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Spatio-Temporal Variation in Species Diversity between Plantation and Secondary Forest of Kakamega Tropical Rain Forest in Kenya

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ABSTRACT

The Kenyan tropical rain forest is under imminent threat of degradation due to the changes in climatic condition and rapid growing human population. This study determined the changes in woody species diversity between natural forest (secondary forest) and plantation forest during different stages of plant succession. The secondary data from three forest blocks was obtained from Kenya Forest Research Institute and used to derive species diversity. Variation in species diversity and abundance was analyzed by SPSS software. Species richness was significantly different between plantation and secondary forest types ($P<0.001$). Shannon diversity index (*H*') values ranged between 0.3 and 3 where highest *H*' was in a middle aged secondary forest. Vegetation types with low species diversity had higher species evenness. Stem density was highest in the secondary forest (1900±18.57 stems ha^{-1}) compared to the plantation forest (516±20.27 stems ha^{-1}). The age of forest influenced the species richness in the plantation forest but species composition strongly influenced species richness in the secondary forest. Therefore, maintenance of higher species diversity in the secondary forest requires protection of remnant species which facilitates recruitment of new species while conservation of rare mature species could facilitate higher diversity in recovering plantation forest. There is need to change the current management practices, which is hardly suitable for maintaining the required plant biodiversity in the Kakamega forest.

Keywords: plantation forest; secondary forest; plant succession; woody species diversity.

INTRODUCTION

Tropical forests store the majority of the world's tree diversity, with an estimated 53,000 tree species (Talbot, 2010) as well as provide many goods and ecosystem services, such as prevention of soil erosion and preservation of habitats for plants and animals (Anbarashan and Parthasarathy, 2013). Besides climate change, forest fragmentation driven by degradation has been one of the most pressing global environmental challenges over the past few decades (Talbot, 2010; Newaj et al., 2016; Strassburg et al., 2010). The forests in the tropics are some of the habitats that have come under a great deal of degradation for several decades, but have received very little attention because of limited empirical research findings (Otuoma et al., 2020). It is therefore critical to assess the biodiversity conservation potential of secondary tropical and plantation forests by analyzing species biodiversity of tropical forests during succession.

Sustainable management of these forests requires good knowledge of all the natural forest resource and plantations through studies of the forest environment. Plantation forests currently represent approximately 187 million ha worldwide, an increase of approximately 20 million ha since 1995 (FAO., 2001; Otuoma et al., 2014). The increase in plantation forests has been accelerated by a decrease in natural forest area by 14.6 million ha per year with 1.5 million ha per year of natural forest cover being converted to plantation forest cover (FAO, 2001). Since majority of deforestation is occurring in tropical countries, several questions have been raised regarding the impacts of plantation forests on biodiversity. Although some plantation forests are typically viewed negatively and considered to be "biological deserts" (Hartley, 2002), little work has been done to establish a link between biodiversity and forest management in most forest types in Kakamega forest.

Secondary forests regrowing after abandonment of lands increase rapidly in extent and may constitute important biodiversity reservoirs (Grubb, 1977; Otuoma et al., 2014). Regeneration of tropical forest relies on several conditions and ecosystem processes along different stages in the life cycle of a tree (Wang and Smith, 2002). It requires the presence of pollinators in the case of sexual reproduction and of seed dispersers in order to escape the mortality under parent trees and to colonize vacant sites (Bleher and Böhning-Gaese, 2001; Ghazoul, 2005; Howe and Smallwood, 1982). Recruitment of seed is affected by secondary seed dispersal, microclimatic conditions, intra- and inter-specific competition, seed predation and herbivory.

Traditionally, studies on plant succession have focused largely on secondary forests. In recent times, however, it has been reported that plantation forest stands are also undergoing plant succession (Otuoma et al., 2014; Farwig et al., 2009b). Since plantation forests are intended primarily for timber production, it is important to understand the succession dynamics in these forests with a view of understanding tree species diversity and abundance over time and whether this warrants the change of forest management option from timber production to biodiversity conservation or both and how this would affect the silvicultural operations. Natural regeneration may be prevented due to grazing and lack of remaining sources of seeds; hence, natural selection is re-established by plantation of tree seedling (Otuoma et al., 2014). This study seeks to understand the similarities and differences in plant succession in the secondary forest of Kakamega. This study is expected to provide information to forest management decision makers in regard to silvicultural management of plantation forest stands.

Since the Kakamega tropical forests are under great anthropogenic pressure and require management interventions to maintain the overall biodiversity (Otuoma et al., 2014; Kituyi et al., 2018), it is imperative to understand tree species biodiversity as a vital instrument in assessing the sustainability of the forest, species conservation, and management in Kenya. Long-term biodiversity conservation depends basically on the knowledge of the structure, species richness, and the ecological characteristics of vegetation. The aims of this research paper are to compare species richness and evenness in natural secondary forest and plantation forest through successional stages by use of three measures of woody plant diversity (Shannon's (H'), Simpson's (D), and evenness (e) indices). The authors hypothesized that although richness and life form diversity vary greatly between units, plantations show lower values than natural forests, regardless of their composition and structure.

MATERIAL AND METHODS

Study area

The Kakamega Forest is located between longitudes 34°40'00" and 35°9'30" E and latitudes 0°29'30" and 0°3'00" N in western Kenya. It lies along the northeastern edge of the Lake Victoria basin. Along its eastern edge, rises the Nandi Escarpment which runs the western edge of the Rift Valley. Historic and biological evidence suggests that it once covered most of western Kenya and represents the easternmost edge of the Congolean forest belt that covered equatorial Africa (Kumelachew, 2008; Miao, 2008; Kendall, 1969; Kokwaro, 1988; Wass, 1995; Mitchell, 2004). Currently, it consists of a large forest block and six forest fragments (Peters et al., 2009). The main forest block is approximately 8,245 ha (excluding natural glades) and forest fragments, from 65 to 1370 ha. Almost 50% of the forest area has been lost since the forest was officially gazetted for protection in 1933. The study was carried out in Isecheno, Ikuywa and Kisaina blocks of Kakamega Rainforest (Table 1). The forest is renowned for its biodiversity and for laying claim to the title of the easternmost relic of the Guineo- Congolian rainforest (Kokwaro, 1988). The forest is home to a large number of endemic fauna and flora species. Yet, the remaining natural forest is under imminent threat of degradation due

Table 1. Plot size of the blocks in the Kakamega rainforest

Block	Plot size (ha)
Ikuywa	2.4416
Isecheno	2.8214
Kisaina	2.6934
Grand total	7.9564

to a rapidly growing population in its vicinity and a poverty rate far above the national average. The growing demand for forest resources and ecosystem services has continued to exert great pressure on the remaining forest fragments (Bleher et al., 2006; Gebrewahid and Meressa, 2020; Müller and Mburu, 2009).

The vegetation in the Kakamega forest consists of a disturbed primary forest, secondary forest in different stages of succession, mixed indigenous and exotic forest plantation and natural and man-made glades (Tsingalia and Kassily, 2009). The plantation forests comprise mixed indigenous species, indigenous monoculture species and exotic monoculture species, which were established between 1937 and 2005 (Lung and Schaab, 2006, 2010; KFWG, 2010).

Mixed indigenous plantation forests comprise *Olea capensis* L., *Croton megalocarpus*, *Zanthoxylum gilletii*. And *Prunus Africana* (KFWG, 2010). Indigenous monoculture plantations consisted of *Maesopsis eminii*, *Zanthoxylum gilletii* and *Prunus africana*, while exotic monoculture plantations comprised *Pinus patula*, *Bischofia javanica* and *Cupressus lusitanica*. Old-growth closed canopy natural forest stands are dominated by tree species such as *Funtumia Africana*, *Antiaris toxicaria*, *Ficus exasperate*, *Croton megalocarpus* and *Celtis mildebradii* (Lung, 2004).

Study design

This study was carried out in the Kakamega Forest (0° 10’ N & 0° 21’ N and 34° 47’ E & 34° 58’ E; Elev. 1,580 m), which covers 238 km^2 , of which 133 km^2 is forested, consisting of old secondary forest, young secondary forest, mixed indigenous plantation forest, and monoculture indigenous or exotic plantation forest (Mitchell et al., 2009).

Retrospective research design was adopted in carrying out the assessment in three blocks of Kakamega Forest, namely: Isecheno, Ikuywa and Kisaina. In each forest block, data was taken showing the DBH of trees species, tree height, species diversity (richness and abundance). In the forest block after disturbance, some trees species were planted; hence, a plantation forest and others grew on their own leading to a secondary forest. During the growth of different forests, self-thinning occurred and this also lead to arising of natural recruit during different stages of growth.

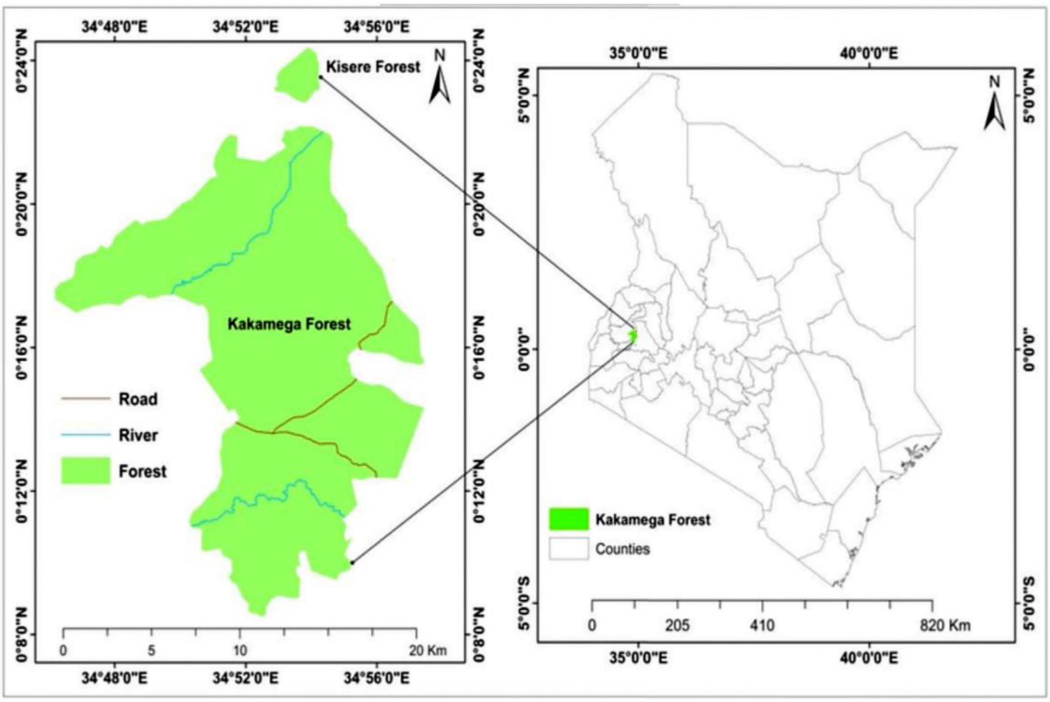

Figure 1. Kakamega forest located in western Kenya

Tree species planted include: *Bischofia javanica, Cupressus lusitanica, Maesopsis eminii* and *Pinus patula* which are exotic monoculture plantation.

The natural recruit include: *Acacia abyssinica, Acrocarpus, Afrocelasia sp, Albizia grandbractata, Albizia gummifera, Alchornea laxiflora, Alengium chinensis, Aningeria altissima, Antiaris toxicaria, Bequaertriodendron oblanceolatum, Bersama abyssinica, Bischofia javanica, Blighia unijugata, Bridelia micrantha, Casearia battiscombei, Casepourea ruwenzoria, Celtis afracana, Celtis gomphophylla, Celtis mildebradii, Chaetachme aristata, Chrysophyllum albidum, Clausena anisata, Cordia abyssinica, Croton megalocarpus, Croton silvatica, Cupressus lusitanica, Cussonia arborea, Diospyros abyssinica, Dovyalis macrocalyx, Erythrococca atrovirense, Eucalyptus saligna, Fagaropsis angolensis, Ficus exasperate, Ficus lutea, Ficus natalensis, Ficus sur, Ficus thoningii, Funtumia Africana, Harungana madagascariensis, Heinsenia diervilleoides, Kigelia musa, Lantana camara, Macaranga kilimandscharicum, Maesa lanceolata, Maesopsis eminii, Manilkara butungii, Markhamia lutea, Morus mesosygium, Olea capensis, Piliostigma thoningii, Pinus patula, Polyscias fulva, Premna angolensis, Prunus Africana, Psidium guajava, Rothmania longiflora, Sapium ellipticum, Solamun mauritiana, Spathodea campanulaata, Strombosia scheffleri, Trema orientalis, Trichilia dregiana, Trichilia emetic, Trilepisium madagascariense, Turrea holstii, Vangueria apiculata, Veperis nobilis, Vernonia sp, Zanthoxylum gilletii,* and *Zanthoxylum mildebradii.*

Data collection

The secondary data on tree species was obtained from KEFRI, to compare the data on woody tree species types, tree height, diameter breast height, species abundance and species diversity in secondary and plantation forest in the three blocks of Kakamega forest. The data contained: the blocks, vegetation type, year established, woody species, the recruit and planted species, the family, diameter breast height (DBH) and height of tree species.

Plant species diversity

This study utilized Shannon-Weiner diversity index (H') and Simpson's index of diversity (D).

Shannon-Weiner diversity index (H')

Shannon and Weiner (1963) index of diversity was calculated using the Eq. 1. Shannon-Weiner diversity index was measured through a combination of the number of species per sample (species richness) as described by Begon et al. (2006). This diversity index ranges typically from 1.5 to 3.5 and rarely reaches 4.5 (Gaines, 1999). This index (*H*') was applied as a measure of species abundance and richness to quantify diversity of the woody species. This index takes both species abundance and species richness into account:

$$H' = -\sum_{i=1}^{s} pi \ln pi \qquad (1)$$

where: *H'* is Shannon diversity index, *S* is the number of species, *pi* is a proportion of species (individuals) found in the *i*th species, and *ln* is the natural logarithm.

Simpson's index of diversity (D)

Simpson's index measures the probability that two individuals randomly selected from a sample will belong to the same species. It is a weighted arithmetic mean of proportional abundance. The value of Simpson's D ranges from 0 to 1, with 0 representing infinite diversity and 1 representing no diversity, so the larger the value of D, the lower the diversity. Simpson's index of diversity was calculated using Eq. 2:

$$D = \frac{\sum n(n-1)}{N(N-1)} \qquad (2)$$

where: *D* is the Simpson's index, *n* is the number of individuals each species, and *N* = the total number of individuals of the species for the site.

Data analysis

The data obtained was used to derive woody species richness, abundance and diversity. The species richness was described in Excel, species evenness was analyzed using Simpson diversity index. Tree species diversity was described using Shannon diversity index (Pena-Claros, 2003; Magurran, 2004; Newton, 2007). Variation in species diversity and abundance was analyzed using analysis of variance at 5% significance level (Buysse et al., 2004).

RESULTS

Species richness

Species richness ranged from ~5 to ~26 in both plantation types and secondary forest (Fig. 2). Although only a single tree species was planted in each forest, the high values implied possibility of secondary plant succession. Species richness was significantly different between plantation and secondary forest types (P<0.001). It was also noted that *Pinus patula* was significantly different from other plantation forest types (Table 2). Middle age had consistently higher diversity throughout the years compared to a young secondary forest type and hence, secondary plant succession was highly influenced by stand age (Fig. 2). When the data was compared within the years, species richness was significant across the measurement period with varying significant levels at P<0.05 and P<0.001.

Species diversity (Shannon diversity index)

The biodiversity did not vary greatly from between plantation and secondary forest types but varied greatly between years. Shannon diversity index (*H*') values ranged between 0.3 and 3 where highest *H*' was in the middle aged secondary forest. The differences were also noted in biodiversity between secondary forest types.

In the plantation forest, *B. javanica* had consistently lower diversity index than other species regardless of the age of the forest, which suggested that secondary plant succession was not influenced to a larger extent by stand age. As expected, Shannon diversity index indicated that species diversity of secondary forest increased with stand age in most of the other species and hence diversity tends to increase to certain age. When the data was compared within the years, Shannon diversity was significant across the measurement period with varying significant levels at P<0.01 and P<0.05.

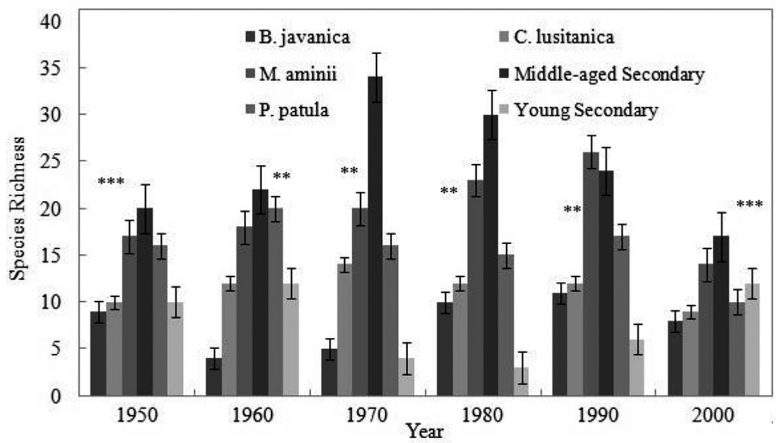

Figure 2. Species richness in plantation and secondary forest types in the Kakamega rainforest; data represents μ±SE; * = 0.01, ** = 0.05, *** = 0.001, Ns = Not significant

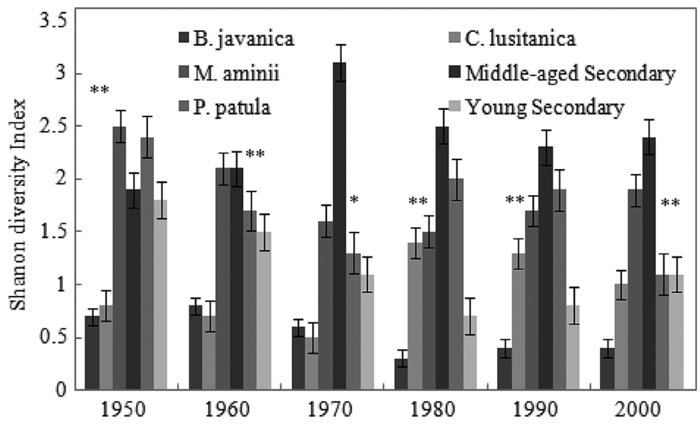

Figure 3. Species diversity in plantation and secondary forest in the Kakamega rainforest; data represents μ±SE; * = 0.01, ** = 0.05

Species evenness (Simpson index)

Vegetation types with low species diversity tended to have higher species evenness and vice versa. For instance the *B. javanica* plantation stand which had least species diversity recorded the highest species evenness (Fig. 4). In turn, the middle age secondary forest which had high species diversity recorded the lowest species evenness. The species were evenly distributed in both plantation and secondary forests, which increased with increase in the age of the forest. Similar to species richness, species evenness was significantly ($P<0.001$) different between the secondary and plantation forests (Table 2). When the data was compared within the years, species evenness varied during the measurement period but was not significant in 1980 and 1990. However, significant levels at $P<0.05$ and $P<0.001$, were recorded in 1950, 1960, 1970 and 2000.

Stem density was highest in secondary forest (1900±18.57 stems ha^{-1}) compared to a plantation forest (516±20.27 stems ha^{-1}). In all vegetation types, secondary plant succession led to a significant difference in stem density ($P<0.001$). This suggested that secondary plant succession was active in all plantation forests. Similarly, the DBH decreased significantly as a result of secondary plant succession in all plantation forest types ($P<0.001$). The pattern was similar in the plantation forest type with regard to mean tree density.

Species composition

In the each forest plantation (Bischofia, Pinus, cupressus, maesopsis) there were different species emerged in different canopy layers. The canopy layers were: emergent layer, main canopy, subcanopy layer, shrub layer, understory and saplings. This study identified over 1200 individuals that were distributed within the secondary and plantation forests. More than half of the identified species were found in the secondary forest with a quarter in middle aged secondary forests. The young secondary forest was dominated by a few early successional species. In this young forest, few rare species were also recorded (data not presented). In addition, the middle age secondary forest sites were more similar in species composition to a plantation forest than younger secondary forest.

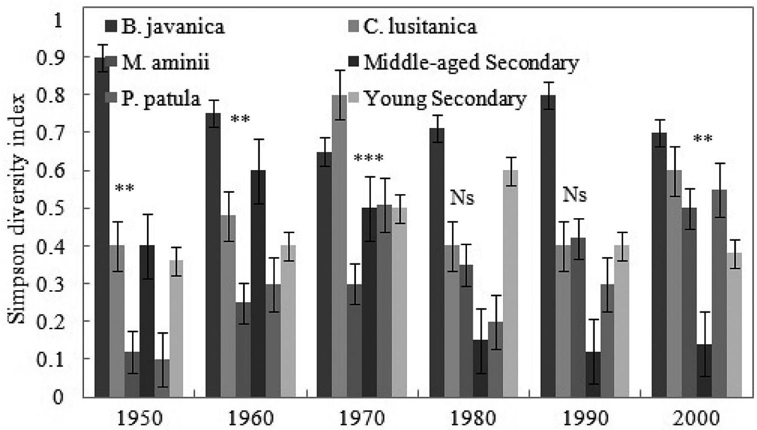

Figure 4. Species evenness as recorded using Simpson diversity index in the Kakamega forest; data represents μ±SE; * = 0.01, ** = 0.05, *** = 0.001, Ns = Not significant

Table 2. Relationship between measured indices for all vegetation types

Specification	Species richness	Species evenness	Mean dbh (cm)	Tree density (ha)
B. javanica	7.83±0.99 [a]	0.75±0.1 [a]	28±1.54	822±53.20 [a]
C. lusitanica	11.5±0.52 [a]	0.51±0.22 [a]	33±3.55	816±61.14 [a]
M. eminiiieminii	19.66±0.97 [a]	0.32±0.23 [a]	49.33±1.32	516±20.27 [a]
Middle-aged secondary	24.5±1.2 [b]	0.32±0.37 [b]	30±1.32	533±28.86 [b]
P. patula	15.66±0.82 [c]	0.33±0.31 [c]	30.16±2.54	700±58.40 [a]
Young secondary	7.83±1.4 [b]	0.44±0.14 [b]	15±1.25	1900±18.57 [c]
F value	16.75	7.71	2.62	2.51
P value	0.001	0.001	0.08	0.07

DISCUSSION

Tropical rainforest function have been disturbed within ecological time scales and hence viewed as an integral part these ecosystems. Generally, disturbances can be one of the management strategies where natural forests are cleared and left undisturbed for natural recruitment (secondary forest) or introduction of new species (plantation forest). Since tropical forest forms one of the rapidly expanding ecosystems (Chazdon, 2017), any management strategy must foster the increase in species diversity. The extent to which these tropical forests recruit and contribute to mature forest biodiversity has attracted extensive attention in the recent past (Wright and Muller-Landau, 2006; Laurance, 2007). Disturbance promotes high species diversity when intermediate in terms of intensity and frequency (Connell, 1978). In this study, high species diversity which varied depending on the forest type and forest age was found. The causes of such spatial variations in species richness have been explored for many taxonomic groups, from microscopic to global scales, using descriptions, experiments and spatial environmental models (Cornwell and Grubb, 2003; Yuelin et al., 2013; Kwon et al., 2018). Variation in species diversity in the current study could be attributed to a management system that led to regeneration of natural recruits (secondary forest type) and plantations. Variation within the natural recruits could be explained by spatial variation in soil environment, forest block ecology and evolution as well as temporal frequency and magnitude.

Tropical forest recovery from degradation is very important for conservation. The findings from the secondary forest ecosystems in this study showed potential for quick recovery due to high biological diversity inherent in mature forests. Restoration of the human impacted Kakamega forest ecosystem can be achieved inexpensively on large scale based on this increasing spatial extent. The obtained result indicates that young secondary forests had lower species diversity than the nearby middle aged forests. Since these diversity increased with forest age, it is possible that convergence in species within the forest community could be witnessed depending on the forest management. Stand age within secondary forests was demonstrated previously by Letcher and Chazdon (2009) to be an important predictor of increasing tree diversity. They also found such convergence in plant community composition within mature forests. Although tree compositions of the secondary forests were not similar to the plantations forest, young secondary forest species compositions converged with middle aged forests. Variation in species composition across the years within the plantations forest signified the role of inherent factors that influenced tree species growth and development in this ecosystem. Since specific factors were not considered, the recorded significant differences in diversity and species composition in the Kakamega forest ecosystem across the years requires further investigation. Furthermore, since the investigated site is an ecosystem that has been degraded for long periods (Kituyi et al., 2018), soil resources and propagule availability are important for regeneration as evidenced from high species diversity in the secondary forest. Therefore, the remnant forest played an important role for natural recruitment by accelerating succession via a range of biotic and abiotic processes. This confirms the previous findings where remnant trees provided perching and foraging habitat for vertebrate dispersers (Schlawin and Zahawi, 2008; Sandor and Chazdon, 2014), improved soil conditions for seedling establishment (Rhoades and Coleman, 1999), shaded out competitive plant species (Goosem and Tucker, 2013) as well as reduced microclimatic extremes of open habitats (Cole et al., 2010).

The obtained results indicate that the effect of remnant species pool on forest recovery is more pronounced in the secondary forest than the plantation forests. In general, the secondary forests exhibit higher species diversity than the plantation forests, since the disturbance is higher through soil plowing, species selection and high intensity disturbance as compared to self-regeneration in the secondary forest (Kituyi et al., 2018; Otuoma et al., 2020; Gebrewahid and Meressa, 2020). In the secondary forest, the niches have been basically fixed because of the existence of pioneer species and hence the role of regional species pool in forest recovery can be very strong. However, the plantation forest may have been affected by competition between local species and alien species, as well as other diverse random factors which led to low species diversity as well as species composition.

The obtained higher Shannon-Weiner and Simpson's diversity indices were driven by species richness and evenness in middle aged secondary forest which was comparatively similar to plantation forest types. The presence of higher species evenness and richness with corresponding higher Shannon-Weiner diversity has been reported by Gebrewahid and Meressa (2020). The variation in the forest species richness, diversity and evenness observed in the plantation forest could have been due to site characteristics and management strategies in the different forest blocks.

Mean tree species richness and evenness were not significantly different within the plantation forest except *P. patula* species. This was probably due to higher sampling frequency compared to the secondary forest which had generally a higher diversity. Since the secondary (natural) forest was intact, a low stem density was inevitable where larger DBH exhibited low tree species diversity. This has also been demonstrated in miombo woodland by Shirima et al. (2011) where high plant diversity may result in more effective resource utilization, and hence an increase in forest biomass.

The recorded low diversity within plantation forest in the investigated study site is likely to create losses of important species that may negatively affect the functioning of the entire ecosystem. Species biodiversity is an important variable that drives tree species composition, soil characteristics, ages of trees, climatic factors as well as management programs (Newaj et al., 2016; Denslow, 1987). It is therefore important to consider the nature of ecosystem before initiating management programs aimed at restoring biodiversity. Although other studies have supported planting of small groups of trees as an effective and less intensive method to restore forests than large-scale restoration (Holl et al., 2011), the obtained results did not support this approach. From the obtained results, the remnant pioneer trees are important in restoration of the Kakamega forest, since they will accelerate succession, even after long periods of land use.

The stand density ranged from 516±20.27 to 822±53.20 stems ha^{-1}, in the plantation forest and 533±28.86 to 1900±18.57 stems ha^{-1} in the secondary forest. The values for the plantation forest falls well within the range (245–859 stems ha^{-1}) recorded for various tropical forests (Campbell et al., 1992). The average density for secondary forest (1900±18.57 stems ha^{-1}) recorded in this study was within the range for most regenerating forests. The previous studies in regenerating forest in cattle ranches in Brazil forest have indicated that a forest aged between 12 to 14 years had 2250 stems per hectare (5 cm DBH) (Feldpausch et al., 2005), which was twice the stems than post-pasture forests reported by for similar aged forests in the region (Steininger, 2000). This indicates more frequent disturbance in the three blocks of the Kakamega forest. Higher density recorded in the secondary forest indicated the high potential for increased afforestation programs in plantation. This information is important for predicting maximum forest density and hence permits more accurate and comprehensive comparisons of alternative forest management systems. It is worth noting that forests are composed of long-lived tree species with large inter- and intra-specific size differences. This heterogeneity in tree size might have similar effects to tree species diversity. Therefore, future studies should consider structural diversity as a dominant factor in forest productivity and standing biomass.

CONCLUSIONS

The current findings indicated the effect of remnant species pool on forest recovery, which was more pronounced in the secondary forest than in plantation forests. Remnant forest played an important role for natural recruitment by accelerating succession via a range of biotic and abiotic processes in secondary forest and hence the recorded high species diversity. This emphasizes the importance of soil resources and propagule availability in a landscape that has been degraded for long periods. The secondary forests exhibited higher species diversity than the plantation forests, since the disturbance is higher through soil plowing, species selection and high intensity disturbance as compared to self regeneration in secondary forest. Furthermore, a plantation forest may have been affected by the competition between local species and alien species, as well as other diverse random factors which led to low species diversity as well as species composition. The plantation forests frequently support lower diversity when compared to natural forests and higher diversity when compared to other-intensive land uses. Therefore, conservation and management of a planted forest could be achieved through controlled rotational harvesting. Maximizing representation of young growth stages will help maximize plant diversity in such cases. However, few studies have systematically assessed biodiversity in a wide spectrum of land uses and forest types, much less using multiple bio-indicators. In order to successfully assess biodiversity across a broad spectrum of forest types, it is essential to identify appropriate biological indicators that will allow for the extrapolation of the abundance and functioning of other species.

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