploited forests of Maruhubi. Similar cases were found in Makoba and Mkokotoni forests where they accounted for 69% and 77%, respectively. In contrast, in Tumbatu the most affected species was *Rhizophora mucronata,* which accounted for approximately 70% of all partially cut trees.

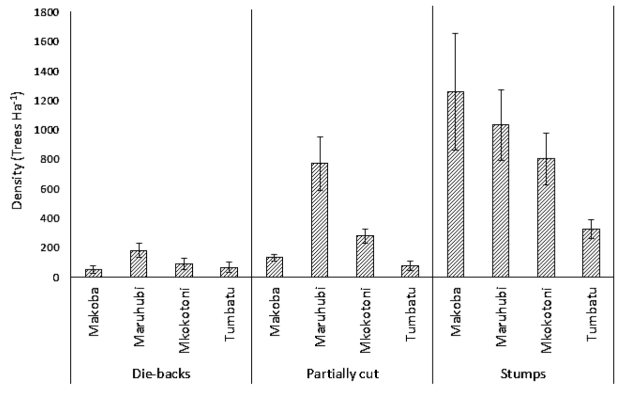

Fig. 4. Degradation status of the mangrove forests in the western coast of Unguja Island.

Die-backs

Besides the partially and completely cut trees, tree die-backs were also recorded in the mangrove forests in the western coast of Unguja Island. Overall 98.1 diebacks ha^{-1} were recorded, with highest incidences being found in the most urban mangroves of Maruhubi (Mean ± SE = 181.35 ± 45.58 trees ha^{-1}, N = 59), while the lowest density (Mean ± SE = 53.33 ± 24.74 trees ha^{-1}, N = 45) was found in Makoba (Fig. 4). However, no statistical differences in the abundance of die-backs were found among the four mangrove forests ($F_{3,175}$ = 2.44, P = 0.065)

Forest regeneration potential

Despite the high levels of deforestation recorded for the mangrove forests of western Unguja Island, considerable levels of regeneration (abundance of juvenile plants and coppicing trees) were observed.

Abundance of juveniles

The overall density of juveniles ranged from 0 - 579,000 trees ha^{-1}, with an average of 37600 ± 5820 tree ha^{-1} (N = 179). Significant spatial differences in the abundance of mangrove juveniles were observed along the rural-peri-urban gradient ($F_{3,175}$ = 12.7, P < 0.001), with the highest density being recorded in the most rural forests of Tumbatu (Mean ± SE = 105000 ± 21200, N = 30), and lowest in the most urban stands (Maruhubi) (6382.8 ± 893.44, N = 59). Posthoc analysis revealed significant differences between Mkokotoni and Maruhubi (P = 0.008), Tumbatu and Maruhubi (P < 0.001, and Tumbatu and Makoba (P = 0.015). Species-wise, differences in the abundance of juveniles were also observed. For instance, the most abundant juveniles in the urban mangroves of Maruhubi were *Avicennia marina* (Mean ± SE = 8731 ± 248 trees ha^{-1}) and *Sonneratia alba* (Mean ± SE = 433 ± 39 trees ha^{-1}), while in the more rural forests of Tumbatu and Mkokotoni, juveniles of *Bruguiera gymnorrhiza* and *Rhizophora mucronata* were the most abundant, respectively. Species-wise statistical comparison of the juvenile mangrove plant abundances is summarized in Table 2.

Rate of forest regeneration

Differences in the rates of forest regeneration were found along the rural-peri-urban gradient on the western coast of Unguja Island ($F_{3,175}$ 3.0 = 14.38, P < 0.001). At 94.0%, the most rural mangrove forests of Tumbatu had the highest rate of regeneration, while the most urban forests of Maruhubi had the lowest (53.3%) (Fig. 5). Pairwise comparison showed significant differences between Makoba and Maruhubi (P < 0.001), Tumbatu and Makoba (P = 0.003), and Tumbatu and Mkokotoni (P < 0.0001). The majority (65%) of juvenile mangroves were of recruitment class 1 (RC1), followed by RC2 and RC3, accounting for 34.7%

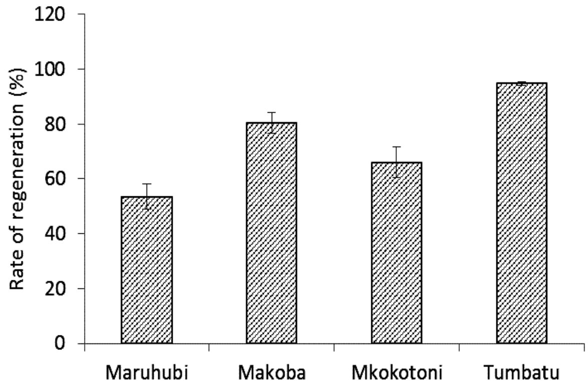

Fig. 5. Rates of regeneration for the mangrove forests in the western coast of Unguja Island.

and 0.23%, respectively. When the abundances of different recruitment classes were compared along the rural-peri-urban gradient, RC1 were found to be higher in the more rural forests than the more urban forests. A similar trend was observed for RC2 (Fig. 6)

Coppicing trees

Besides the juveniles, the mangroves forests in the western coast of Unguja Island were observed to exhibit considerable regeneration as a result of the coppicing of the cut trees. Overall, the density of coppicing trees was 32.27 ± 7.33 trees ha^{-1} (N = 179). Although no significant spatial differences in the density of coppicing trees were observed along the rural-urban gradient ($F_{3,175}$ = 0.621, P = 0.602), the most rural forests of Tumbatu generally had the highest density of such trees (Mean ± SE = 53.33 ± 6.98 trees ha^{-1}, N = 30) compared to the urban mangrove stands.

Table 2: Statistical comparison of the abundances of juvenile mangrove plants among the mangrove forests in the western coast of Unguja Island.

Species	ANOVA		Pairwise comparison	
	F	*P*–value	Forest pairs	*P*-value
Avicennia marina	6.75	< 0.001	Maruhubi > Tumbatu	<0.001
			Makoba > Mkokotoni	0.05
			Makoba > Tumbatu	0.006
Sonneratia alba	0.90	0.439	N/A	N/A
Ceriops tagal	17.70	< 0.001	Tumbatu > Maruhubi	0.001
			Tumbatu > Makoba	0.032
			Tumbatu > Mkokotoni	0.002
Bruguiera gymnorrhiza	12.28	< 0.001	Tumbatu > Maruhubi	0.050
Rhizophora mucronata	4.70	0.003	Makoba > Maruhubi	0.014
			Tumbatu > Maruhubi	0.008
Xylocarpus moluccensis	0.99	0.300	N/A	N/A

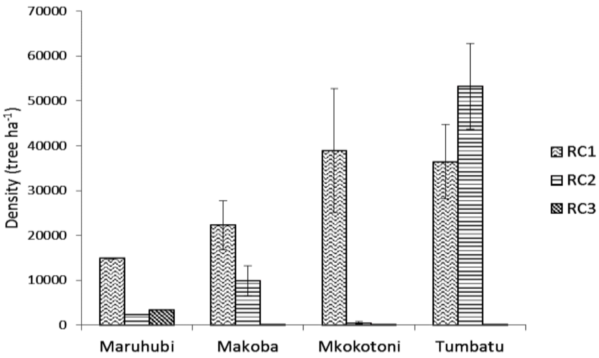

Fig. 6. Abundances of juvenile mangroves by regeneration classes in the mangrove forests in western coast of Unguja Island.

Discussion

In the present study, floral community structures, levels of deforestation and regeneration potentials of the mangroves in the western coast of Unguja Island were assessed along a rural-urban gradient. Understanding key ecological traits in an ecosystem is an important step in determining the levels of community stability, productivity, susceptibility, as well as its potential for recovery following disturbances (Gamfeldt & Hillebrand 2008; Hooper *et al.* 2005). Structural assessment of forest ecosystems such as mangroves also enables the development of proper and adaptive forest management plans (Holdridge *et al.* 1971), which ensures sustainable utilization of the inherent resources.

Floristic composition and community structure

A total of six mangrove species were encountered in the mangrove forests in the western coast of Unguja Island. This was four species short of the 10 species reported to occur on the Island (Shunula 1996), the others being *Heritiera littoralis*, *Lumnitzera racemosa*, *Xylocarpus granatum,* and *Pemphis acidula* (Jumah 2009). Although significant changes in community composition may have occurred over time, differences in the sampling strategies, as well as possible changes in relative species abundances may have accounted for the observed discrepancy. While understanding the level of species composition for a given mangrove forest is an important management aspect, the main focus of the present study was rather to determine the current status of the mangrove ecosystems in terms of their floral structure, levels of deforestation and their potential for regeneration. It is the overall structure of a mangrove ecosystem which largely determines the extent of its productivity, which in turn forms the basis for complex food webs typical of such biological systems (Joshi & Ghose 2014). Both uni- and multivariate analyses of species assemblages revealed interesting patterns in mangrove species composition along the rural-peri-urban gradient on the western coast of the Unguja Island, with the most rural forests exhibiting the most diverse and distinct species assemblages. The higher level of distinctness of the Tumbatu forests is likely explained by their unique location in comparison to the rest of the studied forests, being located on an islet with minimal physical connectivity to the mainland mangrove forests. This pattern was further supported by the high assemblage similarity between the more contiguous forests of Makoba and Mkokotoni as opposed to the higher dissimilarities observed between the more distantly–separated forests.

An average tree density of 2134 trees ha^{-1} was found in the mangroves of western Unguja, with the peri-urban mangroves of Maruhubi exhibiting the highest abundance. This level of abundance is comparable to what was reported by Jumah *et al.* (2009) when assessing the forests for the Zanzibar Mangrove Inventory, albeit with the application of a different sampling strategy. Being closest to the main town centre, such peri-urban forests likely have been impacted by the anthropogenic influences of a typical populated urban setting (Lee *et al.* 2004; Mohamed *et al.* 2009). For instance, the area receives sewage effluents poured directly into the mangrove stands, and also receives direct raw sewage from a nearby outfall (UNEP 1998). Although the impact of increased input of raw domestic sewage was not assessed in the present study, several studies have linked enhanced mangrove growth rates to such inputs (e.g. Boonsong *et al.* 2003; Feller *et al.* 2003). It has to be noted however, that with the exception of the significant difference in stand density observed between the Maruhubi and Makoba forests, generally the density in the mangrove forests in the western Unguja were similar.

Species-wise, *Rhizophora mucronata* represented the majority of the established trees. This may not be surprising as this is a hardy, fast-growing species that is easily propagated (Sukardjo & Yamada 1992). It flourishes naturally in estuaries and tidal creeks (Duke 1983), the latter of which were highly common in the mangrove forests on the Island. This is at least in part because of their extensive system of prop roots that can withstand wave action along the main tidal channels (Ahmed & Abdel-Hamid 2007), as well as to their tolerance to the relatively high sediment acidity common on such habitats (Hart 1962). Although *Rhizophora mucronata* had the highest overall density, variations in species importance (IV) were observed within the respective mangrove forests, with *Avicennia marina*, *Rhizophora mucronata,* and *Sonneratia alba* being the most important species in Maruhubi, Makoba/ Tumbatu, and Mkokotoni, respectively. Because the importance value is not only a function of the relative density of a particular species, but also a reflection of the overall growth potential (biomass), such differences may be attributed to the spatial differences in the physico-chemical and anthropogenic influences among habitats (e.g., Perera *et al*. 2013). Overall, the structural complexities of the mangrove forests in the western coast of Unguja Island were observed to be generally low, even though there is a lack of comparable studies in other parts of the Island. This is an indication of a relatively dominant young vegetation with low basal areas and tree heights (Mohamed *et al*. 2009). However, the relatively higher complexity observed for the more rural mangrove forests suggests the existence of more pristine forests in those areas, having possibly attained more growth in terms of height and girth compared to the more peri-urban forests.

Mangrove deforestation

High levels of deforestation, as indicated by the presence of stumps, partially cut trees and die-backs, were observed within the mangrove forests of western Unguja. Mangroves, wherever they occur are under enormous harvesting pressure due mainly to increasing demand for cheap fuel wood and building materials. High levels of poverty; dwindling alternative sources of income, building materials and fuel; and inadequate conservation efforts are some of the possible underlying explanations for the observed deforestation trends in mangrove forests in western Unguja (Jumah *et al*. 2009). Besides the overall high levels of deforestation, spatial differences were also observed. The mangroves in Makoba for instance, had the highest abundances of stumps while those in Tumbatu, the most rural, had the lowest. Partially cut trees and diebacks were most abundant in the peri-urban mangroves of Maruhubi than in the more rural forests, revealing a rural-urban gradient in rate of degradation and deforestation within the mangrove forests in the western coast of the Island. Such a trend somehow contravenes the widely-held belief in the relationship between rural poverty and incidences of mangrove deforestation (e.g. Jumah *et al.* 2009; Mohamed *et al*. 2009). The impact of urban development on mangroves and other coastal wetlands has been widely reported. Through direct habitat alteration (Heap *et al*. 2001; Lee *et al*. 2004) and increased pollution (Abbu & Lymo 2007; Costanza & Greer 1998), rapid growth in urban populations have had enormous impact on the structure, composition, and functioning of mangrove ecosystems worldwide. This has significantly, and in some cases irreversibly, compromised the ability of such systems to provide for the highly needed socio-ecological goods and services.

Deforestation and degradation within the mangroves in the western coast of Unguja were noticed to be highly species-biased. The incidences of partially cut trees, one of the most salient features of forest degradation, was overwhelmingly concentrated among a few species. For instance, in the peri-urban forests of Maruhubi, which was the most degraded, 99% of the cut trees were *Avicennia marina* and *Sonneratia alba.* Although they were the most abundant in the forests, this might not be the only reason for their selective over-exploitation. Besides their high abundances, suitability for various purposes could be one of the reasons for their selective harvesting. The big sizes of most of these trees in terms of their heights could have rendered them more favorable for construction purposes (Msangameno, pers. obs.). The observed targeting of *Avicennia marina* could also be due to their provision of specially-arched poles used as flooring planks in boat construction and repair, activities common around the area (Msangameno, pers. obs.). The selective harvesting of mangrove species for various ends has also been reported by several authors. For instance Walters (2005), when assessing the patterns of local wood use and cutting of Philippine mangrove forests, reported on the preference for *Rhizophora* sp. over other mangrove wood for construction of *bunsods*, a special type of fish pens. Similarly, Blanco *et al.* (2012) reported on the skewed tree diameter distributions in the mangroves in the eastern coast of Colombia due to the selective over-harvesting of *Rhizophora mangle* for poles and *Avicennia germinans* for planks and pilings.

In addition to the observed over-harvesting, considerable tree die-backs have been observed within the forests. At an average 98.1 trees ha^{-1}, such die-backs could have a foreseeable impact on the integrity of the mangrove ecosystems. The peri-urban mangrove forests of Maruhubi had the highest incidences of die-backs compared to the more rural forests. Although it was beyond the scope of the present study to determine whether or not such die-backs were a result of natural or anthropogenic causes, higher abundances of die-backs within the peri-urban forests may suggest a possible link of such incidences to human-induced physico-chemical alterations, resulting in habitat degradation. Although mangrove diebacks can be part of natural life cycles of individual trees (Jiménez & Lugo 1985), increased environmental stress has been shown to play a major role in amplifying the problem, with a number of causes being reported. They include: human damage by cutting; violent storms (Duke *et al.* 2000); pathogens (Pegg & Forsberg 1982; Pegg *et al.* 1980); siltation (Duke *et al.* 2000; West *et al.* 1983); herbivory and foliage loss (West *et al.* 1983); petroleum hydrocarbons due to oil spills (Abuodha & Kairo 2001; Duke *et al.* 1997; Duke *et al.* 2000; FAO 2005; Kairo *et al.* 2005); atmospheric and soil pollution; fluctuations in rainfall and climatic patterns; and excess nutrient inputs through use of fertilizers and sewage discharges (Duke *et al.* 2000). By virtue of their urban location, the Maruhubi mangrove forests are therefore subjected to some of the above mentioned sources of anthropogenic stress. High levels of direct sewage input observed in the area, for instance, may be among the possible reasons. Being in the proximity of the main sea port and several of the Island's main oil depots (Msangameno, pers. obs.) could have exposed the mangrove forests to petrochemical pollution. Although mangrove forests act as filtering systems by trapping sediments, litter, minerals and other materials and thus limiting their dispersal offshore (Duke 1992); the subjection of such systems to overwhelming levels of pollution may significantly compromise such assimilation capacity (Mato 2002).

Forest regeneration potentials

Natural regeneration, quantified as abundances of juvenile mangroves is an important indicator of the capacity of a forest to restock itself, with the higher density of juveniles implying better chances of the forest to replenish naturally (Snedaker & Snedaker 1984). Despite the high level of deforestation among the mangrove forests in the western coast of Unguja Island, considerable levels of natural regeneration were observed. At an average of 37600 trees ha^{-1}, the forests were well above the recommended baseline density of 2500 seedlings ha^{-1} for a successful natural re-stocking (FAO 1994). Although the forests may seem to have enormous natural regeneration potentials, caution must be used. This is because the majority of such juveniles (65%) were of young seedlings (RC1), with a low density of saplings observed. The failure in the number saplings to match the higher abundances of young seedlings may putatively suggest high mortality of the latter, resulting in low recruitment into successive regeneration classes and eventually adulthood (Mohamed *et al.* 2009). The observations alone from the present study cannot explain the causes of the discrepancies between the different regeneration classes. However, several factors could explain such a failure. They include: desiccation, predation and sensitivity to physico-chemical stress factors such as flooding, and variations in tidal inundation regimes (McKee 1995).

The establishment and survival of juveniles have also been linked to the spatial and temporal heterogeneities resulting from canopy gap formation of adult trees, as well as siltation (Flower & Imbert 2006). The relative sizes of canopy gaps within mangrove forests have been negatively correlated to levels of mangrove recruitment, with higher densities of juveniles found within smaller gaps and under canopies than in larger gaps (Mohamed *et al.* 2009). Although it was beyond the scope of the present study to investigate the effect of canopy gap size, the lower level of regeneration observed for the peri-urban mangroves of Maruhubi could partly be related to higher levels of deforestation, and thus more canopy gaping. Extreme local dispersal of propagules, habitat heterogeneity due to disturbance and altered topography have been cited as some of the major causes of minimal regeneration in forests with large canopy gaps, compared to those with closed-canopies (Clarke & Kerrigan 2000; Minchinton 2001),

Conclusion

The mangrove forests in the western coast of Unguja Island form an important resource base, providing considerable socio-ecological goods and services. Recognizing this potential, an assessment was carried out to determine their current status in terms of their structure, levels of deforestation and recruitment along a rural-urban gradient. The observed levels of species diversity and abundances make the mangrove forests worth-conserving. However, high levels of deforestation observed in most of the mangrove forests are a cause for concern, if these vital habitats are to continue to offer the needed ecological services in a sustainable manner. Although high regeneration potentials were observed within most of the mangrove forests, in terms of the abundance of juvenile plants, caution should be used. As long as most of the juvenile plants are young seedlings, there is no absolute guarantee of them being recruited into high regeneration classes and eventually adulthood. In fact, the disproportionately high abundance of such seedlings compared to saplings is enough evidence that most of these seedlings do not make it into successive regeneration classes, and thus the only mechanism to ensure sustainability is rather, to restrict harvesting at a rate low enough to guarantee natural forest restocking.

Although absolute generalizations are far from being simple, the present study was able to clearly show trends in the extent of tree abundances, diversity, deforestation and regeneration along a rural-peri-urban gradient. The higher species diversity, structural complexity, and regeneration potential, as well as relatively low deforestation observed in the more rural forests compared to those in the peri-urban, underline the possible impact of urbanization on the health of coastal wetlands such as mangrove forests. This confirms what has been reported by several other authors in areas with similar spatial settings. It is concluded that, although the present study has shown more environmental stress among the peri-urban mangroves in the western coast of Unguja Island, this trend is however, not irreversible. With the enforcement of the extant conservation measures and more so within the framework of the newly instituted Marine Conservation Areas (MCAs), the ecological potential of the mangrove forests in the western coast of Unguja Island may be preserved or even enhanced.

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