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Implication of forest zonation on tree species composition, diversity and structure in Mabira Forest, Uganda

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Abstract

The study aimed to investigate effectiveness of forest management zoning in conserving biodiversity of Mabira forest reserve. The study sites buffer, production, and strict nature reserve management zones were purposively selected. This was undertaken through investigating woody species diversity, composition and structure. A total of 60 sampling plots with a size of 20 m x10 m were used to collect vegetation data. Variables such as woody plant species identification and counts as well as diameter at breast height (DBH) of trees were done. The result depicted a total of 65 woody species; 39 in buffer, 19 in production and 37 in strict nature reserve. Of these, only 9 trees species were found common to all zones and their Sorenson similarity coefficient was 0.2213. The population structure of the buffer and strict nature reserve zones was found to be a J - shape pattern, whereas the production zone shown an inverted J-shape pattern. Higher woody species diversity was depicted in the buffer and strict nature zones with ($H'=2.73512$) and ($H'=2.68412$) respectively, and lower in a production zone ($H'=1.63628$). The evenness index value of a buffer zone was ($J=0.746574$), strict nature ($J=0.743335$) and production ($J=0.555719$). The production zone had shown higher IVI values followed by buffer and strict nature reserve zone. The most important woody species identified based on their IVI value were *Broussonetia papyrifera* (Production), *Acalypha neptunica* (Buffer), *Funtumia Elastica* (strict nature reserve). The existing forest management is effective in conserving the biodiversity of the forest reserve. Nevertheless, the production zone was still suffering from exploitation of the surrounding community, hence serve for protecting the remaining management zones from further human interference. Further investigation is also required on the adjacent community perceptions of the forest management zoning.

Keywords: composition, diversity, population structure, woody species, management zones, Mabira Forest Reserve

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1. Introduction

Significant extent of tropical rain forests has been destroyed through deforestation and degradation, leading to loss of biodiversity (Lawer et al. 2013; Putz and Redford 2010) and destabilizing the forests structures(Carreño-Rocabado et al. 2012). Biodiversity fosters the functioning and stability of forest ecosystems and, consequently, the provision of crucial ecosystem services that support human well-being and quality of life (Pedro et al. 2015). Hence, the urgent need for interventions to restore and maintain forest biodiversity and ecological functioning (Lamb et al. 2005).

Forest management strategy like forest zonation has been adopted as means to protect the ongoing degradation of the intact forests. In Uganda, forest zoning is practiced in forests reserves like Mabira. Mabira forest reserve (MFR) is categorized as a protected area of core conservation values. The forest is a central forest reserve relatively rich in biodiversity and ecologically important forest species(Howard 1991). It provides habitat for different faunas and flora; and is also a home for some endemic tree species in Uganda (Fungo et al. 2013). Over the years, Mabira forest reserve has been subjected to multiple threats to its status (Devine 2004), within and outside the protected forest boundaries. The forest is flanked by tea and sugar plantations and factories, and has several enclave communities within its boundaries (Devine 2004), all of which extract resources like timber and firewood from the forest, imposing enormous pressures on it. Consequently, the forest has been degraded, calling for a new management strategy (Bahati et al. 2008).

Zoning of the forest has been adopted as a management strategy of MFR. According to Haas et al. (1987), this management strategy gives clear, specific, and effective management directions and minimizes conflicts between forest users (Zhang 2005). It allows maintaining the forest ecosystem condition while providing products and services to forest users (Côté et al. 2010). Thus, the forest zoning strategy allows for comprehensive conservation of the forest, particularly its tree species diversity, composition, and structure. For the forest zoning purpose, the forest was subdivided into three zones; a strict nature reserve, buffer zone and production zone (Nabanoga et al. 2010). In the strict nature reserve, no extractive use is allowed, except where research activities are conducted, but even then, removal of material such as plant is strictly restricted (Fungo et al. 2013). The Buffer zone has activities such as ecotourism and harvesting of limited plant material for medicinal purposes by local communities (Fungo et al., 2013).The production zone is one where harvesting trees for timber are permitted (Fungo et al. 2013).

However, although the aim at zoning of Mabira forest was to conserve and enhance its biodiversity and ecological conditions, the status of the forest, particularly its biodiversity is still being adversely affected (Obua et al. 2010). Therefore, there is a need to determine the effectiveness of the forest zoning in order to provide information about the forest conservation status and explore on sustainable management strategies. Currently, information on the effectiveness of the management zones is lacking. Thus this study aimed at assessing the effectiveness of forest management zones for tree species diversity, composition, and structural conservation of Mabira forest reserve.

2. Study area and methods

2.1. Study area

The study was conducted in Mabira forest reserve (figure1). It is a tropical rain forest located in South Central Uganda between $0^{\circ} 22'$ - $0^{\circ} 35'N$ and $32^{\circ} 56'$ - $33^{\circ} 02'E$. The forest covers an area of 306 km^2 (31,293 ha) traversing Mukono and Kayunga districts of Uganda (Fungo et al. 2013). The forest is a medium altitude forest, located between 1070 and 1340 m above sea level, occupying gently undulating plains with numerous flat-topped hills and wide shallow valleys (Fungo et al. 2013). The reserve is isolated from other protected areas by agricultural land.

The area is characterized by ferritic soil type of texture ranging from loamy to sandy clay loams with isolated cases of waterlogged clays in the valley bottoms(AES 2001). The climate in and around the forest is tropical humid with bimodal rainfall from March to June and September to November for the long and short duration rains respectively with annual mean precipitation ranging between 1250 and 1400 mm. The annual mean minimum and maximum temperatures range between 16°C to 17°C and 28°C to 29°C, respectively.

The forest has a dense undergrowth of various shrubs, lianas, climbers and herbs with a closed canopy. It is rich in biota harbouring 47% of Uganda's total plant species including 151 species of forest birds, 2 species of diurnal forest primates, 39 species of forest swallow tail and 218 species of butterflies. Many of these are on the list of globally endangered species (Baranga 2007). According to Lung and Schaab (2004), the population density within 2 km of Mabira forest reserve in 2002 was 302 inhabitants/km². Within MFR, there are also 27 villages (Baranga 2007), commonly known as enclaves, where subsistence farming is the primary activity for the 3,506 families within. The most commonly grown crops are maize, cassava, bananas, sugarcane and beans. A large section of the community is involved in some illegal activities like charcoal burning, pit sawing and collection of poles for construction as well as collecting medicinal plants mainly for their local use. The forest reserve receives more than 62% of all tourists visiting the country.

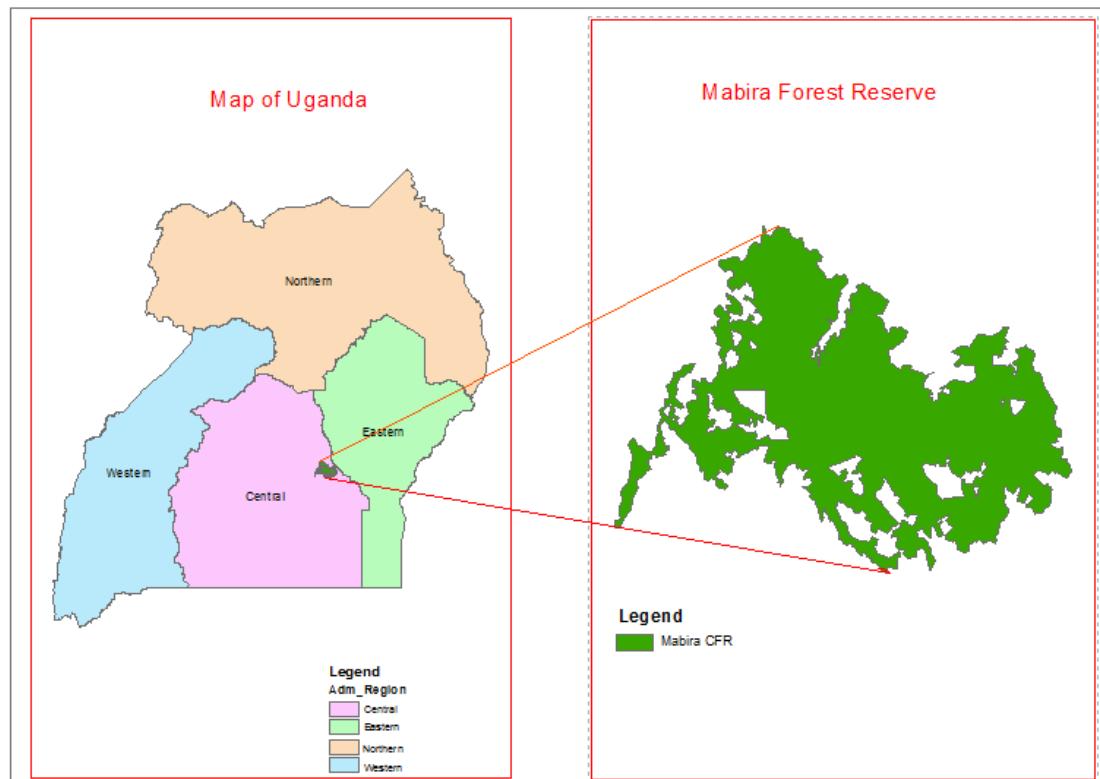


Fig. 1 Study area map.

2.2. Field methods

All the required data used as input in this research was collected from the end of Januray and to mid February 2014. Prior to the establishment of the sampling plots, a reconnaissance survey was done to select the best way and route for laying a transects. Two transects in each management zone were established following the procedures(Kent and Coker 1992). Each transect in the forest zone was 500 m long. Ten plots were alternately laid on each transect. The orientation of the transect line was NS direction and this was done by using a compass traverse. The distance between two consecutive plots

was 50 m. A total of 60 sample plots were laid in the study area. The systematic sampling method was employed to collect the data. To avoid the edge effects the first plot was established by measuring 50m away from the edge of the forest. Following Eilu & Obua (2005) the main study plots was 20 m x 10 m (Fig. 2). The plots were nested into 10 m x10 m, 10 mx5 m, and 5 m x5 m plot size (Alder and Synnott 1992). In the 20 × 10 m plot, tree species of diameter at breast height (dbh) ≥ 20 cm were sampled. In the 10 × 10 m subplot, tree species of size class 10 < 20 cm dbh were identified, in the 5 × 10m subplot tree species of dbh 5 < 10 cm were identified and in a 5 × 5m subplot the size class 1< 5 cm dbh was sampled. The tree species sampled were identified, counted and their respective dbh were recorded.

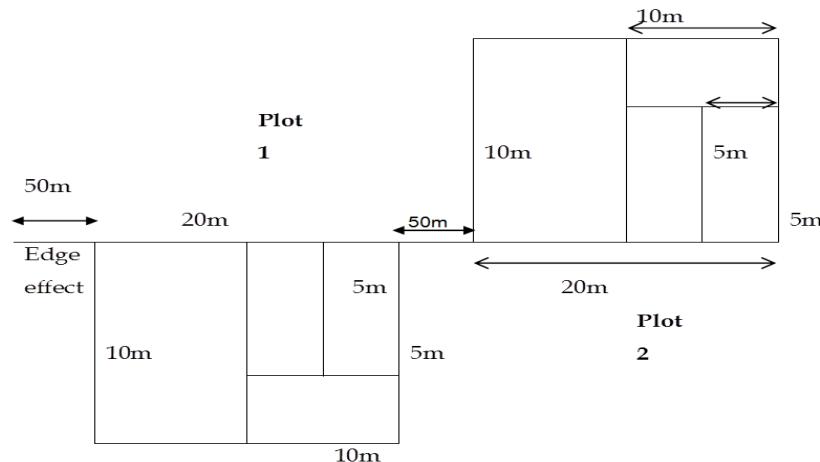


Fig. 2 Field sample plot layout.

Global Positioning System (GPS) coordinate for each sampling points were also collected. Other variables such as evidence of the state of human activities, canopy cover, undergrowth, different shrubs, lianas, climbers and herbs species were recorded in each transect with the help of field assistant. The ground covers abundance and canopy cover for each study plots were estimated by using visual eye judgment.

2.3. Methods of data analysis

The collected data was compiled entered , cleaned and analysed using MS excel software. To compare the woody species successional stage of each management zones a combined population structure using frequency histograms for each identified diameter class distribution following Peters (1996) was obtained. Species abundance for each management zones was computed using excel window.

The tree species richness (the number of species) was determined by summing up the number of species identified within each management zone. Shannon-Weiner diversity index was used to quantify woody species diversity and evenness index. Shannon-Wiener diversity index accounts both for species richness and evenness, and it is not affected by sample size(Kent and Coker 1992). Species diversity and richness 4.1.2 software and excel windows were used to compute these variables.

Shannon-Weiner diversity index and evenness index was calculated as follow:

$$H' = - \sum_{i=1}^s p_i \ln p_i \quad Eq. 1$$

Where, H' = Shannon diversity index, S = the number of species, Pi = the proportion of individuals or the abundance of the ith species expressed as a proportion of total cover and ln = log base n.

Evenness (Equitability) $J=H'/H'\max$, where: J = Evenness, H' = Shannon-Wiener diversity index and, $H'\max = \ln s$ where s is the number of species. The values of Shannon's diversity index, H' , typically lie between 1.5 and 3.5, although in exceptional cases, they can exceed 4.5.

Importance Value Index (IVI) enables comparison of the ecological significance of species in a given forest type. IVI was calculated following (Roberts-Pichette & Lynn, 1999):

$$IVI = RDom + RF + RD \quad Eq. 2$$

Where IVI is the importance value index; RD is relative density; RDom is relative dominance; RF is relative frequency.

The Sorenson similarity coefficient was computed to compare the existing similarity between woody species in the three management zones. Following Kent and Coker (1992), Sorenson coefficient of similarity (S_s) was calculated as follows: promptly

$$S_s = \frac{2a}{2a+b+c} \quad Eq. 3$$

Where S_s = Sorenson similarity coefficient, a = number of species common to both samples, b = number of species in sample 1, c = number of species in sample 2.

3. Results

3.1. Tree population structure

The population diameter class distribution pattern of woody species depicted two diameter class distribution patterns. The first were inverted J-shape pattern of distribution in which the numbers of woody species in the lower diameter class were found to be higher than that of woody species at higher diameter class. The second pattern was a J- shape pattern of distribution where tree species at lower diameter class had shown a lower number of individuals. The overall diameter class distribution pattern revealed the production zone had inverted J-shape, whereas the buffer and strict nature reserve management zones had shown a J-shape pattern of diameter class distribution (Fig. 3).

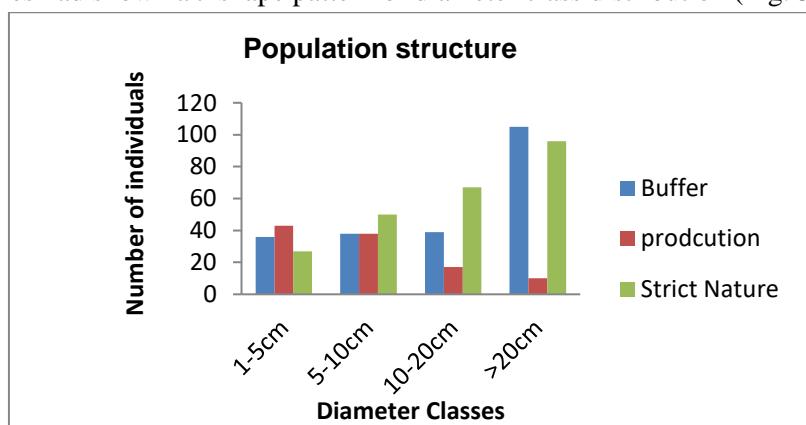


Fig. 3 Population structure of woody trees species in the management zones.

3.2. Abundance, composition, and similarity of woody species

A total of sixty-five woody species were identified in the three management zones. Of these, thirty-nine tree species were found in the buffer, nineteen in the production, and thirty-seven in the strict nature reserve management zone (Fig. 4). The overall tree species abundance of the strict nature reserve and buffer management zones was found to be higher than production zone (Fig. 4). The most abundant tree species identified in each management zone were given as follows; *Broussonetia*

papyrifera(31.19%) ,*Funtumia elastica*(7.79%),(*Acalypha neptunica*(7.79%) in the buffer zone. *Broussonetia papyrifera*(62.96%), *Ficus exasperata*(7.4%) and *Markhamia lutea*(4.62%) in the production zone. *Funtumia elastica*(31.25%) ,*Teclea nobilis*(16.66%) and *Celtis Africana*(8.33%) was the most abundant woody species in the strict nature zone.

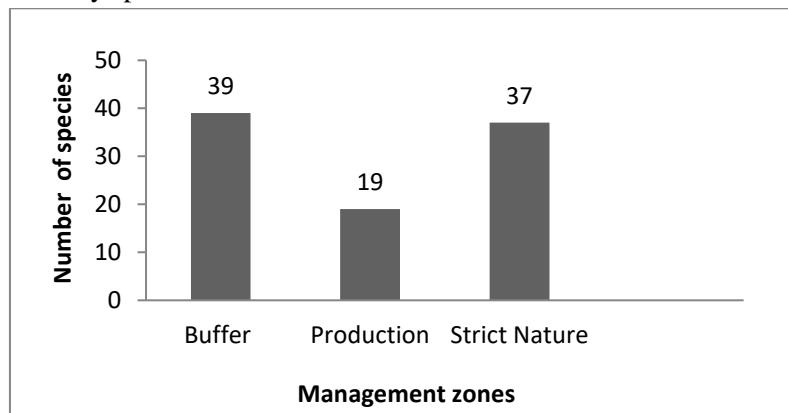


Fig. 4 Overall species composition of each management zone.

The Sorenson similarity coefficient was 0.2213 and this value indicated lower species similarity between the three management zones. Out of the sixty-five identified woody species, only nine tree species were found common to all management zones. Some of the commonly available woody species were; *Antiaris toxicaria* Lesch. , *Broussonetia papyrifera*, *Celtis durandii* , *Coffea canephora* , *Ficus sur* , *Maesopsis eminii*, *Markhamia lutea* , *Teclea nobilis*, and *Trelipismum madagascariensis*. Similarly, the production zone has a lower species abundance than the buffer and the strict nature reserve zones (Fig. 5).

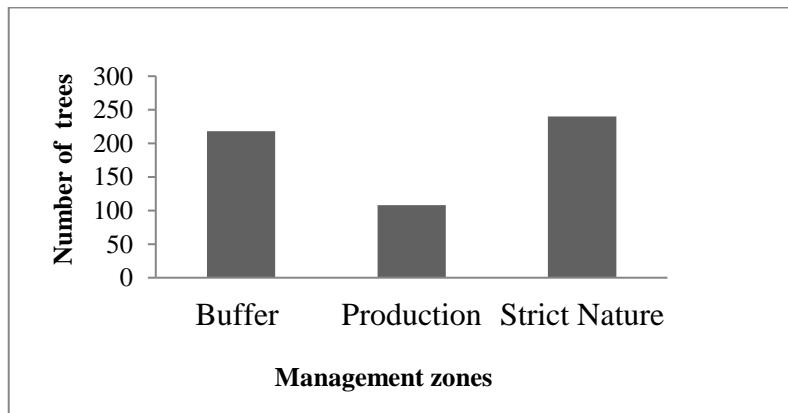


Fig. 5 Woody Species abundance of each management zone.

3.3. Woody species diversity and evenness

The wood species diversity and evenness indexes for each site were analyzed. The result revealed that among the three management zones, buffer and strict nature reserve zone had shown the highest species diversity index value of ($H'=2.73512$) and ($H'=2.68412$) respectively, and the lowest species diversity index was found in the production management zone ($H'=1.63628$).

The species evenness index was higher for both buffer ($J=0.746574$ and strict nature ($J=0.743335$) management zones and production management zone had shown relatively the least evenness value of ($J=0.555719$) (Tab. 1). The higher evenness values for buffer and the strict nature zone would indicate the even distribution of species in the sites as compared to the production zones.

Tab. 1 Tree species diversity, evenness, and richness.

	Buffer Zone	Production Zone	Strict Nature Zone
Diversity	2.735	1.636	2.684
Evenness	0.746	0.555	0.743
Richness	39	19	37

3.4. Importance Value Indices (IVI)

Tab. 2 shows the most important woody species identified with the highest IVI value were *Acalypha neptunica* (62), *Broussonetia papyrifera* (38), *Funtumia elastica* (23) in the buffer zones. *Broussonetia papyrifera* (138), *Artobotrys spp.* (22), *Ficus exasperata* (17), *Markhamia lutea* (17) in the production zone. *Funtumia elastica* (56), *Canthium vulgare* (38), *Teclea nobilis* (34) was the most important woody species found in the strict nature zone. Furthermore, the IVI value of less important tree species in each management zone was shown in Appendix 1.

Tab. 2 Woody species density, composition, and important value index of management zones.

Species name	Family name	Zone	AB	D/ha	RD	RF	Rdom	IVI	IVIR
<i>Acalypha neptunica</i> Müll.Arg.	Euphorbiaceae	B	17	300	19	3	40	62	1
<i>Blighia unijugata</i> Baker.	Sapindaceae	B	3	40	3	3	3	9	10
<i>Broussonetia papyrifera</i> (L.) L'Hér. ex Vent	Moraceae	B	68	368	24	6	9	38	2
<i>Celtis durandii</i> Engl.	Ulmaceae	B	4	63	4	3	4	11	8
<i>Celtis africana</i> N.L.Burm	Ulmaceae	B	16	78	5	5	2	11	6
<i>Celtis mildbraedii</i> Engl.	Ulmaceae	B	15	65	4	6	1	11	7
<i>Coffea canephora</i> .	Rubiaceae	B	4	80	5	2	13	20	4
<i>Funtumia elastica</i> (Preuss) Stapf.	Apocynaceae	B	17	170	11	6	6	23	3
<i>Manicala spp</i>		B	1	20	1.3	2	8	10	9
<i>Markhamia lutea</i> K. Schum .	Bignoniaceae	B	10	40	3	5	0.9	8	11
<i>Trilepisium madagascariensis</i>	Moraceae	B	12	68	4	6	1.4	12	5
<i>Acalypha neptunica</i> Müll.Arg.	Euphorbiaceae	P	1	20	2	3	3	8	9
<i>Antiaris toxicaria</i> Lesch.	Moraceae	P	3	45	3	6	2	12	5
<i>Artobotrys spp.</i>	Annonaceae	P	3	60	4	3	15	22	2
<i>Broussonetia papyrifera</i> (L.) L'Hér. ex Vent	Moraceae	P	68	935	69	9	60	138	1
<i>Celtis durandii</i> Engl.	Ulmaceae	P	2	25	2	6	1	9	7
<i>Ficus exasperata</i> Vahl	Moraceae	P	8	48	4	13	0.9	17	3
<i>Ficus sur</i> Forssk.	Moraceae	P	3	18	1.3	9	0.4	11	6
<i>Margaritaria discoidea</i> (Baill.)	Euphorbiaceae	P	1	20	2	3	4	9	8
<i>Markhamia lutea</i> K. Schum .	Bignoniaceae	P	5	55	4	9	3	17	4
<i>Trelipismium madagascariensis</i>	Moraceae	P	2	15	1.1	6	0.5	8	10
<i>Broussonetia papyrifera</i> (L.) L'Hér. ex Vent	Moraceae	SNR	9	75	5	6	3	13	5
<i>Canthium vulgare</i>	Rubiaceae	SNR	11	165	10	4	24	38	2
<i>Celtis africana</i> N.L.Burm	Ulmaceae	SNR	20	128	8	6	5	19	4
<i>Celtis mildbraedii</i> Engl.	Ulmaceae	SNR	11	53	3	4	1.2	9	8
<i>Celtis wightii</i> Planch.	Ulmaceae	SNR	6	45	3	6	2	11	7
<i>Chrysophyllum albidum</i> G. Don	Sapotaceae	SNR	2	30	2	3	3	8	10
<i>Entandrophragma angolense</i> (Welw.)	Meliaceae	SNR	6	50	3	3	2	8	9

Species name	Family name	Zone	AB	D/ha	RD	RF	Rdom	IVI	IVIR
<i>Funtumia elastica</i> (Preuss) Stapf.	Apocynaceae	SNR	75	470	29	6	21	56	1
<i>Teclea nobilis</i> Hook. f . ex Oliver	Rutaceae	SNR	28	223	14	6	15	34	3
<i>Trilepisium madagascariensis</i>	Moraceae	SNR	17	88	5	4	3	13	6

Only the 10 most abundant tree species in each management zone were presented. Legend: B=Buffer zone, P=Production zone, SNR=Strict Nature Reserve Zone, AB=Abundance, D/ha=Density per hectare, RD=Relative Density, RF= Relative Frequency, Rdom= Relative Dominance, IVI= Important Value Index, IVIR=Important Value index Rank

4. Discussion

Information on the population structure of a tree species would indicate the history of past disturbance of the species taken into consideration and its associated environment, which can also be used to forecast the future trend of the population of particular species (Bekele 1994; Teketay 1997).The population structure of the production zone was found to be a typical inverted J-shape distribution pattern. This indicated a good seedling recruitment and sapling development potential which is important for future population self-maintenance of the forest reserve. This result is in agreement with a related study done by (Okiror et al. 2012). The presence of less mature trees (i.e. <20dbh) in this zone was due to the problem of disturbance whereby the matured trees were removed for the purpose of charcoal burning, fuel wood collection, fruit collection and timber harvesting (personal observation of the site). According to , Chapman et al. (1997) and Whitmore and Sayer (1992) disturbance through uncontrolled logging were considered as the main factors destroying mature and young trees. However, the buffer and strict nature reserve zone, depicted the highest distribution of mature trees than younger saplings and seedlings trees. The population diameter class size distribution pattern in this management zone showed J-shape pattern. As it was shown in Peters (1996)a J-shaped pattern of distribution indicates the presence of severe limitation in the newly regenerating seedlings and sapling trees. This could be linked to many factors like anthropogenic and natural factors. Such a condition also could have been resulted from little canopy opening that affecting undergrowth and regeneration. According to Laughlin et al. (2005) and Giliba et al. (2011),one of the factors associated with this difference in population structure could be anthropogenic activities. Similarly, frequent human interference could lead in disturbing the ecosystem, community, or population structure and changes resources availability(Chapman et al. 1997; Pickett and White 1999).

Our study sought *Broussonetia papyrifera* as the most abundant tree species depicted in the two management zones namely buffers and production zone. The dominancy of these zone by this tree species might be because of its growth habits and its potential to tolerate diverse environmental condition. Similarly ,Winterbottom and Eilu (2006) and Nabanoga et al. (2010) reported *Broussonetia papyrifera* as the most dominant colonizing understory species within Mabira central forest reserve. Furthermore, Bahati et al. (2008) also reported a 30% cover abundance MFR by this tree species. *Broussonetia papyrifera* tree species has a tendency towards hampering the abundance of other indigenous broadleaf species growing in association with it (Bosu et al., 2013),hence can be considered as an invasive species.

The strict nature reserve had the highest species abundance followed by the buffer zone while the production zone has least species abundance. However, the species composition of the buffer zone was relatively higher followed by the strict nature and production zone. The higher abundance and composition of the two management zones was related to the current management practices they are receiving. The disturbance level and the management practices resulted in the variation of species composition and abundance in each management zones.

Our result revealed the buffer and strict nature reserve had shown the highest species diversity index than the production management zone. The higher diversity index can tell us an even representation of individuals species in each sampling plots. Furthermore, this can be due to less

disturbance activities in the other two zones than the production zone. Our result also agree with a study done by Lalfakawma et al. (2009) whereby undisturbed stand showed higher species diversity as compared to disturbed stands. The low woody species diversity obtained from the production zone could be due to the excessive wood harvesting practice exhibited by the local community; as evidenced we visualized charcoal burning activities carried out in this zone (personal observation). Laughlin et al. (2005) studied the effect of various types of disturbance on species diversity and had investigated their negative implication on species diversity. The higher evenness index value obtained from the strict nature zone and buffer zone indicated an even distribution of species in this management zone. Conversely, the low evenness index in the production zone suggests the dominancy of this area by a single tree species like *Broussonetia papyrifera* covered 62.96% of the total surveyed area in this zone compared to the other associated tree species. This result is in agreement with that of (Bahati et al. 2008).

The importance value index (IVI) is an aggregate index that summarizes the density, abundance, and distribution of a species (Okiror et al. 2012). This reflects the degree of dominance and abundance of a given species in relation to other species (Giliba et al. 2011; Kent and Coker 1992). Similarly, IVI can give as an indication of the ecological significance of a species in the site (Muthuramkumar & Parthasarathy, 2000). Wider variation in IVI was depicted in the production management zone and this shows the different ecological importance of the species in the area. However, the IVI value of tree species in the strict nature management zone was relatively narrow. This implies the less dominancy of the area by a few tree species and showing equally are equally important. As described in Simon & Girma (2004) and Worku (2007), a species with the highest dominance indices is considered as most important species in the area. Likewise, *Acalypha neptunica*, *Broussonetia papyrifera* and *Funtumia elastica* tree species were depicted as the important tree species in each management zones. Similarly, woody species with highest abundance and density had shown to be the most important trees species in all management zones (Tab. 2). The dominance of these tree species could have been due to their growth habits and their ability to withstand harsh conditions (Wright 2002).

Overall, the forest management zones are serving their purposes. The strict nature reserve is protecting species disturbance and stopping species invasion conversely, the buffer zone has signs of disturbance, however the level of disturbance was less when compared to the production zone. In the absence of the buffer zone, degradation of the strict nature reserve would have been faster. The production zone is performing its task of allowing people to exploit forest products and preventing people from accessing the other zones. Nevertheless, this zone was found to have less of mature trees, biodiversity, and composition than the Buffer and Strict nature reserve zones as a result of large trees overharvesting practice. Further research should be done on how the abundant tree species behave in association with the other rare/less abundant tree species in the forest reserve. Management should find a way of making the Production zone self-sustaining as over-harvesting can prove a threat to it. Moreover, management should also find out a way of eliminating invasive species like *Broussonetia papyrifera* and limit its distribution over the reserve. Research has to be done on the less abundant tree species to find out how to improve their abundance. Since this study only focused on assessing the vegetation status further investigation has to be done on the adjacent communities' perception of the zoning. There is also a need of strengthening the existing regulations to reduce the rate of encroachment activities done by the surrounding community, especially in the production zone.

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