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Exploring Trees Diversity and Ecological Value of Mountain Forests in the Blue Nile Region of Sudan

Dafa-Alla M. Dafa-Alla[1], Haytham H. Gibreel[1], Ahmed A. H. Siddig[1,2*], Yousif E. Yagoub[1], Hashim A. Abdelkarim[3], Khatir H.T. Saeed[4], Ahmed I. Abuelbashar[5]

[1]Faculty of Forestry-Shambat, University of Khartoum, Khartoum, Sudan
[2]Harvard Forest, Harvard University, Petersham, MA, USA
[3]Faculty of Forest Science and Wood Technology, University of Gezira, Wad-Medani, Sudan
[4]Department of Forestry and Range Sciences, Faculty of Natural Resources and Environmental Studies, Alsalam University, Alfula, Sudan
[5]Forest Research and Gum Arabic Centre, Agricultural Research Corporation, Khartoum-Soba, Sudan
Email: *ahmed_nyala@gmail.com

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Abstract

We carried out this research at Abu-Gaddaf Natural Forest Reserve (ANFR) which is located east of Blue Nile River, in Blue Nile State, Sudan. It aims at exploring tree composition assessing their diversity indices, and ecological importance values. For survey of types and estimation of density of tree species in the forest, we randomly distributed 97 circular sample plots (0.1 hectare (ha)). In each sample plot we identified all trees to the species level, recorded their frequencies and computed species diversity and importance value indices (IVI). A total of 13 tree species, which belong to 12 genera and nine families, were identified in the tree layer of the forest. Mean tree density in ANFR was 116 trees/ha, composed mainly of *Boswellia papyrifera* (Del.) Hochst. (48), followed by *Combretum hartmannianu* (19) and *Lannea fruticosa* (18). Fabaceae was the most common family followed by Combretaceae and Malvaceae. *B. papyrifera* Delile Hochst was the most abundant while *Acacia seyal* was the least abundant species. Species richness (R = 1.71), evenness (E = 0.69), dominance (0.24) indices and Simpson's Index of Diversity (D' = 0.76) suggest a moderate diversity, moderate numbers of individuals in each species and a moderate community stability. The research provides empirical results on diversity and ecological importance value of species, signifies the urging need to safeguard threatened species and to prioritize them for conservation, as well as the need to promote management of abundant species to provide multiple forest ecosystem services.

Keywords

Tree Species, Diversity, Dry-Land Forest, Sudan

1. Introduction

Forests and Savannah woodlands in Africa and particularly in Sudan are biodiversity rich ecosystems and contribute significantly to livelihoods of millions of people in these areas. However, these ecosystems are facing unprecedented threats including deforestation for fuel and buildings, urbanization, agricultural expansion, and climate change. 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 [1] and help in developing management choices and setting priorities. Through changes in the composition, structure and spatial arrangement of trees, management can have profound effects on forest ecosystems and plays a key role in determining both the amount of habitat available to support biodiversity, as well as the stocks of carbon in different ecosystem pools [2].

Many of Sudan's ecological assets such as forests and rangelands are threatened by environmental degeneration. The country is seriously affected by deforestation, biodiversity loss, reduced rangeland carrying capacity, pollution, and increased incidence of environment related diseases [3]. The forest area of Sudan, which is estimated at 18.36 million ha in 2020, is composed of 18.23 natural regeneration and 0.13 planted forests [4]. The latter is composed of both riparian (mainly *Acacia nilotica*) and irrigated (mainly *Eucalyptus* spp.) forests. Several species are under threat either due to lack of natural regeneration or the human activities of agricultural expansion, over felling, over exploitation, gold mining and over grazing [3].

Research on vegetation composition and structure in Sudan reveals varying species diversity profiles with several constraints of natural regeneration due to anthropogenic factors, unanimously stressing the needs for development of national strategic plans of species conservation, management interventions, and development of national species importance value maps. While dry-land forests in Sudan play central roles in environmental regulation and socio-economic benefits, yet they have received less formal scientific management and research attention than the smaller riparian and irrigated planted forests leading to information gaps on their species composition, structure and community stability. For instance, knowledge about trees diversity in mountain forests and woodlands is very sparse. Also, these forests are known as essential niche for the *Boswellia papyrifera* trees, an exclusive producer for the highly valuable gum olibanum and frankincense. Moreover, these unique mountainous habitats are in the most politically instable and conflict affected regions of Sudan (e.g. Blue Nile, South Kordofan, and Darfur) where deforestation and forest fires among many

other human interventions are common symptoms. This makes the need for detailed studies in these ecosystems pertinent and needed more than ever before. Specific research questions of interest are: 1) what is the status of tree species diversity and distribution in these uplands and, 2) what is trend of these woody vegetation community. Also, a question of great significance will be knowing the common threats there and their contribution to the magnitude and direction of the tree's diversity changes. This research aims to explore composition of tree species in Abu-Gaddaf Natural Forest Reserve (ANFR), east of Blue Nile River in Blue Nile State, south-eastern Sudan, and to assess their diversity indices and ecological importance values.

2. Materials and Methods

2.1. Study Area

We carried out this study in ANFR which lies east of Blue Nile River, Blue Nile State, between longitudes 34˚50'45" and 34˚54'45" and altitudes 11˚ 25'10" and 11˚30'10" (**Figure 1**). With an estimated area of about 4624.4 ha, it is one of a few dry-land natural forests remaining within an extensive agricultural landscape in the state. The main forest ecosystems in the state are dry-land and riparian forests with an estimated total area of 1.07 out of a total state area of 4.22 million ha [5]. For centuries the state has been a theater of land use change where forests have been cleared to pave the way for crop production encouraged by national polices that aim at local food security and export earnings.

2.2. Species Composition and Growing Stock Inventory

We collected field data between November 2019 and March 2020. For survey of types and stocking of tree species, we randomly distributed 97 circular sample plots (0.1 ha) within the forest. We identified the collected plant specimens to the species level in the field using standard references for the Sudan's flora [6] and taxonomic information from [7]. We updated families, genera and species according to the classification of the orders and families of angiosperms adopted in Angiosperm Phylogeny Group "APG IV" [8] and [9]. We compiled vernacular names from the knowledge of the local people of the area and published literature. In each sample plot we identified all tree species, enumerated them and recorded their frequencies.

2.3. Species Diversity Metrics

We quantitatively analyzed field data to compute ecological metrics of frequency (*FR*), mean density (*DE*), richness (*R*), dominance (*D'*), Pielou's evenness (*E*), Simpson's Index of diversity (*D*), abundance ($A^{`}$) and IVI. We calculated absolute frequency of a species (FR_a), which refers to the number of plots in which the species encountered was calculated using Count Function of MS Excel and relative frequency (FR_R) as the percentage of the absolute frequency of a given species to the sum total (FR_{all}) of the frequency of all species (Equation (1)). We

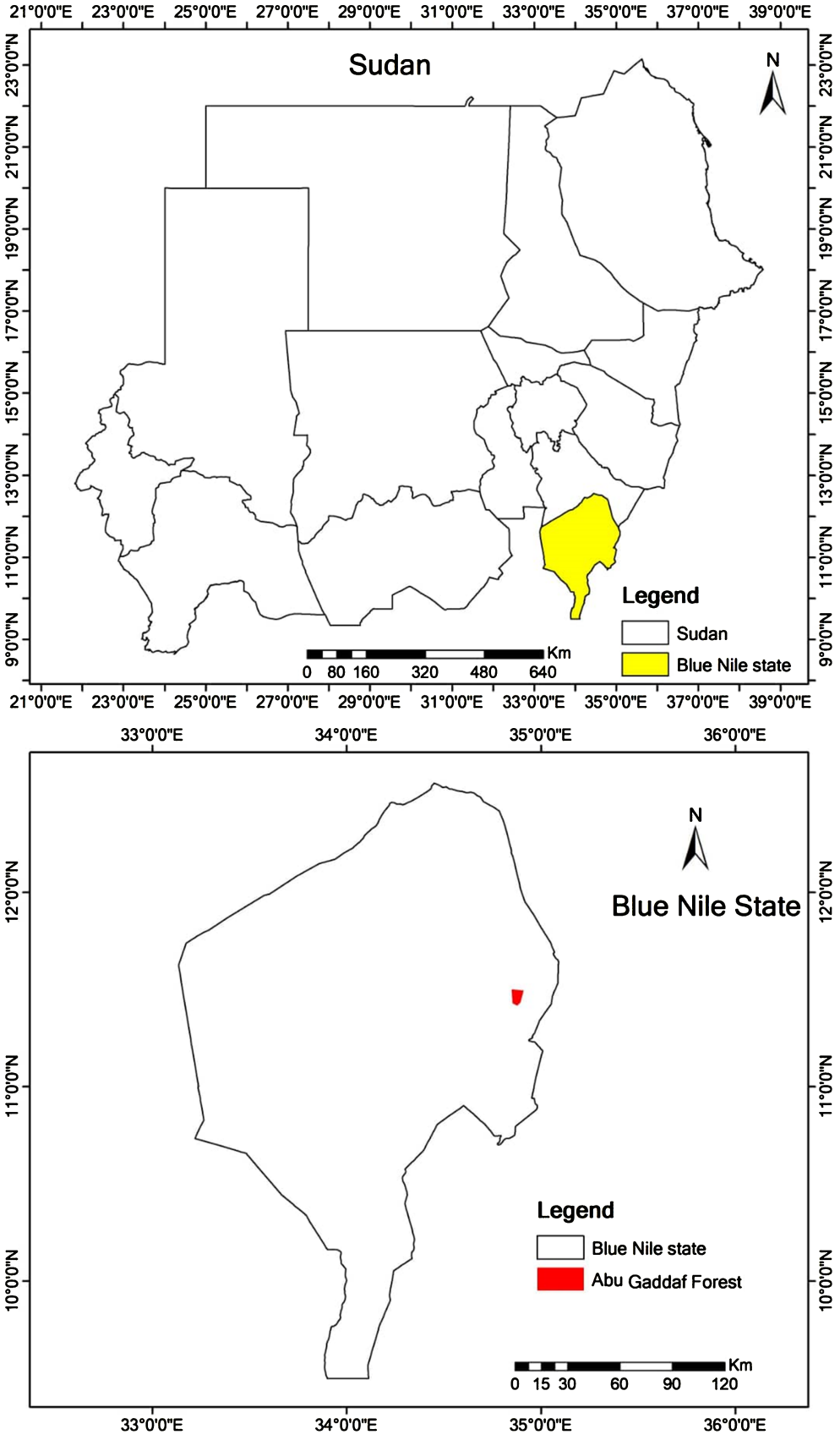

Figure 1. Location map of Abu-Gaddaf Natural Forest Reserve (Source: Authors).

used Equation (1), hereafter, to calculate relative metrics of density, dominance, and abundance. We determined DE 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 [10].

$$FR_R X = \frac{FR_R X}{FR_{all}} * 100 \quad (1)$$

We determined species richness by direct counts of species. Further, we calculated Margalef's (1958) index of species richness using (Equation (2)) [11].

$$R = \frac{S-1}{\ln N} \quad (2)$$

where

R = species richness index;

S = total number of species;

N = total number of individuals of all species.

We calculated dominance of species (D') in the vegetation community using Simpson's index of dominance (Equation (3)) [12], and relative dominance (D_R) of species using Equation (1).

$$D' = \sum_{i=1}^{S} \frac{(n_i)^2}{N} \quad (3)$$

where:

n_i = number observed from the i^{th} species;

N = total number of individuals of all species S = number of species.

We calculated abundance (A), which refers to density of individuals of a species in those sampling units only in which a given species occurs [13], as the number of individuals per species per hectare [14] using Equation (4). We calculated relative abundance and then ranked the species from most to least relative abundances and drew species abundance rank curve.

$$A = \frac{\text{Total number of individuals of a species in all plots}}{\text{Total number of sampling units in which species occurred}} \quad (4)$$

We calculated species Importance Value Index (IVI) by summing up relative frequency, relative density and relative dominance (Equation (5)) [15], then ranked all species from highest to lowest IVI_S. Likewise, we calculated the Family Importance Value Index (FIVI) for botanical families by adding together the IVI for different species of the same family [16] [17].

$$\text{IVI} = FR_R + DE_R + D_R \quad (5)$$

To determine the homogeneity and distribution patterns of species, we calculated Pielou's evenness index (E) (Equation (6)) [18].

$$E = -\sum_{i=1}^{S} \frac{p_i * \log(p_i)}{\log(S)} \quad (6)$$

where:

E = evenness index;

p_i = ratio of frequency of a species (n_i) to total frequencies of all species (N) S = number of species.

We calculated diversity of tree species using the Simpson's Index of Diversity (D) [19] (Equation (7)).

$$D = 1 - \sum_{i=1}^{S} \left(n_i / N\right)^2 \tag{7}$$

n_i = number observed from the i^{th} species,

N = total number of individuals of all species S = number of observed species

3. Results

3.1. Species Composition and Growing Stock Inventory

A total of 1,127 individual trees of all species were counted in all 97 sample plots. Mean density of ANFR was 116 trees/ha. *Boswellia papyrifera* took the lead in species density (48) followed by *C. hartmannianu* (19) and *L. fruticosa* (18). Fabaceae was the most common family (23.1%) contributing with three species followed by Combretaceae and Malvaceae (15.4%) with two species each, while each of other six families was represented with a single species.

3.2. Species Diversity Metrics

In total thirteen tree species (Species richness (R)), which belong to 12 genera and nine families, were identified in the tree layer of the forest (**Table 1**). Calculated Margalef's index of species richness was 1.71 which categorizes the forest as of low species richness ($1 \le R \le 3$) [20].

The dominance in a vegetation community can be centralized on a single species, some species or in many species [21]**.** Dominance index of species at ANFR was 0.24 which classifies the species community as of low species dominance ($0 < D' \le 0.5$) [22].

Species relative abundance (A_R) extended between 1.8% and 18.43%. The results revealed that *A. seyal* was the least abundant; *A. digitata, S. setigera, H. thebaica, Z. spina-christi, and L. fruiticcosa*, *C. hartmannianum*, *A. senegal, B. aegyptiaca, A. leiocarpa, D. cinerea* and *C. abyssinica* were of moderate abundance, while a single species, *B. papyrifera,* was most abundant.

IVI values ranged between 0.18 and 154.9. The result reveals higher IVI of *B. papyrifera* (155 out of 300 total IVI score value) indicating that the species is more likely a dominant species in the community, with intermediate IVI values of a few and a short tail of other fewer tree species (**Figure 2**). The IVI_R ranking portrays the tree species that are potential for management to produce different ecosystem services and other ones in need of conservation and restoration interventions.

The calculated species evenness (E) was 0.69 indicates moderate species evenness, as low values indicate that one or a few species dominate, and high values

Table 1. Species diversity indices of Abu-Gaddaf natural forest reserve.

Species	*FR*	FR_R	*MDE*	DE_R	*D*	D_R	*IVI*	IVI_R	*Rank*	FR_a	*A*	A_R
Acacia senegal L. Wild "Fabaceae: Mimosaceae" (Hashab)	25	2.22	2.6	2.2	0.00049	0.208	4.64	1.55	8	11	2.3	8.18
Acacia seyal Del. "Fabaceae: Mimosaceae" (Talih)	5	0.44	0.5	0.4	0.00002	0.008	0.90	0.30	10	5	1.0	3.60
Adansonia digitata L. "Malvaceae: Bombacoideae" (Tabldi)	1	0.09	0.1	0.1	0.00000	0.000	0.18	0.06	13	2	0.5	1.80
Anogeissus leiocarpa (DC.) Guill. & Perr. "Combretaceae" (Sahab-Silk)	66	5.86	6.8	5.9	0.00343	1.448	13.16	4.39	6	32	2.1	7.42
Balanites aegyptiaca (L.) Delile "Zygophyllaceae" (Heglig)	92	8.16	9.5	8.2	0.00666	2.814	19.14	6.38	4	34	2.7	9.74
Boswellia papyrifera (Delile) Hochst. "Burseraceae" (Trag Trag)	466	41.35	48.0	41.3	0.17097	72.198	154.90	51.63	1	91	5.1	18.43
Combretum hartmannianum Schweinf.	183	16.24	18.9	16.2	0.02637	11.134	43.61	14.54	2	70	2.6	9.41
Combretaceae" (Habeel Al Gabal)												
Cordia abyssinica (R.) Br. "Boraginaceae" (Andrab)	3	0.27	0.3	0.3	0.00001	0.003	0.54	0.18	12	3	1.0	3.60
Dichrostachys cinerea L. White & Arn. "Fabaceae: Mimosaceae" (Kadad)	72	6.39	7.4	6.4	0.00408	1.724	14.5	4.83	5	22	3.3	11.78
Hyphaene thebaica (L.) Mart. "Arecaceae" (Dom)	5	0.44	0.5	0.4	0.00002	0.008	0.90	0.30	10	4	1.3	4.50
Lannea fruticosa (Hochst. ex A. Rich.) Engl. "Anancardiaceae" (Layoun)	175	15.53	18.0	15.5	0.02411	10.182	41.24	13.75	3	58	3.0	10.86
Sterculia setigera Delile "Malvaceae: Sterculioideae" (Tartar)	28	2.48	2.9	2.5	0.00062	0.261	5.23	1.74	7	19	1.5	5.30
Ziziphus spina-christi L. Desf. "Rhamnaceae" (Sidr).	6	0.53	0.6	0.5	0.00003	0.012	1.08	0.36	9	4	1.5	5.40
Sum	1127		116.2		0.24		300				27.8	

indicate that relatively equal numbers of individuals belong to each species [12].

Simpson's Index of Diversity of tree species (*D'*) was 0.76. Since the higher the value of the index the higher the diversity of species [23] [19], the result implies that species diversity at ANFR is moderate. In terms of FIVI, *Burseraceae* was the single most ecologically important family (**Figure 3**).

4. Discussion

4.1. Species Composition and Growing Stock Inventory

The species identified in the forest are common in the Blue Nile state flora [24], however, number of tree species identified varies between forests which may be attributed to environmental heterogeneity where some of the forest reserves lie southwards in comparatively wetter environments, to climate change manifested

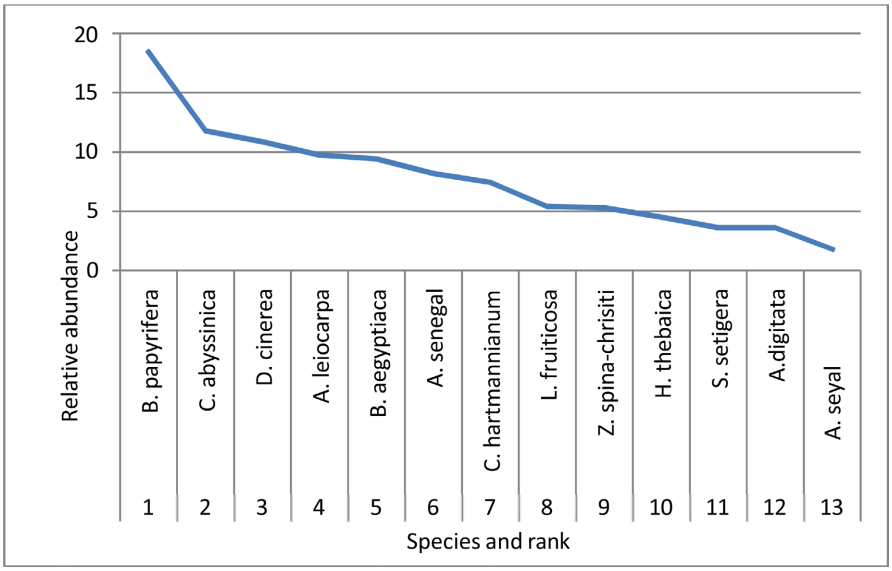

Figure 2. Species abundance rank curve of woody species in Abu-Gaddaf Natural Forest Reserve 2020.

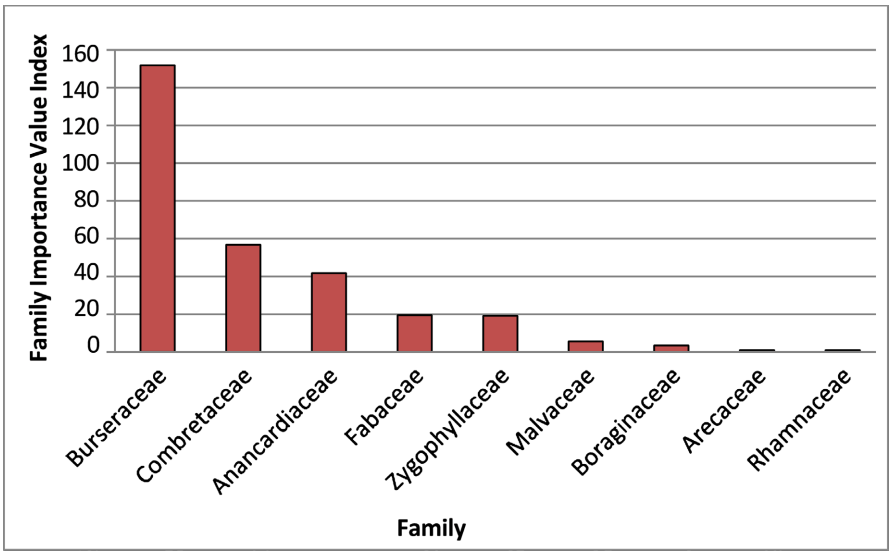

Figure 3. Family importance value in Abu-Gaddaf Natural Forest Reserve in 2020.

in movement of rainfall isohyets southwards with strong impact on drier environments, and anthropogenic factors with differences in governance and accessibility [25].

High occurrence of *B. papyrifera* in the study area reflects its growth adaptation to the habitat. It is the single most tree species of economic importance in the area where it has been traditionally tapped for centuries for the production of Frankincense to support local economies and for export markets. Yet, the current population of the tree is declining due to anthropogenic factors with notable lack of natural regeneration [26] [27]. *L. fruticosa* and *C. hartmannianu* are important contributors to tree density of ANFR. They are among ten top rated species in Sudan in terms of biomass volume [4], together with *B. aegyp-*

tiaca, *C. hartmannianum*, *A. leiocarpa*, *A. seyal* and *A. senegal* which are potentially suitable to be managed for different products of forest ecosystem services.

4.2. Species Diversity Metrics

Species richness of ANFR is relatively low compared to that reported of some geographically close Natural Forest Reserves [25] [28].

Low value of species richness index at ANFR is suspected to be caused by a less heterogeneous environment, as a more heterogeneous environment could support more species through partitioned niche space [29] and to closeness to human settlements associated with high disturbance frequency and intensity. In ecological terms, increased richness has been shown to both enhance community functionality (i.e. increase productivity) and to stabilize it in the face of disturbances [23]. It is also the most sensitive to the difference in sampling effort, since it weights all species equally independent from their relative abundances. Low species richness and frequency may be attributed to use practices that generate disturbances that alter critical components and processes of a forest [5].

A community is perfectly even if every species is present in equal proportions and uneven if one species dominates the abundance distribution [22]. Following [30] evenness categories, the value of evenness in ANFR suggests to describe the community as unstable. Evenness index was 0.69 which indicates moderate species evenness, unstable species community at ANFR, and unbalanced distribution of the number of individuals of each species.

High ranking species, *B. papyrifera*, having much higher abundance than other species, illustrates that tree community in ANFR is uneven as one species dominates the abundance distribution [15] [23]. The dominant species are those that can utilize the environment they occupy more efficiently than other species in the same place [31] [32]. This dominance of few species could be due to rapid reproduction strategies of some plant species relative to other species. It also reflects the tolerance and adaptation of species to their environment and the growth rate of regeneration in their habitat [21].

High IVI of *B. papyrifera* indicates that it occupies most of the sampled area [16] [17] and it is the leading dominant species of the particular vegetation. Moreover, the low IVI value of some species could be attributed to low reproduction strategies, to some anthropogenic factors including forest fires and livestock grazing, or trampling of some selected species. The low IVI value of the species indicates that they are threatened and need immediate conservation [33] [34]. It was reported that some species could be dominant while others are lower in their abundance under a given ecosystem due to their variation in survival mechanism [35], the properties of species themselves and the environmental factors that can affect the spatial distribution and dominance of species [36].

5. Conclusion

The diversity of woody species is a known prerequisite for provision and sus-

taining forests ecosystem services. The ecosystems of ANFR are not only very essential habitats for fauna and flora diversity but are also important sources for livelihood support. Tree ecosystem of ANFR may be best described as of low to moderate diversity and community stability; yet, it suffers anthropogenic threats that affect both. A need arises for authentic interventions to safeguard and restore threatened species prioritized for conservation and to urge management of dominant species for maintaining resource base enough to sustain provision of multiple ecosystem services. Overall, outcomes of this study are not only expected to enhance the knowledge about trees richness and diversity of mountainous woodlands in the Blue Nile region of Sudan, but also will pave the way for more in depth inquiries as well as inform conservation planning in these both economically and ecologically significant zones.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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