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Cover image: Ponta Rasa mangrove, Inhaca Island (© José Paula, 2005)

Mangrove change detection, structure and condition in a protected area of eastern Africa: the case of Quirimbas National Park, Mozambique

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Abstract

Given the high dependence of coastal communities on natural resources, mangrove conservation is a challenge in Mozambique, even within several types of marine protected areas. This study assesses the condition of a mangrove forest in the Quirimbas National Park (QNP), where use by the local community is allowed with restrictions. Satellite imagery (1991 – 2013) and ground forest assessment were used to assess forest structure, conservation status, and regeneration potential of the forest. Random 10x10 m quadrats were set within the forest, for species identification, diameter at breast height (DBH), height measurement, assessment of levels of cut, and quality of the main pole. Young individuals were also counted to assess the regeneration potential.

The overall mangrove cover has increased by 10% from 11 244 ha to 12 348 ha between 1991 and 2013. The forest is dominated by *Ceriops tagal* and *Rhizophora muctonata*, but other 4 species were also identified (*Avicennia marina*, *Bruguiera gymnorhiza*, *Sonneratia alba*, and *Xylocarpus granatum*). Trees tend to be small in height and width (mean: 5.96 ±3.2 m and 7.69 ± 4.5 cm respectively), with a total density of 572 trees/ha. Statistical analysis indicated distinct patterns of transformation; the south with higher densities of crooked poles ($p < 0.05$) (369 trees/ha), and the north with higher density of stumps ($p < 0.05$) (250 stumps/ha). The north and south parts of the park also had higher densities of crooked than straight and semi-straight poles ($p < 0.05$). Natural regeneration was observed with adequate seedling/sapling density of between 36 733 to 126 133 saplings/ha. The results indicate that, despite being a protected area, the mangroves of the QNP are subject to pressure from the community, reflected in the loss of certain areas areas, and high density of cut trees and stumps. Appropriate measures are necessary to effectively protect these mangroves and meet conservation objectives.

Keywords: mangrove mapping, anthropogenic pressure, mangrove management, protected area

Introduction

Mangrove forests are unique and complex systems providing an array of ecosystem services to coastal communities such as firewood, timber, water purification, nursery grounds for fisheries, nesting sites for birds, cultural sites, and costal protection against extreme events (Kathiresan & Bingham, 2001; Alongi, 2002; FAO, 2007; Komiyama *et al.*, 2008, Cohen *et al.*, 2013). Furthermore, they have the potential for carbon sequestration, nutrient cycling, and worldwide contribution to climate change mitigation (Donato *et al.*, 2011; Giri *et al.*, 2011). Human-induced disturbances of mangrove ecosystems are related to direct exploitation for timber, fuel wood, aquaculture, urban development (Taylor *et al.*, 2003; Williams *et al.*, 2007; Gilman *et al.*, 2008; Paling *et al.*, 2008), and to the deleterious consequences of climate change (eg sea level rise, flooding, erosion and sedimentation, fluctuating precipitation and temperature regimes, storms and cyclones) (McLeod & Salm, 2006; IPCC, 2013; Gilman *et al.*, 2008).

Despite their recognised importance, mangrove forests are among the most threatened ecosystems worldwide (Valiela *et al.*; 2001) with 35% of the original global area being degraded or destroyed since 1980, and current global rates of loss running between 1 - 2% per annum. According to several studies, 11 of the 70 mangrove species (or 16%) are classified as threatened, and are on the IUCN Red List (Valiela *et al.* 2001; FAO, 2007; Donato *et al.*, 2011; Cohen *et al.*, 2013).

Mangrove forests in Mozambique rank 13th worldwide and third in Africa in terms of cover area, with around 300 000 ha (Giri *et al.*, 2011). They occur on protected shorelines, deltas and estuaries that are distributed all along the coastline (Barbosa *et al.*, 2001; Hoguane, 2007). Eight mangrove species occur in Mozambique (Barbosa *et al.*, 2001) with the dominant species being *Avicennia marina* (Forssk.) Vierh., *Bruguiera gymnorhiza* (L.) Lam., *Ceriops tagal* (Per.) C. B. Robinson, *Rhizophora mucronata* Lam. and *Sonneratia alba* Smith. Others species are *Heritiera littoralis* Aiton, *Lumnitzera racemosa* Willd. and *Xylocarpus granatum* Koenig (Barbosa *et al.*, 2001; Macamo *et al.*, 2016a).

In Mozambique mangroves are mostly used for building, firewood, fish trapping and medicine (Barbosa *et al.*, 2001). Ecologically they provide protection to the shoreline and act as fish nurseries for commercially important fish and shrimp (Duke, 2001). The major threats to mangroves in Mozambique are related to clearance of mangrove forests for agriculture, aquaculture, salt production, and diminishing freshwater flow to mangroves due to dam constructions, high development along the Mozambican coast, and climate change impacts (Saket & Matusse, 1994; Barbosa *et al.*, 2001; Macamo *et al.*, 2016a).

Analyses of forest cover change, structural characteristics, species composition, and regeneration patterns can shed light on the degree of damage inflicted on forest ecosystems by the joint influence of man-induced and climate-related disturbances. Similarly, understanding the ecological status, compositional, functional and structural diversity, is imperative to obtaining the necessary information required for planning management interventions (Satyanarayana *et al.*, 2011).
Remote sensing techniques and forest structure assessments have been adopted increasingly to estimate mangrove forest area, productivity, species distribution and density (Satyanarayana *et al.*, 2011; Kirui *et al.*, 2013; Fatoyinbo & Simard, 2013). Commonly, satellite imagery used in forestry include SPOT, Landsat Thematic Mapper and Enhanced Thematic Mapper (ETM), Quickbird, IKONOS, and Shuttle Radar Topography Mission (SRTM) (Fatoyinbo & Simard, 2013; Hirata *et al*., 2014; Macamo *et al*., 2016b). These techniques can easily quantify changes in forest structure over time, and monitor dynamics (Fatoyinbo *et al.*, 2008). Low resolution imagery such as Landsat (Shapiro *et al*., 2015) are adequate to capture cover over larger areas, whereas higher resolution such as Quickbird and IKONOS, are used to detect cover changes in small areas and to document mangrove zonation up to individual species. 3D structure can be accomplished using imagery from Lidar, ICESat/GLAS (Ice, Cloud, and land Elevation Satellite /Geoscience Laser Altimeter System combined with SRTM (Shuttle Radar Topography Mission)); these drawn from Landsat imagery as documented (Fatoyinbo & Simard, 2013).

Quirimbas National Park (QNP) includes 6 districts of Cabo-Delgado Province, northern Mozambique, covering an area of 7 506 km^2, where 5 984 km^2 are terrestrial mainland (with inland *inselbergs*), and 1 522 km^2 are coastal and marine habitats. The park contains four eco-regions of worldwide conservation importance, including South-east African Coastal Forest, East African Mangrove, miombo forest and Eastern Savannah (Gabrie *et al.*, 2008). The QNP was created in 2002 and is considered as a regional and global priority area for biodiversity conservation (MITUR, 2009, MITUR, 2014).

Around 160 000 people live permanently within the QNP distributed in 90 villages, and approximately 20% of the population is located along the coastal zone. Over 95% of the coastal population is economically dependent on natural resources, particularly wood exploitation, agriculture and small-scale fisheries (INE, 2013; MITUR, 2014). Due to the high levels of natural resource dependence, anthropogenic impacts on critical ecosystems are of a key concern within QNP. The QNP has a system of zoning that includes: i) full protection zones, where resource extraction is prohibited; ii) community development zones in which sustainable harvesting is permitted for the benefit of fishers;

and iii) special use zones, which include Saint Lazarus Banks, reserved for sports fishing (Gabrie *et al.*, 2008).

The Management Plan for Quirimbas National Park includes several measures to promote human welfare and sustainable use of natural resources within the park. Mangrove management measures include appropriate use and protection of mangrove ecosystems (Law 10/1999, from July 7th – Forestry and Wildlife Law; and Law 16/2014 from 18th July – Conservation Law). Exploitation of mangrove resources is only allowed for local use (firewood, and timber for construction of boats and houses) and strictly prohibited for commercial purposes; harvesting of mangroves is prohibited in the Total Protection Zones (MITUR, 2014).

This study aimed to analyse temporal changes in mangrove cover from 1991 to 2013; assess mangrove structural parameters, conservation status, as well as natural regeneration potential. The information generated from this study will inform the Park Authorities in designing a co-management programme for mangroves and fisheries resources in QNP, and build-up information for ecosystem-based management of coastal and marine ecosystems in QNP.

Material and Methods

Study Area

Quirimbas National Park (QNP) is located in Delgado Province, northern Mozambique, and is characterized

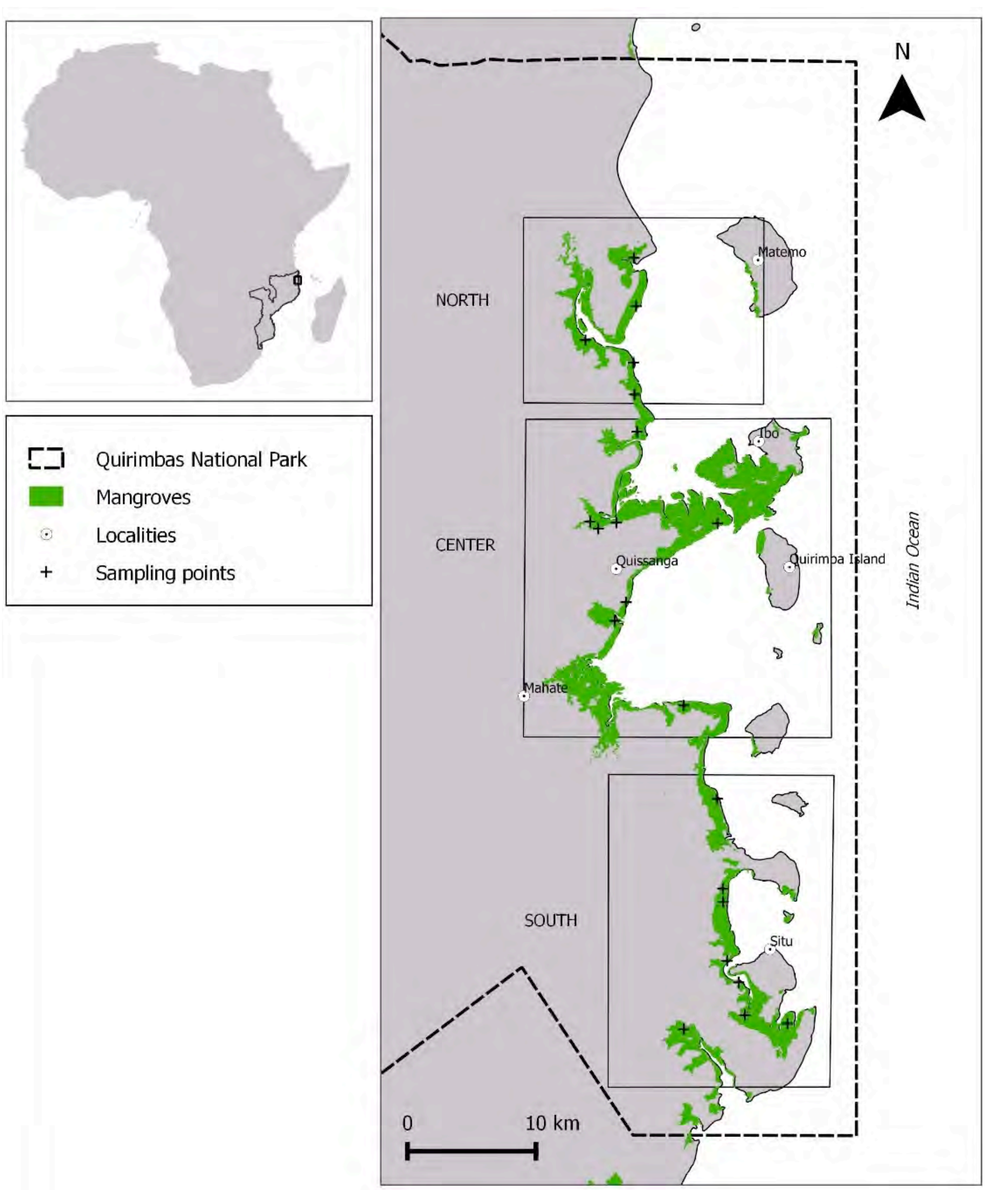

Figure 1. Geographic Location of Quirimbas National Park.

by a relatively narrow coastal plain with few rivers, a coastline of sandy beaches, mangrove forests, seagrass meadows, fringing coral reefs, scattered islands, and a narrow continental shelf (S: 12 ° 00 '00 "and 12 ° 55' 04" and E: 39 ° 10 '00 "and 40 ° 39' 44" East; Fig. 1) (MITUR, 2003). The climate in the study area is tropical with two distinct seasons during the year; a wet and warm season (November to April), and a drier and cooler season (May to October). The mean temperatures vary between 25°C and 27°C and rainfall is restricted to the warm season (MITUR, 2014). The tidal range is an average of 2.4 m and the coast is subject to occasional tropical cyclones (4 in the past 16 years) (INGC, 2009).

Mangrove Mapping

In order to develop information on mangrove extent over time within QNP, Landsat images from three epochs (August, 1991; May, 2002; and May, 2013) were used. The imagery was acquired from the US Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) website (www.glovis.usgs.gov) repository. Imagery with low cloud coverage scenes (less than 10%) were selected to minimize differences in mangrove cover due to seasonal effects. Imagery classification consisted of a hybrid process, which included an unsupervised algorithm, followed by a supervised process. The unsupervised process used a k-mean algorithm in order to provide the

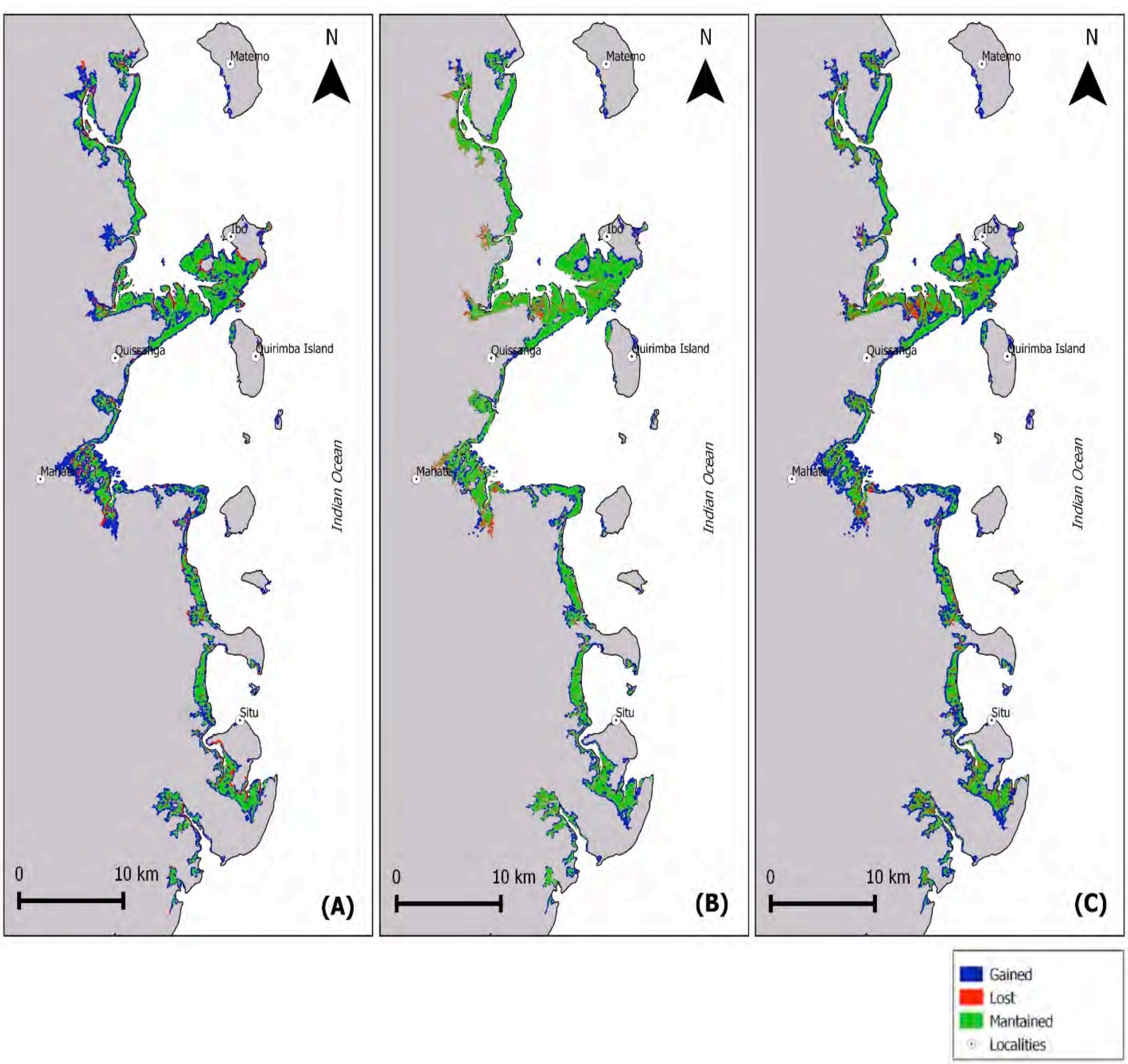

Figure 2. Detailed maps of mangrove cover change within Quirimbas National Park in 1991 (A), 2002 (B) and 2013 (C).

Table 1. Mangrove cover area dynamics from 1991 to 2013 in the Quirimbas National Park.

	Timeline			
Variables	**1991**	**2002**	**2013**	
Area extent (ha)	11 244	12 812	12 348	**Net change**
Cover variation (gain and loss) (ha)	-	1 568	- 464	+1 104
Annual change percentage (%) (ha)	-	1.27	- 0.33	9.8%

statistical distribution of spectral classes for each image. Land use classes were assigned to spectral classes, and ground-truthing work undertaken to train and validate the supervised algorithm. Some samples of land use classes where acquired using Google-earth high-resolution imagery. Maximum likelihood supervised algorithm was used in a second stage classification process resulting in a land use classification for each imagery. The main land use classes identified were: mangrove forest; mud; sand; water; and terrestrial areas. Confusion Matrices and classes accuracy assessment were derived for each image classification. The classification scheme resulted in maps of mangrove vegetation cover between 1991 and 2013, and 2002 to 2013.

The distinction between potentially confusing areas of mangrove and terrestrial vegetation, including ecotone areas, and the discrimination of patches of terrestrial vegetation within areas of mangrove forest, was based on visual interpretation of the imagery available from Google-earth and from ground-truthing information.

Forest Assessment

To assess the forest structure, condition, quality, and regeneration pattern within QNP, the park was systematically classified into three sampling areas, each reflecting similar proportions of mangrove distribution: (i) North - Macomia and Darumba; (ii) Center - coastal area of Quissanga, Ibo and Quirimba Island; (iii) South - Arimba and Situ (Fig. 1).

A total of 31 (10 x 10 m^2) plots were randomly set in the 3 subsampling areas (based on a grid of 1 km intervals). All individual mangrove trees inside the

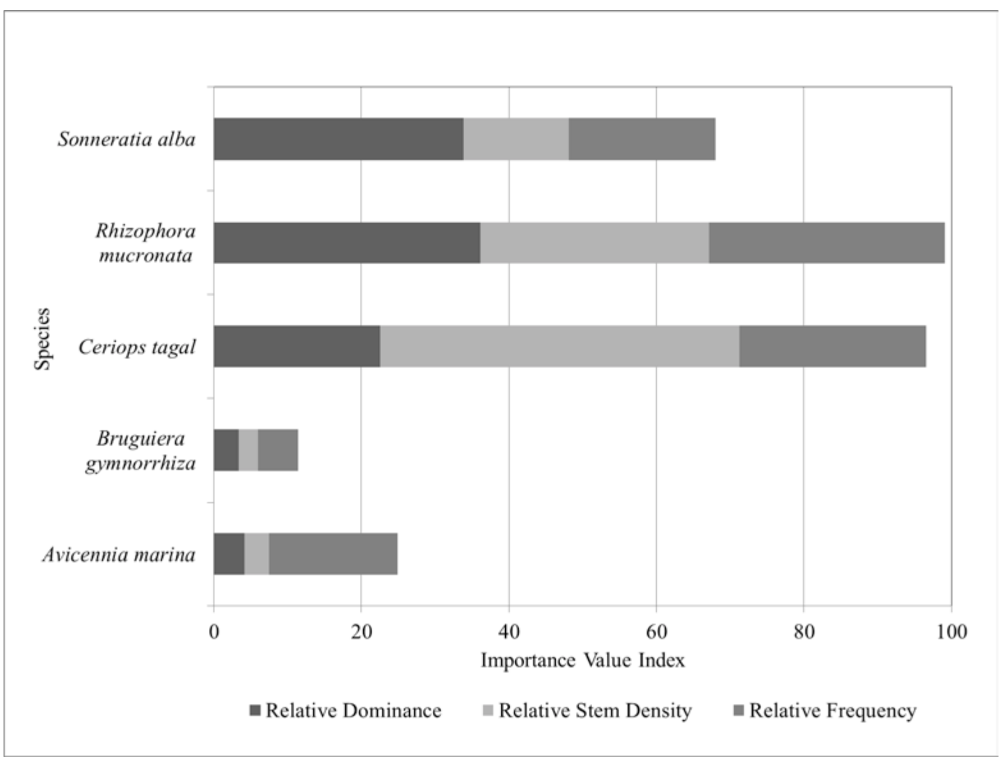

Figure 3. Importance Value Index of mangrove species in QNP.

Table 2. Importance value (IV) of the mangroves within QNP in the 3 sub-sampling areas. All adult trees with (DBH) > 2.5 cm were measured.

		Relative Values (%)			
Region	**Species**	**Dominance**	**Density**	**Frequency**	**IV**
North	*Avicennia marina*	4.15	3.32	17.47	24.94
	Bruguiera gymnorhiza	3.32	2.69	5.42	11.43
	Ceriops tagal	22.57	48.7	25.3	96.57
	Rhizophora mucronata	36.14	31.01	31.93	99.08
	Sonneratia alba	33.82	14.27	19.88	67.98
Centre	*Avicennia marina*	11.34	13.62	19.29	44.26
	Bruguiera gymnorhiza	1.97	1.56	7.29	10.82
	Ceriops tagal	8.69	23.66	20	52.35
	Rhizophora mucronata	43.33	44.29	32.24	119.85
	Sonneratia alba	34.26	16.4	20.47	71.13
	Xylocarpus granatum	0.41	0.47	0.71	1.59
South	*Avicennia marina*	6.11	7.33	12.15	25.59
	Bruguiera gymnorhiza	1.76	3.23	14.98	19.97
	Ceriops tagal	18.44	47.51	28.34	94.29
	Rhizophora mucronata	64.08	39.63	37.25	140.95
	Sonneratia alba	9.62	2.31	7.29	19.21

Total areas: North – 0.21 ha; Center – 0.62 ha and South 0.32 ha. Number of individuals sampled: North - 648, Center – 2040 and South -1315.

quadrates were counted, identified to species, measured for diameter at breast height (DBH) ≥ 2.5cm, and tree height (m) estimated (Kairo *et al.*, 2002; Komiyama *et al.*, 2005; Bandeira *et al.*, 2009; Kauffman & Donato, 2012).

From the data collected information was derived on species composition, species diversity, structural parameters, and community indices including basal area (m^2/ha), mean stand height (meters), stem density (stems/ha), relative frequency (%), relative dominance (%), importance value (I.V.), and complexity index (C.I.) which was calculated as the product of number of species, basal area (m^2/ha), mean stand height (m) and density (number of stems/ha) following the methodology described by Kairo *et al.* (2002) and Dahdouh-Guebas & Koedam (2006).

To assess forest condition all individuals were counted and grouped into five degradation categories. These were: intact, for trees with no sign of cut; partially cut, for those with one or more branches which had been cut, but with the main trunk intact; severely cut, with most branches cut; stump, for those whose main trunk had been cut; and die back, for those dead from natural causes (Kairo *et al.*, 2001; Bandeira *et al.*, 2009). Diameter of stumps was measured to estimate preferred sizes for cutting. The same measurements of dead standing trees were taken as for live trees.

The usage quality of poles in the forest was assessed based on the form of the lead stem, which was categorized either as form 1, 2 or 3. Form 1 stems denotes those whose lead stem are straight and therefore excellent for construction, while Form 2 stems represent poles that need slight modification to be used for construction. Form 3 stems are crooked poles which are unsuitable for construction (Kairo *et al.*, 2001; Kairo *et al.*, 2008).

Regeneration status was assessed by species identification and counting individuals (DBH less than 2.5 cm). The frequency (%) of each species was recorded and juveniles were grouped in 3 regeneration classes (RC) based on height, as RC I, II or III. Seedlings less than 40 cm in height were classified as RCI; saplings

Table 3. Structural attributes of the mangroves in Quirimbas National Park per subsampling area.

Region	Specie	Diameter (cm)	Height (m)	BA (m2/ha)	Density (stem/ha)	No of Species	CI*
North	*Avicennia marina*	12.64 ± 5.31	6.03 ± 2.08	2.73	102 ± 44	5	1.5
	Bruguiera gymnorhiza	7.79 ± 3.10	6.50 ± 1.88	5.09	83 ± 56		
	Ceriops tagal	6.01 ± 0.22	3.17 ± 0.66	7.99	1.507 ± 599		
	Rhizophora mucronata	8.29 ± 1.40	6.52 ± 1.54	10.39	956 ± 291		
	Sonneratia alba	12.38 ± 3.01	6.23 ± 0.98	17.29	442 ± 295		
Centre	*Avicennia marina*	8.61 ± 0.90	6.61 ± 0.93	5.18	452 ± 202	6	1.6
	Bruguiera gymnorhiza	8.27 ± 1.48	6.51 ± 0.93	2.43	52 ± 21		
	Ceriops tagal	5.28 ± 0.67	4.80 ± 0.98	3.97	784 ± 264		
	Rhizophora mucronata	7.70 ± 0.73	7.16 ± 0.63	12.14	1.468 ± 275		
	Sonneratia alba	12.03 ± 1.00	8.22 ± 0.89	14.57	544 ± 206		
	Xylocarpus granatum	7.82 ± 0.00	7.95 ± 0.00	5.11	16 ± 16		
South	*Avicennia marina*	11.53 ± 2.81	6.21 ± 1.94	6.19	294 ± 252	5	2.2
	Bruguiera gymnorhiza	7.21 ± 1.45	4.79 ± 0.59	1.19	130 ± 47		
	Ceriops tagal	5.11 ± 0.36	3.41 ± 0.23	6.79	1.908 ± 494		
	Rhizophora mucronata	8.09 ± 1.08	6.02 ± 0.64	18.53	1.592 ± 336		
	Sonneratia alba	16.09 ± 1.91	7.96 ± 1.29	15.57	93 ± 50		

*Complexity Index
**Values are mean ± standard error, SE.

between 40 and 150 cm height were classified as RCII, while RCIII was for all small trees with height greater than 1.5 m but less than 3.0 m as described by Kairo *et al.* (2002), Kairo *et al.* (2008) and Bandeira *et al.* (2009).

All data (DBH, height, tree quality, forest condition and regeneration) were subjected to tests of normality and homogeneity variances. One-way ANOVA at 0.05 probability tests were performed to test differences in stocking densities, DBH, and height (m) between sites (north, centre and south). Non-parametric data were subjected to the Kruskal-Wallis test following the procedures described by Kairo *et al.* (2001) and Dahdouh-Guebas & Koedam (2006).

Results

Mangrove Mapping

Mangroves occur extensively within the maritime perimeter of the QNP with the exception of some islands peninsulas. Based on results of this research, the total estimated area of mangroves in the QNP was 12 348 ha, a net increase of about 1 104 ha (or 9.8% of the initial area) from 1991 to 2013 (Fig. 2), with an annual increase of 50 ha/year. While there was an overall net increase in mangrove cover from 1991 to 2013, there was a net loss of 464 ha in specific areas from 2002 to 2013 (Table 1). The area weighted accuracy assessment for the Landsat change analysis showed an overall accuracy of 85% (originated from Confusion Matrix) for current mangrove cover.

Mangrove Forest Structure

A total of 4 003 adult individuals were sampled in 3 sub-sampling areas (north, centre, and south) within the mangrove forests of QNP. A total of 6 mangrove species were found, namely *A. marina, B. gymnorhiza, C. tagal, R. mucronata, S. alba*, and *X. granatum*. Relative dominance, density, frequency and importance values of these species are shown in Fig. 3 and Table 2.

Based on species importance values, *R. mucronata*, *C. tagal* and *S. alba* were the most abundant species within QNP (Table 2). *X. granatum* was very rare with only a few individuals sampled (this species was not included on the statistical analysis). *A. marina, B. gymnorhiza* and *C. tagal* were often found in landward

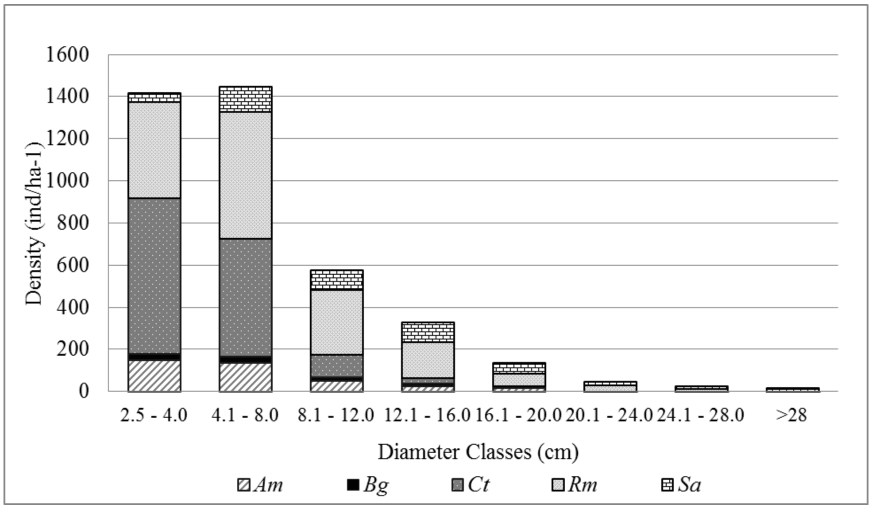

Figure 4. Species diameter distribution classes in QNP.

areas and mixed with *R. mucronata* which was widespread and also found on regularly flooded areas and small creeks. *A. marina* was also distributed on seaward areas in association with *S. alba*.

Stand density, DBH, tree height values per species, and sampling areas are presented in Table 3. DBH varied between 5.1 and 16 cm, and height from 3.1 to 7.9 m. Despite the high DBH, dwarf stands were commonly found in the forest within highly saline areas. When comparing species, mean minimum and maximum diameter ranged between 5.11 cm (for *C. tagal*) and 16.09 cm (*S. alba*), while mean height varied between 3.41 m (*C. tagal*) and 8.22 m (*S. alba*). The tallest trees observed were *S. alba* (8.22 m), followed by *X. granatum* (7.96 m) and *R. mucronata* (7.16 m).

The mean stem density of individuals in the forests of the QNP was 579 stems/ha. The species abundance shows some variation amongst species accounting for

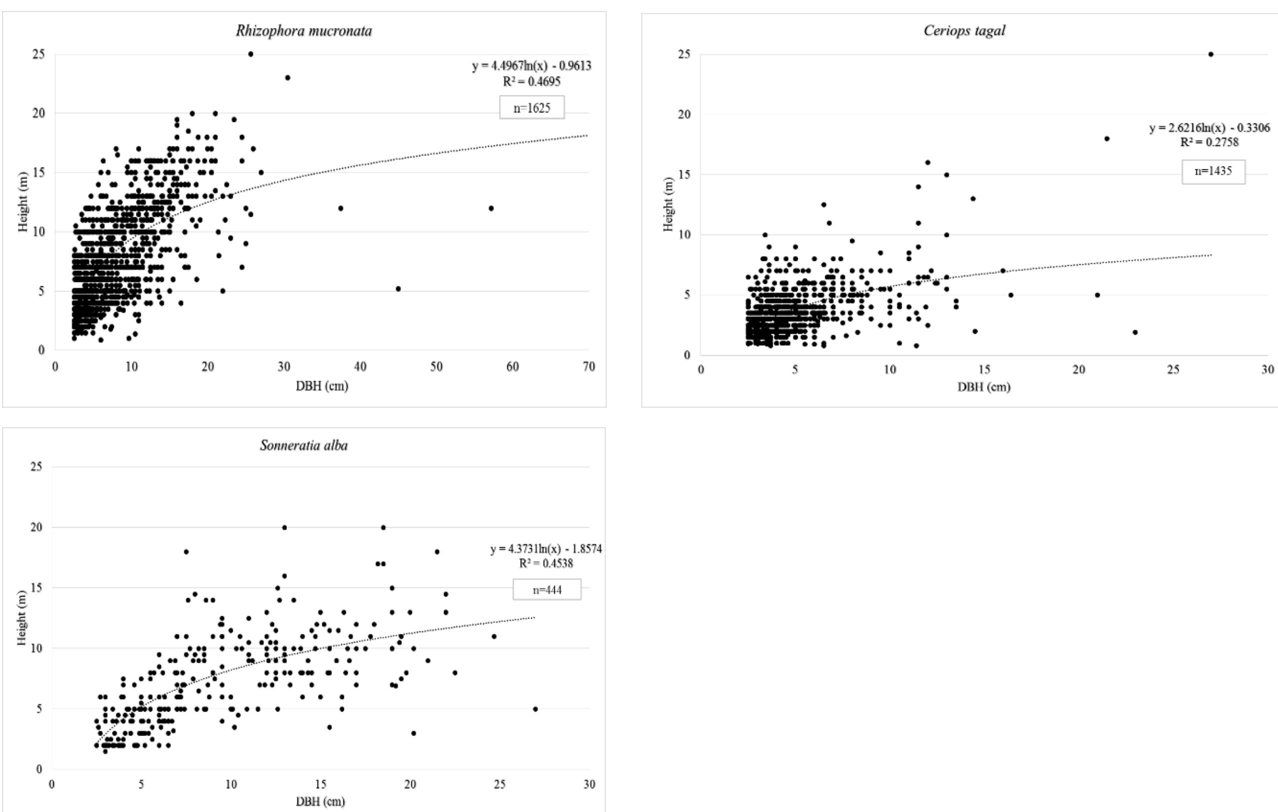

Figure 5. Height-diameter distribution of *Rhizophora mucronata*, *Ceriops tagal* and *Sonneratia alba* within QNP.

1 406, 1 251, 393, 338, 80 and 8 stems/ha for *R. mucronata*, *C. tagal, S. alba*, *A. marina, B. gymnorhiza*, and *X. granatum*, respectively.

There was significant differences in the stem density between species and subsampling areas ($p < 0.05$). The variation in complexity index between areas in the QNP is evident, with the south region recording a higher index (Table 3).

Fig. 4 shows species diameter class distribution in the QNP. Overall, the forest had high densities of trees in the lower diameter size classes (below 8 cm). *C. tagal* was characterised by high densities of trees in the low size class (2.5 – 4.0 cm); *R. mucronata* had a wide distribution of stems in the low-mid and high classes (4.1 – 24.0 cm), and *S. alba* dominated the high size class (24.0 – >28.0 cm). The observed stem size distribution displays some selective harvesting of stems, within classes (8.0 - 16.0 cm). Preferred species for cutting were *C. tagal*, *R. mucronata*, and *A. marina* (Fig. 4).

Fig. 5 shows scattergrams of height – diameter distribution of high importance value (IV) species in the QNP.

Mangrove Cut Condition and Pole Quality

The mangrove forest cut condition and quality of existing poles is represented in Fig. 6 and 7 respectively. Different densities were found amongst categories (Table 4): partially cut (PC) with 231 stems/ha; severely cut (SC) with 395 stems/ha; stump (S) with 188 stems/ha; and die back (DB) with 171 stems/ha. The intact stands (I) had the highest mean density in the entire research area with 941 stems/ha. There are statistical differences between the densities of all categories of cut conditions (<0.05).

Partially and severely cut trees had high densities in the north and south of with 225 stems/ha, and 395 stems/ha, respectively. These categories showed a distribution pattern in sampling areas, and the entire forest, as displayed in Fig. 6 below. A higher density of stumps was found in the north with *C. tagal* (636 stem/ha), while the highest die back was found in the south region for *C. tagal* (461 stem/ha). In the north and centre regions of QNP, *R. mucronata* and *C. tagal* appeared to be the preferred species for cutting, whereas in the south it was *A. marina.*

Semi-straight and crooked poles dominated over straight poles throughout the park. The highest density of semi-straight poles (880 stems/ha) was found in the centre region (Fig. 7), while the southern region accounted for the highest density of straight and crooked poles (504 stems/ha and 639 stems/ha, respectively). These differences are however not statistically significant ($p > 0.05$). At species level, half of the total poles of *A. marina* and *S. alba* were crooked (Table 5), and the majority of intact and semi-intact poles were recorded from *C. tagal*. Half of *Rhizophora* sampled were semi-intact.

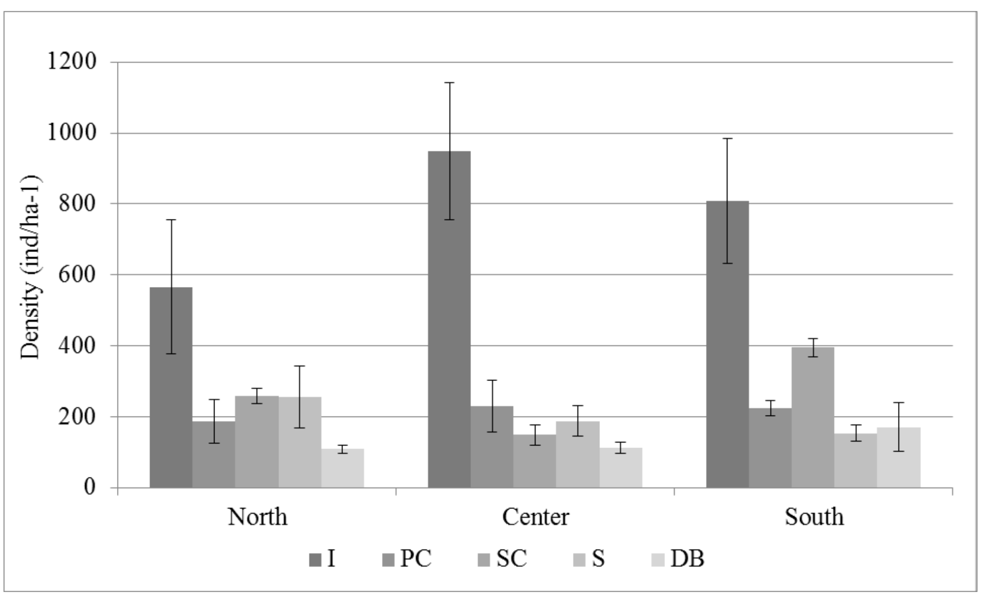

Figure 6. Mangrove forest density of trees of different cut levels in the 3 sampling areas (north, centre and south) within QNP. Classes are described as follows: (I) Intact; (PC) partially cut; (SC) severely cut; (S) stump and (DB) die back.

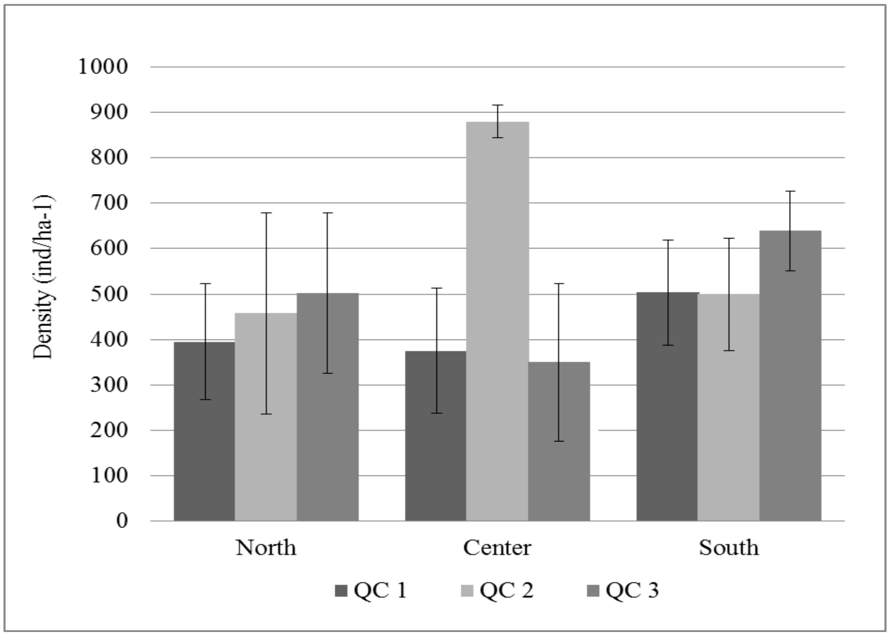

Figure 7. Quality pole distribution in the 3 sampling areas (regions). QC1 – represents straight poles suitable for building, and QC 2 - represents poles that need some modification prior to use in construction, while QC 3 - represents crooked poles unsuitable for construction (Kairo *et al.* 2001).

Regeneration

Natural regeneration was observed at all sites within the QNP. On average, total juvenile densities ranged from 36 733 – 126 133 juveniles/ha, with *R. mucronata* representing the highest density with 180 400 juveniles/ha as indicated in Table 6. Statistical differences between regeneration classes were not significant ($p > 0.05$).

The highest juvenile density was observed in the centre sampling area (286 200 juveniles/ha) and southern parts (202 500 juveniles/ha), while the north had the lowest regeneration densities of 93 033 juveniles/ha. When comparing regions, there were significant differences between species within regions ($p < 0.05$). Comparing species, the highest density was observed in *R. mucronata* (180 400 juveniles/ ha) and *C. tagal* (134 600 juveniles/ha) followed by *A. marina* (34 767 juveniles/ha), *B. gymnorhiza* (4 933 juveniles/ha) and *S. alba* (1 000 juveniles/ha).

The regeneration ratios (RCI: RCII: RCIII) for the entire forest was 2:1:1, 1:2:1 for the north, 1:1:1 for the center, and 2:1:1 for the south region. The regeneration did not reach the effective rate of stocking of 6:3:1 for juveniles, as described by Kairo *et al.* (2002). However, based on seedling densities, QNP mangroves can be considered to potentially have good regeneration capacity. The centre and south regions present the same pattern of species distribution and densities.

Discussion

The temporal analyses of mangrove cover within the QNP show an overall 10% increase in mangrove cover over the time period of 22 years (1991 to 2013),

Table 4. Forest condition class distribution in QNP showing the densities per ha and percentage (in brackets) composition per species. Categories are described as follows: (I) Intact; (PC) partially cut; (SC) severely cut; (S) stump and (DB) die back.

Condition	I	PC	SC	S	DB
A. marina	420 (26.2)	318 (19.8)	671 (41.8)	119 (7.4)	77 (4.8)
B. gymnorhiza	294 (31.1)	150 (15.9)	250 (26.5)	183 (19.4)	67 (7.1)
C. tagal	1887 (61.4)	330 (10.7)	180 (5.9)	442 (14.4)	234 (7.6)
R. mucronata	1268 (59.0)	255 (11.9)	151 (7.0)	318 (14.8)	158 (7.3)
S. alba	444 (30.7)	236 (16.3)	386 (26.7)	132 (9.1)	250 (17.3)
X. granatum	333 (100.0)	-	-	-	-

Table 5. Quality class distribution in QNP showing the densities per ha and percentage (in brackets) composition per species.

Quality Class	1	2	3
A. marina	256 (21.8)	313 (26.6)	606 (51.6)
B. gymnorhiza	216 (28.4)	262 (34.4)	283 (37.2)
C. tagal	1094 (38.7)	1073 (38.0)	658 (23.3)
R. mucronata	469 (23.4)	1027 (51.3)	506 (25.3)
S. alba	215 (19.4)	347 (31.2)	548 (49.4)
X. granatum	-	1000 (100.0)	-

despite the slight decrease observed between 2002 and 2013. Areas showing an increase and decrease of mangrove cover were visible in the field. For example, newly colonized areas had a high density of juveniles from all tree regeneration classes, whilst decrease and degradation was depicted by high levels of mortality (eg several dead trees often found along the shoreline and inner areas of the mangrove forest). Increases in mangrove cover in Mozambique and elsewhere have been related to factors such as sediment accretion, increased salinity, upstream inundation of salt water due to changes in rain patterns, and the natural dynamic of the system (Giri *et al*., 2007; Eslami-Andargoli *et al*., 2009; Macamo *et al*., 2015; Shapiro *et al*., 2015). Cabo Delgado Province is among those that has shown less variation in mangrove area

Table 6. Juvenile density (juveniles/ha) in QNP

Region	Species	Ind/ha			Total Ind/ha
		RC I	RC II	RC III	
		0 - 40 cm	40.1 - 150 cm	150.1 - 300 cm	
North	*Avicennia marina*	1 333	1 700	1 067	4 100
	Bruguiera gymnorhiza	0	0	700	700
	Ceriops tagal	32 800	4 267	6 667	43 733
	Rhizophora mucronata	3 867	11 800	28 200	43 867
	Sonneratia alba	233	300	100	633
	Total	**38 233**	**18 067**	**36 733**	**93 033**
Centre	*Avicennia marina*	32 667	400	1 700	34 767
	Bruguiera gymnorhiza	400	633	3 900	4 933
	Ceriops tagal	42 600	9 500	13 000	65 100
	Rhizophora mucronata	50 267	72 233	57 900	180 400
	Sonneratia alba	200	300	500	1 000
	Total	**126 133**	**83 067**	**77 000**	**286 200**
South	*Avicennia marina*	4 667	400	400	5 467
	Bruguiera gymnorhiza	200	200	300	700
	Ceriops tagal	66 033	26 267	42 300	134 600
	Rhizophora mucronata	28 367	18 700	14 433	61 500
	Sonneratia alba	233	0	0	233
	Total	**99 500**	**45 567**	**57 433**	**202 500**

in Mozambique (Fatoyinbo *et al*., 2008; Ferreira *et al*., 2009), possible due to the remoteness and low population density in the province in general (Ferreira *et al*., 2009). Being in a protected area, the mangroves of the QNP are expected to be under some degree of protection from human transformation, which would allow expansion from natural processes. However, in the regions of Sundabarns (India and Bangladesh), protection and appropriate management measures resulted in little to no-change in forest area (Giri *et al*., 2007). Globally, unlike the trend in the QNP, mangrove loss is more expected than expansion (Valiela *et al.*, 2001; Mohamed *et al.*, 2008; Giri *et al.*, 2011; Kirui *et al.*, 2013; Bosire *et al*., 2016).

In general, the forest complexity index was low, indicative of a young forest, and possible natural or anthropogenic impacts. Low complexity index and dominance of small trees in the forest was also observed in severely impacted peri-urban forests in Kenya (Kairo *et al*., 2002; Mohamed *et al*., 2008) and other regions of Cabo Delgado Province (Bandeira *et al*., 2009). Natural regeneration was observed extensively in QNP, contrasting with low recruitment in human impacted mangrove areas such as those in Kenya (Kairo *et al.*, 2002; Mohamed *et al.*, 2009). In the QNP seedlings were frequently found growing in clusters close to the mother tree, similar to the situation documented in Kenya by Bosire *et al.* (2005), this possibly providing an advantage against predation, diseases, erosion and sedimentation (Olagoke *et al*., 2013). Furthermore, seedlings were abundant in forest canopy gaps similar to what has been found by Duke (2001) and Bosire *et al.* (2005) in other regions. Such canopy gaps are common in mangroves and are the result of natural parameters such as increased light and temperature, high water evaporation rates, and high pore-water salinity impacting on the dispersal, survival and growth of seedlings.

Conclusions

The geo-spatial data generated from this study revealed an overall increase of 10% of the area covered by mangroves (11 244 to 12 348 ha) in the QNP for the period from 1991 to 2013). Signs of anthropogenic pressure on forest structure, condition, and pole quality were noted. The high density of juveniles (36 733 – 126 133 juveniles/ha) corroborates with mangrove forest area increase at QNP.

Structural data (low complexity index, small tree dominance, die back) indicate that the forest is under pressure. Nonetheless, there appears to be feasible potential for natural regeneration. Despite the QNP being a protected area, anthropogenic use of mangroves was noted in several areas. There was also some mangrove die back evident along the shoreline. This study provides a baseline that can be used to reinforce the current QNP Management Plan (2014 -2019), and to identify additional research needs such as high resolution mapping to detail both anthropogenic and natural impacts and other related parameters affecting mangrove structure and condition. Community Based Natural Resources Management (CBNRM) focusing on mangrove forests and the surrounding ecosystems, may be the catalyst needed to encourage socio-ecological mangrove research within the QNP.

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