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Cover image: Woman collecting ascideans at Ponta Mazondue, Inhaca Island, Mozambique (© José Paula, 2005)

Phenology of mangroves and its implication on forest management: a case study of Mida Creek, Kenya

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Abstract

Mangrove forest decline has continued despite establishment of protected areas, restoration and other conservation efforts. This is due to anthropogenic pressure, and phenological traits that together with adverse environmental factors derail natural and artificial regeneration. An understanding of phenological traits can inform planning and management of mangrove forests with benefits to restoration and increased mangrove area cover. Phenological traits of *Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza* and *Sonneratia alba,* were studied in Mida Creek. Litter fall data was collected monthly on 10 m × 10 m plots from July 2010 to July 2012, oven dried, sorted into leaves, stipules, flowers and propagules, and weighed. Results obtained showed that leaf production occurred throughout the study period for all the species. Propagule fall occurred in the dry season for *Ceriops tagal* and *Bruguiera gymnorrhiza*, and during the wet season for *Rhizophora mucronata* and *Sonneratia alba.* Immature propagules accounted for 99 %, 86 % and 67 % of the cumulated propagules for *R. mucronata, B. gymnorrhiza* and *C. tagal* respectively. The longest propagule for *R. mucronata* was 40.5 cm. This indicates the need for nursery propagation of propagules of these species for seed availability. The findings of this study are discussed in relation to mangrove forest management,

Keywords: Leaf production, Leaf fall, Mida Creek, Phenology, Propagule abscission

Introduction

Mangrove forests provide a wide range of goods and services to coastal communities and are important in carbon sequestration (Alongi, 2012), and have the potential for climate change mitigation (Murdiyarso *et al*., 2015). However, world mangrove ecosystems are continually being threatened by anthropogenic factors and climate change, leading to 20% loss of mangroves since 2005 (FAO, 2007). Climate change has been projected as a serious threat to mangroves through sea level rise, temperature increase and changes in rainfall patterns (Field, 1995; Ellison, 2000; Elizabeth and Rodney, 2006; Hoegh-Guldberg and Bruno, 2010; McKee, 2012). This may lead to localized extinction of species that will not be able to cope with sea level rise due to differences in growth characteristics and environmental preferences for different mangrove species (Ellison, 2000; Di Nitto *et al*., 2014). In order to effectively address the continued mangrove forest loss, there is a dire need for forest managers involved in restoration of degraded mangrove forests to understand phenological traits of mangrove species and to integrate this information for successful restoration of mangrove forests.

A link between vegetative and reproductive phenologies of mangroves has been reported widely (Duke, 1990; Coupland *et al*., 2005) and is attributed to resource partitioning by plants. Phenological studies enhance the understanding of growth and development characteristics of mangrove species. This helps with understanding of how mangroves are likely to be affected by changing climatic factors. Longer leaf growth periods could affect benthic fauna and other food webs that are dependent on mangrove leaf litter for their survival. Mangrove benthic fauna are ecosystem engineers, hence important for healthy mangrove ecosystems (Kristensen, 2008; Nagelkerken *et al*., 2008). Changes in plant phenological traits have already been documented in terrestrial forests (Chung *et al*., 2013). Increased temperatures have been observed to result in longer leaf growing seasons characterized by earlier emergence and late senescence of leaves in terrestrial forests, in addition to other impacts on biotic and abiotic factors (Chung *et al*., 2013).

Propagules are predated on and damaged by insects and crabs while still growing on the mother tree, after abscission, during dispersal and early planting stages, leading to their death (Dahdouh-Guebas *et al*., 1998; Clarke *et al*, 2002; Sousa *et al*., 2003; Langston *et al*., 2017). This causes a decline in the establishment, viability and overall success rate of mangrove seedlings during artificial planting and natural regeneration.

Substantial studies have documented the phenology of mangrove species worldwide; however, there is paucity in the application of the findings in mangrove forest management. Creation of protected areas in the form of natural reserves and national parks is a positive step towards mangrove conservation (Field, 1998). Mida Creek which is located within Watamu National Reserve in Kenya is one such site, having been declared a national reserve in 1968. However, mangrove destruction has continued in the recent past (Dahdouh-Guebas *et al*., 2000; Warui, 2011; Alemayehu *et al*., 2014) indicating that mangrove conservation is still ineffective. In Mida Creak the abundant mangrove species are *Ceriops tagal* (Perr.) C.B. Robinson, and *Rhizophora mucronata* Lamk.; also the most preferred by the local community for wood, fuel and other uses, hence they are likely to be most affected by cutting and destruction.

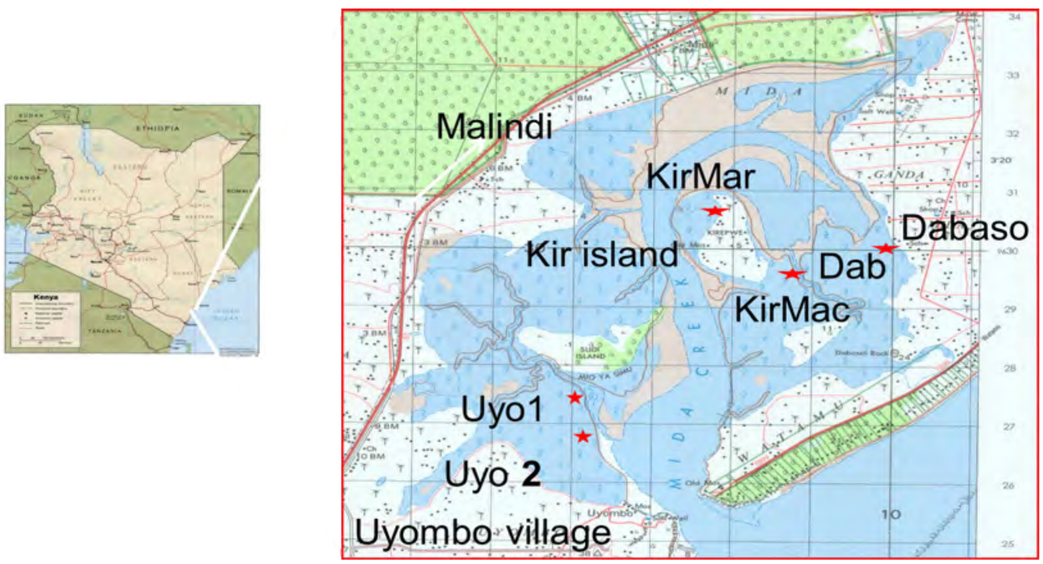

Figure 1. Map of Kenya (left) and Mida creek (right) indicating the study stations. Dab - Dabaso; Kir - Kirepwe; KirMac- Kirepwe Mach; KirMar - Kirepwe Mark; Uyo - Uyombo.

Availability of mangrove propagules for planting is affected by continued loss of mangrove forests, lack of planting material (seedlings) and propagule predation, prior to and after abscission, which in turn negatively affects restoration projects. Natural and reforested mangroves forests experience high floral and propagule abortion rates (Coupland *et al*., 2006; Ewe, 2007) and this affects the availability of seedlings for natural regeneration or artificial planting. Ewe (2007), in his study on *Rhizophora mangle*, observed that not all abscised propagules are viable and viability is size dependent, and that seedling survival can be predicted from propagule size. Propagule size has also been reported to have an effect on early seedling growth of mangrove species (Sousa *et al*., 2003).

Restoration, planning and management of mangrove forests requires an understanding and documentation of phenological traits of mangrove species geared towards informing management practices by foresters. This includes information such as: (1) leaf litter productivity that will inform the choice of species combination during planting, to ensure provision of mangrove litter throughout the year for mangrove benthic fauna and continued organic matter supply that will ensure heathy mangrove ecosystems; (2) propagule size at the time of abscission will guide the timing for collection for nursery propagation of the immature propagules to mitigate scarcity during lean seasons; (3) knowledge on seasonal availability and quantity of mature propagules for planting will inform planning of restoration projects and planting activities.

This purpose of this study was to: (a) investigate the vegetative phenology of *Rhizophora mucronata Ceriops tagal*, *Bruguiera gymnorrhiza* and *Sonneratia alba* Sm, in mono and mixed species stands in Mida Creek; (b) quantify propagule productivity of the Rhizophoraceae species; and (c) determine the size of abscised propagules of the Rhizophoraceae species and link the findings to mangrove management.

Materials and methods

Description of the study area

The study was conducted in three stations (Dabaso, Kirepwe and Uyombo) in Mida Creek within Watamu Marine National Reserve (Fig. 1). Study site co-ordinates, and inundation classes are shown in Table 1. The reserve was declared a protected area and established as a reserve in 1968. It was gazetted under the Wildlife Conservation Management Act in 1976. Seven out of the nine mangrove species in Kenya are found in Mida Creek, of which the dominant species are *Rhizophora. mucronata* Lamk. *Ceriops tagal* (Perr.) C.B. Robinson, and *Avicennia marina* (Forsk.) Vierh. (Kairo *et al*., 2002). A mangrove forest cover of 1 746 ha for Mida Creek has been reported (Kairo *et al*., 2002) and 1 655.7 ha in 2010 (Alemayehu *et al*., 2014). The community in Mida Creek utilizes the mangrove species for wood (house and boat construction, fuel, and medicinal purposes (Dahdouh-Guebas *et al*., 2000).

Determination of phenological trends

Ten randomly selected 10 m × 10 m plots were established in the study sites from which phenological trends were extrapolated through monthly

Table 1. Site co-ordinates, elevation and inundation classes for the study sites.

Station/Site/Species	Elevation	South	East	Inundation class
Dabaso Site 1and 2: *R. mucronata*	26 feet	S 03° 20.748	E 039° 59.349	II
Kirepwe Macho Site 1:(*S. alba*) Site 2: (*R. mucronata)*	22 feet	S 03°21.107	E 039° 58.740	I/II
Kirepwe Mark Site 1: *R. mucronata*; *C. tagal* Site 2: *R. mucronata, C. tagal,* *A. marina, B. gymnorrhiza*	18 feet	S 03 ° 20.616	E 039° 58.005	II
Uyombo 1 Site 1: *R. mucronata, C. tagal,* marina, B. gymnorrhiza Site 2: : *R. mucronata, C. tagal,* B. gymnorrhiza	29 feet	S 03° 22.991	E 039° 57.541	III
Uyombo 2 Site 1: *R. mucronata, C. tagal,* marina, B. gymnorrhiza *Site 2: R. mucronata, C. tagal,* *B. gymnorrhiza*	19 feet	S 03° 23.107	E 039° 57.654	III

Table 2. Stand structure of the study sites (±S.E).

Site	n	Height (m)	DBH (cm)	Density (trees/ha)
Monospecific stands				
Dab site 1; *Rhizophora mucronata*	12	14.6 ± 0.7	85.5 ± 4.3	1,200
Dab site 2; *Rhizophora mucronata*	17	17.5 ± 3.2	87.2 ± 3.5	1,700
Kir mc site 1; *Sonneratia alba*	31	6.5 ± 0.2	29.6 ± 2.4	3,100
Kir mc site 2; *Rhizophora mucronata*	47	7.4 ± 0.9	29.7 ± 4.1	4,700
Multispecific stands/abundant species				
Kir mk site 1; *Rhizophora mucronata*	27	7.9 ± 0.7	35.9 ± 3.8	2,700
Kir mk site 2; *Rhizophora mucronata*	47	6.0 ± 0.5	37.5 ± 4.2	4,700
Uyo 1 site 1; *Bruguiera gymnorrhiza*	26	10.7± 1.1	42.2 ± 6.5	2,600
Uyo 1 site 2; *Rhizophora mucronata*	54	4.6 ± 0.5	29.5 ± 4.4	5,400
Uyo 2 site 1; *Ceriops tagal*	37	9.7 ± 0.7	33.1 ± 4.2	3,700
Uyo 2 site 2 ; *Ceriops tagal*	51	4.4 ± 0.4	26.6 ± 3.5	5,100

Key: *n*= number of trees in 10x10m study site; **Dab**-Dabaso; **Kir mc**- Kirepwe Macho; **Kir mk**- Kirepwe mark; **Uyo**- Uyombo

mangrove litter collection by use of 10 litter traps per plot. Dabaso had 2 study sites (Dabaso 1 and Dabaso 2); Kirepwe had 4 study sites (Kirepwe Macho site 1 and 2, and Kirepwe Mark site 1 and 2), and Uyombo also had 4 study sites (Uyombo 1 (site 1 and 2), and Uyombo 2 (site 1 and 2). Litter traps with a trap mouth of 0.25m^2 were randomly suspended below the crown canopy but above the highest tide mark to avoid litter submergence during high tide. Litter collected in the traps (hereafter referred to as litter fall) was collected monthly from July 2010 to July 2012 from the stands. For comparative purposes, a second site was established adjacent to each study plot and data collected from November 2010 to July 2012 (referred to as site 2 in each study station). Collected litter was processed according to the procedure of Pool *et al.* (1975), whereby litter was dried at 70° C for 72 h to a constant dry weight and sorted into leaves, reproductive parts (buds and flowers), propagules/fruits (hereafter referred to as propagules) and small branches (twigs), and weighed. Length of propagules at time of fall was also measured. The stand structure for the mangrove stands was determined using trees with a D_{130} of ≥25 cm.

Statistical Analysis

Data on vegetative and reproductive phenology of seasonal production of leaves, stipules, reproductive parts and twigs was not different within a single species, therefore the phenological time series data for each of the four species is represented from a representative study site where the species was dominant. Propagule size data for each Rhizophoraceae species has been pooled (cumulative) from all the study sites due to the low number of propagules produced over the entire study period.

Data sets were tested for normality and homogeneity of variance for analysis of productivity of the various phenophases. However, the data were analyzed by non-parametric methods since it did not meet these requirements even after log transformation. Kruskal–Wallis ANOVA and pairwise comparison of mean ranks was used to determine significant differences in the weight of litter components. For presentation purposes of the phenograms, data presented is from representative sites.

Results

Stand structure

Rhizophora mucronata was the most abundant species and was present in all the study sites except in Kirepwe Macho site 1, which comprised a single species stand of *S. alba* (Table 2). This was followed by *C. tagal* and *B. gymnorrhiza* respectively. Though not included in this study, *A. marina* was the least abundant species in the study sites. *Rhizophora mucronata* sites in Dabaso had a stand density of 1 200 trees/ha, D_{130} of 87.2 ± 3.5 cm, and mean tree height of 17.5 ± 3.2 m, whereas Uyombo 1 site 2, where *R. mucronata* was the most abundant species, had a stand density of 5 400 trees/ha.

Vegetative and reproductive phenology

Rhizophora mucronata

Data presented for this species is from Dabaso site 1 and site 2, and Kirepwe Macho site 2 for comparative purposes. In the three study sites leaf fall in *R. mucronata* occurred throughout the year without distinct peaks (Fig. 2). Dabaso site 1 recorded a leaf fall at 3.55 g m^{-2} day^{-1} in November 2011. Dabaso site 2 and Kirepwe Macho site 2 showed leaf fall peaks of 6.03 g m^{-2} day^{-1} in November 2010. There was no significant difference in leaf fall between sites $H_{(2,\ N=67)}$ = 2.805, p=0.2386). New leaf production as demonstrated by stipule production was continuous with no distinct peaks, but highest production was in September 2011. There was no significant differences in leaf growth,

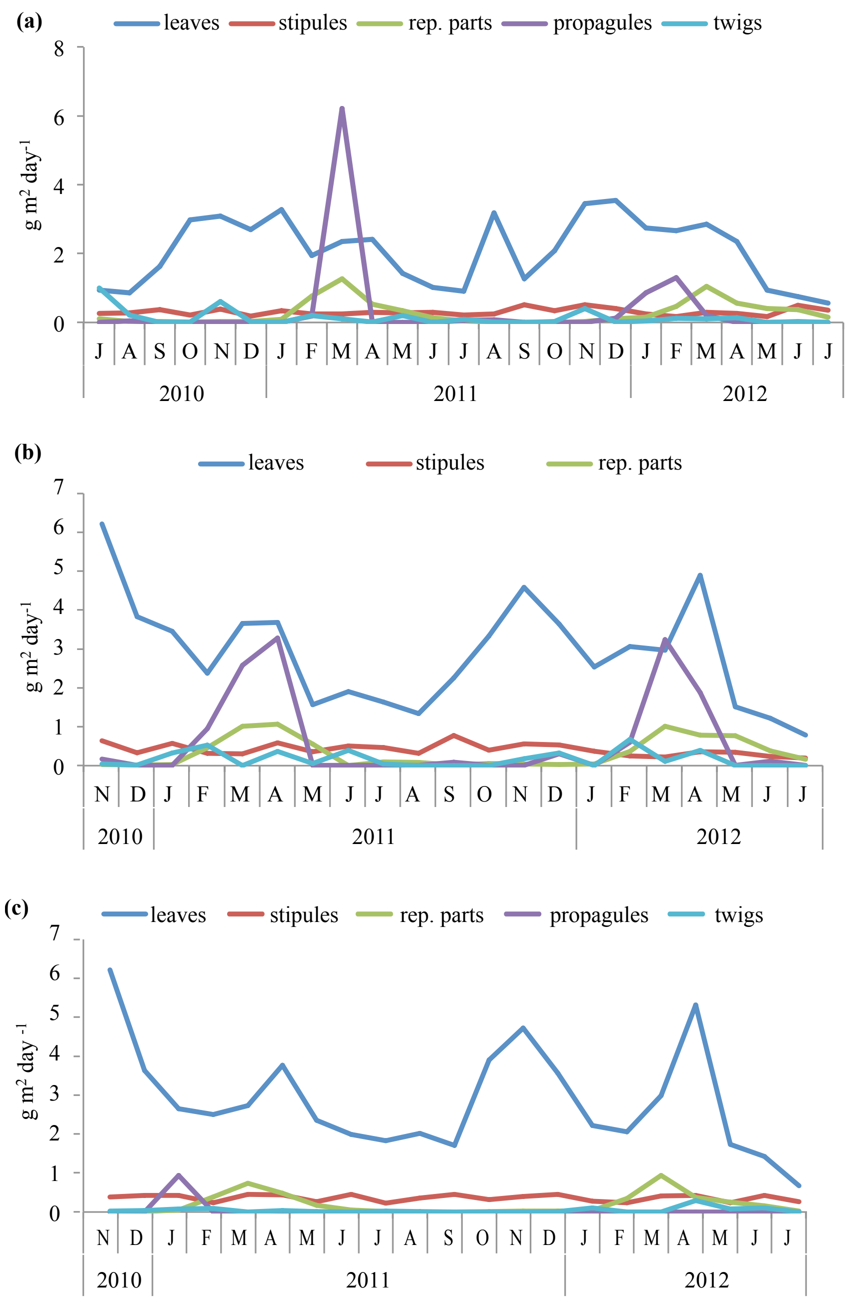

Figure 2. Monthly production of phenological components *of Rhizophora mucronata* in (a) Dabaso site 1, (b) Dabaso site 2, and (c) Kirepwe Macho site 2.

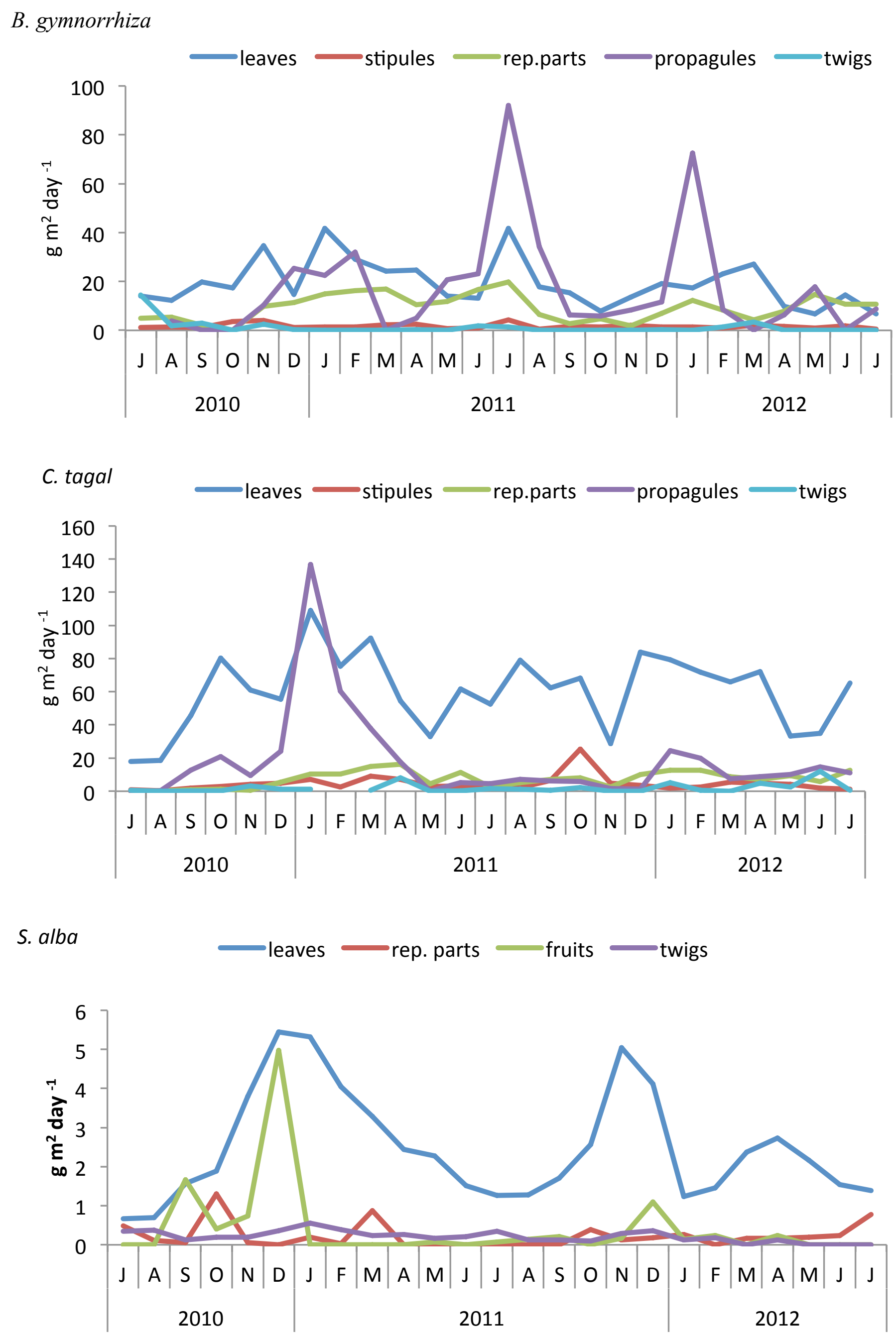

Figure 3. Monthly production of phenological components of *Bruguiera gymnorrhiza*, *Ceriops tagal* and *Sonneratia alba*.

$H_{(2, N=67)} = 5.0769$, p=0.0790) between sites. Production of twigs was minimal in comparison with the other litter components, with some months recording no fall. Reproductive parts of *R. mucronata* peaked in March in the three study sites with Dabaso site 1 showing a peak of 1.27 g m^{-2} day^{-1} in March 2011, but this was not significantly different from the other sites ($H_{(2, N=67)}$=1.934, p=0.3801). Propagule fall was significantly different between sites ($H_{(2, N=67)} =$ 9.781, p = 0.0075). Dabaso site 1 had a peak production in March 2011, and January and February 2012. Dabaso site 2 had a longer and consistent propagule production period from February to April in 2011 and 2012. Kirepwe Macho site 2 showed the least propagule production which occurred only in January 2011. The highest peak of 6.21 g m^{-2} day^{-1} was recorded for Dabaso site 1. The total number of propagules recorded for Dabaso site 1, 2 and Kirepwe Macho site 2 throughout the study period was 14, 33 and 1 respectively. This translated to 700, 1 650, and 50 propagules ha^{-1} yr^{-1}, respectively.

Bruguiera gymnorrhiza

Leaf growth and stipule production occurred throughout the year with no consistent peaks (Fig. 3). Highest leaf fall was observed in January and July of 2011 and 2012 measuring 41.8 g m^2 day^{-1}. Stipule production which signifies new leaf production occurred throughout the year with peaks in November 2011 and July 2012 (4.1 and 4.2 g m^2 $day^{-1)}$ respectively. Fall of twigs was minimal in comparison to other components and was totally absent in most of the months during the study period. Production of buds and flowers was observed throughout the study period with increased production from November 2010 to July 2011. Propagule fall was observed in most months with peaks in July 2011 and January 2012 (92.1 and 72.6 g m^2 day^{-1} respectively), which coincided with the dry season.

Ceriops tagal

Leaf fall in *C. tagal* occurred throughout the study period with the highest peak recorded in January 2011 at 109.1 g m^2 day^{-1}. Leaf growth was also continuous, peaking in October 2011 at 25.5 g m^2 day^{-1}. Fall of twigs was minimal as observed in all the studied species with the highest peak in June 2012 at 12.1 g m^2 day^{-1}. Reproductive parts were observed in all the months except in July 2010. Peak months were March to April and January to February of 2011 and 2012, respectively. The highest production was recorded in April 2011 at 16.3 g m^2 day^{-1}. Fall of propagules in *C. tagal* was observed in most months from September 2010 to April 2011, with a smaller peak in 2012. However, peak propagule production was observed in the dry months of January and February in both years, with the highest peak in January at 136 g m^2 day^{-1}.

Sonneratia alba

Leaf fall, as in the other species, was continuous, but peaks were observed from November to January 2010 and November to December 2011. The highest peak in leaf fall was in December 2010 at 5.45 g m^{-2} day^{-1}. Twig production in *S. alba* was the lowest among the species studied and occurred in most of the months, peaking in January 2011 at 0.56 g m^{-2} day^{-1}. Reproductive parts were produced in most of the months. However, peaks were inconsistent in the studied years at 1.3 and 0.87 g m^{-2} day^{-1} in October and March of 2010 and 2011, respectively. Fruits in *S. alba* were observed in 13 out of the 25 months of the study. There were consistent peaks in December at 4.98 and 1.1 g m^{-2} day^{-1} in 2010 and 2011, respectively.

Propagule length at abscission

Due to the low number of propagules collected in the litter traps at different study sites, data has been pooled from all the plots for each species. The number and length of abscised propagules varied with the species (Fig. 4). *Rhizophora mucronata* had the highest cumulative number of propagules followed by *C. tagal* and *B. gymnorrhiza* at 293, 104 and 74, respectively. The longest abscised propagule was 40.5 cm, 30 cm and 28 cm in length for *R. mucronata*, *B. gymnorrhiza* and *C. tagal*, respectively. The size class with the highest number of abscised propagules for *R. mucronata* was 10.1 -15 cm (60 propagules), and 5.1 – 10 cm for both *C. tagal* and *B. gymnorrhiza* at 26 and 30 propagules respectively. Immature abscised propagules were recorded at 99 %, 86 % and 67 % for the three species. The recommended mature propagule size for *R. mucronata, B. gymnorrhiza* and *C. tagal* is >40 cm, >15 cm and >20 cm, respectively (Kairo, 2010). The number of abscised propagules decreased with an increase in size class.

Discussion

Mangrove species display very different growth and reproductive characteristics as outlined by Tomlinson (1986). Three species were studied (*R. mucronata*, *C. tagal*, *B. gymnorrhiza*) belonging to the family Rhizophoraceae, all of which exhibit the adaptation of being viviparous, and one fruit bearing species, *S. alba*. Despite the varying characteristics, it is important to make a comparison and document the phenological characteristics of the species in order to derive information that can be used for forest management and conservation. Various studies have discussed their findings in light of their application to mangrove forest conservation (Nagarajan *et al.*, 2008) (Raju & Karyamsetty, 2008). The findings from this study are discussed with the aim of providing information with application in planning, management, restoration and conservation of mangrove forests locally, and in other geographical regions.

Leaf production and fall characteristics of the four species indicate a continuous growth throughout the study period, characterized by multimodal peaks. This has also been reported for mangroves locally (Gwada and Kairo, 2001; Wang'ondu *et al.*, 2013), elsewhere in the Western Indian Ocean region (Shunula and Whittick, 1999), and globally (Wium-Andersen and Christensen, 1978; Wium-Andersen, 1981). Kamruzzaman *et al.* (2016) reported high and low litter fall in summer and winter respectively for *B. gymnorrhiza*. Peak leaf fall for *R. mucronata* and *S. alba* was in the wet season, whereas that for C. *tagal* and *B. gymnorrhiza* was in the dry season. Mangrove stands composed of these Rhizophoraceae species can therefore be recommended, where possible, to ensure continued detrital input into the mangrove ecosystem all year round.

In this study the highest leaf production and fall was observed in *C. tagal* and *B. gymnorrhiza* in the mixed species stands. These sites also had the highest organic matter content in the sediments, in comparison with the single species stands. Sources of organic matter content in mangrove ecosystems are many and diverse, and mangrove litter input is important (Bouillon *et al.*, 2003). The high and continuous input of leaf litter all year round could be a contributing factor as this ensures availability of detrital material for benthic fauna that are responsible for processing and degrading this litter into organic matter. This is an indication that, where possible, mixed stands of these species should be prioritized in conservation, due to this high leaf litter productivity.

The four mangrove species demonstrated varying characteristics in production of reproductive inflorescence with regard to their seasonality and number of

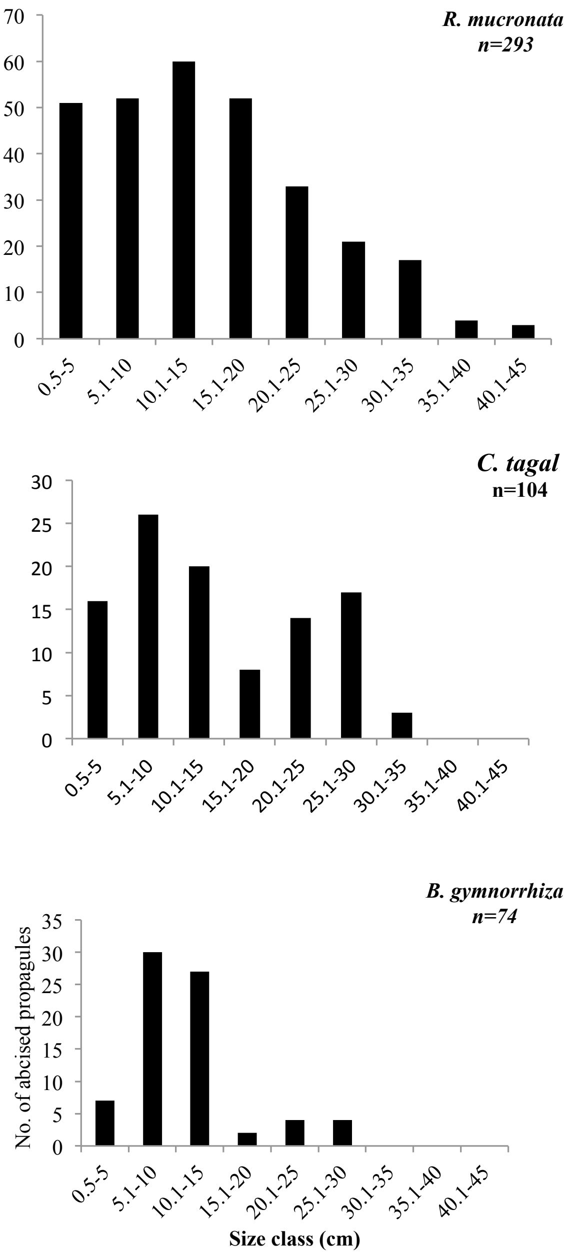

Figure 4. Cumulative number and length (cm) of abscised propagules for *R. mucronata* (>40 cm), *C. tagal* (>20 cm) and *B. gymnorrhiza* (>15 cm) for all study sites. () represents the recommended abscission size for a mature propagules.

production months. *R. mucronata* has been reported to have a prolonged development period from initiation of floral buds to maturation of propagules, ranging between 16-20 months (Wang'ondu *et al.*, 2013), while this can last up to 3 years for *R. apiculata* (Christensen and Wium-Andersen, 1977). Documentation of peak propagule production months is important to ensure that proper planning of planting activities occur in restoration projects.

Abortion of reproductive structures has also been reported widely with a few mature propagules apparent at the end of the reproductive season (Christensen and Wium-Andersen, 1977; Wium-Andersen, 1981; Coupland *et al.*, 2006; Sharma and Kamruzzaman, 2012). Prolonged propagule development coupled with high abortion rates (abscission of immature propagules), and propagule predation prior to and after abscission, are some factors that may lead to a scarcity of propagules either for natural or artificial regeneration. This study also observed that a high propagule production season in one year was followed by a lower propagule production in the following year. This is important information for forest managers as they can plan for propagule harvesting during peak production for nursery propagation, to ensure availability of seedlings in the following year when productivity is low. This is especially so for *C. tagal* which was observed to have peak propagule fall during the dry months. A study by Robert *et al.* (2015) reported that *C. tagal* propagules are more prone to dehydration upon abscission than those of *R. mucronata*, and this is likely to aggravate the situation for *C. tagal*. This further emphasizes the need for nursery propagation of mangrove propagules of these species.

In this study *R. mucronata* stands showed different reproductive potential (Dabaso site 2 >Dabaso site 1 > Kirepwe Macho site 2, in decreasing order) even for sites at close proximity to each other. This indicates that mangrove forest productivity is site specific, and that there is a likelihood of no propagule production in some stands. This necessitates the identification of the highly productive mangrove stands for conservation as live seed banks. In this study, the mixed species stands in Uyombo were more productive compared to the other single species stands, and should be earmarked as no take areas within Mida Creek National Reserve to ensure seed availability for either natural regeneration through seed dispersal, direct planting, or nursery propagation. Highly productive single species stands should also be identified and those found to be productive should be used for conservation purposes.

Rhizophora mucronata, *C. tagal* and *B. gymnorrhiza* are the preferred species for the supply of wood for construction and fuel which top the list of uses of mangroves in Mida Creek (Dahdouh-Guebas *et al.*, 2000; Kairo *et al.*, 2002). The three Rhizophoraceae species showed varying propagule abscission sizes, however, it was clear that most of the propagules (50%) abscised before attaining the recommended maturity size. According to Kairo (2010), the recommended size at maturity for nursery rearing is >15cm, >20cm and >40 cm for *B. gymnorrhiza, C. tagal* and *R. mucronata*, respectively. Propagule size, pre- and post- dispersal damage by insects and crabs before and after abscission, are important aspects, and to some extent, determines dispersal, recruitment and establishment (De Ryck *et al.*, 2012; Sousa *et al.*, 2003). Even though, *R. mucronata* recorded the highest propagule abortion rates, more than 50% of propagules of the other two species were immature. In addition, *C. tagal* has been reported to have lower establishment rates due to its small propagule size, sensitivity to dessication, and slower root growth (De Ryck *et al.*, 2012; Robert *et al.*, 2015). Sousa *et al.* (2003) also noted that irrespective of the species, propagule size contributes significantly to initial seedling establishment and early growth. *Sonneratia alba* is also on the IUCN red list of threatened mangrove species (Kathiresan *et al.*, 2010). This study therefore indicates that there is need for nursery propagation of propagules of these species for continued availability of seedlings for artificial regeneration.

This study provides important information to forest managers, suggesting that the four mangrove species included in the study should be at the top of the conservation list. It also emphasizes the need for species-guided conservation strategies with the needs of the dependent human communities for sustainable utilization and provision of goods and services taken into account. This is coupled to the fact that mangrove forests are on the decline locally, experiencing losses of between 2.7-5.1%, rates higher than the global mean, due to anthropogenic pressure (Bosire *et al.*, 2014).

The unique characteristics of the studied mangrove species cannot be overemphasized, but it is important to note that management and conservation of mangrove forests should not be generalized. Characteristics of each species should be considered if effective conservation and management strategies are to be achieved. Planning, management and conservation practices for mangrove forests should be guided by the phenological traits of species as well as the needs of the local community. This study further recommends nursery propagation studies to establish which of the aborted propagule sizes are viable in the nursery to guide collection of abscised immature propagules for nursery propagation in the future.

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