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# Assessing Trees Diversity in Jebel Elgarrie Forest Reserve in the Blue Nile State, Sudan

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## Abstract

The study aims to examine population indices of mature trees in Jebel Elgarrie forest, Blue Nile State, Sudan. We used remote sensing techniques to stratify the forest into vegetation classes depending on tree density. We distributed 97 circular sample plots (0.1 ha) proportionally to the area of the vegetation classes. In each sample plot we identified, counted and recorded all mature trees (DBH $\geq$10 cm). We calculated frequency, density, abundance, richness, evenness and diversity for each species and we drew abundance rank curve of mature trees. We used One-Way ANOVA to test for differences ($\alpha$=0.05) in mean density (No./ha) of mature trees between vegetation classes. Results revealed that the forest was conveniently sub-divided into high density (C1), medium density (C2), low density (C3) and bare farm land (C4) classes. We identified fifteen tree species that belong to 10 families and 14 genera. Combretaceae and Fabaceae were the common families while *Anogeissus leiocarpa* was the most frequently occurring species. While species diversity varied between vegetation classes, diversity of the forest as a whole is low. While mean density of mature trees in C1, C2, C3 and C4 it was 100, 74, 10, and 0, respectively, it was 54 for the whole forest indicating low stocking, Following One-Way ANOVA, multiple comparisons revealed significant differences in mean density of mature trees between C1 & C3 and C2 & C3. The study provided empirical results on population indices of mature tree species, which would be of importance for successful management and conservation of the forest.

**Key Words:** conservation, mountain forest, species composition, sustainable management

## Introduction

Mountain ecosystems cover about 12% of the world's earth land, and support 22% of the world's people who live within mountain areas (Spehn et al. 2010). While it delivers numerous ecosystem services and hosting biological diversity, mountain forests play significant role in global and regional climates (Perrigo et al. 2020). To ensure the continuity of these economic, social as well as ecological services, sustainable management of dry forest resources is crucial. However, this requires information on past dynamics in the population (Tolera et al. 2013). While knowledge about stand structure assists in understanding forest ecosystems changes (Su et al. 2010), also it may provide insight into ecosystem responses to past disturbances hence, used to forecast future trends in the species' turnover and richness (Young et al. 2017; Hido et al. 2020). Tree species inventory and diversity studies help to understand the species composition and diversity status of forests which also determine the information for forest conservation (Yakubu et

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al. 2020) and management of forest resources (Teketay 2005; Mishra et al. 2013).

Despite of ecological and socio-economic importance of dry forests, they face great threats in terms of degradation through the high rates of anthropogenic activities, such as changes in land use, and climate (Siyum 2020). This degradation contributes to biodiversity loss and accelerates climate change (Pickett and White 1985; Alvarez et al. 2017). These losses of biodiversity may take many forms but at its most fundamental and irreversible, it involves the extinction of species (Groombridge 1992). The vast majority of this extinction occurrs in the tropical rainforests (Wilson 1988).

To meet the increasing demands of rapidly increasing human population, natural forest resources are being utilized far beyond their regenerative capacity. This has resulted in decreasing size and quality of natural forests at alarming rates in Africa and other parts of the world (Neelo et al. 2015). In order to properly manage dry forests and assure the sustainable supply of their goods and services, up to date information about their current status and trend is much needed. For this purpose the phytosociological assessment is very helpful and provides the information about the status of tree population and its' future diversity (Bajpai et al. 2012).

Moreover, Sudan's natural resources, especially the mountainous and other forests of the Blue Nile State, have suffered from decades of ongoing political instability, governance issues and lack of support from government that led to minimal forest restoration and conservation efforts (Siddig 2014; Siddig et al. 2019). Recent reports revealed that forest area decreased from 23.57 million ha in 1990 to 19.21 in 2015, to 18.36 in 2020 (FAO 2020). Particularly forests that grow on fragile dry land environments are more affected. Lack of up-to-date information on the population status of high value tree species, especially those that produce commercial gum and resins at national scale is among the key factors hindering strategic consideration of dry forests (Eshete et al. 2011). Therefore, the aim of this study is to examine and quantify the population indices of mature tree species in Jebel (mountain) Elgarrie dry forest reserve, Blue Nile State, Sudan.

## Materials and Methods

### *Location and description of the study area*

We carried out this study in Jebel Elgarrie dry forest reserve which is located in El Roseires locality, Blue Nile State (Fig. 1), which inhibits a human population of 215,857 being second most populated locality in the state. Blue Nile State is located in the south-eastern part of the Sudan lying between latitudes 9° 30' and 12° 30' N and longitudes 33° 5' and 35° 3' E (Musa et al. 2011). It is classified below tropical sub-humid zone with rainfall of 300-800 mm/annum (Chikamai 2003). Average relative humidity during the dry season is less than 50%, but it could reach up to 80% in the wet season. The major land uses in the state are agriculture, forests, pastoralism and residence (Omer 2013). The main forest ecosystems in the state are riparian, mountain and woodland savanna with an estimated total area of 1,071,771.5 ha out of a total state area of 4,219,409.7 ha (FAO 2015). The estimated total gazetted area of Jebel Elgarrie Forest Reserve is 5805.1 ha (Glen 1996). The topography of forest is a mixture of a series of mountains and plateaus that generally characterized by savanna woodland formations. The current main formal management objectives of the forest are production of frankincense from *Boswellia papyrifera* trees and protection of environment.

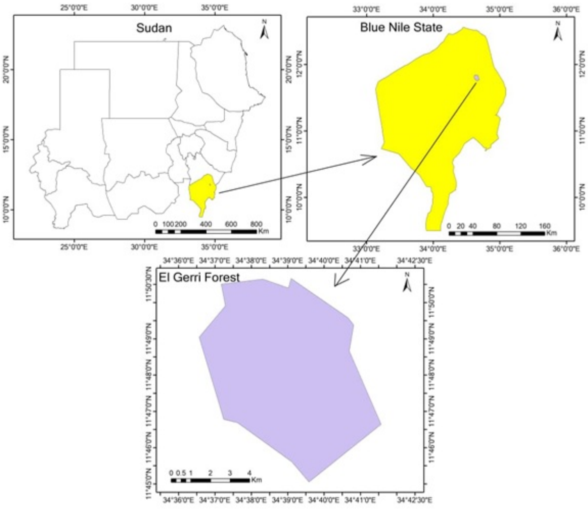


**Fig. 1.** Map of study area.

### *Trees and growing stock assessment*

We gathered the data of vegetation cover between December 2018 and January 2019. Initially we used remote sensing techniques to stratify the forest into vegetation classes on the basis of tree density. Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) multi-spectral image were the main remote sensing data used in the current study for the year 2018. One Land sat satellite image located by path/row 171/052 was used; the image was downloaded free of cost from https://earthexplorer.usgs.gov (USGS 2018). Unsupervised classification by using ArcMap (Version 10.2) software was used to divide the image into land cover categories.

To identify species and estimate stocking of mature trees (trees with DBH $\geq$10cm), we distributed a total of 97 circular sample plots (0.10 ha each) proportional to the areas of vegetation classes, with 14, 37, 28 and 18 sample plots randomly located in class C1, C2, C3 and C4, respectively. We used one-way ANOVA to test for differences ($\alpha$=0.05) in mean density of mature trees between vegetation classes. When mean difference was significant, we carried out multiple comparisons, using LSD criterion, of mean densities. We Identified trees in the field using standard references for the Sudan's flora (El Amin 1990; Darbyshire et al. 2015) as well as selected publications for African flora (Friis and Vollesen 2005) and taxonomic information from WCVP (2022), Aluka (2020) and African Plant Database (2020). Further authentication of the identified species was made with herbarium specimens in the Forestry Research Centre Herbarium of the Agricultural Research Corporation (ARC) at Soba, Khartoum and Department of Silviculture, Faculty of Forestry, University of Khartoum. We compiled vernacular names from the knowledge of the local people within the study area and available literature (Gibreel 2008; Gibreel et al. 2013; Ismail and Elawad 2015). We updated families, genera and species according to the classification of the orders and families of angiosperms adopted in Angiosperm Phylogeny Group "APG IV" (2016).

To analyze their status and importance we recorded data of species identity and frequency of mature trees. We ordered mature trees alphabetically in a checklist and then we estimated according to Gibreel et al. (2013) genus relative frequency (Eq.1) and species relative frequency (Eq.2) per the identified families.

$$\text{Genus relative frequency\%} = \frac{\text{No. of genera per identified family}}{\text{Total No. of genera per all families}} \quad (1)$$

$$\text{Species relative frequency\%} = \frac{\text{No. of species per identified family}}{\text{Total No. of species per all families}} \quad (2)$$

To identify threatened species to be prioritized for conservation and dominant ones to urge their management for maintaining resource base and to sustain provision of multiple ecosystem services, we further quantitatively analyzed field data to compute ecological variables of frequency (FR), relative frequency (RFR), mean density (MDE), relative density (RDE), abundance (A'), richness (R), evenness (E) and diversity (H') of the entire species composition using Shannon-Weiner diversity index. We analyzed species diversity per vegetation classes of the forest too.

Frequency (FR) displays the presence or absence of a given species in each sample plot. We calculated absolute frequency (FRabs) of a species, which refers to the number of plots in which the species encountered, using Count Function of MS Excel. We calculated relative frequency as in Eq.3 (Abay and Gebretsion 2019).

$$\text{Relative frequency} = \frac{\text{Frequency of species X}}{\text{Frequency of all species}} \times 100 \quad (3)$$

Density refers to the total number of individuals of a species and of all other species occurring per land unit area. We calculated absolute density ($D_{abs}$) and relative density ($D_{rel}$). We calculated $D_{abs}$ for each species as the sum of all counts of individuals from all sample plots and then translated into a density per hectare base. We calculated $D_{rel}$X as the percentage of the $D_{abs}$ of a given species (X) to the sum total of the density of all species (Eq.4). We determined the MDE of woody species by converting the total number of individuals of each woody species encountered in all the sample plots of all classes to equivalent number per hectare (Neelo et al. 2013).

Relative density =

$$\frac{\text{Density of species X (trees/ha)}}{\text{Density of all species (trees/ha)}} \times 100 \quad (4)$$

Abundance (A) refers to density of individuals of a species in those sampling units only, in which a given species occurs (Saha et al. 2016; Maua et al. 2020). We calculated it using Eq.5. We then ranked species ascending upon their relative abundance and drew abundance rank curve of mature trees.

A =

$$\frac{\text{Total number of individuals of a species in all plots}}{\text{Total number of sampling unitsin which species occurred}} \quad (5)$$

A diversity index is a mathematical measure of species diversity in a given community based on the species richness and species abundance. For species diversity, we computed Shannon index, which assumes all species are represented in a sample and that they are randomly sampled (Basavarajaiah 2018). We calculated Shannon diversity index (H) using Eq.6 according to Frerebeau (2019). Typical values of Shannon index are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4 (Gaines et al.1999; Kerkhoff 2010). The Shannon index increases as both the richness and the evenness of the community increase (Kerkhoff 2010).

$$H' = -\sum_{i=1}^{S}\left[\frac{n_i}{N}\text{loge}\left(\frac{n_i}{N}\right)\right] \quad (6)$$

Where:
H' = Shannon diversity index,
$n_i$ = number observed from the $i^{th}$ species
N = total number of individuals of all species
S = number of observed species

Species richness (R) is the total number of different woody species present in a particular community. It does not take into account the proportion and distribution of each species (Neelo et al. 2013). We calculated species richness and evenness following Jannat et al. (2020). We calculated Margalef's (1958) index of species richness by using Eq.7.

$$R = \frac{(S-1)}{Ln(N)} \quad (7)$$

Where,
R = species richness index
S = total no. of species
N = total no. of individuals of all species

We calculated the evenness index E for each plot. The value of equitability is equal to one when all the species have same abundance and tend towards zero when the near total of flora is concentrated on only one species (Ifo et al. 2016). Moreover, species evenness is shown from the slope of the line that fits the graph (Magurran 2004). We calculated Pielous's measure of evenness using Eq.8.

$$E = \frac{H}{LnS} \quad (8)$$

Where,
E = species evenness
H = the Shannon index of Diversity
S = total no. of species

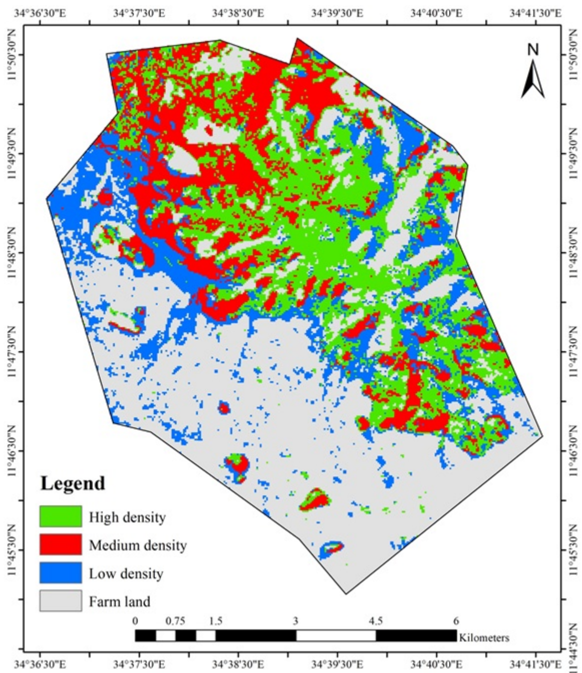


**Fig. 2.** Vegetation classes of Jebel Elgarrie forest.

## Results and Discussion

### *Vegetation and growing stock*

Fig. 2 displays that the forest was conveniently stratified into four classes according to growing stock density. The classes were high density (C1) at high elevation, medium density (C2) at low elevation, low density (C3) at the mountain foot and flat bare farm land (C4). Their respective estimated areas were 818.8, 2241.1, 1687.6 and 1057.6 ha.

Results of growing stock inventory revealed that mean densities of adults (trees/ha) in C1, C2, C3 and C4 were 100, 74, 10, and 0, respectively, while that of the whole forest was 54. One-Way ANOVA of mean density of mature trees revealed significance difference ($p=0.000$) (Table 1). Further multiple comparisons revealed significant differences ($\alpha=0.05$) in mean density of matures between C1 & C3 ($p=0.000$) and C2 & C3 ($p=0.000$) (Table 2). Relatively higher tree mean densities in C1 and C2 may be attributed to harsh conditions, elevation and isolation. Comparatively the overall tree density was lower than that in Kajinat Reserved natural Forest (126±78) and Tajmala unreserved natural forest (87±52) in Sudan (Abtew et al. 2011). Low mean density may be attributed to anthropogenic factors. Forests are increasingly threatened as a result of deforestation, fragmentation, climate change and other stressors that can be linked to human activities such as agricultural expansion, forest clearance for fire wood, construction materials, timber and charcoal production (Yonas 2001; Tesfaye and Teketay 2005; JLG 2013; Mohammed et al. 2021).

Agriculture remains the main driver of increasing tropical deforestation. Conversion to cropland dominates forest loss in Africa and Asia, with over 75% to pave the way for crop production encouraged by national polices that aim at of the forest area lost converted to cropland (FAO 2021). An area of 1057.6 ha (C4), equivalent to 18.2%, was delineated as bare farm land due to conversion of original forest into cropland driven by local and foreign demands. The state has been for centuries a theatre of land use change where forests have been cleared food security and export earnings. The remaining forests are under pressure as they constitute main source of fodder for a livestock population of 15.28 million (MoAARF 2014). Continued deforestation of dry forests cannot be explained by lower returns alone, but other factors such as awareness, market access, property right and institutional issues may also play a role to drive deforestation and conversion of dry forests to croplands (Wickens 1991).

### *Trees diversity indices*

From 97 sample plots, we found in the tree "woody vegetation" layer of Algarry Natural Forest Reserve 382 individual of mature trees which classify into 15 species that belong to 14 Genera and 10 families. Species composition includes *Acacia seyal var seyal*, *Adansonia digitata*, *Anogeissus leiocarpus, Azadirchta indica, Balanites aegyptiaca, Boswellia papyrifera, Cassia arereh, Combretum hartemannianum, Ficus sycomorus, Lannea schmperi, Pterocarpus lucens, Sterculia africana, Stereospremum kunthianum, Terminalia brownie* and *Ziziphus spina-christi*. However species number varies between classes where 10, 11, 3 and 0 species were present in C1, C2, C3 and C4, respectively, with only A. leiocarpus and S. Africana common in C1, C2 and C3.

The relatively most common families in the forest were Combretaceae and Fabaceae which contributed three spe-

**Table 2.** Multiple comparisons of mean density (No./ha) between vegetation classes in Jebel Elgarrie forest

| Vegetation class | | Mean difference | Std. error | Sig. |
|---|---|---|---|---|
| 1 | 2 | 25.17 | 13.36231 | 0.064 |
| 1 | 3 | 90.0* | 13.36231 | 0.000 |
| 2 | 3 | 64.83* | 10.78267 | 0.000 |

*The mean difference is significant at the 0.05 level.

**Table 1.** ANOVA of mean density (No./ha) between vegetation classes in Jebel Elgarrie forest

| Source of variation | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|
| Between classes | 98,336.973 | 2 | 49,168.487 | 29.165 | 0.000 |
| Within classes | 116,324.138 | 69 | 1,685.857 | | |
| Total | 214,661.111 | 71 | | | |

cies each followed by Malvacea, with two species whereas the remaining seven families contributed with only one species each (Table 3; APG III & IV 2009). Most frequently occurring species was *Anogeissus leiocarpa* (Sahab) under family Combretaceae. The maximum value of relative density was recorded for *A. leiocarpa* (36.9%). Together with S*terculia setigera* (Tartar), *Lannea fruticosa* (Lieon) and *C. hartmannianum* they made 78.3% of species composition in the forest. Unlike Adem et al. (2014) that dry forests are known to support high species diversity and endemism, this study reveals that Jebel Elgarrie dry forest is of low species richness as only a few species are abundant (Brower and Zar 1977) and are not equally abundant (Yeom and Kim 2011). The study further revealed that, out of the identified 15 species, five produce NWFPs of high economic value and other five species produce timber of important local uses, with no any formal management.

The species identified in this study are common in the Blue Nile flora and were recorded by Mohammed et al. (2021) in Abu Gadaf Natural Reserved Forest, El-Mugheira and Hassan (2015), Gibreel (2008) and Gibreel et al. (2013) in El-Nour natural forest reserve, 9-10 kilometers northeast Jebel Elgarrie forest, However, number of tree species identified varies between forests as Mohammed et al. (2021) identified 47 tree species belonging to 18 families in Abu Gadaf Natural Reserved Forest, El-Mugheira and Hassan (2015) reported 17 tree species, Gibreel (2008) and Gibreel et al. (2013) identified 55 medicinal woody plant species that belong to 36 genera and 18 families in El-Nour natural forest reserve, The variation of species number is attributed to that both Abu Gadaf and El Nour forest reserves are located southwards in comparatively wetter environments than Jebel Algarrie, climate change manifested in movement of rainfall isohyets southwards with strong impact on drier environments, anthropogenic factors with differences in governance and accessibility.

The most diverse family in Elgarrie forest was Combretaceae where higher genus and species relative frequency were recorded (Table 4), followed by Fabaceae and Malvaceae. Likewise, in El Nour natural forest, within the same locality, the sub-family Miomsoideae in the family Fabaceae, showed high genus and species frequency, followed by

**Table 3.** Species composition and population indices of mature trees in Jebel Elgarrie forest

| Family | Species | Local name | FR | FRabs | RFR | A | H' |
|---|---|---|---|---|---|---|---|
| Anacardiaceae | *Lannea fruticosa* (Hochst. ex A. Rich.) Engl. | Layoun-Um Zag | 53 | 24 | 0.139 | 2.208 | -0.274 |
| Bignoniaceae | *Stereospermum kunthianum* Cham. | Khashkhash Abiad | 10 | 6 | 0.026 | 1.667 | -0.095 |
| Burseraceae | *Boswellia papyrifera* (Delile) Hochst. | Gafal-Rutrut-Tarag Tarag | 12 | 4 | 0.031 | 3.000 | -0.109 |
| Combretaceae | *Anogeissus leiocarp*a (DC.) Guill. and Perr. | Sahab-Seilk | 141 | 35 | 0.369 | 4.029 | -0.368 |
| Combretaceae | *Combretum hartmannianum* Schweinf. | Habiel-Habeil Al Gabal | 49 | 18 | 0.128 | 2.722 | -0.263 |
| Combretaceae | *Terminalia brownie* Fresen. | Sobagk-Shaf | 9 | 8 | 0.024 | 1.125 | -0.088 |
| Fabaceae (Mimosoideae) | *Acacia seyal* Delile var. Seyal | Talih | 5 | 11 | 0.013 | 0.455 | -0.057 |
| Fabaceae (Caesalpinioideae) | *Cassia arereh* Delile | Al Gaga | 3 | 2 | 0.008 | 1.500 | -0.038 |
| Fabaceae (Faboideae) | *Pterocarpus lucens* Lepr. exGuill.and Perr. | Taraia | 2 | 2 | 0.005 | 1.000 | -0.027 |
| Malvaceae (Bombacoideae) | *Adansonia digitata* L. | Tabaldy | 5 | 2 | 0.013 | 2.500 | -0.057 |
| Malvaceae (Sterculioideae) | *Sterculia setigera* Delile | Tartar | 56 | 25 | 0.147 | 2.240 | -0.281 |
| Meliaceae | *Azadirachta indica* A. Juss. | Neem | 1 | 1 | 0.003 | 1.000 | -0.016 |
| Moraceae | *Ficus sycomorus* L. | Gumaize | 2 | 2 | 0.005 | 1.000 | -0.027 |
| Rhamnaceae | *Ziziphus spina-christi* (L.) Desf. | Sider | 1 | 1 | 0.003 | 1.000 | -0.016 |
| Zygophyllaceae (Tribuloideae) | *Balanites aegyptiaca* (L.) Delile | Higleeg | 33 | 17 | 0.086 | 1.941 | -0.212 |
| Total | | | 382 | 158 | | | 1.928 |

FR, frequency; FRabs, absolute frequency; RFR, relative frequency; A, abundance; H', diversity.
Families and botanical names updated based on African Plants database (2020) and Angiosperm Phylogeny Group (APG) III and IV (2009).

**Table 4.** Number of genera, number of species and relative frequency (%) of genus and species per the identified families in Jebel Elgarrie forest, Blue Nile State, Sudan

| Family | Number of genera | Number of species | Genus relative frequency (%) | Species relative frequency (%) |
|---|---|---|---|---|
| Anacardiaceae | 1 | 1 | 7.14 | 7.14 |
| Bignoniaceae | 1 | 1 | 7.14 | 7.14 |
| Burseraceae | 1 | 1 | 7.14 | 7.14 |
| Combretaceae | 3 | 3 | 21.43 | 21.43 |
| Fabaceae | 2 | 2 | 14.29 | 14.29 |
| Malvaceae | 2 | 2 | 14.29 | 14.29 |
| Meliaceae | 1 | 1 | 7.14 | 7.14 |
| Moraceae | 1 | 1 | 7.14 | 7.14 |
| Rhamnaceae | 1 | 1 | 7.14 | 7.14 |
| Zygophyllaceae (Tribuloideae) | 1 | 1 | 7.14 | 7.14 |
| Total | 14 | 14 | 100.0 | 100.0 |

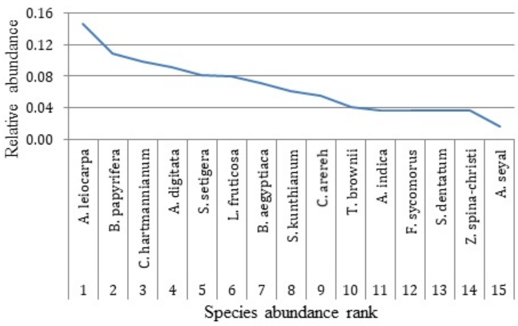


**Fig. 3.** Abundance rank curve of mature trees.

Combretaceae and Capparaceae (Gibreel 2008; Gibreel et al. 2013).

The comparatively low species richness in Jebel Elgarrie forest may be attributed to some anthropogenic factors that influence stocking including land clearance for crop production, tree cutting for household or commercial use, and forest fires or due to sample size as it is too sensitive to (Yeom and Kim 2011).

Species richness of mature trees varies between vegetation classes within the forest where 10, 11, three and zero species were present in C1, C2, C3 and C4, respectively, out of the total of 15 identified species. In mountain ecosystems, species richness varies along the elevation gradients (Pandey et al. 2018). This may be attributed to that plant community of a region is a function of time; however, altitude, slope, latitude, aspect, rainfall and humidity also play a role (Kharkwal et al. 2005). Climatic factors and biotic interference influence the regeneration of different species in the vegetation (Dhaulkhandi et al. 2008) including soil properties, biotic factors, and disturbance history (Saha et al. 2016).

Results revealed different abundances of species in the forest. It ranged from a minimum value of 0.455 for A. seyal to a maximum of 4.029 for *A. leiocarpa* (Table 3). Abundance rank curve of mature trees (Fig. 3) displays a steep gradient which indicates low evenness as the high ranking species have much higher abundances than the low ranking species (Magurran 2004) especially, one species (*A. leiocarpa*) was single most dominant. The abundance and dominance of *A. leiocarpa* in Jebel Elgarrie forest indicate that the forest could serve as important seed source for seedling production (Gebeyehu et al. 2019).

Worth noticing that B. papyrifera, which is currently the species of economic importance, was found only in C1, ranked 5th on the basis of relative frequency contributing about only 3% of all stocking of the forest.

Species richness and evenness in the forest were 2.35 and 0.78, respectively. The computations of diversity index (Table 3) were made with natural logarithm. Shannon index of mature trees in the study area was 1.9 reassures typical values of Shannon index in most ecological studies (Gaines et al. 1999; Kerkhoff 2010).

## Conclusion

About 18% of the forest land has already been converted to crop land due to natural factors and anthropogenic influences which may requires natural resource use policy revision and governance regulation. Mean density of mature trees, species composition and diversity in Jebel Elgarrie Forest are generally low. Unless appropriate conservation and management interventions are undertaken to put the forest under sustainable management to achieve multiple objectives, the future of the forest will be jeopardized.

Perhaps, the information gathered and extracted knowledge from this study can act as a good baseline for achieving two important management implications. First, this broader understanding can lead to build detailed conservation plan for rare and heavily utilized tree species in the forest, and second, the findings will pave the way for further comprehensive and long-term monitoring program in this forest.

Nevertheless, this study has some constraints during ground surveys for data collection. They consist of inaccessibility of some sampling plots due to difficult topography including steep slopes, defoliation of some tree species, and the presence of some unfriendly wildlife which influenced sampling distribution process. Another constraint is the absence of earlier systematic monitoring reports of the forest necessary for temporal comparisons of forest composition and dynamics.

We recommend future research work to focus on first, improving design, increasing sample size and assessing effects of sample size and sampling pattern on trees diversity estimates; Second, running of comparative studies to examine population structure to give a much better picture for the forest diversity status and facilitate prediction of future forest dynamics, third, quantifying and analyzing value chains of forest goods and services, and fourth examining impacts of anticipated climate change in this mountain forests as a much needed research.

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