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Full Length Research Paper

Regeneration pattern and size-class distribution of indigenous woody species in exotic plantation in Pugu Forest Reserve, Tanzania

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Pugu Forest Reserve is among coastal forests in Tanzania which is highly degraded through exploitation. To conserve the forest, part of natural forest was cleared and established exotic plantation to provide forest resource needs for the nearby residents. However, the regeneration pattern of indigenous trees in the exotic plantation was not monitored. It was aimed at assessing diversity, population structure, size class distribution and natural regeneration pattern of indigenous trees in exotic tree plantation. Vegetation data was collected using nested plots established along transects on both exotic tree plantation and the natural forest. The diameter size classes for most trees were less than 25 cm with poor recruitment at lower size classes implying an unstable plant population structure. Significant difference existed on the abundance of indigenous plant species between those in exotic tree plantation and the natural forest. However, the indigenous plant species regenerated successfully in exotic tree plantation as it occurred in the natural forest. Conclusively, establishing exotic plantation through clearing natural forests required monitoring as a management strategy because indigenous woody plants recovered through natural regeneration and outcompeted exotic trees in the plantation.

Key words: Pugu, exotic, indigenous, plantation, sizeclasses, regeneration.

INTRODUCTION

Pugu Forest Reserve is among coastal forests in Tanzanian that are remnants of the former extensive forest ecoregion known as Zanzibar-Inhambane Phytochorion (White, 1983). The coastal forests are part of the greatest vegetation cover recognized globally as biodiversity conservation hotspot (Myer et al., 2000). The forests harbour a wide range of vegetation communities composed of indigenous tree species, grasses, forbs, climbers, lianas and shrubs where their co-existence plays a great role to the ecosystem and humankind. The basic human support system of coastal forests has been characterized by inevitable change consequences of utilization of products such as timber, firewood, charcoal, poles, medicines and bush meat throughout human history (Frontier, 2004). Earlier on, the human population was low and the aforementioned activities were environmentally friendly and biodiversity conservation was achieved through mutually supportive relationship between human and biodiversity for many years (McNeely et al., 1995). However due to human population growth in villages and towns as well as in the nearby settlements (Census, 2002), the demand for forest products has increased. Plant species from natural forests are therefore exploited at much faster rate than the rate at which they are replaced through natural regeneration (Feyera and Luttge, 2001).

Regardless of being part of the world biodiversity conservation centers, Pugu Forest Reserve has been suffering from severe degradation because of increasing human activities within the forest. The forest is under exploitation pressure for pole, timber, charcoal production, fire (reckless human induced) and clearance for cultivation. After the World War II, the expansion of

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Dar-es-salaam city and the nearby settlements created high demand for timber, fuel wood and charcoal which increased exploitation pressure (URT, 1997). However, there has been efforts to conserve large part of Pugu Forest Reserve which date backs in 1923, when exploitation of the forest products increased and this was considered a threat. The Forest Department established exotic tree plantation to offer for alternative source of timber, charcoal and fuel wood resource than depending on scattered indigenous hard woods (Sunseri, 2005). A portion of Pugu Forest (approximately 18%) was cleared and replaced with fast growing exotic trees where *Senna siamea, Pinus patula* and *Eucalyptus maidenii* were the selected candidates to be introduced in the cleared part of the natural forest. However, the regeneration pattern of indigenous in exotic tree plantation was not monitored. According to Feyera et al. (2001), exotic tree plantations in Menagesha-Suba Forest Reserve promoted regeneration of native wood species. Until this study no information on regeneration pattern of the indigenous plant species in the exotic tree plantation in Pugu Forest Reserve. Also the plant population structure, species composition within the plantation and the adjacent natural forest is not known. The objective of this study was to determine 1) plant species diversity/evenness, 2) population structure and size class distribution; and 3) natural regeneration potentials (seedling, poles, sapling and seedling) of indigenous plant species in the exotic tree plantation.

The assumption was that edaphic factors are homogeneous and anthropogenic activities cut across both in exotic tree plantation and the natural forest in Pugu Forest Reserve.

MATERIALS AND METHODS

Description and location of the Pugu Forest Reserve

Pugu Forest Reserve is located at Kisarawe District in the Coast Region in Tanzania (Figure 1). It was gazetted in 1947 and covers a land surface area of 23 km^2 southwest of Dar es Salaam. It is found between latitudes 39° 03' 38" E and 39° 06' 80" E and longitudes 6° 52' 00" S and 6° 08' 20" S. Pugu Forest Reserve is among coastal forests in Tanzania with a characteristic pattern of inner tropical region with large diurnal temperature oscillations with small amplitude in the course of the year. Due to being close to equatorial position, the daylight period is nearly constant all year round which is an important factor for vegetation growth in the Tanzanian coastal forests. The forest receives a mean annual rainfall of 1160 mm (Ndangalasi, 1997). The driest months in the area being from June to October and the wettest months being May. The "long rains" last from March to June while the "short rains" occurs from October and December hence; the rainfall pattern is bimodal. Meteorological data of Coast Region show a peak annual rainfall of 2385 mm and minimum rainfall of 502 mm which once occurred between 1936 and 1970 (Clarke and Dickinson, 1995).

Topographically, Pugu Forest Reserve has a complex landscape with valley bottoms, dry ridge tops and intermediate undulating landscape.

The existence of various topographies contributes to the heterogeneous vegetation communities in the forest (Bussmann, 2001).

Vegetation sampling procedures

A reconnaissance survey was carried out to identify various tree stands in the exotic tree plantation and natural forest in Pugu Forest Reserve. The exotic tree stand (plantation) was identified as one sampling site and the second sampling site was established in the natural forest adjacent to the exotic tree plantation. Two transects, one in each stand, parallel to each other at 100 m apart were laid out in the study area. Along each transect, 5 nested plots were systematically established at an interval of 20 m in the exotic tree plantation and the natural forest. The plot sizes of 25 × 20 m were used for measuring trees of >10 cm diameter size classes at breast height (DBH). A plot size measuring 2 × 5 m nested in a bigger plot (of 25 × 20 m) (Stohlgren et al., 1995) was then used to measure poles with diameter size class of 7 to 10 cm. The regeneration plots measuring 2 × 5 m were used to assess the density of sapling and seedlings (regeneration potential) in both the exotic tree plantation and the natural forest. Saplings were the young trees with diameter size class of 2 to 6 cm. The tree seedlings were those with diameter size class <2 cm as recommended by Luoga (2004) and Lejju (2004) and each individual of the tree species in the regeneration plot were enumerated. Information (parameters) gathered from this study were the diameter at breast height (DBH), species composition, regeneration potentials (density of seedlings, saplings and poles in reference to a hector unit) and number of individual trees per hector (density).

Plants were identified to species level in the field and those found difficult to identify in the field, specimens were identified through comparison with the preserved specimen in the herbarium of Botany Department University of Dar es salaam.

Data analysis

The diversity of plant species was determined from the raw data obtained using Shannon's diversity index (Shannon and Weaver, 1948) as follows:

$$Diversity\ Index\ (H') = -\sum_{i}^{\infty} pi \ln pi$$

Where *pi* = ni/N, the number of individuals found in the *ith* species as a proportion of the total number of individuals found in all species. ln = natural logarithm to base *e*.

The assumption underlying this formula can be confirmed when there is a proportionate distribution of plant species in the woodland. The Shannon -Wiener diversity index assumes that individual species are sampled randomly from an even larger population, and that each representative sample species has an equal chance of being included at each sampling point (Magurran, 2004). However, species diversity was determined separately for each plot and the mean diversity was calculated from the indices by stand. Evenness (E) was calculated using the following formula (Alatalo, 1981):

$$Evenness(E) = \frac{H'}{\ln S}$$

Where *H'* is the Shannon-Weaver diversity index and *S* is the total number of species at a site. Paired sample test (t-test) was used to compare diversity, evenness, abundance, and regeneration of indigenous tree species in exotic tree plantation and the natural

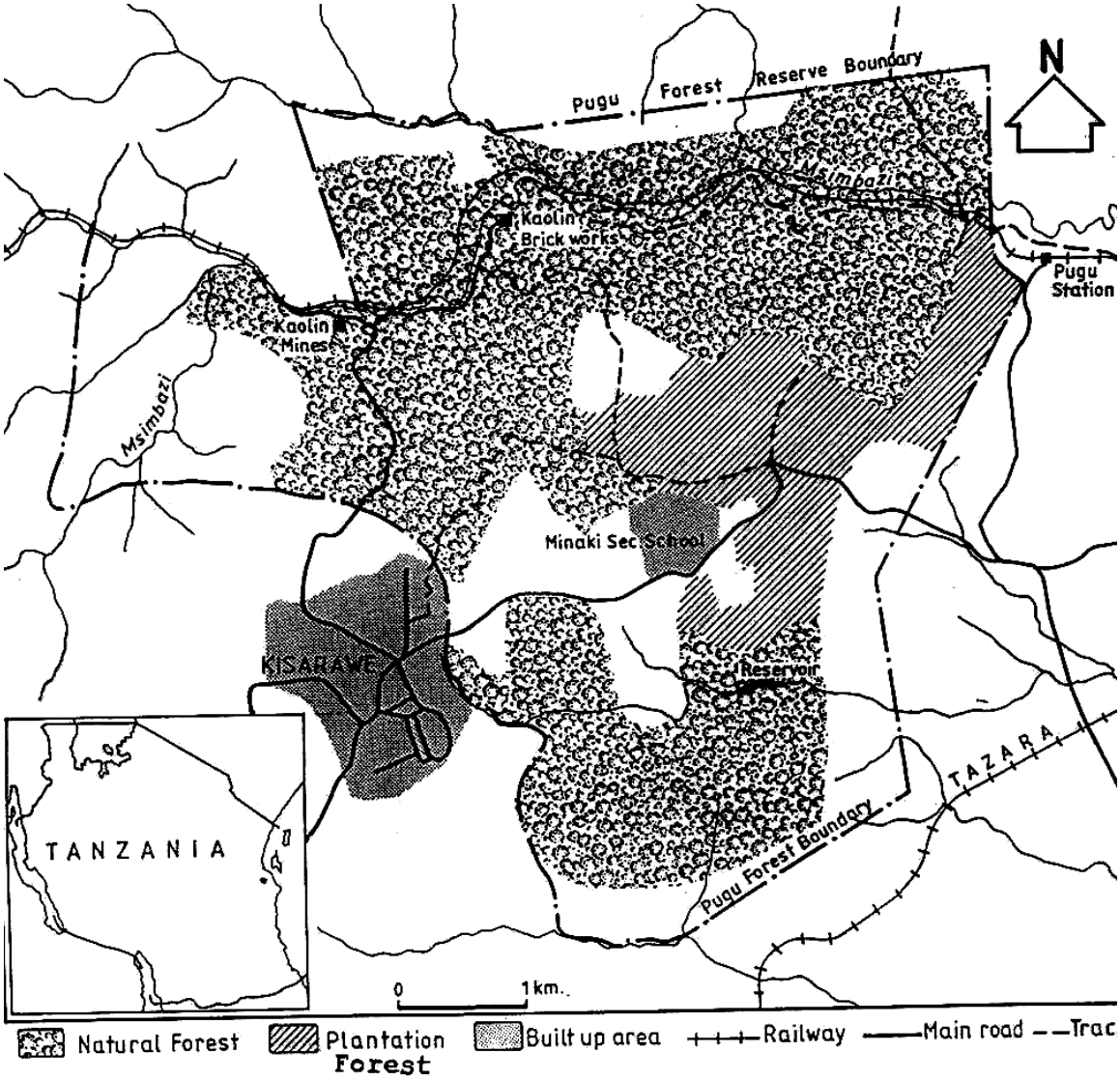

Figure 1. Map of Pugu Forest Reserve showing the location of exotic plantation between natural stands.

forest (Zar, 1999).

RESULTS

The indigenous plant species diversity and evenness in exotic tree plantation and the natural forest in Pugu Forest Reserve

There were a total of 260 (1400 stems/ha) individuals of indigenous trees distributed across 29 woody species in the natural forest and 380 (4800 stems/ha) individuals of indigenous trees distributed across 25 plant species in the exotic plantation in Pugu Forest. The results showed a higher plant species diversity in natural forest than in exotic plantation (Figure 2). On the basis of two sample t-test, the indigenous tree species diversity in natural forest was significantly higher than in exotic tree plantation ($t = 3.095$, $d.f = 8$, $P = 0.014$). Also the indigenous plant species in natural forest (uncleared parts) were significantly evenly distributed than those in exotic plantation ($t = 3.095$, $p = 0.014$) (Figure 2).

Population structure and diameter size class distribution of indigenous trees in the exotic plantation in Pugu Forest Reserve

There was a considerable difference in indigenous tree species abundance at different size classes based on the combined data from both the natural forest and the exotic tree plantation in Pugu Forest Reserve (Figure 3). It was

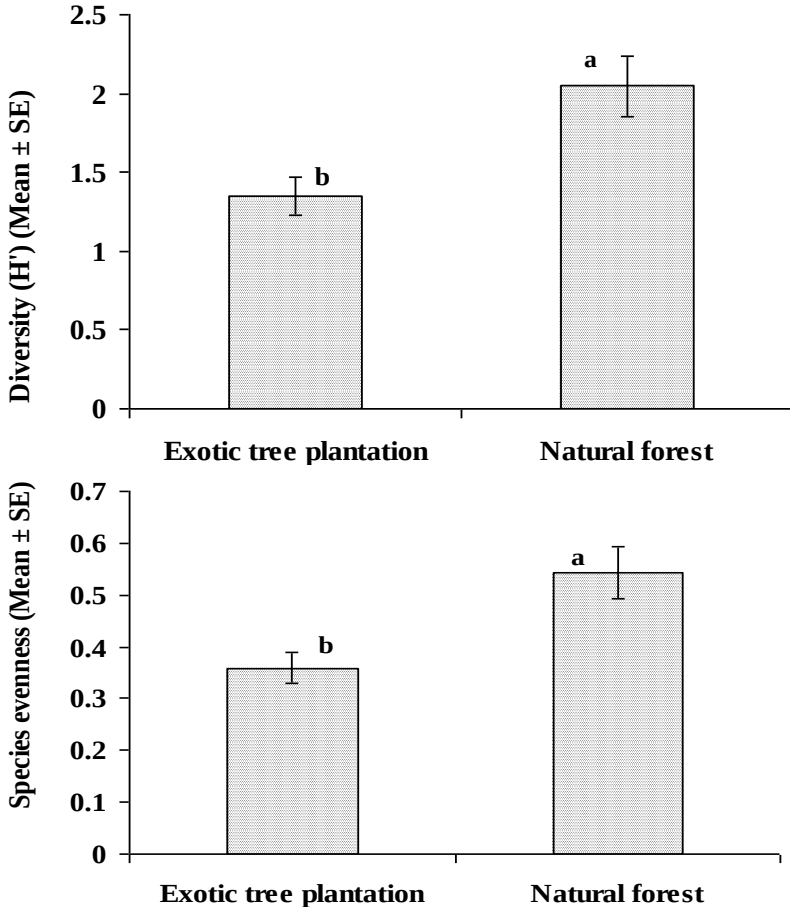

Figure 2. The diversity and evenness of indigenous plants species in plantation and in the natural stand of Pugu Forest Reserve (a and b means the difference in diversity and evenness is significant P = 0.05).

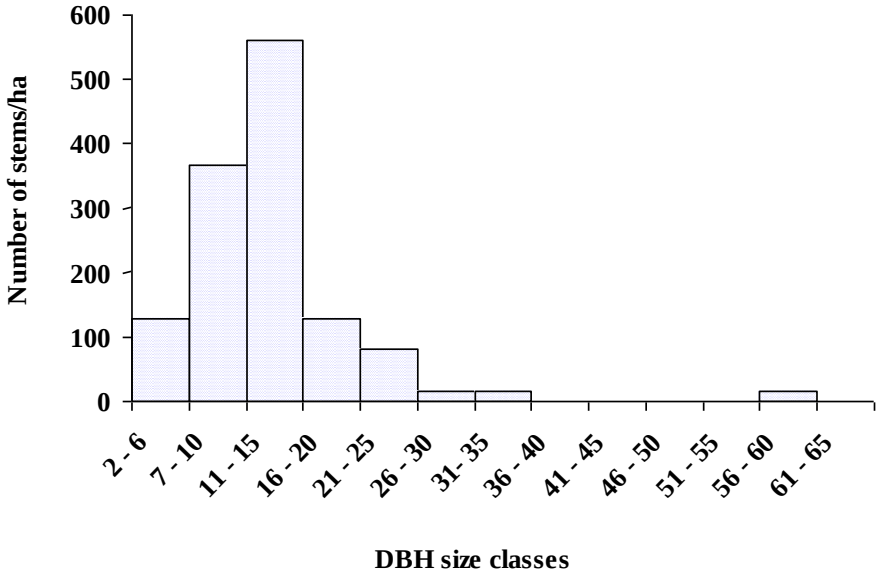

Figure 3. Population structure and DBH size class distribution of indigenous trees for the combined data from both natural forest and exotic plantation in Pugu Forest Reserve.

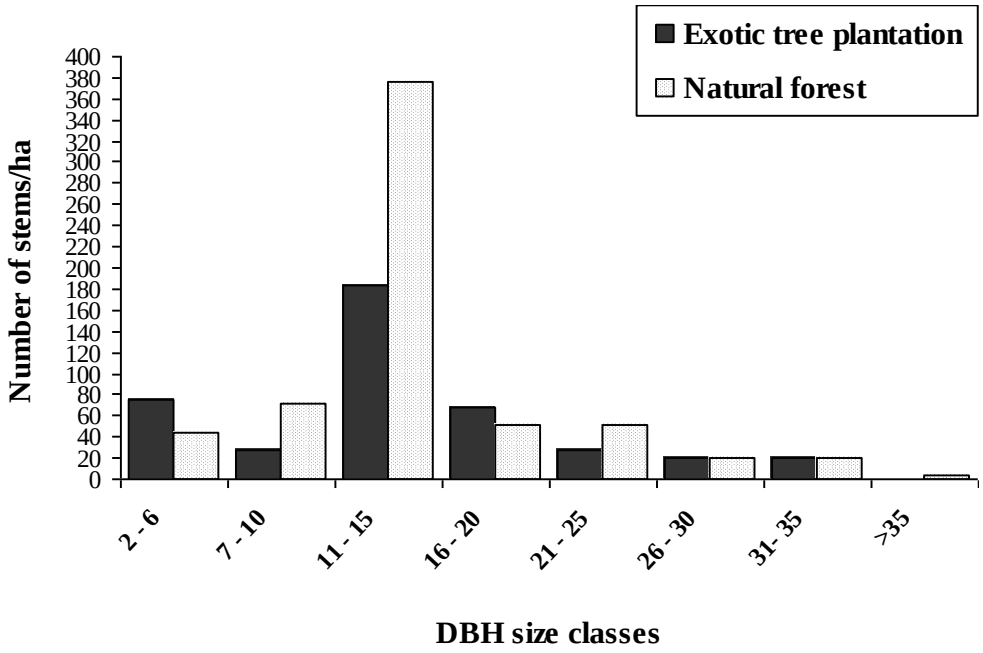

Figure 4. Comparative structure and diameter size class distribution of indigenous trees species between the exotic tree plantation and the native stand in Pugu Forest Reserve.

found in only a few individual trees in a range beyond diameter size classes of 7 and 25 cm for the composite data from exotic tree plantation and the natural forest (Figure 3). The population structure of indigenous trees showed a diameter size class distribution in form of a bell shaped pattern as many individuals were in size classes between 7 and 15 cm (Figure 3). Similarly, the comparative population structures of indigenous trees between individual stands (natural forest and the exotic tree plantation) also showed similar patterns where more individuals were at diameter size class of 11 to 15 cm (Figure 4). The size class distribution at breast height (DBH) of many individuals of the four selected dominant tree species in the exotic tree plantation were between 10 to 20 cm for *Hymenaea verrucosa* Geartn, 10 to 30 for *Afzelia quanzensis* Welw and 10 to 35 cm for *Senna siamea* Delile. The population structures of *Hymenaea verrucosa* Geartn and *S. siamea* forms an inverted J-shaped pattern with many individuals at low size classes and many are missing at high size classes (Figure 5). However, high density of individuals at lower size classes within an individual species implies an expanding population through active recruitment of small sized individuals. However, *Pteleopsis myrtifolia* (M. A. Lawson) Engl. & Diels had few individuals at lower diameter size classes than at higher size classes and only a few individuals are being recruited to higher size classes.

On the other hand, *A. quanzensis*, one of the native and highly valued timber tree species recorded in the plantation showed poor representation throughout the size class (Figure 5). This size class structure was also identified in the natural forest as an indication that *A. quanzensis* is vulnerable to exploitation in both vegetation stands.

The abundance and regeneration potential of indigenous trees in the exotic tree plantation

The t-test showed a significantly higher abundance of indigenous plant species than exotic species in the plantation ($t = 5.035$, $d.f = 8$, $P = 0.0010$) (Figure 6). This reflects secondary succession of indigenous plants through natural regeneration. The assessment of the regeneration pattern that was based on seedlings, saplings, poles and trees per hectare in the plantation and natural forest in totality. Higher regeneration potential was recorded in the natural forest than in the plantation (Figure 7). The comparison by paring similar growth form sizes of the indigenous tree regenerants between natural forest and the plantation showed significant difference for saplings ($t = 50.25$, $df = 8$, $P<0.05$) and poles ($t = 84$, $df = 8$ $P<0.05$) (Figure 7). Similarly, higher density of seedling recruitments was recorded in the exotic tree plantation than in the natural forest. However, on the basis of t-test, the difference in densities of indigenous tree seedlings between the native stand and the plantation was marginally significant ($P = 0.0507$). Low tree densities of indigenous trees were recorded in both exotic tree plantation and the native stand, however the difference was not significant ($P>0.05$). Both habitat types showed

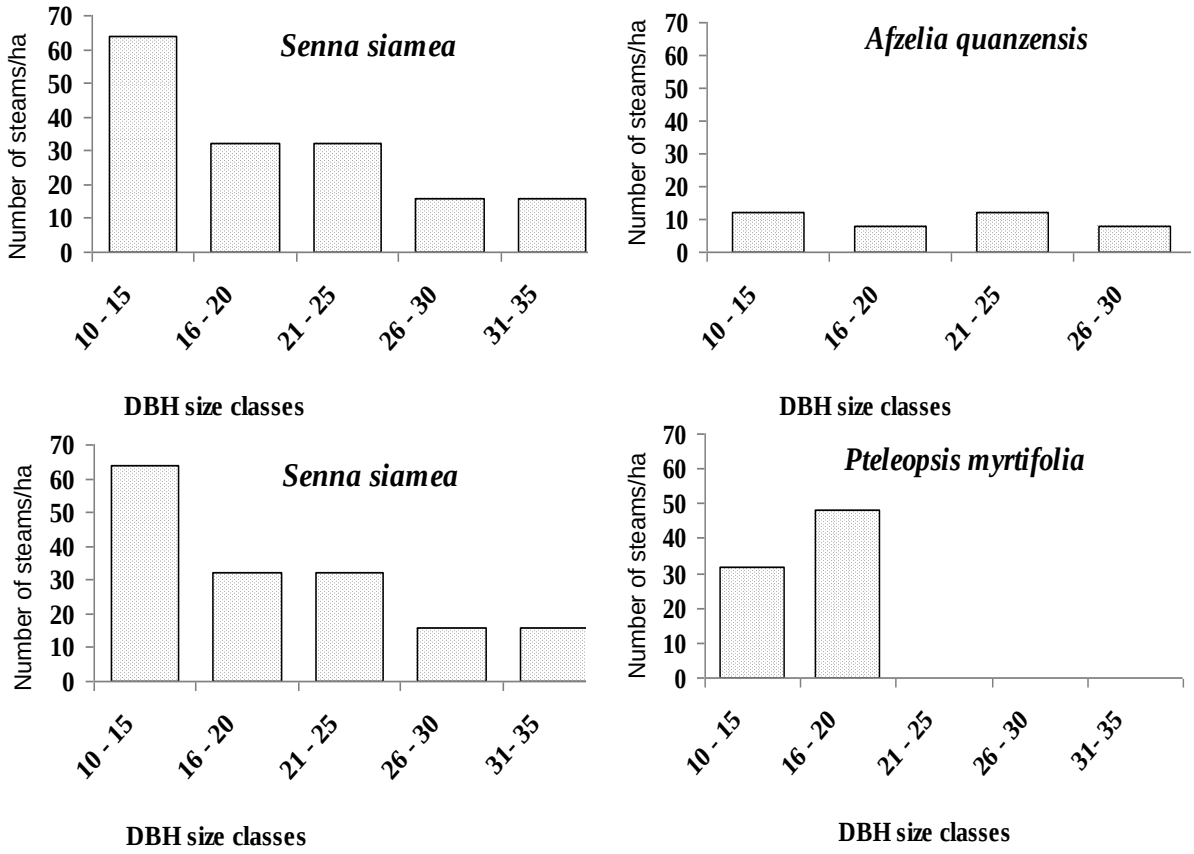

Figure 5. The DBH size class distribution of the most common indigenous tree species in the exotic tree plantation in Pugu Forest Reserve.

Figure 6. Variation in abundance between indigenous and exotic species in the plantation. Different letters (a and b) means the difference is significant at P = 0.05.

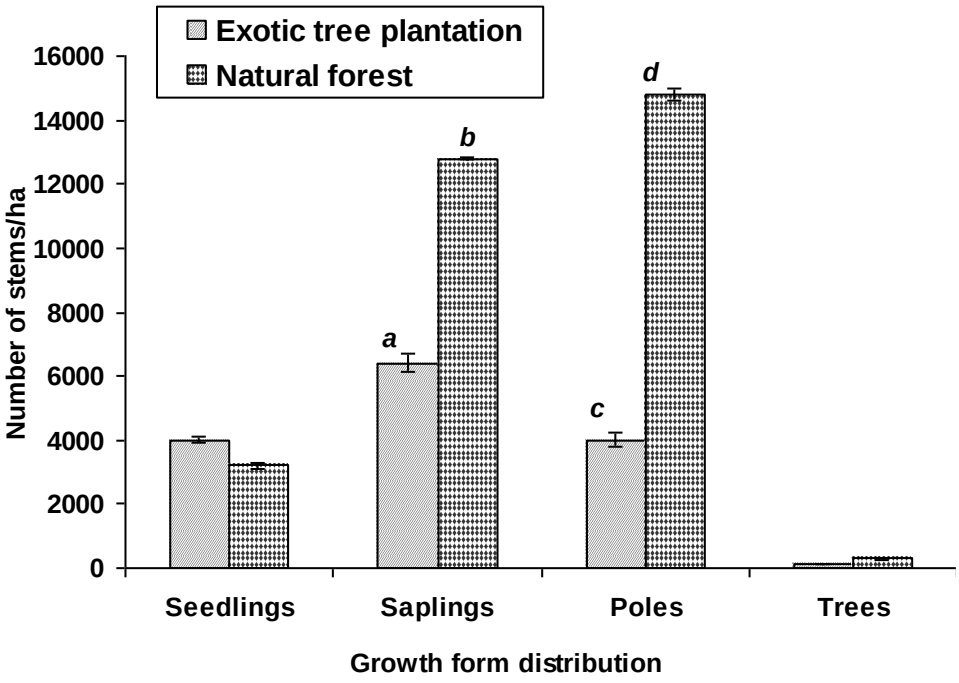

Figure 7. Comparative population structure and growth size distribution of indgenous trees in the natural forest and exotic tree plantation in Pugu Forest Reserve (the size classes are presented in terms of mean stem density per hectares including standard error). Different letter in the bar graph means the different is significant at P = 0.05.

low seedling density surviving to the saplings, poles and small size class trees with slightly decline in the large size classes (Figures 7 and 8).

The partitioned growth forms for each regeneration size class in the plantation showed that sapling contributing high percentage proportion (43%) of all the growth forms in the plantation followed by seedlings (26%) and poles (26%) of the total regeneration count while the percentage proportion for trees was only 5% (Figure 8).

DISCUSSION

The indigenous plant species diversity and evenness in plantation and the native stand in Pugu Forest Reserve

Most naturally regenerated indigenous tree species in natural forest were more diverse than in the exotic plantation. Low indigenous tree diversity and evenness may be contributed by the slow pace of indigenous tree species succession in the exotic tree plantation in Pugu Forest Reserve. Regardless of the presence, high abundance of woody species in the natural forest adjacent to the plantation, the diversity in natural forest (2.045 ± 0.191) was lower than in other Tanzanian coastal forests with similar habitat conditions such as Pande (2.415 ± 0.022) which is a highly conserved forest reserve (Photo 1). Lower diversity in the native stand in Pugu Forest than other forests may be caused by exploitation pressure which is still going on in this forest. Although, low diversity exists in the exotic plantation since many indigenous tree species that are present in the adjacent natural forest are not represented in the plantation. On the other hand, some indigenous trees found regenerating in the plantation had no representation in the natural forest. Probably, the indigenous species regenerants in the exotic tree plantation are originated from trees that have been selectively exploited recently in both native and exotic stands or from soil seedbank. Some indigenous plants may not have regenerated to co-exist with exotic trees regardless of the presence of their seeds in soil seedbank. This can be a preliminary evidence of the presence of higher species diversity in the natural forest than in the exotic tree plantation. Florence et al. (1986) reported that *Eucalyptus globulus* allowed successful regeneration of native plants under its canopy contributing to the increase in species diversity. Similar findings are being reported in this study that *E. maidenii* highly fostered regeneration of native species such as *P. myrtifolia* and *A. quanzensis* (Photo 2) and some populations of *Manilkara sulcata*, *Abizia glaberriena, Acacia brevispica, Albizia gummifera Albizia petersiana, Carrissa edulis, Dichapetalum stuhlmannii, Grewia microcarpa, Grewia platyclada* and *Xylotheca tetensis*

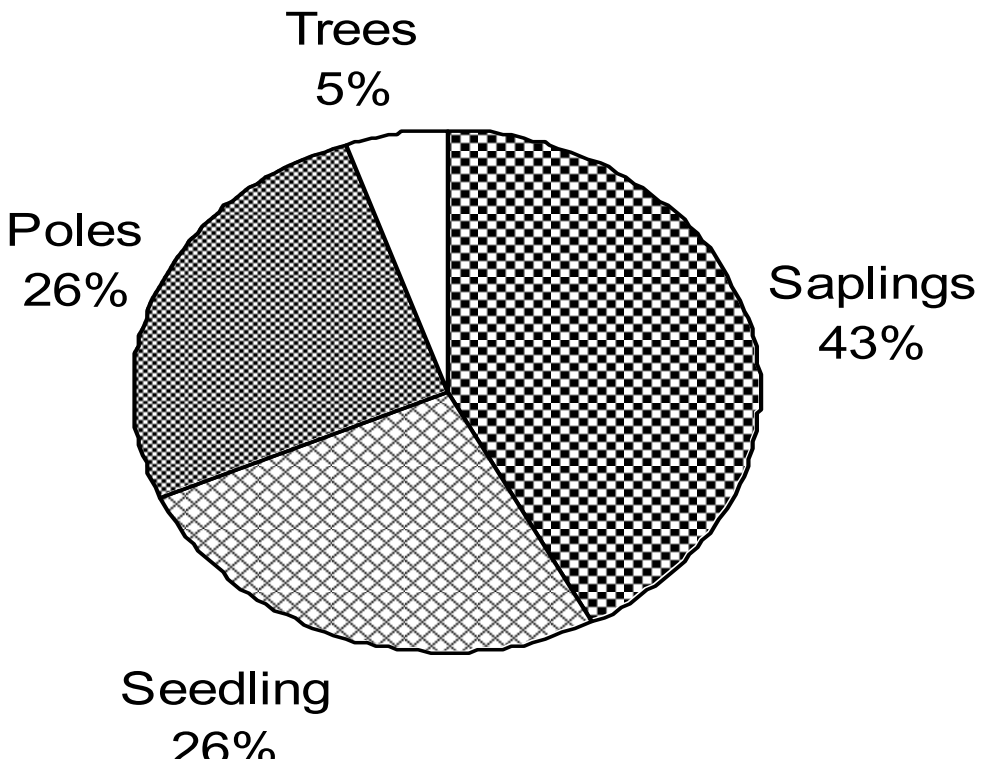

Figure 8. The percentage proportions of indigenous plant species regenerants (in different size classes) in the exotic tree plantation in Pugu Forest Reserve.

were also represented. However, *Hymenaea verrucosa, Landolphia kirkii, Alchornea laxiflora, Milletia usaramensis, Ozoroa mucronata, Polysphaeria parvifolia, Suregada zanzibarica, Blepharis maderaspatiensis* and *Deinbolium borbonica* were not found co-existing with exotic tree species in the plantation rather co-existed with other indigenous species in the natural forest stands.

High abundance of a naturally regenerated indigenous tree species under *S. siamea* stands as in the adjacent natural forest in Pugu Forest Reserve implies that *S. siamea* could not suppress the regeneration of indigenous tree species rather co-exists in the exotic tree plantation (Photo 3). However, non-selective exploitation of both indigenous and exotic trees in the plantation has been intensive at all size classes which affects the forest recovery through natural regeneration. One may expect to find exotic trees dominating in the plantation at different size class distribution as trees, poles, saplings and seedlings. If this could have been the case, then it could have been possible to utilize forest resources at different size classes to cater for people's needs. In contrast, most individuals of *S. siamea* remained as coppices without a significant number of new recruits at low size classes. As observed in the field, exotic tree stands cannot satisfy the nearby human population needs because it has been already overexploited and insignificant regeneration is taking place.

Population structure and size class distribution of indigenous trees in exotic tree plantation and the native stand in Pugu Forest Reserve

Plant population structure may change due to changes in recruitment of individuals at low diameter size classes or exploitation of individual at high size classes or throughout the class size structure. The population structural change is the function of regeneration pattern of individuals within the community (Cunningham, 2001). The size class distribution of naturally regenerating plant species in this study provides insight of their regeneration pattern of both indigenous and exotic trees. Ecologically, there is co-existence of individuals both with small and large size classes among successional guilds unless disturbance has occurred. The diameter size class structure and distribution of woody species was characterized by the absence of certain size classes in both the exotic tree plantation and the natural forest (Photo 4). This suggests that recruitment has been affected during the course of establishment of the current population structure. The presence of many trees with size classes below 35 cm diameter in Pugu Forest was an indication that some indigenous plant species that grow beyond these size classes were missing in both exotic tree plantation and the natural forest. This type of class size structure implies a population recruitment

bottleneck caused by intensive exploitation. This means that plant species with high diameter size classes in Pugu Forest Reserve have been selectively exploited and the forest is intermittently recovering through natural regeneration.

Pugu Forest Reserve is at close proximity to human settlements and therefore suffering from high exploitation pressure. In both exotic tree plantation and the natural forest, there were a few individuals with diameter size classes lower than 7 cm as well as indigenous trees with diameter size classes higher than 25 cm due to poor recruitments and exploitation pressure within these ends. Lack of individuals at low size classes and mature reproductive individuals may be related to their regeneration failure in combination with over exploitation for poles, fuel wood, charcoal burning and timber extraction. Selective cutting of matured trees leaving out the few stunted and genetically poor individuals causes population decline (Lyaruu et al., 2000). Regeneration of indigenous plant species in exotic plantation depends on seed dispersal mechanisms from mature plant species from the native stand and the soil seed bank. If a few stunted and genetically impoverished individual tree species are left behind after selective exploitation, recovery through natural regeneration may proceed slowly. This may lead to interruption of the regeneration pattern if disturbances occur at any portion within the size class structure. Diameter size class distribution both in exotic tree plantation and the native stand appears with a bell shaped curves. This is an indication of poor recruitment and the plant populations are likely to crush if intensive disturbance continued in Pugu Forest Reserve. The size class distribution for a few exotic trees in the plantation such as *S. siamea* had an inverted J-shaped pattern with many individuals in low size classes and a few in high size classes (Figure 7). This implies that their populations are expanding through active recruitment of individuals at lower size classes.

Whilst *P. myrtifolia* had a few individuals at lower size classes than at higher size classes as an indication of poor recruitment and probably exploitation for poles and small size class trees (Photo 2). *A. quanzensis*, one of the native species recorded in the plantation as well as in natural forest showed poor representation throughout the class size structure (Photo 3). This is an indication of regeneration failure of this species caused by overexploitation at all size classes and the remaining individuals of this species are unsuitable for specific use due to poor quality.

The indigenous plant species regeneration pattern in an exotic tree plantation in Pugu Forest Reserve

Successful regenerating plant species is a function of the number of individuals at both lower (which contribute a significant number of poles, sapling and seedling) and higher size classes including the reproductive individual trees (that are capable of contributing a significant number of viable seeds). High density of indigenous regenerants for example in *S. siamea* stand implies a regeneration success and intimately co-existence with this exotic tree (Photo 3). Florence et al. (1986) urged that, some exotic species may co-exist with indigenous plant species and both can equally naturally regenerate. Although, some exotic tree species may promote regeneration of indigenous species; some tend to suppress them. Feyera and Demel (2001) pointed out that exotic tree plantation may foster the regeneration of native wood species. Similarly, Julius et al. (2000) reported that exotic plant species allows successful regeneration of indigenous tree species and this observation was used as a means to restore the disturbed areas. However, Lejju (2004) found lower regeneration potential of indigenous plant species under exotic woodlot than what was observed in the natural forest. This contradicts with findings from studies highlighted earlier (Florence et al., 1986; Julius et al., 2000; Feyera and Demel, 2001) as well as the findings from this study such that indigenous species regenerated in the exotic tree plantation, co-existed with *S. siamea* but out-competed other exotic trees.

The difference in regeneration potential between the exotic plantation and the native stand was not significant. This implies that indigenous trees can equally compete and successfully regenerate in the exotic plantation as it was in the native stand in Pugu Forest Reserve (Photos 2 and 3). There has been again failure of the recently trials within natural forest in Kazimzumbwi, a forest reserve adjacent to Pugu on the southern border, that aimed mainly to establish plantation for exotic timber species such as *Tectona grandis, S. siamea, E. maidenii, P. patula* and *Hevea brasiliensis* and one indigenous tree (*Pterocarpus angolensis*) (Burges and Dickinson, 1993). However, only pine plantation was successfully established such that only *P. patula* successfully regenerated and colonized in the plantation. The two forests (Pugu and Kazimzumbwi Forest Reserves) are adjacent to each other and have similar habitat conditions and equally affected by similar types of anthropogenic activities. Since *P. patula* successfully regenerated in Kazimzumbwi Forest, therefore Pugu forest can also be regarded as marginal to suitable site for *P. patula* plantation only since other exotic species regenerated poorly in the area. On the other hand, natural regeneration of plant species in a particular habitat may depend on each species colonization power (Sawyer, 1993). Colonizing characteristics of exotic species occasionally compete successfully against native plant species for resources (Sawyer, 1993). *Trema orientalis* L. Blume and *Lantana camara* L. (Photo 5) in particular does not regenerate in intact natural forest rather in disturbed forest parts and was the most common species in the plantation due to previously clearance of natural

vegetation for establishment of exotic tree plantation. This means that not all members of regenerating exotic trees in the plantation should have representatives in the natural forest.

Some invasive plant species (*T. orientalis* and *L. camara*) from elsewhere can colonize and dominate parts in the exotic tree plantation since clearance of the previous natural forest was a form of disturbance. This can be supported with a study by Brokaw (1985) that successional plant species in tropical forests can regenerate in large gaps created by human disturbance. Demel (1996) reported that under naturally regenerated individuals in the plantation stands, seedling populations dominates, followed by saplings and the proportion of the tree category amounts lowest. This is opposed to findings from this study that saplings contributed the highest proportions followed by poles and seedlings; however trees contributed lowest in the exotic tree plantation (Figures 7 and 8). Colin et al. (2006) pointed out that exploiting reproductive adults reduces the potentials for regeneration. Furthermore, Muchanguzi et al. (2007) pointed out that active regeneration could have been influenced by the presence of relative abundant reproductive mature trees scattered in the forests. However, poor seedling establishment might be contributed by intensive exploitation of mature reproductive individuals and therefore limiting the amount of propagules in both exotic tree plantation and natural forest.

In this study, high proportion of individuals of lower size classes in the plantation (sapling, seedlings and poles) is an indication of active recruitment regardless of low densities due to intensive exploitation in all size classes.

Conclusion

The establishment of exotic tree plantation through clearing part of the native stand was a good idea towards protecting indigenous plant species and the Pugu Forest Reserve in general. This was a potential management plan of forest reserves through providing alternative forest resource needs to the surrounding communities. However, the successful colonization of exotic trees in the plantation has been poor such that the indigenous trees recovered significantly through natural regeneration. The exotic tree plantation fostered the regeneration of indigenous trees and has enhanced secondary succession over time by providing a nurse effect for the colonizing indigenous tree species. Generally, native stand had high diversity than in exotic plantation, however abundance of indigenous trees in the plantation was higher than that of exotic trees. Although only a few tree species were selected for establishment of a plantation but their regeneration capacity has been low in favour of diverse indigenous trees. This conclusion is similar to that of Feyera et al. (2001) that exotic tree plantations enhanced plant diversity of indigenous species. Within the plantation, indigenous species out-competed exotic trees in terms of regeneration potential. The increased abundance of indigenous species inhibits performance of exotic species. Therefore, the strategy of establishing exotic trees in areas formerly pre-dominated by indigenous plant species as management plan for providing alternative forest resource to the surrounding community cannot work properly as a means to conservation of Pugu Forest Reserve. This is due to exotic tree species regeneration failure and easily being out-competed with indigenous plant species in the plantation.

For this reason, monitoring of regeneration in the plantation was a necessity to ensure successful regeneration of exotic trees to provide sufficient forest resources to the surrounding community and conserve natural forest resources in Pugu Forest Reserve.

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APPENDIX.

Photo 1. The regenerating indigenous tree species of the native stands in Pugu Forest Reserve (the trees in the photo are regenerants of *Antiaris toxicaria* and *Scorodophloues fischeri*).

Photo 2. The *Pteleopsis myrtifolia*, one of the indigenous trees (on the left of the photo) regenerating in the exotic tree plantation co-existing with *Eucalyptus maidenii* in Pugu Forest Reserve.

Photo 3. The *Afzelia quanzensis*, one of the indigenous valued timber tree regenerating in the exotic tree plantation together with other native species co-existing with *Senna siamea* (on the left side of the photo) in Pugu Forest Reserve. All individuals of *Afzelia quanzensis* that had low DBH size classes were beyond these sizes that have been exploited.

Photo 4. Exploitation of both large and small DBH size class trees in the plantation and the naïve stand in Pugu Forest Reserve (the log on the left side is *Afzelia quanzensis* and pieces in the right part is of *Senna siamea*).

Photo 5. Regenerated population of invasive plant species (for example *Lantana camara* L.) in the exotic tree plantation in Pugu Forest Reserve. Clearance of natural forest for establishment of plantation was a form of disturbance which invited colonization by invasive species.