



Effects of Large-Scale Teak Plantation Establishment on Plant Species Composition and Diversity in Kilombero Valley, Tanzania

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ABSTRACT

Kilombero Teak Company (KVTC) have cleared more than 7,500 ha of natural miombo woodland since 1992, to establish a teak plantation in Kilombero valley. Currently, less is known about how this large teak plantation supports the previous existed plants species before its establishment. This study, investigated the understory plant species found in teak plantation and made reference on natural remnants around the plantation. The main hypothesis was that, natural remnants around the teak plantation would be richer and diversified in species, than teak plantation. Nested plots of 40 m x 20 m, 20 m x 10 m and 1 m x 1 m were established and used to survey plant species within plantation and natural remnants. Results showed that, natural remnants and plantation were 58% similar in plant species recorded. Natural remnants observed to have a statistically significant higher plant species richness ($p = 0.043$), families ($p = 0.049$) and abundance ($p = 0.004$) but lower plant species diversity ($p = 0.01$) than the plantation. The higher plant diversity scenario in teak plantation, shows that a plantation can support a variety of non-teak plant species that existed in the valley before its establishment in any favorable

condition.

Key words: Natural remnants - plant species richness - plant abundance.

INTRODUCTION

Teak (*Tectona grandis*) is a large deciduous tree in a flowering family of Lamiaceae (Lowe and Volkaerts 2013). This species is native to Myanmar, India, Thailand, and Laos, covering 23 million ha of natural forest (Kaewkrom *et al.* 2005, Cañadas *et al.* 2018). High demand for teak products since the 14th century led to its introduction into plantation even far from its original earthly locality (Hansen *et al.* 2017). To date, teak tree species has been introduced to about 65 countries in the tropical and subtropical regions (Verhaegen *et al.* 2010). As a result, teak plantations are estimated to cover about 5.7 million hectares globally (Koonkhunthod *et al.* 2006).

Global increase in teak cover has been catalyzed with its high growth rate and usefulness in production of furniture, boats, carvings veneer, and turnings in the global market (Palanisamy *et al.* 2009). Teak plantations have high production proportion, making them crucial in wood market industries (Calvino-Cancela *et al.* 2012). The tree has high capacity of surviving against



pests and diseases while providing a high quantity of wood products at a relatively low cost of production and time, even outside their original locality, as an exotic species (Cubbage *et al.* 2012).

In Africa, teak tree was introduced for the first time in 19th century to countries like Benin, Cameroon, Cote d'Ivoire, Ghana, Senegal, Sudan, Tanzania, and Togo (Huang *et al.* 2015). Beginning of the 20th century, the first teak plant was introduced in the garden at Dar es Salaam, Tanzania by planting seeds from India (Malende and Temu 1990). In 1992, Tanzania experienced the first large investment on teak tree plantation in Kilombero valley, Morogoro (Johansson and Isgren 2017). This plantation was established by Kilombero Valley Teak Company (here after KVTC) following high demand for teak wood products in the world market (Bekker and Monteus 2004).

Development of teak plantation in the valley was in expense of natural vegetation loss in the valley (Hinde *et al.* 2001a). The activity of establishing the new plantation in the area, involved clearing most of miombo woodland (Bamford *et al.* 2010). Out of 28,000 ha that KVTC holds, about fifty percent of land was found to be suitable in producing high-quality teak wood required in the world market (Bekker and Monteus 2004, Bergius *et al.* 2020). However, a recent study in the valley by Msofe *et al.* (2019) reported that, the extent of converting the previously natural miombo woodland into exotic teak tree cover by KVTC and other small scale farmers in the valley has reached around 30% to date.

The tradition of converting natural vegetations into exotic plantations is doubted and less supported globally (Hartman *et al.* 2010). Exotic tree plantations are considered to be large green deserts with just simple structure that can barely support existence of native species to

most of activists (Horak *et al.* 2019, Kremir and Bauhus 2020). Saha (2001) and Harley and Gara (2003) supported that teak tree plantation had lower species, once compared to natural or abandoned old fields. Another study on exotic and monoculture tree plantation of *Eucalyptus* sp. showed that, plantations had fewer species richness, abundance, and diversity of herbs than native forests (Goded *et al.* 2019).

However, the contribution of large plantations such as that of teak in lessening the harvesting pressure in natural forests is remarkable (Kanowski *et al.* 2005, Lindell and Thurston 2013). As a result, there is no doubt that we will need them even in future to come. The focus is now required to understand how the existing plantation affects the previous native plant species before its establishment, so as to improve the management practices (Calvino-Cancela *et al.* 2012). Studies on the effect of teak plantation establishment on biodiversity at Kilombero Valley have been limited on large mammals (Hinde *et al.* 2001a, Bonnington *et al.* 2009) and Anurans (Hinde *et al.* 2001b).

Less is known about the existed plant species before the development of teak plantation in the valley. The information concern native plants survival in teak plantation is crucial considering the contribution of plants on earth and its living forms (Chittapur and Patil 2017). To a large extent, plant diversity has supported existence of different other species such as bird and insects (Ollerton *et al.* 2011, Lindell and Thurston 2013). Plants provide essential habitats and foraging materials that in returns enhance pollination and dispersal in plantation ecosystem (Corlett 2016). Seeing the importance of plant in provision of ecosystem and biodiversity restoration, this study was conducted to assess the effectiveness of teak plantation in supporting previous plant species existed in an area before its development using the



reference from the retained natural remnants around teak plantation.

MATERIALS AND METHODS

Study site

This study was conducted in teak plantations owned by KVTC. This plantation is found at Kilombero Valley located south east of Morogoro region in Tanzania. The Valley is one of the largest East Africa's seasonal wetlands, centered 80030'16.96" S; 112 36015'51.19" E with an area of about 7,946 km² (Jenkins *et al.* 2002; Höllermann *et al.* 2021). The established KVTC plantations have been divided into four blocks, two on each side of

the river Kilombero. Those blocks include the Nakafulu block (in Ulanga districts), Mafinji block (in Malinyi districts), Narabungo block, and Ichima block (both in Kilombero district). Each block has several compartments with trees of different ages, surrounded by small to large conserved natural vegetation patches (hereafter natural remnants) (Fig. 1).

Climate

Climate in the valley is normally sub humid tropical with a distinct seasonality (Höllermann *et al.* 2021). The rainfall is largely unimodal with an annual mean between 1200 and 1400 mm (Jenkins *et al.* 2002).

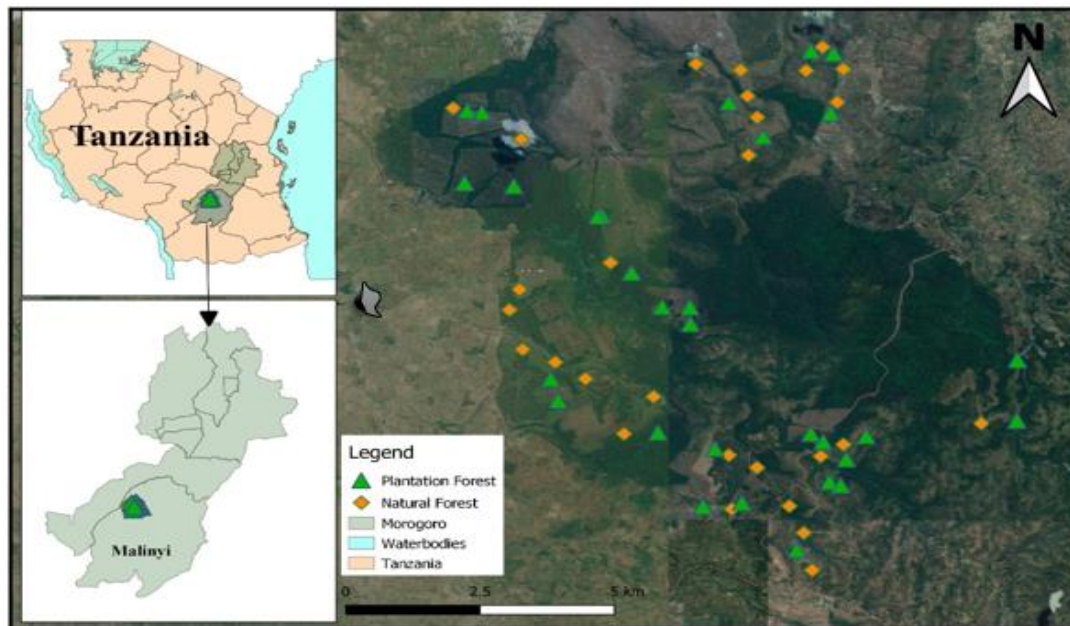


Figure 1: Map of a study area

Sampling design

Data was collected in teak plantation compartments of different ages and natural remnants around the plantation. A reconnaissance survey was conducted between October and November 2020 before the commencement of data collection. Mafinji block was purposively selected out of the rest blocks for data collection because, it was observed to possess most of the vegetation types present

in other blocks and was easily accessible at a time of survey compared to the rest. Stratified random sampling method was applied and data was collected from 32 plots in teak plantation and 31 in natural remnants respectively (Table 1). The method aimed to capture the difference on habitats variations in plantations and natural remnants observed in the study site as described in Table 2.

Table 1: Proportion of age groups and habitat types surveyed in this study



Vegetation	Age/Habitat	Number of plots	Proportion (%)
Teak plantation	Young age	11	34.38
	Medium age	11	34.38
	Old age	10	31.25
Natural remnants	Woodland	14	45.16
	Forest	6	19.35
	Grassland	5	16.13
	Riparian	4	12.90
	Wetland	2	06.45

Nested plots of 40 m x 20 m were laid 300 m apart and 100 m away from the edges of habitat at each habitat. In each 40 m x 20 m plot, other small subplots of 10 m x 10 m, and 1 m x 1 m were established in the center. The large plot (40 m x 20 m) was used for sampling trees while, 10 m x 10 m plot was used to sample shrubs, ferns, and climbers and 1 m x 1 m plot was used in sampling grasses and herbs (Asare *et al.* 2020).

Data collection

During the survey, the following vegetation information was recorded; plant life form, scientific name, and the number of each individual. All the collected plants were identified in the field by a botanist, with the aid of plant identification field guide books to species level.

Data Analysis

All data collected were coded into a Microsoft Excel spreadsheet. Plant species richness and number of families were computed by counting the number of each plant species and family in each particular habitat. To obtain relative abundance for each plant species, we divided the number of individuals of a particular species by the total number of all individual species combined in such vegetation as follows;

$$\text{Relative abundance} = n / N$$

where n is the total number of plant individuals of a particular species and N is the total number of plant individuals of all species.

Table 2: Description of major vegetation types found in Kilombero valley teak plantation

Major vegetation	Habitats	Description	Management practice
Plantation	Young age	Involved all plantation compartments that range from 0 to 5 years of age. New teak plants emerge from the root stem as buds after the activity of wood teak harvest.	Post-harvest burning, slashing, application of weed killers
	Medium age	Involved all the compartments aged from 6 to 10 years of age.	Slashing, pruning, and thinning
	Old age	Involved all plantation compartments aged from 11 to above years. At this age, teaks are ready for harvest.	The pre-harvest slashing of grasses and shrubs
Natural	Woodland	Involved all habitats dominated by trees that are spaced apart and have a full range of understory plant types.	Conserved area
	Forest	Involved an area of land with at least 0.5 ha of natural trees, with a minimum tree crown cover of 10% and with trees which have the potential or have reached a minimum height of 3 m at maturity	Conserved area
	Grassland	Involved habitats that are vegetated with herbaceous with less than 10 percent tree and shrub cover.	Conserved area
	Riparian	Involved all vegetation units along the banks of a river or water stream.	Conserved area
	Wetland	Involved all vegetated areas of land with flooded soil or with an indication of frequent prolonged flooding.	Conserved area



One-way ANOVA was performed in R-program to compare means of plant species richness, families, and relative abundance within each habitat in a vegetation type. A proportion of each plant life form was generated and illustrated in a histogram for each vegetation by taking the sum of individuals in a particular plant life form in a habitat over the overall sum of all individual plant life form in a particular habitat. Moreover, Sorenson's similarity coefficient was equally calculated between pairs of habitats as follows:

$$\text{Similarity} = 2a / (2a + b + c)$$

Where a = number of plant species common to both two habitats; b = number of plant species only belonged to the 1st habitat; c = number of species only belonged to the 2nd habitat. The Bray–Curtis's dissimilarity index was used in PAST software to measure the extent of similarity in plant species composition between all habitats in this study. Shannon-Weiner Diversity Index (H'), Dominance (D), and Evenness were also computed in PAST software using the formula:

$$H' = - [\sum P_i * \text{LN}(P_i)]$$

where H' is the Diversity Index, P_i is the proportion of each species in the sample, and $\text{LN}(P_i)$ is the natural logarithm of this proportion.

Dominance (D) was measured by the following formula:

$$D = 1 - \{[\sum n / n-1] / \{N * (N-1)\}\}$$

where n is the total number of plants of a

particular species and N is the total number of individual plants of all species.

Evenness Index (J') was calculated using the ratio of observed diversity to maximum diversity using the equation:

$$J' = H' / H_{max}$$

where H' is the Shannon Wiener Diversity index and H_{max} is the natural log of total number of species.

A diversity t-test was used to compare plant species diversity between the two vegetations. The level of significance was set at $p < 0.05$ for this study.

RESULTS

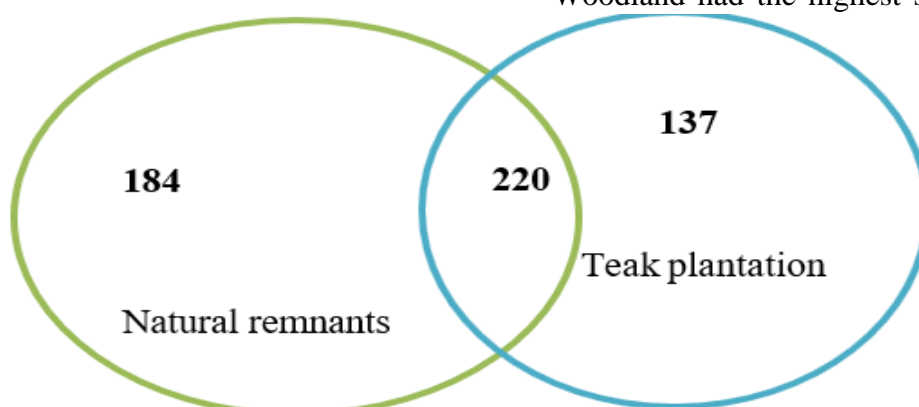
Plant species composition and relative abundance

A total of 541 plant species belonging to 88 families were recorded in natural and teak plantations habitats. In this study, 184 plant species were restricted to natural remnants, 137 species to teak plantation while 220 plant species were found in both vegetations (Fig 2). Climbers, ferns, grasses, herbs, shrubs, and trees were the major plant life forms recorded in this study. About 98 percent of plant individuals were contributed by trees, shrubs, herbs, and grasses while the remained 2 percent was contributed by climbers and ferns. Among the habitats, natural habitats observed to have a statistically significant higher number of plant species ($F_{1, 65} = 4.26, p = 0.043$), families ($F_{1, 65} = 4.03, p = 0.049$) and relative abundance ($F_{1, 65} = 8.17, p = 0.004$) than teak plantation.

Figure 2: Number of plant species common and unique to natural and teak plantations

Plant species composition and relative abundance in natural remnants

A total of 404 plant species from 78 plant families were recorded in natural remnants. Woodland had the highest species richness





followed by forest, grassland, riparian, and wetland remnants. On the other hand, high numbers of plant families were recorded in woodland, forest, and riparian remnants. The highest relative abundance was observed in woodland followed by forest, grassland, riparian and the least was in wetland remnants (Table 3).

Table 3: Plant species composition and relative abundance in natural habitats

Habitat	Species richness	Number of families	Relative abundance (%)
Woodland	193	50	49.7
Forest	145	46	16.9
Grassland	135	43	11.6
Riparian	121	44	11.1
Wetland	34	21	10.7

Comparison of plant species composition within the natural habitats revealed a significant variation in plant relative abundance ($F_{1, 65} = 14.31, p = 0.001$) and species richness only. However, among the groups wetland revealed to be significant different ($p < 0.05$) in mean value from the rest of the groups after Post hoc test. Within the natural remnants, relative abundance ranged between 0.02 and 3.56. Highest plant life forms were recorded from trees, grasses, and shrubs from six plant families in this study.

Such species included *Diplorhynchus condylocarpon*, *Brachystegia bussei*, *Sorindeia madagascariensis*, *Margaritaria discoidea*, *Uapaca nitida*, *Pseudolachnostylis maprouneifolia*, *Phragmites australis*, *Cyperus esculentus*, *Oplismenus hirtellus*, and *Pericopsis angolensis* (Table 4). Within the natural habitats, trees, shrubs, herbs, and grasses appeared to have higher number of individuals. However, ferns appeared to be restricted to forest remnant while climbers contributed to lower plant individuals in almost all of the natural habitats (Fig 3).

Table 4: Plant species with high relative abundance in natural habitats

S N	Species	Family	Plant form	Relative abundance (%)
1	<i>Diplorhynchus condylocarpon</i>	Apocynaceae	Tree	3.6
2	<i>Brachystegia bussei</i>	Fabaceae	Tree	3.2
3	<i>Sorindeia madagascariensis</i>	Anacardiaceae	Tree, shrub	2.4
4	<i>Margaritaria discoidea</i>	Phyllanthaceae	Tree, shrub	2.3
5	<i>Uapaca nitida</i>	Phyllanthaceae	Tree	2.2
6	<i>Pseudolachnostylis maprouneifolia</i>	Phyllanthaceae	Tree	2.1
7	<i>Phragmites australis</i>	Poaceae	Grass	2.1
8	<i>Cyperus esculentus</i>	Cyperaceae	Grass	1.9
9	<i>Oplismenus hirtellus</i>	Poaceae	Grass	1.7
10	<i>Pericopsis angolensis</i>	Fabaceae	Tree	1.6

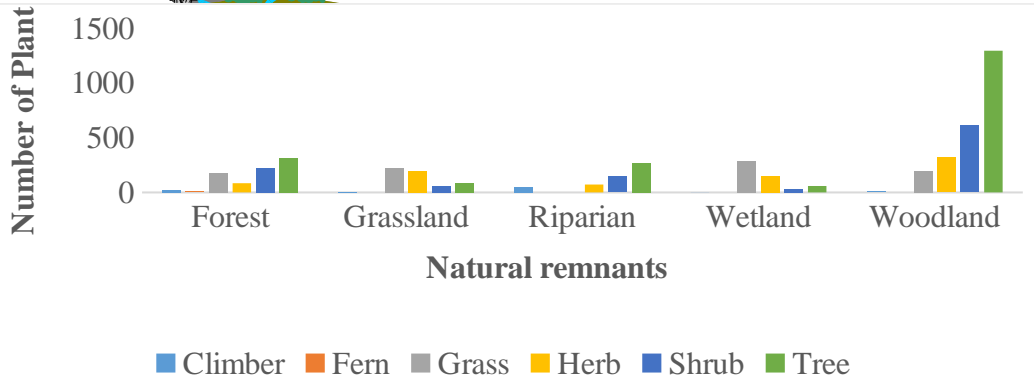


Figure 3: Distribution of plant life forms in natural remnants

0.05) in the number of plant species, family or relative abundance across the teak plantations. However, the relative abundance ranged between 0.35

and 3.60 in teak plantations. Trees and shrubs were the dominant plant life forms from Apocynaceae, Fabaceae, Ebenaceae, Nyctaginaceae, and Rutaceae families that together contributed to species with higher proportion. Such species included *Harrisonia abyssinica*, *Diploerhynchus condylocarpon*, *Brachystegia spiciformis*, *Diospyros squarrosa*, *Millettia usaramensis*, *Diospyros fischeri*, *Holarrhena pubescens*, *Commicarpus pedunculatus*, *Commicarpus pedunculatus*, *Dalbergia melanoxylon*, and *Pterocarpus angolensis* (Table 6).

Plant species composition and relative abundance in teak plantation

A total of 357 plant species from 69 families were recorded in teak plantations. The highest number of plant species was recorded in old age plantations followed by young age and the least was in medium age plantations. The highest number of plant families was recorded at a young age followed by old age and medium age habitats. Young age plantation had the highest plant relative abundance that was followed with old age and medium age habitats (Table 5).

There were no significant variations ($p >$

Table 5: Plant species composition and relative abundance in teak plantation

Habitats	Species richness	Number of families	Relative abundance (%)
Young age	190	51	39.2
Old age	191	52	35
Medium age	171	48	25.8

Table 6: Plant species with higher relative abundance in teak plantations

S N	Species	Family	Plant form	Relative abundance (%)
1	<i>Harrisonia abyssinica</i>	Rutaceae	Shrub Herb	3.6
2	<i>Diploerhynchus condylocarpon</i>	Apocynaceae	Tree	3.3
3	<i>Brachystegia spiciformis</i>	Fabaceae	Tree	2.7
4	<i>Diospyros squarrosa</i>	Ebenaceae	Tree	2.3
5	<i>Millettia usaramensis</i>	Fabaceae	Tree	1.6



6	<i>Diospyros fischeri</i>	Ebenaceae	Shrub Tree	1.4
7	<i>Holarrhena pubescens</i>	Apocynaceae	Shrub	1.4
8	<i>Commicarpus pedunculatus</i>	Nyctaginaceae	Herb	1.3
9	<i>Dalbergia melanoxylon</i>	Fabaceae	Tree	1.3
10	<i>Pterocarpus angolensis</i>	Fabaceae	Tree	1.2

Teak plantations were highly dominated by trees, shrubs and herbs. Ferns recorded the lowest proportion of individuals among all the plant life forms in all of the three plantations, followed by climbers and grasses (Fig. 4). Also, Sorensen similarity index showed that wetland had the lowest similarity index when compared with all other habitats. The lowest value was recorded against the Wetland habitat (0.045). The maximum value (0.457) of plant species similarity was recorded between Medium age and Old age

plantations (Table 7). The Bray–Curtis dissimilarity index for plant species composition formed four distinct clusters (Fig. 5). One cluster is comprised of woodland and young age plantation. The second cluster involved forest, riparian habitats that were observed to be similar to old and medium age plantations. The previous was much similar to woodland habitats and young age plantations as compared to grassland and wetland habitats that were less similar to the rest of the



Fig ure 4: Distrib ution of plant life forms in teak plantat ions

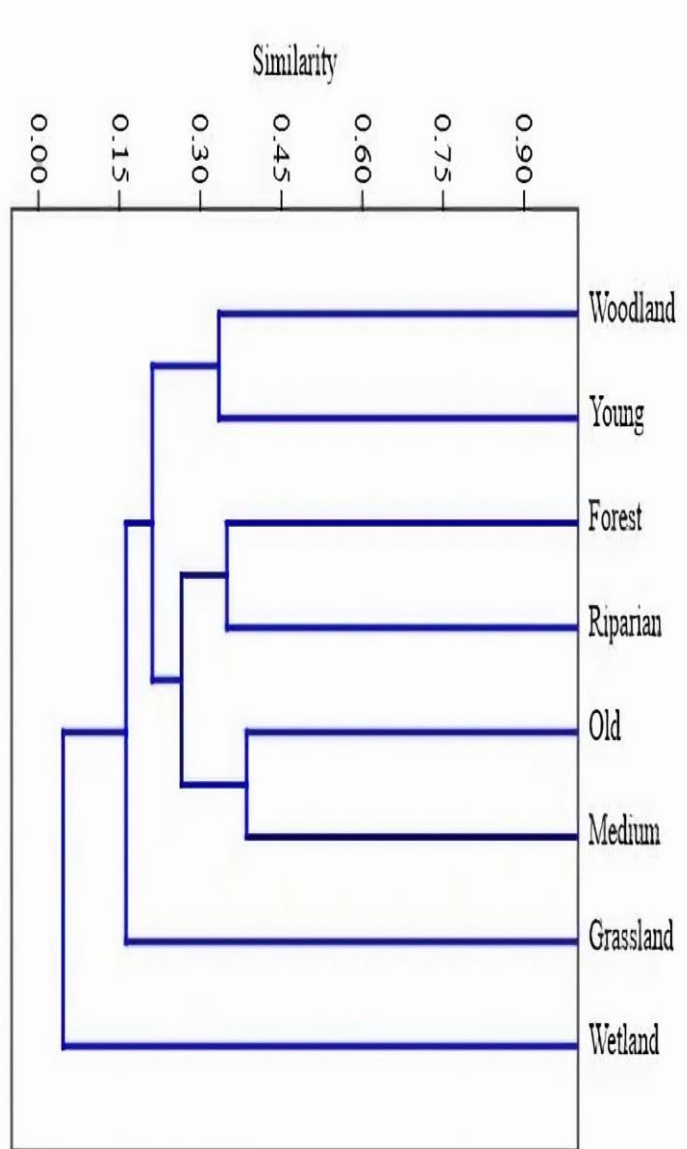


Table 7: Plant Sorensen similarity index among habitats in teak plantations and natural remnants

Habitats	Young age	Medium age	Old age	Forest	Grassland	Riparian	Wetland	Woodland
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Young age

Medium age 0.442



Old age	0.452	0.457						
Forest	0.302	0.395	0.45					
Grassland	0.317	0.23	0.302	0.186				
Riparian	0.391	0.393	0.382	0.386	0.227			



Wetland	0.045	0.069	0.09	0.079	0.189	0.08	
Woodland	0.429	0.39	0.426	0.263	0.38	0.3	0.302

Figure 5: Bray–Curtis similarity measure of plant species composition between teak plantation and natural habitats

Plant species diversity, dominance, and evenness in natural remnants

Shannon’s diversity index indicated that natural remnants had a significant ($t = 3.7663, p = 0.01$) lower species diversity ($H' = 5.17$) than teak plantation ($H' = 5.28$). Grassland had higher plant species diversity followed by woodland, forest, riparian and the least was in wetland remnants. However, the observed variation in plant species diversity was not significantly different ($p > 0.05$) among the natural habitats.

Species dominance was highly recorded in wetland followed by riparian, forest, and the least was in the grassland remnants. However, within the natural remnants, *Oplismenus hirtellus* dominated forest, *Combretum fragrans* dominated grassland, *Sorindeia madagascariensis* dominated riparian, *Phragmites australis* dominated the wetland, while *Diplorhynchus condylocarpon* dominated the woodland. Plant species in natural habitats were more evenly distributed in grassland and the least was in wetland (Table 8).

Table 8: Plant species diversity in natural habitats

Parameters	Forest	Grassland	Riparian	Wetland	Woodland
Shannon (H')	4.398	4.455	4.323	2.617	4.411
Dominance (D)	0.023	0.0207	0.0267	0.1111	0.02182
Evenness (J)	0.561	0.6374	0.6235	0.4029	0.4267

Plant species diversity in teak plantation

Young age plantation had higher plant species diversity than the rest plantation age habitats. As teak trees matured, plant diversity was observed to decrease in medium to old age plantations respectively. However, along teak plantations, there was no notably significant variation ($p > 0.05$) in plant species diversity. High species dominance and lower species evenness were recorded in old age plantations. However, within the teak plantations, *Brachystegia spiciformis* dominated young age, *Diospyros squarrosa* and *Uvaria welwitschii* dominated the medium age while *Harrisonia abyssinica* dominated the old age. On the other side, Medium age plantations had high species evenness followed by young age plantations (Table 9).

Table 9: Plant species diversity, dominance, and evenness in teak plantation

Parameters	Young age	Medium age	Old age
Shannon (H')	4.809	4.738	4.719
Dominance (D)	0.0119	0.0128	0.0167
Evenness (J)	0.6417	0.6679	0.5867

DISCUSSION

Plant species composition and relative abundance

This study was conducted between December and February 2021, which is a low rainy season for the area. However, given the nature of the soil in the area, there was enough water in the soil that influenced high growth rate of the understory vegetation observed in teak plantation



habitats (Pers. Observation). Along the plantation's understory, trees and shrubs life forms were highly distributed compared to other plant life forms as for the most of natural remnants. Closeness of the natural remnants to plantation's habitats, have influenced availability of enough non teak seed bank in the plantation through seed dispersal.

However, the distribution of plant life forms, was higher in natural remnants than teak plantation. Such superiority is contributed by presence of management activities such as slashing, burning or utilizations of weed killers in the plantation which affects growth of understory vegetation (Boreux *et al.* 2013). Management activities, intends to prohibit regeneration of non-teak plants especially grasses which have a competitive advantage towards other plant life forms in the plantation (Asare *et al.* 2020). In consequence, they affect accumulation and decomposition of organic matters on the soil and leads to lower number of plant species, families and abundance (Saha 2001, Goded *et al.* 2019).

In most circumstances, natural remnants are characterized with a variety of old vegetative structures that are rich in energies from decomposed organic matters and enhance growth of different plant species (Hartman *et al.* 2010). Allelopathy is one of the factors that is less observed in natural remnants but have proved to inhibit growth of native plant species within the teak plantation (Healey and Gara 2003). However, there is high plant species similarity observed in this study between natural remnants and teak plantation. The observation suggests that, other factors apart from it could have influenced the results.

Such factors may include the observed open canopy in young to medium age plantations which created a favorable habitat for native plant species recruitments (Lopez-Bedoya *et al.* 2021). According to Halpern and Spies (1995) and Loumeto and Huttel (1997) as

the plantations matures, there is an increase in accumulation and decomposition of organic matters on the soil floor. That facilitates rapid growth of tree canopy and shade cover which leads to increase in plant species richness and abundance (Boch *et al.* 2013).

However, number of species in our study had no notable difference between young age and old age plantations. Such circumstance may have attributed by the factor that young age habitat in the case of our study, was a result of what remained after teak harvest in old age habitats. As a result, the high seed bank remained after harvest exercises, germinates rapidly to produce different species of different plant life forms as that of old age habitat. On the other side, medium age and old age habitats, had the highest species similarity in this study. Such observation is influenced by reduction in management activities as teaks matures, leading to decrease in alteration of species within the habitats.

Plant species diversity

Large part of teak plantations habitats in this study was closely surrounded with natural remnants, a reserved forest and a wetland (Pers. Observation). According, to Loumeto and Huttel (1997) closeness of the plantation to a natural forest favors floristic diversity and its development towards secondary native forest. Thus, it's not surprisingly that teak plantation recorded higher and significantly plant species diversity than natural remnants. This observation differs from other studies conducted on teak plantations such as that of Saha (2001) and Healey and Gara (2003) that reported high plant species diversity in natural remnants than in teak plantations.

Conferring to Mligo (2018) species diversity is significantly determined by species evenness and dominance. In this study, natural remnants had high species dominance and lower species evenness than teak plantations. On top to that, plant relative abundance was relatively close in



teak plantation habitats as compared to natural habitats. The higher the plant species evenness and closer its abundance, directly influences its higher plant species diversity (Moore 2013). Within the plantation, plant diversity was observed to decrease as teak plantation habitats aged. This observation is in line to those of López-Bedoya *et al.* (2021).

As teaks mature, canopy closure increase while decreasing in light penetration, lower temperature and moisture on the soil floor (Asare *et al.* 2020). Such condition creates a poor optimal condition for seed dormancy to break and results in high species dominance and less evenness in the understory of a plantation (Carnus *et al.* 2006). Despite woodland dominating the natural remnants in terms of area size, high species richness, and abundance, grassland dominated species diversity over the rest. Such results have been influenced with low species dominance and high species evenness observed in grassland over the rest habitats.

CONCLUSION AND RECOMMENDATION

This study has demonstrated that teak plantation can facilitate growth of plant species of different life forms that are more diversified as natural habitats. However, the higher diversity in plant species observed in this study has highly contributed to the closeness of this plantation to the nearest natural habitats as we observed. Natural vegetation between or around teak plantations act as a seed bank that supplies in this vast desert of teak plantation. Considering the trends deforestation in Tanzania, this study suggests the use of teak trees in other degraded areas as an alternative for biodiversity restoration. However, such exercise should consider using a form of mixed-species plantations in early stages of its development.

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