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Natural recovery of mangroves in abandoned rice farming areas of the Rufiji Delta, Tanzania

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Abstract

Natural recovery of mangroves in abandoned rice farming areas is important for reviving its multiple ecosystem services including climate change mitigation. This study aims at understanding the natural recovery rate and pattern of mangroves in the abandoned rice farming areas of the Rufiji Delta. Mangrove areas were stratified into early and intermediate succession as well as old growth forest. Forty-five nested plots, fifteen at each site, were randomly selected, where plant and soil data were collected. Based on the Importance Value Index, the most abundant tree species in the early succession was *Barringtonia racemosa*, a mangrove associated tree species having a value of 67.9. The mangrove *Avicennia marina* was the most abundant in both intermediate succession and old growth forest having a value of 170.7 and 163.1, respectively. Pairwise comparison of means indicated a significant change ($p < 0.05$) of structural parameters with fallow age. No significant change ($p > 0.05$) was detected in the measured soil properties among the three succession categories. The findings demonstrate that even a period of up to 15 years would not allow full recovery of structural attributes for a mangrove forest converted to agricultural land, with grass cover being among factors limiting the recovery due to obstruction of propagule dispersal.

Keywords: Succession; structural attributes; soil properties; fallow; abundance

Introduction

The mangrove ecosystem in the Rufiji Delta, Tanzania, has over the years been severely affected by a complex set of factors, including climate change and anthropogenic pressures, triggering their loss (Wagner and Sallem-Mtui, 2016). The anthropogenic threats include over harvesting of mangrove trees (for fuel wood, building materials), conversion of mangrove areas for other uses, such as salt works, human settlements and agriculture, and in particular rice farming (Semesi, 1992; Mangora *et al.*, 2016). Rice farming is reported to be a major cause of mangrove cover loss in the delta. Nindi *et al.* (2014) estimated that 4,140 ha of mangroves was cleared for rice farming between 1989 and 2010. Most recently (Monga *et al.*, 2018) reported the loss of mangroves due to rice farming at about 7,298 ha between 1991 and 2015, implying an annual loss of about 304 ha per year.

Similar trends in mangrove losses due to conversion into other uses are reported from other places. In particular, South-East Asia has been in the spot light where conversion for aquaculture has led to unprecedented losses of mangroves, with about 22,000 ha lost between 2000 and 2012 (Richards and Friessa, 2016). Likewise, in Guinea (West Africa) about 64,000 ha has been converted to rice farming (Adesina and Baidu-Forson, 1995). Mangrove deforestation also has implications for the provision of ecosystem services (Richards and Friessa, 2016), as it results in a loss of carbon (Lagomasino, 2019) and other biodiversity supported by the mangroves.

Despite these reported losses, gains from natural recruitments have also been reported to compensate the losses, reducing the net loss. (Lagomasino *et al.*, 2019; Monga *et al.*, 2018). Monga *et al.* (2018) reported an average mangrove cover gain of 109 ha

from 1991 to 2015 in the Rufiji delta. Mangrove forest gain occurs through natural regeneration (Lagomasino, 2019) and planting (Monga *et al.*, 2018).

Rice farming has been practiced in the Rufiji Delta in areas close to fresh water sources by converting the mangrove forest to farmland (Lagomasino, 2019). Due to poor agronomic knowledge, the farming approach in the delta is of a shifting nature where farms are cultivated in a rotation of 3-5 years before farmers move on to open new farm fields by clearing mangrove forests (Monga *et al.*, 2018), and leaving the rice farm fallow. A field is referred to as fallow when it is left uncultivated (Wezel and Haigis, 2002). Natural recovery in the fallow fields has been observed taking place along

understanding the pattern of natural recovery in abandoned agricultural areas is important to inform management decision and plans, particularly with regards to restoration initiatives. The vegetation components in the abandoned rice fields vary on spatial and temporal scales depending on the number of years the land has been left without agricultural activities (Iwara *et al.*, 2014). Moreover, species composition of secondary forest often fails to converge with that of nearby mature forest (Letcher and Chazdon, 2009). Undertaking this kind of a study is important as it will assist in making decisions on whether to attempt restoration or not, as restoration is recommended when an ecosystem can no longer self-correct, or self-renew (Lewis III, 2005).

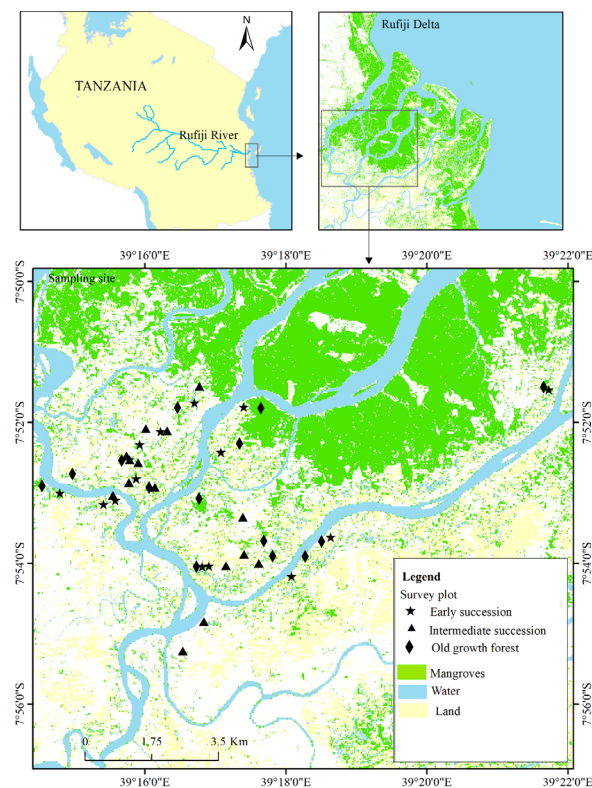


Figure 1. Map showing location and survey plot layout in the study area of the Northern Rufiji Delta.

different trajectories. While in some areas natural regeneration may take place immediately after abandonment (1 year), others remain infested with weeds.

This study aimed to assess the pattern of natural recovery on the abandoned rice farms and how successive transitions back to mangrove stands takes place through analysis of the sediment characteristics, forest species composition and structural attributes. Since succession recovery implies a return to the original type of mangrove forest (Lugo, 1980),

Materials and methods

Study area

The Rufiji Delta is located between latitudes 7°50' and 8°03' S and longitudes 39°15' and 32°17'E 7.47° E (Fig. 1). The delta is the culmination of the Rufiji River basin that drains about 20% of Tanzania, extending over an area of approximately 177,000 km² (Mwalyosi, 2018). This critical habitat supports diverse estuarine, coastal and marine ecosystems that are ecologically interconnected. One of the key components of the Delta is the largest mangrove area in Tanzania covering about

45,519 ha (Monga *et al.*, 2018). Geologically, the Delta is underlain by Cretaceous and Jurassic limestones and shales, which are overlain by alluvial sand, silt, and clay deposited from the Tertiary period to the present (Mwansasu, 2016). Based on data from the nearby Kilindoni station (Mafia Island District), the Rufiji Delta is characterised by two rainy seasons with rainfall ranging from 750 mm to 1250 mm per annum. The short rains usually start in October and end in December, and the long rains are from February to May. Average temperature in the Delta ranges from 13°C to 41°C.

There are eight mangrove tree species occurring in the Delta, namely *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum* (Lupembe, 2014; Wagner and Salama-Mtui, 2016). The current population data from the ward offices of Sarale and Mwambao, shows that the population in the villages adjacent to the rice farming areas of the Delta is around 25,788. The distribution of people in the villages is as follows: Mtunda A (4900), Kikale (1822), Ruaruke B (4109), Mchungu (1396), Mdunda B (2581), Mfisini (2281), Nyamisati (2601), Kiomboni (3472) and Nchinga (2625). The major livelihood activities of these communities are rice farming (mainly farming in the Rufiji Delta), fishing and mangrove cutting. Other crops grown include cassava, pulses and legumes, coconuts, cashew nuts and mangoes, which are used for home consumption and as a source of income. Rice farming in the Rufiji Delta started in the 1970s with the preferred cultivation areas being along the main rivers and fringes of mangrove areas, where seasonal floods bring fresh water to the fields (Mwansasu, 2016).

Study design

A chronosequence method was used to study plant succession as described by Lagerström (2009). Accordingly, the targeted study area was categorized into three age classes: (i) Early succession, where rice farming activities have recently ceased (for less than five years) and natural plant recovery has started; (ii) Intermediate succession, areas abandoned for about 10 - 15 years; and (iii) Old growth forest, areas with mangrove trees of over 20 years and that have not been cleared for rice farming. The later was considered as reference forest as described by Lewis III, (2005). This succession age categorization was facilitated by local knowledge. A total of 45 nested plots (11.6, 2 and 0.5 m radii) were randomly established, with 15 plots for each succession category.

Field data collection

Vegetative measurements and data processing

In the main plots (radius of 11.6 m), all trees with ≥ 5 cm stem diameter were measured for diameter at breast height (DBH) (DBH, defined as 1.3 m above the ground) and height using a diameter tape and a Suunto hypsometer respectively. For *R. mucronata* trees, stem diameter measurements were taken at 30 cm above the highest prop root. Subplots of 2 m radius were established at the centre of the main plot, and within the subplot, DBH and heights of small trees (0.5 - 4.9 cm stem diameter) were measured. Only saplings/juvenile (trees less than 0.5 cm stem diameter) were counted. Non-tree species such as grasses and climbers were counted within a plot of 0.5 m. Species richness was determined as the total number of species represented in the plot. Importance Value Index (IVI) was used as a measure of the abundance and ecological success of the plant species. In a given plant community, the higher the IVI, the more abundant and successful, and importance of the role of a vegetation species (Shrestha *et al.*, 2000; Reddy *et al.*, 2008; Winata *et al.*, 2017). The IVI for each individual plant species was determined using the following formula (Mueller - Dombois and Ellenberg, 1974; Munishi *et al.*, 2007; Nzunda, 2008):

$$IVI = RD + RF + RDo \dots\dots\dots(1)$$

Where:

RD = 100 (Number of individuals of the species/Number of individuals of all species)

RDo = 100 x Total basal area of the species/Total basal area of all species

RF = 100 x Number of occurrences of the species/Number of occurrences of all species

Vegetation density (woody and non-tree species)

Number of plants per hectare for trees and non-tree species were computed as:

$$N = \frac{ni}{a} \dots\dots\dots(2)$$

Where: N = Number of plants per hectare; n_i = number of plants counted; and a = plot area in ha

Basal area

Basal area (m²/ha) was calculated from measured DBH for all woody stems in each plot expressed as:

$$gi = \frac{\sum dbh^2}{4} \dots\dots\dots(3)$$

$$G = \frac{\sum g_i}{A} \dots\dots\dots(4)$$

Where: G = Basal area per plot (m²ha⁻¹); DBH = Diameter at Breast Height (m);

Π = Π_i; A = Plot area (ha); g_i = Basal area of a tree/shrub (m²)

Soil sampling and laboratory treatments

Soil samples were collected at the centre of the plot by retrieving a soil core to a depth of 100 cm using a stainless steel gouge auger (AMS Inc., American Falls, Idaho, USA). These soil samples were collected at different depth ranges (0 - 30, 30 - 60 - 100 cm), and three soil samples of 5 cm length were extracted at each depth range of 15 - 20, 40 - 45 and 70 - 75 cm, hereafter referred to as L₁, L₂, and L₃ respectively. Each sample was divided into two sub-samples, with some oven dried at different temperatures to determine sediment characteristics. Organic matter content was determined by the loss ignition method, with samples placed in a muffle furnace (AAF 11/7, Wolf Laboratories Limited, UK) at 540°C for 5 hours.

The soil sub-samples for the determination of nitrogen, phosphorus and potassium were oven dried at 105 ± 0.5°C until constant weight was attained (typically 72 hours) using a Universal Oven (UN30 Memmert GmbH + Co. KG, Germany). The dry samples were sieved through a 2 mm sieve to obtain a fine earth fraction. Total Nitrogen (TN) was determined using the Kjeldahl method. The sample was first subjected to a sulfuric acid digestion to convert ON compounds to NH₄⁺. Secondly, the converted NH₄⁺, along with any NH₄⁺ that was originally present, was further converted to NH₃ using an alkali distillation process. The NH₃ liberated was quantified to determine the TN in the original digest. A separately determined value for NH₃ and NH₄⁺ was then subtracted from the value obtained by the Kjeldahl method, and the difference was considered to be the mineralizable, or potentially plant-available nutrients (Klute, 1986).

Extractable phosphorus was determined by the Bray-1 method by shaking 1g of dried soil in 10 ml of 0.025 M HCl and 0.03 M NH₄F for 5 minutes. Phosphorus was determined on the filtrate by the molybdate-blue method using ascorbic acid as a reductant. Colour development was measured using a UV VIS

Table 1. Plant species richness and dominance in the studied sites in the Rufiji Delta.

Plant type	Names Family	Species	Succession stage		Old growth Forest IVI
			Early IVI	Intermediate IVI	
Trees	Acanthaceae	<i>Avicennia marina</i>	58.9	170.7	163.1
	Rauraceae	<i>Heritiera littoralis</i>	25.5	14.2	131.8
	Rhizophoraceae	<i>Brugueira gymnorrhiza</i>	14.7	19.3	53.4
	Rhizophoraceae	<i>Ceriops tagal</i>	-	13.0	21.6
	Rhizophoraceae	<i>Rhizophora mucronata</i>	-	-	5.7
	Lecythidaceae	<i>Barringtonia racemosa</i>	67.9	83.7	17.7
Non-tree plants	Palmae	<i>Phoenix reclinata</i>	12.5	37.7	28.1
	Poaceae	<i>Pothriochlo aglabra</i>	91.2	64.7	0
	Apocynaceae	<i>Derris trifoliata</i>	51.5	63.9	34.8
	Pteridaceae	<i>Acrostichum areum</i>	12.9	32.6	112.0
	Cyperaceae	<i>Fuirena zambesica</i>	78.4	87.8	0
	Poaceae	<i>Penisetum spp</i>	189.4	124.1	0
	Fabaceae	<i>Sesbaniam acrantha</i>	12.8	13.1	0
	Cyperaceae	<i>Cyperus latifolius</i>	26.4	65.3	0

spectrophotometer (Bray and Kurtz, 1945). The concentration of potassium was analyzed using an AAS flame spectrophotometer (Van Reeuwijk, 2002). Soil samples were extracted with a 1 M NH_4OAc solution at pH7.00. The soil solution slurry was shaken for 2 h, and the solution was separated from the solid by centrifugation.

Data analysis

Statistical analysis of the data was carried out by using IBM SPSS Statistics 20. One - way analysis of variance (ANOVA) was used to test the variation of means of structural parameters and soil characteristic values from the early and intermediate succession stages as well as the old growth forest sites. Pair wise tests of

the mean values of data sets collected from the three different sites were carried out using Least Significant Differences ($P < 0.05$).

Results

Floristic composition

A total of six tree species of three different families were recorded (Table 1). The highest plant species richness was found in the old growth forest, followed by the intermediate succession and then the early succession sites. Among the tree species recorded, one was a non – mangrove tree species (*Barringtonia racemosa*). The mangrove species, *Rhizophora mucronata*, was only found in the old growth forest, and *Ceriops tagal* in the intermediate succession. *Barringtonia*

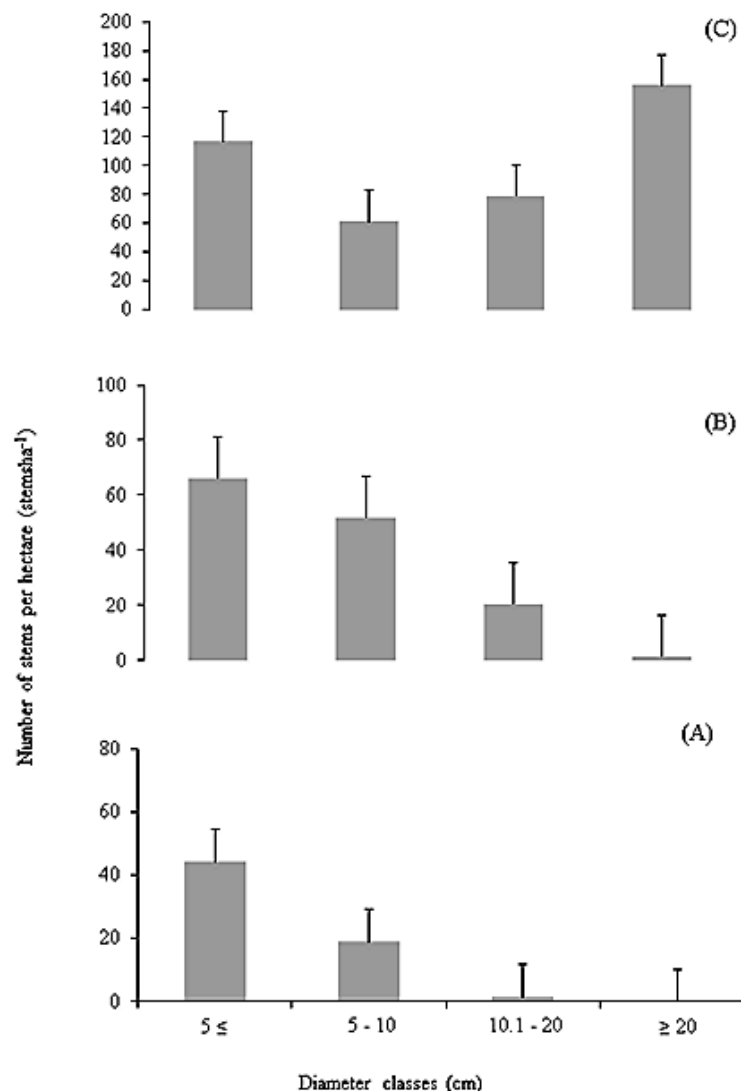


Figure 2. Number of stems per hectare across diameter classes of the different succession categories studied in the Rufiji Delta. (A) = Early succession; (B) = Intermediate succession; and (C) = old growth forest.

racemosa, *Avicennia marina*, *Heritiera littoralis* and *Bruguiera mnorrhiza* were found in the early, intermediate and old growth forest. *Avicennia marina* was the most abundant mangrove tree species in the intermediate and old growth forest. However, in the early succession, *B. racemosa* was the most abundant (Table 1).

For non - tree plant species, the intermediate succession had the highest species richness, followed by the early succession, while the old growth forest had the least. *Phoenix reclinata*, *Derris trifoliata* and *Acrostichum areum* were the most common species found in both early and intermediate succession sites (Table 1). Among the non - tree plants, *Penisetum spp* was the most abundant species in the early and intermediate succession while *Acrostichum areum* was the most abundant in the old growth forest.

Diameter size class distribution, stem density and basal area of trees

In general, as the mangrove aged, tree sizes increased, while stem density per diameter size class decreased successively, depicting a reverse 'J' shape (Fig. 2). A larger diameter size of ≥ 20 cm was mostly recorded in the old growth forest, with a decrease in the intermediate succession, and was completely absent in the early succession site (Table 2). However, tree height increased significantly ($p = 0.001$) with mangrove age. The trend was similar to that of stocking parameters (stem density and basal area) which also increased with mangrove age.

Soil characteristics

The highest values of Soil Organic Carbon (SOC) in the old forest and intermediate succession sites were recorded in the topmost soils (0 - 30 cm depth),

Table 2. Structural attributes of trees and soil nutrients in the in the studied sites in Rufiji Delta; values are means and standard deviation for three sites: old growth; intermediate; and early succession. Means with different letters are significantly different at $p < 0.05$.

Variables	Unit	Old growth Forest (mean \pm SD)	Sites		Test of variation	
			Intermediate (mean \pm SD)	Early (mean \pm SD)	F	P
Stem density	(stems ha ⁻¹)	417 \pm 162 ^a	334 \pm 147 ^b	98 \pm 97 ^c	18.50	P = 0.001
Basal area	(m ² ha ⁻¹)	17.67 \pm 6.11 ^a	0.98 \pm 1.43 ^b	0.12 \pm 0.24 ^c	115.20	P = 0.001
Height	(m)	16.41 \pm 5.00 ^a	4.78 \pm 2.47 ^b	2.74 \pm 1.44 ^c	120.13	P = 0.001
Overall TN	(%)	0.15 \pm 0.06	0.15 \pm 0.06	0.13 \pm 0.06	1.99	P = 0.597
Total Nitrogen L ₁	(%)	0.17 \pm 0.07	0.19 \pm 0.06	0.15 \pm 0.07	1.949	P = 0.155
Total Nitrogen L ₂	(%)	0.14 \pm 0.07	0.14 \pm 0.05	0.12 \pm 0.05	0.296	P = 0.745
Total Nitrogen L ₃	(%)	0.13 \pm 0.05	0.13 \pm 0.05	0.13 \pm 0.05	0.114	P = 0.892
Overall P	(mgKg ⁻¹)	10.07 \pm 6.92	9.04 \pm 6.53	10.04 \pm 10.40	0.79	P = 0.574
Phosphorous L ₁	(mgKg ⁻¹)	10.62 \pm 7.30	9.08 \pm 6.10	10.00 \pm 10.81	0.131	P = 0.877
Phosphorous L ₂	(mgKg ⁻¹)	8.86 \pm 6.33	7.74 \pm 4.48	7.54 \pm 4.48	0.283	P = 0.755
Phosphorous L ₃	(mgKg ⁻¹)	10.74 \pm 7.39	10.31 \pm 8.55	11.81 \pm 13.22	0.10	P = 0.905
Overall K	(%)	2.78 \pm 1.15	2.06 \pm 0.97	2.24 \pm 0.93	5.902	P = 0.249
Potassium L ₁	(%)	2.70 \pm 1.18	1.78 \pm 0.90	1.90 \pm 0.71	4.23	P = 0.210
Potassium L ₂	(%)	2.72 \pm 1.09	2.10 \pm 0.84	2.29 \pm 0.84	1.794	P = 0.179
Potassium L ₃	(%)	2.91 \pm 1.25	2.32 \pm 1.13	2.53 \pm 1.07	1.002	P = 0.376
Overall SOC	(%)	5.97 \pm 1.48	5.77 \pm 1.25	5.70 \pm 1.70	1.24	P = 0.480
Organic C L ₁	(%)	6.06 \pm 1.24	6.14 \pm 1.24	5.51 \pm 1.08	1.24	P = 0.301
Organic C L ₂	(%)	5.99 \pm 1.45	5.62 \pm 1.18	5.97 \pm 2.23	2.12	P = 0.296
Organic C L ₃	(%)	5.83 \pm 1.76	5.53 \pm 1.30	5.54 \pm 1.68	0.170	P = 0.844

while at the early succession sites, the highest value was in the depth range of 30 to 60 cm. This was the same Total Nitrogen (TN) (Table 2). However, values for Phosphorus and Potassium were highest at deeper soil 60 to 100 cm depths. There was no significant change ($p > 0.05$) in the values of the studied soil properties (Total Nitrogen, Phosphorus, Potassium) between old forest, intermediate and early succession sites.

Discussion

Vegetation recovery trajectory and structural development

The number of mangrove species recorded in the old growth forest site (Table 1) is less than that reported in earlier studies, which reported 8 true mangrove species in the Rufiji Delta (Semesi, 1992; Wagner and Salama-Mtui, 2016; Mangora *et al.*, 2016). This implies that only six mangrove species grow well in the studied sites. The two missing species, *Sonneratia alba* and *Lumnitzera racemosa*, are rare in the Rufiji Delta, probably due to their limited ecological range.

The general trend in the natural recovery of mangrove tree species shows that species richness increases with fallow age (Table 1). An increase of one species from early succession to intermediate succession was apparent; with the same observed between intermediated succession and old growth forest. This implies that regeneration in the fallow rice fields would result in the development of a forest similar to the old growth forest in terms of tree species composition. Likewise, Ball (1980) reported a successional trend that may lead to the development of a forest similar to the historical forest in Southern Florida, USA. In other forest types, Haripal and Sahoo (2011) reported an increase in species richness with age in the tropical dry deciduous forest in the Western part of Orissa, India. This indicates that different vegetation types may have a similar successional trajectory.

The findings of the present study on the natural recovery trajectory of tree species did not fully support the initial floristic composition succession model, which suggests that species present at the early succession stages will also occur in the subsequent stages (Almazan - Nunenz *et al.*, 2016). While species like *A. marina*, *H. littoralis* and *B. gymnorrhiza* were encountered in both the early and the intermediate succession stages, *R. mucronata* was encountered only in the old growth forest, implying failure of these mangrove tree species in contributing to natural recovery.

This suggests that the initial floristic composition succession model might be applicable only if there are favourable conditions for natural recovery of the mangrove tree species. Such conditions include the presence of mother trees producing propagules, and the absence of hydrologic restrictions or blockages (i.e. dikes) which prevent natural waterborne transport of mangrove propagules to a restoration site (Lewis III, 2005). Ball (1980) reported that direction of winds and currents may prevent substantial transportation of propagules to a site where they can germinate in a mangrove forest of Southern Florida.

In terms of dominance, the results from the old growth forest (Table 1) are similar to those described for the entire coast of Tanzania (Njana *et al.*, 2017). However, other inventory studies in the Rufiji Delta indicate a shift of dominance from *A. marina* at early forest development stages (under story) to *C. tagal* at mature stages (over story) (Mangora *et al.*, 2016). In a study in an upland forest ecosystem, Haripal and Sahoo (2011) reported on the shift in dominance of species along the chronosequence of rice fallows in the Western part of Orissa, India. Similarly, in the present study there was a shift of dominance from *B. racemosa*, in the early succession to *A. marina* in the intermediate and the old growth forest. According to Guariguata and Ostertag, (2001), together with the presence of remnant trees that can strongly influence the rate of initial colonization through their effects on seed dispersal, sprouting ability determines the abundance of the species. Buoyancy of propagules and tidal regime in the Rufiji Delta may also influence the abundance of species. Two factors might have contributed to *B. racemosa* being the most abundant tree species in the early succession of the fallows. Firstly, the seed disposal strategy of the plant may play a role. The fruit of *B. racemosa* is coated with buoyant fibrous tissue which allows them to be carried great distances by water currents (Osman *et al.*, 2015). When deposited in a favourable location, the seed germinates to form a plant. Secondly, *B. racemosa* has the ability to sprout from stumps. Guariguata and Ostertag, (2001) argued that sprouting is likely to be important in forest regeneration, as many species are capable of producing either sprouts originating from boles or branches (above ground sprouts) or subterranean tissues (root sprouts). In the present study, species like *B. racemosa* mainly regenerated through sprouting from stumps. According to Osman *et al.* (2015) *B. racemosa* is a mangrove-associated species which grows well in wet areas (fresh water swamps, riverbanks and lakes) and can tolerate slightly saline conditions. In the Rufiji Delta, the

plant is found close to the fresh water inflow, where the main Rufiji river starts branching into distributaries, and the influence of saline water is reduced. Mangrove species such as *A. marina*, *H. littoralis*, *B. gymnorhiza*, *C. tagal*, and *R. mucronata* are regenerated through buoyant seeds and their dispersal is facilitated by water movement, particularly during the highest tides. The influence of physical environmental factors on the relative competitive abilities of the species probably accounts for the distribution of mangroves in characteristic zonation patterns (Ball, 1980).

Non-tree species in the recovering and old growth forest, and their associates threats

In terms of species richness, while previous studies reported only one species (*Acrostichum areum*) growing in the reference old growth forest (Wagner and Salama-Mtui, 2016), the present study found three species growing here (Table 1), among which *A. areum* and *D. trifoliata* were mangrove-associated species (Lobo and Krishnakumar, 2014; Raju and Kumar, 2016). Non-tree species do not fully correspond to the initial floristic composition succession model (Almazan-Nunenz, *et al.*, 2016), as not all species present in the early succession stages persist to subsequent succession stages (Table 1). In terms of dominance, the trend showed that this changes with fallow age. For example, *Pennisetum spp.* (Poaceae family) was dominant in the early and intermediate succession while *A. areum* and *D. trifoliata* were dominant in the old growth forest. *Pennisetum spp.* are usually perennial rhizomatous herbs and are often woody and tree like (Gibson, 2009). They are fast growing, form dense ground cover, have well-developed root systems and are able to grow at various contaminated sites, display moderate salinity tolerance, and have an extensive root system that can firmly hold the soil and withstand adverse environmental conditions (Radhakrishnan *et al.*, 2006; Mane *et al.*, 2011). They have an extremely effective seed dispersal mechanism, and low soil nutrient requirements which facilitates their colonization on fallow rice fields (Haripal and Sahoo, 2011). In the mangrove forests of Bangladesh, few additional invasive species that inhibit normal growth of mangroves were recorded (Biswas *et al.*, 2007). *A. areum* is the only fern in the mangrove ecosystems of the Indian coast, and the species is widely distributed throughout the mangrove forest irrespective of local ecological and environmental conditions (Lobo and Krishnakumar, 2014).

The presence of non-tree species has been noted to pose threats to the natural recovery of mangrove tree

species. For example, in the Sundarbans mangrove forest of Bangladesh. The climber *D. trifoliata* has been reported to pose a threat to many regenerating seedlings owing to its aggressive twinning and strangulating habit. Dense populations of *D. trifoliata* form a cover over seedlings and saplings of *Heritiera fomes*, *Excoecaris agallocha*, *Sonneratia apetala*, among others (Biswas *et al.*, 2007). Likewise, in the Rufiji Delta, this climber (Liana) suppresses the growth of regenerating tree species. It smothers mangrove trees and may eventually lead to their death. In areas with no trees, this species covers the ground (Plate 1). In addition to smothering, the climbers and grasses negatively affect transportation and germination of propagules by preventing access to the soil. This affects the natural regeneration of the deforested and degraded parts of the mangrove forest, as well as species richness and recovery rate in the rice fallows of the Rufiji Delta.

Structural development

The diameter size class distribution curves (reverse 'J' distribution curve) obtained in the present study (Fig. 2) corresponds to that earlier reported from the mangroves of Gazi Bay in Kenya (Githaiga, 2013). According to Phillip (1994), a reverse 'J' distribution curve is commonly associated with natural forests with active recruitment and which are recovering from anthropogenic disturbances. Such disturbances include selective removal of poles from the forests (Githaiga, 2013). The 'J' distribution curve from the present study indicates that there was active natural regeneration of trees in the early and intermediate sites, while in the old growth forest sites the mangrove forest is recovering from selective harvesting. The early successional recovery had a low DBH range compared to other successional stages (Fig. 2). The presence of a small number of mature trees in the intermediate succession site and their complete absence in the early succession site indicates that the tree sizes increased with fallow age. Likewise, Ball, (1980) reported that mature individuals of *Avicennia germinans* (DBH approximately 20 - 30 cm) were very rare in the in a Mangrove Forest of Southern Florida, USA. Likewise, in the Rufiji Delta, larger diameter size trees of ≥ 20 cm was mostly recorded in the old growth forest, decrease in the intermediate succession while completely absent in the early succession site.

The value of stem density found in the old growth forest (Table 2) was less than that earlier reported in previous studies (Lupembe, 2014; Mangora *et al.*, 2016). The low stem density in the present study is



Plate 1. Grasses and the climber *Derris trifoliata* covering mangrove trees and land surface of the fallow rice farming areas in the Rufiji Delta.

probably because of selective harvesting of mangrove for poles and timber. This area is surrounded by many people who depend on the mangrove forest products for domestic and commercial purpose. However, the value of basal area and height obtained from this study was higher than that reported earlier for all mangrove forests of Tanzania (Njana *et al.*, 2017). This implies that the old forest site studied was composed of larger tree sizes, as the larger the tree sizes, the larger the basal area. Similarly, Sukardjo and Yamada (1992) reported basal area and height at one site to be higher than four other sites in a *R. mucronata* plantation in Tritih, Central Java, Indonesia, as a result of variation in growth caused by differences in soil fertility.

The recovery trends in this study shows that structural attributes, stem density, basal area and height increased significantly with fallow age ($p = 0.001$), but they are much lower compared to the old growth forest (Table 2). This implies that for the mangrove forest of Rufiji Delta, a period of up to 15 years would be insufficient to allow full recovery from losses from conversion to agriculture. However, Lugo (1980) reported that the rate of succession recovery after disturbances varies in the different types of mangroves and depends on the characteristics of nearby ecosystems and growth conditions at each site.

Soil properties

The TN, Available Phosphorus (AP) and SOC values obtained in the Rufiji Delta were less than that reported in the mangrove forest of the Apar Nature Reserve in Indonesia, where the TN was 0.34 ± 0.02 %, while SOC, and AP were 3.96 ± 0.18 % and 19.87 ± 0.22 mg/kg, respectively, in an *Avicenia officinalis* pure stand (Sukardjo, 1994). TN was 0.97 ± 0.01 %, while SOC, and AP were 60.27 ± 1.03 % and 19.87 ± 0.22 ppm, respectively, in a *C. tagal* pure stand. Dasgupta *et al.* (2018) reported that SOC ranges between 0.9 to 1.4 % in mangrove soils of the Sundarbans, West Bengal, India. However, Hossain and Nuruddin (2016) reported TN and SOC to range between 0.09 - 0.97 % and 0.38 - 13.31 % respectively in different mangrove forests of the world. Therefore, the value of TN and SOC obtained from the present study in both intact and the regenerating forest were within the global estimates. The value of Potassium found in the Rufiji Delta was higher than that of 0.27 ± 0.02 found in *A. officinalis* and 0.17 ± 0.02 in *C. tagal* reported in the mangrove forest of the Apar Nature Reserve in Indonesia.

The studied soil properties from converted sites and intact forest does not follow the paradigm of significant declines following conversion (Allen, 1985; Raich, 1983; Guariguata and Ostertag, 2001). Neither

significant increase nor decline in soil nutrient properties of the fallows was found. This might be because there is a continuous inflow of soil sediments carried by the river from upstream. Alongi *et al.* (2005) found that sediment and associated elements, including nutrients within mangroves is a result of intense human activity along the south China coast. Walling (1999) showed that the change from natural vegetation to cultivation can increase soil erosion rates by an order of magnitude or more. Elevated sediment loading to estuarine and coastal environments can occur via a number of mechanisms, including urban development, and often results in increased turbidity and sedimentation rates in estuarine and coastal waters (Ellis *et al.*, 2004). However, high levels of radio nuclides suggest that these sediments originate from erosion of agricultural soils within the catchment (Alongi *et al.*, 2005). For instance, in Kenya it has been reported that the two main rivers (Athi- Galana/Sabaki and Tana) which drain into the Indian Ocean are reported to deliver several tonnes of sediments into the coastal areas (Okello, 2016). In the Rufiji Delta, sediments with nutrients from upstream have been carried by the Rufiji River and deposited in the delta. The Rufiji river has a basin which extends over an area of 177,000 km² with a mean annual discharge that ranges between 900 and 1,133 m³/s (ASCLME, 2012; Mwalyosi, 2018). These sediments with nutrients might counterbalance the loss of nutrient in the study area.

Conclusions

The present study has demonstrated that mangroves in the abandoned rice farming areas of the Rufiji Delta are undergoing successional recovery. Favourable conditions for natural regeneration are the presence of mother trees as a source of propagules, absence of vegetation such as the climber *D. trifoliata* and grass cover that prevent natural waterborne transport of mangrove propagules to the restoration site and contact of the propagules with soils. Species dominance varied with the fallow age, with the non-mangrove species, *B. racemosa*, dominating in the early succession stage, but subsequently replaced by *A. marina* in the intermediate succession stage and the intact mangrove forest. The structural characteristics determined in this study demonstrate that a period of up to 15 years would not be sufficient to allow full natural recovery of the degraded areas as a result of clearance and conversion of mangrove areas for traditional rice farming. Anthropogenic disturbance during tree harvesting and rice farming in the study site had no effects on soil nutrients as well as SOC. Sediments with

nutrients from upstream have been carried by the Rufiji River and deposited in the delta and have counterbalanced the loss of nutrients due to rice farming. Therefore, soil nutrients are not a factor that affects the natural recovery rate of the mangrove forest in the studied area. In the areas where natural recovery has not been successful, human intervention geared towards restoration is recommended. Such interventions would include removal of grass cover and or planting to facilitate the recovery of the tree species. Therefore, in the abandoned rice farming areas of the Rufiji Delta, both planting and natural regeneration restoration approaches are applicable, but assessment of potential sites are required to determine the best restoration approach. In addition, permanent sample plots should be established in these parts of the delta for long term monitoring of plant recovery rate.

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