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Impact of altitude and anthropogenic disturbance on plant species composition, diversity, and structure at the Wof-Washa highlands of Ethiopia

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ABSTRACT

The study was conducted in Wof-Washa Forest in the central highlands of Ethiopia, aiming at determining the impact of altitude and anthropogenic disturbance on plant species composition, structure, and diversity of the forest. Eighteen transect lines with 632 meters apart from each other were established from top to bottom. A total of 115 main plots for all communities with 20 \times 20 m, were established along transect lines from the upper part of the forest to the river's edge. To collect data on seedlings and saplings, 5 m \times 5 m and 10 m \times 10 m subplots were laid respectively within the main sampling plots. For each plot the plant species were counted, diameter at breast height and height of trees and shrubs were measured. The human disturbance data were visually estimated for each plot in each community. Plant community classification was made following Ethiopia agro-ecological zones. Plant species diversity and richness were found related to human disturbance and altitude. A total of 108 species belonging to 99 genera and 57 families were identified. The results revealed that Asteraceae was the most diverse higher plant family with nine species (8.3%) followed by Fabaceae, Euphorbiaceae, and Rosaceae with six (5.5%) species each. The overall Shannon diversity and evenness index of the forest were 4.02 and 0.86 respectively. Tree/shrub, sapling and seedling densities were 664.4, 757.2 and 805.7 individual's ha⁻¹ respectively. The total basal area of the forest was 55.99 m²ha¹. About 25.7% of the importance values index was contributed by four species, Juniperus procera, Podocarpus falcatus, Ilex mitis, and Erica arborea. The similarity in species composition within the forest was low, indicating that the different parts of the forest had different floras. The presence of strong human disturbance indicates the need for immediate conservation in order to ensure sustainable utilization and management of the forest.

1. Introduction

In recent decades, the areas covered by mountain forests have been two distinct trends, as for forests around the world: continual loss in developing countries (especially in tropical regions) and progressive development in industrialized countries. In Europe, widespread reforestation has happened in numerous mountain regions, related to agricultural land abandonment and declining deforestation, representing around 66% of land cover changes from 1990 to 2006 [1]. However, in some industrialized countries, the expansion of mountain forests has been offset to some extent by losses due to epidemics of diseases and pests or fire [1]. Tropical forests are among the world's ecosystems with the highest species diversity [2]. East African forests are also considered as the center of botanical endemism [3]. Reports by Coetzee [4] and Tamrat [5] revealed that East African mountain forests are among the most diverse and richest African regions with regard to flora composition.

The Ethiopian highlands are considered as one of the most significant countries in Africa with respect to biological resources, both in flora and fauna [6]. They covered large parts of the Afromontane regions of Africa, which stretch from Cameroon to eastern Africa [7], where many biodiversity hotspots exist [8]. Furthermore, the Ethiopian highlands constitute diverse ecological units, extending from moist forest to overall wetlands in the West and Southwest in the direction of Afar depression in the North [9]. The number of species of higher plants such as flowering plants, conifers, and ferns found in the flora of Ethiopia is about 6000, of

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which about 10% are endemic to the country [10]. As a result, Ethiopia has high levels of biodiversity and it becomes significant for Africa [11].

Although the forests of Ethiopian highlands were characterized by high plant species diversity, they have been reduced and exploited for decades through degradation [12]. This degradation is the outcome of population pressure that increases crop cultivation and livestock grazing in marginal areas. Moreover, agricultural expansion, resettlement systems, charcoal manufacture and persistent extension of actual antagonistic aggressive alive species are taking a deep and determining influence on the plant reserve accessibility [12, 13, 14]. These actions subsidize deforestation and soil erosion on the uplands of the country. Currently, deforestation is estimated to take place at the rate of 160, 000–200,000 ha/year [15] which is extremely high. As a result, there has been a rapid decline in the proportion of the forest coverage of the country from 40% in 1900 to 16% in 1954, 8% in 1961, 4% in 1975, 3.2% in 1980, and finally reduced to 2.3% in 2003 [16]. Currently, it is



Fig. 1. Map of Wof-Washa Forest and distribution of sample plots.

estimated to be 15.7% due to conservation and afforestation campaign launched all over the country in the last ten years [17].

Wof-Washa Forest is among the forests of the Ethiopian highlands, which is registered as one of the National Forest Priority Areas in Ethiopia. The forest is characterized by a high diversity of flora and fauna of the dry Afromontane forests in the country. Although the floristic composition, vegetal community and structural analysis of this forest had been studied so far by Tilahun [18] and Fisaha et al. [19], as in many tropical forests, disturbance (natural and anthropogenic) has been changing the structure and floristic composition of the forest. While Wof-Washa forest is a protected area, it is subjected to human disturbances, resulting in the reduction and a change of the forest cover through time. According to the study conducted by Tilahun [18] and Fisaha et al. [19], deforestation and forest degradation were the major issues in the local area. About 300 hectares of the forest area was completely degraded with very few Juniperus procera on the forest border and cliffy bare areas in the higher regions of the forest [18]. This uncontrolled clearing of the forest has been in progress and will continue until efficient management plans are placed to balance the objective of protection, conservation, and sustainable use. Moreover, sufficient data regarding the impacts of altitude and human disturbance on species diversity, composition, and structure were not available in the study area, while they are essential to be documented. Therefore, this calls for the need to generate relevant information in order to make management decisions to protect the forest. Therefore, the objectives of the study are: (I) to evaluate species composition, diversity and structure along an altitude (II) to assess the impact of human disturbance on species composition, diversity, and structure along with the plant communities.

2. Materials and methods

2.1. Description of the study area

The Wof-Washa forest is located in the Amhara national, regional state, about 60 km far from Debre Berhan town, central highlands of Ethiopia, stretching in three woredas (districts) called Baso, Ankober, and Tarma Ber (Fig. 1). The latitudinal and longitudinal location of the forest is between 9°44′ to 9°46′N and 39°44′ to 39°47′E. The area encompasses an altitude ranging between 1700 m.a.s.l near Gift Michael to 3700 m.a.s.l near Kundi [18]. The forest cover was reduced from 9200 ha since 1994–8200 ha in 2010 and currently, it covers about 7550 ha. The area has the mean annual minimum and maximum temperature that ranges from 11 °C to 20 °C respectively [20]. The rainfall in the area follows a bimodal pattern with a long rainy season between July and September while short rain falls between March and May and the mean annual rainfall is approximately 1400 mm [21].

2.2. Methods of data collection

2.2.1. Reconnaissance survey

At the beginning of the study a reconnaissance survey was undertaken and the basic information on the current forest status, site condition, and vegetation distribution were obtained and the possible sampling sites were also determined. During the survey, additional information for the study was also collected from Wof-Washa kebele (the smallest administrative unit) Agricultural Office and from the local communities living close to the study area.

The study area was classified into three plant communities based on Ethiopia agro-ecologic ranges: 1) the midland plant community (1833–2300 m.a.s.l.), 2) the lower highland plant community (2300–3200 m.a.s.l.) and 3) the upper highland plant community (3200–3691 m.a.s.l.) of Wof-Washa forest. The area of each plant community was calculated to take appropriate samples relatively from the three sites based on the area proportion (i.e. larger area takes a high number of samples). Experienced persons were involved during the data collection.

2.2.2. Sampling technique

Systematic sampling technique was applied to gather vegetation data, following Mueller-Dombois & Ellenberg [22]. Eighteen transect lines were laid from the upper portion of the forest area along the river's edge and roads at 632 m apart. The main plots of size 20 m \times 20 m were established systematically along these transect lines for trees, shrubs, and lianas. For seedlings and saplings, the sub-plots with 5 m \times 5 m and 10 m \times 10 m were established respectively, within the main sampling plot.

2.2.3. Vegetation data collection and identification

All plant species encountered in each sample plot were recorded by using their vernacular names. The local names of the species were recorded and included in the list of taxa. The measurement took place for trees and shrubs with the height >2 m and DBH >12.5 cm. The understory of plant species with the height <1.5 m and DBH <2.5 cm were considered as seedlings. Single-stemmed individuals with the height >2 m and DBH >12.5 cm were the seedlings and trees with DBH \leq 12. 5 cm and heights of 1.5–2 m were considered as saplings [23].

The diameter at breast height of each tree and shrub was measured 1.3 m above the ground by using tree Caliper and Diameter tape, whereas the height of trees and shrubs were measured by using Merritt-hypsometer and visual estimation. For trees and shrubs that are branched around the breast height, the circumferences were measured separately and then averaged. Trees and shrubs with DBH >12.5 cm were measured and recorded with height and DBH and the conversion of DBH to the basal area was made later. During the study, physiographic variables such as altitude, latitude, and longitude were also measured from the center of each main plot by using the Garmin GPS 60.

Taxonomic identification was made from the flora of Ethiopia and Eritrea [24] and by consulting experts. Voucher specimens were also collected and pressed for identification of the species diversity in the study area and taken to the National Herbarium (ETH), Addis Ababa University, and they were properly identified to species and subspecies levels.

2.2.4. Human disturbance variables

Human disturbance data were visually estimated for each of the main plot (400 m^2) in each plant community for comparison with the three plant communities of WWF. The type of disturbances was arranged qualitatively [24]. All types of human disturbances were ranked into relatively absent (score 0), low (1), medium (2) and high (3) levels of disturbances (Table 1). The sum of all scores for each plot provides an overall ranking of anthropogenic disturbance in each community. High ranks signify high levels of anthropogenic disturbance and low ranks reveal low levels of disturbance [25].

2.3. Data analysis

Species diversity, richness, and evenness were determined by using the Shannon-Wiener index [26]. The Shannon-Wiener diversity index, evenness, and richness were determined with respect to the identified species. Principal component analysis (PCA) was performed to show the large pattern over the observed altitudinal gradients and the species overlap between the three plant communities by using an R software

| Table 1 |
|-----------------------------|
| Human disturbance variables |

| Disturbance | Levels | | | | | | |
|-------------------|------------|-----|--------|------|--|--|--|
| | 0 | 1 | 2 | 3 | | | |
| Degree of grazing | No Grazing | Low | Medium | High | | | |
| Fodder | Absent | Low | Medium | High | | | |
| Medicinal plants | Absent | Low | Medium | High | | | |
| Timber | Absent | Low | Medium | High | | | |
| Firewood | Absent | Low | Medium | High | | | |

package (version 3.6) using vegan packages [27]. The type and degree of human disturbance were analyzed for each community. The scores of each type of disturbance obtained from each plot were summed and averaged. Then the final disturbance levels of each community have been placed to show the highest disturbance rate and absence of disturbance (Table 6).

The quantitative structure of vegetation data was designed based on the analysis of DBH, species density, basal area, height, frequency and Important Value Index (IVI). The DBH and tree height were categorized into DBH and height classes. The relative frequency distribution of individual trees in each plot was calculated. The trees and shrubs relative density and basal area values were calculated on a hectare basis. The importance value indexes (IVI) and basal area (BA) of each tree/shrub species were calculated by using the following equations:

$$IVI = Relative \ density + Relative \ frequency + Relative \ dominance$$
 (1)

Where,

Relative density = Number of individual species / Total number of individuals × 100

Relative frequency = frequency of Tree species/ Frequency of all species \times 100

Relative dominance = Dominance of tree species / Dominance of all species \times 100

$$Basal area = \pi \left(DBH \right)^2 \tag{5}$$

Where DBH is diameter at breast height.

The difference in vegetation communities of the forest was determined using analysis of variance (ANOVA) and all vegetation data were tested. One way analysis of variance was used to compare species diversity, evenness, richness, abundance, density, height, DBH and basal area of trees and shrubs of the three plant communities of the forest. The Jaccard's and Sorensen's similarity indices were also used to evaluate the level of species similarities among communities based on their species composition.

3. Results

3.1. Vegetation composition

One hundred eight plant species belonging to 99 genera and 57 families were recorded in Wof-Washa forest (Table 2). Asteraceae was the most species-rich family with nine (8.26%) species; followed by Fabaceae, Euphorbiaceae, and Rosaceae which contain six species each (5.5% each), whereas Lamiaceae had five species (4.6%) and Poaceae had four species (3.7%). Acanthaceae, Rhamnaceae, Rubiaceae, and Oleaceae contributed three species each (2.76% each). Moreover; Sapindaceae, Rutaceae, Ranunculaceae, Solanaceae, Myrtaceae, Moraceae, Scrophulariaceae, Myrsinaceae, Oleaceae, Anacardiaceae, Polygonaceae, Urticaceae, and Cucurbitaceae had two species each (1.83% each). The remaining 34 families contributed one species each (0.92% each).

Among the total species collected in Wof-Washa forest, tree individuals were found dominant than other plant species with 1164 individuals ha⁻¹ followed by shrub (725 ha⁻¹), herbs (669 ha⁻¹), trees/ shrubs (588 ha⁻¹), lianas/climbers (63 ha⁻¹) and ferns (17 ha⁻¹). The midland and lower highland plant communities contain high numbers of tree individuals, whereas, in the upper highland forest community, herbs

Table 2

A list of plant species collected from WWF.

| Scientific name | Family name | Local name | Lifeform |
|---|-----------------------------|-----------------------|------------|
| Acacia abyssinica Hochst. ex Benth. | Fabaceae | Bazira girar | Т |
| Acalypha ornata A. Rich. | Euphorbiaceae | Nacha | S |
| Acanthus pubescens (Oliv.) Engl | Acanthaceae | Kosheshila | S |
| Albizia gummifera (J. F. Gmel.) C. A. Sm | Fabaceae | Sesa | Т |
| Alchemilla pedata A. Rich. | Rosaceae | Yemdr koso | Н |
| Allophylus abyssinicus (Hochst.) | Sapindaceae | Embs | Т |
| Radlk Ofer | | | |
| Aloe vera (L.) Burm.f. | Aloaceae | Eret | H |
| Rich | Asteraceae | Chikugh | н |
| Arundo donax L. | Poaceae | Shembeko | S |
| Asplenium aethiopicum (Burm.f.) | Aspleniaceae | Fern | F |
| Bech. | - | | |
| Berberis holsti Engl. | Berberidaceae | Znkila | S |
| Berchemia discolor (Klotzsch) Hemsl. | Rhamnaceae Malianthaaaaa | Jejeba Anomin | Т |
| Bersunta abyssinica Fresen. Bridelia micrantha (Hochst.) Baill | Funborbiaceae | Azumr Venehir tifr | 5 Т/S |
| Brucea antidysenterica J.F.Mill. | Simarubaceae | Abalo | S |
| Buddeleja polystachya Fresen. | Loganiaceae | Anfar | Т |
| Calpurnia aurea (Ait.) Benth. | Fabaceae | Dgta | S |
| Capparis fascicularis | Capparidaceae | Gumero | Li/C |
| Carissa spinarum L. | Apocynaceae | Agam | S |
| Casuarina cunningnamiana Miq. Celtis africana Burm | Lasuarinaceae | Arzelibanos | |
| Amaranthus graecizans I. | Amaranthaceae | Aluma | и Н |
| Clausena anisata (Willd.) Benth. | Rutaceae | Lmich | S |
| Clerodendrum myricoides (Hochst) | Lamiaceae | Misrch | Н |
| Vatke. | | | |
| Clematis simensis Fresen | Ranunculaceae | Azo hareg | Li/C |
| Clutia lanceolata Forssk. | Euphorbiaceae | Fiyelefej | S |
| Cucumis prophetarum L | Cucurbitaceae | embuay | I H |
| Discopodium penninervium Hochst. | Solanaceae | Ameraro | S |
| Dodonaea angustifolia L.f. | Sapindaceae | Kitkita | S |
| Dovyalis abyssinica (A.Rich.) Warb. | Flacourtiaceae | Koshim | S |
| Echinops kebericho Mesfin. | Asteraceae | Kebericho | Н |
| Ekebergia capensis Sparrm. | Meliaceae | Lol/sembo | Т |
| Eleusine Jioccijoliu (Forssk.) Spreng. Embelia schimperi Vatke | Myricaceae | AKIMU Frikoko | н Li/C |
| Erythrina brucei Schweinf. | Fabaceae | Korch/kwara | T/S |
| Erica arborea L. | Ericaceae | Asta | S |
| Eucalyptus globulus | Myrtaceae | Nech bahirzaf | Т |
| Euphorbia ampliphylla Pax | Euphorbiaceae | Kulkual | Т |
| Euphorbia tirucalli L. Figue sur | Euphorbaceae | Knchib Shola | 5 Т |
| Ficus sur Ficus thonningii Blume | Moraceae | Chibiha | T/S |
| Galiniera saxisfraga (Hochst.) | Rubiaceae | Buna mesay | S |
| Bridson. | | | |
| Galinsoga quadriradiata Ruiz & | Asteraceae | Deha nekay | Н |
| Pavon Calium simonea Freedon | Dubiacoao | Achleit | ч |
| Guizotia scabra (Vis.) Chiov. | Asteraceae | Mech | н |
| Hagenia abyssinica (Bruce) J.F. Gmel. | Rosaceae | Kosso | Т |
| Halleria lucida L. | Scrophulariaceae | Masinkoro | T/S |
| Helicrysum elephantinum Cufod. | Asteraceae | Nechilo | S |
| Hypericum revolutum Vahl. | Hypericaceae | Ameja | S |
| Hypoestes forskaolii (Vahl) R.Sch. | Acanthaceae | Telenj Msar genfo | н |
| Inula confertiflora A Rich | Aquijouaceae | Weinagift | S |
| Jasminum abyssinicum Hochets. Ex | Oleaceae | Tenbelel | Li/C |
| DC. | | | |
| Juniperus procera Hochst. ex Endl. | Cupressaceae | Yehabesha td | Т |
| Justicia schimperiana (Hochst. ex | Acanthaceae | Sensel | S |
| Nees) 1. | Actoração | Dag kimp | c |
| Lippia adoensis Hochst ex Waln | Lamiaceae | Kessie | S |
| Lobelia rhynchopetalum Hemsl. | Lobeliaceae | Jibra | S |
| Maesa lanceolata Forssk. | Myrsinaceae | Kelewa | T/S |
| Maytenus arbutifolia A. | Celastraceae | Atat | T/S |
| Maytenus obscura (A. Rich.) Cuf. | Celasraceae | Kumbel | T/S |
| миета jerruginea (Hochst.) Bak. Myrica salicifolia A Pich | rabaceae Myrtaceae | BIDITA Shinet | 1 T/S |
| Myrsine africana L | Myrsinaceae | Kechemo | S |
| J | , | (continued on | next page) |

Table 2 (continued)

| Scientific name | Family name | Local name | Lifeform |
|--|------------------|-------------------|----------|
| Ocimum lamiifolium Hochst. ex Benth | Lamiaceae | Dama kesie | S |
| Olea capensis L. subsp. macrocarpa (C. H. Wright) | Oleaceae | Damot woira | Т |
| Olea europaea .subsp. cuspidata (Wall.ex G. D | Oleaceae | Woira | Т |
| Olinia rochetiana A. Juss. | Oliniaceae | Tifie | T/S |
| Osvris Quadrinartita Dec. | Santalaceae | Keret | S |
| Otostegia integrifolia A. Rich. | Lamiaceae | Tiniut | S |
| Peucedanum mattirolii Chiov. | Aniaceae | Sire Bizu | H |
| Phytolacca dodecandra L. Herit. | Phytolaccaceae | Endod | Li/C |
| Piliostigma thonningii (Schumach.) Milne-Redh. | Fabaceae | Yekola wanza | T T |
| Pinus Patula Schiede ex Schltdl. | Pinaceae | Patula | Т |
| Pittosporum viridiflorum Sims. | Pittosporaceae | Woil | T/S |
| Plantago lanceolata L. | Plantaginaceae | Gorteb | Н |
| Poa leptoclada Hochst. ex A. Rich. | Poaceae | Dega sar | Н |
| Podocarpus falcatus (Thunb.)R.B.ex Mirb. | Podocarpaceae | Zigba | Т |
| Polyscias fulva (Hiern) Harms | Araliaceae | Yeznjero wober | Т |
| Prunus africana (Hook. f.) Kalkm. | Rosaceae | Tikur enchet | Т |
| Psydrax schimperiana (A.Rich.) Bridson | Rubiaceae | Seged | T/S |
| Ranunculus simensis Fresen. | Ranunculaceae | Ger hareg | Li/C |
| Rhamnus staddo A. Rich. | Rhamnaceae | Tsedo | S |
| Rhiocissus Tridentata (L. f.) Wild & Drummond | Vitaceae | Wodel asfes | Li/C |
| Rhus glutinosa A. Rich. | Anacardiaceae | Tlem | T/S |
| Rhus vulgaris Meikle | Anacardiaceae | Yeregna kolo | T/S |
| Ricinus comminus L. | Euphorbiaceae | Gulo | S |
| Rosa abyssinica Lindley | Rosaceae | Kega | S |
| Rubus steudneri Schweinf. | Rosaceae | Enjory | Li/C |
| Rubus volkensii Engl. | Rosaceae | Yedega enjory | Li/C |
| Rumex abyssinicus Jacq. | Polygonaceae | Mekmeko | Н |
| Rumex nervosus Vahl. | Polygonaceae | Embuacho | S |
| Salix subserrata Willd. | Salicaceae | Aheya | S |
| Solanecio gigas (Vatke) C.Jeffrey | Asteraceae | Shikoko | Н |
| | | gomen | |
| Solanum incanum subsp. Adoënse | Solanaceae | Embuay | Н |
| Sparmannia ricinocarpa (J. F. Gmel.) P. B | Tiliaceae | Wulkifa | Н |
| Stephania abyssinica (Dillon & A. Rich.) | Menispermaceae | Ayt hareg | Li/C |
| Teclea nobilis Del. | Rutaceae | Atesa/seil | S |
| Thymus schimperi Ronnign. | Lamiaceae | Tosign | Н |
| Urera hypsoledendron (A.Rich.) Wedd. | Urticaceae | Lankuso | Li/C |
| Urtica Simensis Steudel | Urticaceae | Sama | Н |
| Verbascum sinaiticum Benth. | Scrophulariaceae | Yahya joro | Н |
| Vernonia amygdalina Del. | Asteraceae | Girawa | T/S |
| Vulpia bromoides (L.) S.F. Gray | Poaceae | Gofer sar | Н |
| Ximenia americana L. | Olacaceae | Enkoy | Li/C |
| Zehneria scabra (L.F.) Sond. | Cucurbitaceae | Etse sabek | Li/C |
| Ziziphus spina-christi L. | Rhamnaceae | Kurkura | T/S |

T-tree, S-shrub, H-herb, T/S-tree/shrub, Li/C- lianas/climbers and F-fern.

were found the most dominant species (Fig. 2).

In the midland plant community, the most dominant tree and shrub

species were *Casuarina cunninghamiana and Erythrina brucei*, respectively. *Artemisia abyssinica, Jasminum abyssinicum* and *Asplenium aethiopicum* are also the most dominant herb, liana and fern species in this community, respectively (Table 3). Whereas, in the lower highland plant community, *Allophylus abyssinicus* is the most dominant tree followed by *Podocarpus falcatus* and *Juniperus procera*. *Erica arborea, Vulpia bromoides, Jasminum abyssinicum* and *Asplenium aethiopicum* are the most dominant shrub, herb, liana and fern species in this community respectively (Table 3). However, in the upper highland community of the forest, *Juniperus procera* is the most dominant tree species and *Erica arborea, Poa leptoclada* and *Stephania abyssinica* are the most dominant shrub, herb and liana species respectively (Table 3).

Acalypha ornate, Berchemia discolor, Capparis fascicularis, Chenopodium ambrosioides, and another seven plant species were recorded only in the midland community of the forest (Table 3). Whereas, species like *Echi*nops kebericho, Calpurnia aurea, Ekebergia capensis, Halleria lucida and another six plant species were recorded from the lower highland plant community only (Table 4). On the other hand, plant species such as Poa leptoclada, Lobelia rhynchopetalum, Helicrysum elephantinum, Thymus schimperi, and Rubus volkensii were recorded only from the upper highland community (Table 4).

Principal component analysis of species composition revealed that the overlap of similar species between the midland and lower highland plant communities. This indicated individuals that are similar are grouped together, and species in the midland community were surrounded by lower highland community plants. However, the surrounding upper

Table 3

| Species name | Abundance | | | | | |
|--------------------------|-----------|----------------|----------------|--|--|--|
| | Midland | Lower Highland | Upper Highland | | | |
| Casuarina cunninghamiana | 57 | 255 | 0 | | | |
| Erythrina brucei | 55 | 262 | 0 | | | |
| Croton macrostachyus | 54 | 207 | 0 | | | |
| Discopodium penninervium | 54 | 187 | 59 | | | |
| Bersama abyssinica | 44 | 258 | 0 | | | |
| Polyscias fulva | 44 | 370 | 0 | | | |
| Allophylus abyssinicus | 31 | 389 | 0 | | | |
| Podocarpus falcatus | 31 | 377 | 0 | | | |
| Juniperus procera | 37 | 311 | 166 | | | |
| Ilex mitis | 27 | 309 | 0 | | | |
| Poa leptoclada | 0 | 0 | 1006 | | | |
| Thymus schimperi | 0 | 0 | 800 | | | |
| Erica arborea | 0 | 275 | 563 | | | |
| Vulpia bromoides | 0 | 199 | 373 | | | |
| Artemisia abyssinica | 8 | 71 | 90 | | | |
| Asplenium aethiopicum | 14 | 67 | 0 | | | |
| Jasminum abyssinicum | 3 | 42 | 0 | | | |
| Embelia schimperi | 2 | 32 | 0 | | | |
| Amaranthus graecizans | 12 | 0 | 0 | | | |
| Ranunculus simensis | 7 | 25 | 0 | | | |
| Stephania abyssinica | 4 | 14 | 3 | | | |
| Buddeleja polystachya | 0 | 268 | 150 | | | |
| Lobelia rhynchopetalum | 0 | 0 | 131 | | | |



Life forms

Fig. 2. Number of individuals/ha in the plant communities.

Plant species found solely in each plant community.

| Midland plant community | Lower highland plant community | Upper highland plant community |
|-----------------------------|--------------------------------|--------------------------------|
| Chenopodium ambrosioides | Calpurnia aurea | Poa leptoclada |
| Clutia lanceolata | Echinops kebericho | Lobelia rhynchopetalum |
| Capparis fascicularis | Ekebergia capensis | Helicrysum elephantinum |
| Acalypha ornate | Halleria lucida | Thymus schimperi |
| Berchemia discolor | Rumex abyssinica | Rubus volkensii |
| Clausena anisata | Eucalyptus globulus | _ |
| Cucumis prophetarum | Pinus patula | _ |
| Dodonaea angustifolia | Urtica Simensis | _ |
| Euphorbia tirucalli | Pittosporum viridiflorum | _ |
| Ficus sur | Berberis holsti | _ |
| Olea capensis | - | _ |

highland plant community did not overlap with the adjacent plant community due to the high altitudinal effects (Fig. 3).

3.2. Species diversity and richness

The Shannon-Wiener diversity index (H') was computed for each plant communities and for the overall Wof-Washa forest. Based on the result of the Shannon-Weiner diversity index analysis, the overall plant species diversity and evenness of the forest were found 4.02 and 0.86 respectively. The lower highland plant community of the forest had slightly higher species diversity, evenness, and richness relative to the midland plant community and the upper highland community. Whereas, the upper highland forest community had the highest average altitude interval (3445 m.a.s.l) but had the least species richness, evenness, and diversity (Table 5).

3.3. Human disturbance along with the plant communities

The estimated disturbance levels in the three plant communities varied from a minimum score of 2 for upper highland plant community and a maximum score of 15 for midland plant communities (Table 6). In the midland plant community, all plots were subjected to disturbance whereas, in the lower highland plant community there were 19 control plots with totally undisturbed. Moreover, in the upper highland plant community, 32 control plots were recorded. Arranged in decreasing disturbance scores, the results from the three communities were midland > lower highland > upper highland forest communities. All three communities are subjected to disturbance by cattle and goat browsing and extraction of medicinal plants. Midland community was ranked as highly disturbed in all categories and had a greater disturbance score than lower highland community because of its proximity to human settlements. Even though the human disturbance in the upper highland forest community is very low, the diversity and species richness of this community are also relatively low as it is found in the higher altitudinal gradient.

3.4. Analysis of vegetation structure

3.4.1. Density and frequency distribution of the plant species

The total density of tree/shrub, sapling, and seedling in the WWF were 664.4, 757.2 and 805.7 individuals ha^{-1} respectively. Top five tree species densities in descending order were *Juniperus procera* (52.8 ha^{-1}), *Erica arborea* (46.5 ha^{-1}), *Allophylus abyssinicus* (32.6 ha^{-1}), *Polyscias fulva* (32.2 ha^{-1}), *Ilex mitis* (32 ha^{-1}) and *Podocarpus falcatus* (30 ha^{-1}). The sapling densities in descending order were *Erica arborea* (89.3 ha^{-1}), *Juniperus procera* (40.4 ha^{-1}), *Polyscias fulva* (31.1 ha^{-1}), *Ilex mitis* (31 ha^{-1}) and *Buddeleja polystachya* (26.1 ha^{-1}) and that of seedling densities were *Erica arborea* (46.3ha-1), *Buddeleja polystachya* (37.4 ha^{-1}), *Podocarpus falcatus* (33 ha-1), *Erythrina brucei* (31.5 ha^{-1}) and *Olinia rochetiana* (31 ha^{-1}).

The frequency of each plant species was revealed that *Juniperus pocera* was the most frequent species (81.7%), followed by *Erica arborea* (61.9%), *Podocarpus falcatus* (58.3%), *Ilex mitis* (55.7%), *Allophylus abyssinicus* (53.9%) and *Buddeleja polystachya* (50.4%). A complete list of species with their frequency and percentage frequency value is presented in Table 7.

3.4.2. Diameter at breast height (DBH) distribution of trees and shrub species

Trees and shrub species were categorized into six DBH classes following Caratti [23]; 1) <2.5 cm, 2) 2.5–12.5 cm, 3) 12.6–25 cm, 4) 25.1–50 cm, 5) 50.1–80 cm and 6) >80 cm. The general pattern of distribution of trees and shrubs in Wof-Washa forest along the different DBH classes seemed to be an inverted J-shaped population distribution. The number of individuals in the forest area decreases significantly from the



Fig. 3. Principal component analysis of species composition across the three plant communities.

Species diversity and richness along with the plant communities.

| Plant- communities | Altitude (m) | Area (ha) | Area (%) | Number of plots | Species Richness | Diversity index (H') | H' max | Species evenness |
|--------------------|--------------|-----------|----------|-----------------|------------------|----------------------|--------|------------------|
| Midland | 1833–2300 | 242.3 | 5.4 | 6 | 83 | 3.93 | 4.41 | 0.89 |
| Lower highland | 2300-3200 | 3107.3 | 69.3 | 78 | 87 | 4.01 | 4.45 | 0.90 |
| Upper highland | 3200-3691 | 1131.1 | 25.2 | 31 | 37 | 2.29 | 3.61 | 0.63 |
| Overall | 1833–3691 | 4480.7 | 100 | 115 | 108 | 4.02 | 4.68 | 0.86 |

Table 6

Degree of human disturbance along with the plant communities.

| Disturbance | Forest communities | | | | | | |
|-------------------|--------------------|----------------|----------------|--|--|--|--|
| | Midland | Lower highland | Upper highland | | | | |
| Degree of grazing | 3 | 1 | 1 | | | | |
| Fodder | 3 | 2 | 0 | | | | |
| Medicinal plants | 3 | 3 | 1 | | | | |
| Timber | 3 | 1 | 0 | | | | |
| Firewood | 3 | 1 | 0 | | | | |
| Total | 15 | 8 | 2 | | | | |

lowest size classes to the highest size class (Fig. 4).

Unlike the upper highland plant community, the number of individuals of the midland and lower highland plant communities of the forest areas decreases drastically from the lowest size classes to the highest size class (Fig. 5). However, the majority of individuals of the upper highland plant community were distributed in the second DBH class (Fig. 5). The majority of tree individuals of the midland community were distributed in the first DBH class with 1783 individual's ha-(39.8%). The distribution of trees in DBH class 2 was 1415 individuals ha⁻¹ (32.4%) and 688 (15.3%), 475 (10.6%), 71 (1.6%), 13 (0.3%) individuals ha⁻¹ in DBH classes 3, 4, 5 and 6 respectively (Fig. 5). Similarly, the majority of individuals of the lower highland plant community were distributed in the first DBH class with 961 individual's ha⁻¹ (37.1%). The distribution of trees in DBH class 2 was 867 individuals ha^{-1} (33.4%) and 414 (16%), 266 (10.3%), 66 (2.5%), 18 (0.7%) individuals ha⁻¹ in DBH classes 3, 4, 5 and 6 respectively (Fig. 5). Unlike the two plant communities, the majority of individuals of the upper highland community were distributed in the second DBH class with 347 individuals ha^{-1} (40.3%). The distribution of trees in DBH class 1 was 221 individuals ha^{-1} (25.7%) and 177 (20.5%), 101 (11.7%), 14.5 (1.7%), 2 (0.2%) individuals in DBH classes 3, 4, 5 and 6, respectively (Fig. 5).

3.4.3. Height class distribution of tree and shrub species

Tree and shrub individuals recorded in the study area were classified into seven height classes: 1) < 5 m, 2) 5.1–10 m, 3) 10.1–15 m, 4) 15.1–20 m, 5) 20.1–25 m, 6) 25.1–30 m and 7) > 30 m. There were a higher number of tree and shrub individuals in the height class 1, which accounts about 1596.7 individuals ha⁻¹ (71.8 %) of the total height classes (Fig. 6).

The highest number of tree individuals in the height class 1 which accounts 3338 individuals ha^{-1} (74.4%) of the total height classes were recorded in the midland forest community (Fig. 7). This appears to be a regular distribution that resembles the inverted J-shaped distribution of individuals in the different height classes with a slight increase in the seventh class (54 individuals ha^{-1}), which was higher than the sixth class (33 individuals ha^{-1}). Likewise, in the lower highland plant community of the forest, there were very high numbers of tree individuals in the height classe. The upper highland plant community had also a similar distribution of individuals in the two plant communities across the height class, but there was a complete absence of individuals in the seventh height class (Fig. 7).

Tree species that contribute most to the highest height class in the

midland community was *Podocarpus falcatus*. Whereas, *Juniperus procera* was the largest tree species, both in the lower highland and upper highland plant communities (Table 8).

3.4.4. Basal area (BA) of the plant species and the plant communities

The total basal area of all tree and shrub species was found to be $55.99m^2ha^{-1}$. Juniperus procera was the dominant species in the forest comprising 16.9% of the total basal area followed by *Podocarpus falcatus* (13%), *Ilex mitis* (7.1%), *Hagenia abyssinica* (6.3%), *Casuarina cunninghamiana* (5.6%), *Euphorbia ampliphylla* (4.9%) and *Polyscias fulva* (4.3%). The basal areas of tree species in the midland, lower highland and upper highland plant communities were found to be 89.2 m²ha⁻¹, 71.9 m²ha⁻¹ and 15.9 m²ha⁻¹ respectively. *Podocarpus falcatus* was the dominant species in the midland community of the forest comprising 18.6% of the total basal area followed by *Prunus africana* (9.9%) and *Polyscias fulva* (7%) (Table 9). On the contrary, *Juniperus procera* was the dominant species in the lower and upper highland communities involving 18.8% and 39.1%, respectively. The second and third dominant species in the lower highland community were *Podocarpus falcatus* (13.1%) and *Ilex mitis* (7.5%) (Table 9).

3.4.5. Important value index (IVI)

According to the IVI of WWF, about 25.7% of the importance values index was contributed by four species, *Juniperus procera*, *Podocarpus falcatus, Ilex mitis*, and *Erica arborea*. These species were abundant, frequent and dominant in the forest. *Juniperus procera* was found to have the highest IVI (30.7), followed by *Podocarpus falcatus* (21.7), *Ilex mitis (15.9), Erica arborea* (13.1), *Hagenia abyssinica* (12.3) and *Polyscias fulva* (12) (Table 10). The tree species in the forest were grouped into five classes based on their IVI values for conservation priority as follows: class 1) >15, 2) 10.01–15, 3) 5.01–10, 4) 1.01–5 and 5) ≤1 IVI.

In the midland plant community, *Podocarpus falcatus* exhibited the highest IVI (about 27.22), followed by *Prunus africana* (16.43), *Polyscias fulva* (15.3), *Erythrina brucei* (14.04) and *Juniperus procera* (13.3). However, the highest IVI in the lower highland plant community was demonstrated by *Juniperus procera* (29.92) followed by *Podocarpus falcatus* (22.89), *Ilex mitis* (17.78), *Polyscias fulva* (12.94) and *Allophylus abyssinicus* (12.75). In the upper highland community of WWF, *Juniperus procera* exhibited the highest IVI (82.01) followed by *Erica arborea* (69.71), *Hagenia abyssinica* (49.55), *Buddeleja polystachya* (37.62) and *Discopodium penninervium* (24.76).

3.5. Species similarity and difference among the plant communities of the forest

The one-way analysis of variance (ANOVA) used in order to check whether there is a significant difference between the three plant communities of the forest along the altitudinal gradient or not were presented as in (Table 11). In post-hoc analysis, Games-Howell's test was also used since equality of variance was not assumed. The post-hoc tests depicted exactly where the differences among the communities have occurred.

The distribution of species among these communities indicated significant dissimilarity; this was observed from the computed Jaccard's and Sorensen's similarity coefficient (Table 12).

Plants species frequency and relative frequency within each plant community of WWF.

| networkNNetworkNNetwork </th <th>Species name</th> <th>Lowland</th> <th></th> <th colspan="2">Lower highland</th> <th colspan="2">Upper highland</th> <th colspan="2">Overall WWF</th> | Species name | Lowland | | Lower highland | | Upper highland | | Overall WWF | |
|--|--|-----------|--------------|----------------|--------------|----------------|--------|-------------|------|
| Accel and produces 3 1.27 28 1.26 - - - 1 1.20 Accentur publicities - - - 18 0.80 13 3.6 31 1.60 Accentur publicities - - 18 0.80 13 3.6 31 1.60 Accentur publicities 1 0.42 39 1.71 - - 42 1.44 Allapity displation 1 0.42 14 0.62 - - 15 0.53 Attentis displation 1 0.46 3 0.16 - - 4 0.01 5 Marcha diss 1.20 4.6 3 0.16 - - 4 0.01 5 1.18 Accentur publicity dissibility - - 4 0.04 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 <th></th> <th>frequency</th> <th>%</th> <th>frequency</th> <th>%</th> <th>frequency</th> <th>%</th> <th>frequency</th> <th>%</th> | | frequency | % | frequency | % | frequency | % | frequency | % |
| Acaptar< | Acacia abvssinica | 3 | 1.27 | 28 | 1.25 | _ | | 31 | 1.09 |
| Acamba pacent:3 | Acalypha ornata | 2 | 0.85 | _ | _ | _ | _ | 2 | 0.07 |
| Abone Abone Abone provincing31.27391.74221.88Abbone provincing10.42170.5071.92250.88Abbone abone abone10.42180.231.00.35Abbone abone10.4280.131.00.33Arundo dono abone10.4280.131.00.33Arundo dono abone51.122.00.01.00.33Berolema dono abone11.022.00.02.00.00Berolema dono abone11.022.01.01.00.31.000.0Carlos dono comportant20.851.02.00.07Carlos dono comportant31.272.00.07Carlos dono comportant31.272.00.07Carlos dono comportant31.272.00.07Carlos dono comportant31.272.00.07Carlos dono comportant31.272.00.07Carlos dono comportant31.272.00.07 <td>Acanthus pubescens</td> <td>-</td> <td>-</td> <td>18</td> <td>0.80</td> <td>13</td> <td>3.56</td> <td>31</td> <td>1.09</td> | Acanthus pubescens | - | - | 18 | 0.80 | 13 | 3.56 | 31 | 1.09 |
| Addemaking peake10.42170.7671.22250.88Addemaking peake10.432.301.351.310.22.16Arranke down10.4230.1340.14Argebrain addown20.8580.36100.35Brochen Made20.8580.36170.60Argebrain addown31.222.66100.35Brochen Made31.222.662.80.98Brochen Made52.122.31.022.80.98Brochen Made52.122.31.022.80.98Brochen Made20.6522.90.02Caloria area20.6512.90.020.03Caloria area20.652.90.02Caloria area31.272.01.602.90.02Caloria area10.421.50.672.90.02Caloria area10.421.50.672.90.02Caloria area10.421.50.672.90.02Caloria area1< | Albizia gummifera | 3 | 1.27 | 39 | 1.74 | - | - | 42 | 1.48 |
| Altering11.40892.836.22.18Altering0.4310.13-1.100.13Arands domar10.4230.13-1.00.13Arands domar10.4230.1310.13Boberis fold70.7610.13Boberis fold11.1010.13Boberis fold11.1010.13Briteria fold11.1020.01Briteria fold11.1020.01Baddel optimization30.131.20Depension formation20.5420.0220.01Companis formation31.2701.1620.010.01Constructuring formation31.2701.1620.010.01Constructuring formation31.2701.1620.010.01Constructuring formation31.2700.0720.010.01Constructuring formation10.4220.010.010.010.010.010.010.010.010. | Alchemida pedata | 1 | 0.42 | 17 | 0.76 | 7 | 1.92 | 25 | 0.88 |
| Adde variant10.42430.8311.50.83Araba dama10.430.330.331.00.35Borberh blod1.70.661.00.35Borberh blod1.70.661.00.35Borberh blod1.01.31.84Borberh blod2.30.08Borberh blod0.203.30.08Borberh blod3.31.241.93.30.08Borberh blod3.40.08Calledor polymerh faccione0.07Carlos exinatione20.850.07Carlos exinatione20.851.00.04Carlos exinatione20.851.00.07Carlos exinatione20.851.00.07Carlos exinatione20.851.00.07Carlos exinatione20.851.00.07 <td>Allophylus abyssinicus</td> <td>4</td> <td>1.69</td> <td>58</td> <td>2.58</td> <td>-</td> <td>-</td> <td>62</td> <td>2.18</td> | Allophylus abyssinicus | 4 | 1.69 | 58 | 2.58 | - | - | 62 | 2.18 |
| Anome any state any state10.4230.131.01.01.00.140.14Algebraine antipope any state170.75170.63Bordenis state any state170.750.15Bordenis state any state0.150.15Bordenis state any state20.150.150.150.15Bordenis state any state381.9020.15Bordenis state any state381.9120.15Conserva state any state381.9220.16Conserva state any state20.16 <td< td=""><td>Alloe vera</td><td>1</td><td>0.42</td><td>14</td><td>0.62</td><td>- 15</td><td>- 4 11</td><td>15</td><td>0.53</td></td<> | Alloe vera | 1 | 0.42 | 14 | 0.62 | - 15 | - 4 11 | 15 | 0.53 |
| applement20.8380.36100.36Berchnis dalcolar52.1250.18Berchnis dalcolar52.1250.18Berchnis dalcolar61.274.00.708.00.108.30.18Berchnis dalcolar61.298.00.108.00.1 | Arundo donax | 2 | 0.83 | 20 | 0.13 | - | 4.11 | 43 | 0.14 |
| product< | Asplenium aethiopicum | 2 | 0.85 | 8 | 0.36 | _ | _ | 10 | 0.35 |
| Barchand absolution51.21251.18Barthand and system1.001.105.31.88Barthand minimum41.0140.11Barthand minimum40.13Barthand minimum40.13Carlos apirutum20.35210.351.69230.13Carlos apirutum20.35210.351.69230.13Carlos apirutum31.272.61.1820.100.11Classarius attributum20.3520.10Classarius attributum20.45 <td>Berberis holsti</td> <td>_</td> <td>-</td> <td>17</td> <td>0.76</td> <td>_</td> <td>-</td> <td>17</td> <td>0.60</td> | Berberis holsti | _ | - | 17 | 0.76 | _ | - | 17 | 0.60 |
| Bersona obysiskic31.2762.0541.01531.88Brace dially standardy contration52.122.391.04340.31Brace dially standardy contration52.122.391.04350.31Contradia splavame20.552.120.311.02320.33Capacity function20.552.120.3020.030.33Class of point31.272.61.6020.030.13Class of point31.2730.130.13Class of point31.2730.130.130.13Class of point31.2730.130.130.130.130.130.140. | Berchemia discolor | 5 | 2.12 | - | - | - | - | 5 | 0.18 |
| Bridin invandu 4 1.99 - - - - 4 0.13 Bundin physinshyn - - 38 1.74 1.9 5.21 5.8 2.04 Bundin physinshyn - - 38 1.74 1.9 - - 2.8 2.04 Cartins a signaria 2 0.85 2.1 0.93 - - - 2.0 0.85 Cartins a signaria 3 1.27 2.6 1.16 - - - 2.0 0.11 Canadria carting antimation 2 0.85 - - - - - 2.0 0.70 Canadria carting antimation 2 0.84 - - - 1.6 0.55 Cartin carting antimation 2 0.85 2.1 2.0 0.77 Cartin carting antimation 1 0.42 1.7 - - - - 1.6 0.55 0.17 | Bersama abyssinica | 3 | 1.27 | 46 | 2.05 | 4 | 1.10 | 53 | 1.86 |
| hnmen dipolentinin52.12231.02280.243Delaksia polymen381.09382.04Corports pinen20.852.30.81Caucaria canninghamian62.54361.602.30.81Caucaria canninghamian62.54361.602.90.102Chessoulding unbrasidifa31.272.90.07Caucaria simulti20.852.00.07Caucaria simulti20.862.00.07Caucaria simulti20.862.00.07Caucaria simulti10.421.00.40Discografing perminervici41.693.31.471.413.84511.79Coucaria simplement11.023.31.471.413.431.171.004Discografing perminervici31.272.00.891.80.63Coucaria simplement11.093.231.471.421.0040.041.004Discografing perminervici20.652.52.56.557.12.90.65Coucaria simplement10.421.27< | Bridelia micrantha | 4 | 1.69 | - | - | - | - | 4 | 0.14 |
| Backang polynakcy - | Brucea antidysenterica | 5 | 2.12 | 23 | 1.02 | - | - | 28 | 0.98 |
| Lappmentation100Casard causely hamina62,54361,6020.61Casard causely hamina62,54361,6020.02Chespecialire infrascistic31,2720.007Clausia infrastic20,8520.007Clausia infrastic10,421.50,6720.007Clausia infrastic20,8520.007Clausia infrastic10,4210.04Discograduit pronitoruin11.64210.04Discograduit pronitoruin11.622.710.04Discograduit pronitoruin11.022.70.710.04Discograduit pronitoruin10.421.30.81110.04Discograduit pronitoruin10.452.50.5510.04Discograduit pronitoruin10.452.50.5510.65 </td <td>Buddeleja polystachya</td> <td>-</td> <td>-</td> <td>39</td> <td>1.74</td> <td>19</td> <td>5.21</td> <td>58</td> <td>2.04</td> | Buddeleja polystachya | - | - | 39 | 1.74 | 19 | 5.21 | 58 | 2.04 |
| Constrain Constrain <t< td=""><td>Calpurnia aurea</td><td>-</td><td>- 0.9E</td><td>38</td><td>1.69</td><td>-</td><td>-</td><td>38</td><td>1.33</td></t<> | Calpurnia aurea | - | - 0.9E | 38 | 1.69 | - | - | 38 | 1.33 |
| Casarding cambing bankan 6 254 160 - - 42 1.48 Casard arises 3 1.27 26 1.16 - - 2 0.07 Classeria simunis 2 0.85 - - - - 2 0.07 Classeria simunis 2 0.85 - - - - 2 0.07 Classeria simunis 2 0.85 - - - - 2 0.07 Cotasseria simunis 2 0.85 - - - - 1 0.04 Discopolini perminin 4 1.69 3.2 1.42 - - 1 0.04 Discopolini perminin 4 1.69 3.3 1.77 - - - 13 0.46 Discopolini perminin 3 1.27 0 88 - - - 13 0.46 Discopolini perminin 3 1.27 <td>Carissa spinarum</td> <td>2</td> <td>0.85</td> <td>- 21</td> <td>- 0.93</td> <td>_</td> <td>_</td> <td>23</td> <td>0.07</td> | Carissa spinarum | 2 | 0.85 | - 21 | - 0.93 | _ | _ | 23 | 0.07 |
| Table grinom31.27261.16200.02Chanpohum mytroxide20.8520.07Clenxidsrinm mytroxide10.42150.6720.07Clenxidsrinm mytroxide10.42150.6720.07Cotan macrostachys41.69321.4230.11Cotan macrostachys41.69321.4230.11Dictoring trephythem10.4230.11Dictoring trephythem10.4230.11Dictoring trephythem31.271.80.350.11Dictoring trephythem31.271.80.350.110.420.550.111.90.650.55 | Casuarina cunninghamiana | 6 | 2.54 | 36 | 1.60 | _ | _ | 42 | 1 48 |
| chanopachian ambraciolize111130.11Clausaria simunsis20.8520.07Clandardam myrakida10.42150.6720.07Clandardam myrakida20.8520.07Clandardam myrakida10.42150.730.12Clandardam myrakida10.42330.12Clausaria graafida10.42330.13Decordam arrosstafida31.2730.81Decordam arrosstafida31.27130.63Exclandar forcing130.65130.65140.65Exclandar forcing180.80130.67Exclandar forcing180.63130.67Exclandar forcing180.80120.67Exclandar forcing180.63180.63Exclandar forcing60.63180.63Exclandar forcing< | Celtis africana | 3 | 1.27 | 26 | 1.16 | _ | _ | 29 | 1.02 |
| Clausics minimis20.8520.077Clendind meny ricolids10.42150.67160.55Clendind mensions20.8520.077Crosen marry stacky is41.09321.42361.26Crosen marry stacky is41.09321.4713.64511.79Decongular perminer vium41.09331.47143.64511.79Decongular perminer vium41.09331.711.43.64511.11Doyalis dysanica31.271.61.60.64Ediang sk berkink1.60.581.60.64Ediang sk berkink1.60.581.60.65Edians in flocifica1.60.652.56.85712.60.65Edians in flocifica80.301.60.65 | Chenopodium ambrosioides | 3 | 1.27 | _ | _ | _ | _ | 3 | 0.11 |
| Clamata simunisis20.8520.05Clavia luncablas20.8520.07Coron mucroschag1.693.21.4231.26Ciscopin grophetarum10.423.01.17Decogonin grophetarum10.423.01.17Decogonic grophetarum10.693.00.81Dovaylis obspace argustifola31.271.30.61Dovaylis obspace argustifola31.27200.891.30.63Echnegs kebreicho1.80.801.30.64Echnegs kebreicho1.80.801.90.65Elasine floccipida20.622.56.857.12.49Endela schnega4.62.052.56.857.12.49Endela schnega4.62.054.60.85Endela schnega4.62.051.60.05Endela schnega1.60.051.60.05Endela schnega1.60.051.61.6< | Clausena anisata | 2 | 0.85 | - | - | _ | - | 2 | 0.07 |
| Carada max synchodia 1 0.42 15 0.67 - - - 2 0.07 Corton max syncholyns 4 1.69 32 1.42 - - 36 1.20 Corton max syncholyns 4 1.69 33 1.47 14 3.84 51 1.03 Deconce angustylba 3 1.27 - - - 3 0.11 Doyalis obysinica 3 1.27 20 0.89 - - 1.3 0.64 Etchings kohrine - - 13 0.58 - - 1.8 0.60 Etchings kohrine - - 18 0.62 - - 1.8 0.63 Etakan forciolation - - 4 0.49 2.15 - - 1.9 0.67 Etakan forciolation - - 8 0.36 - - 8 0.28 Etakan forciolation 0.85 - - - - 4 1.55 Etakan forciolati anglop | Clematis simensis | 2 | 0.85 | - | - | - | - | 2 | 0.07 |
| Clank Increachar 2 0.85 - - - - - - - - - - - 1 0.42 Cacami graphetarum 1 0.42 - - - - - 1 0.40 Dackonas argustfalt 3 1.27 - - - - 3.41 1.41 0.84 5.1 1.79 Dockonas argustfalt 3 1.27 20 0.85 - - - 3 0.11 Dockonas argustfalt 3 1.27 20 0.85 - - 13 0.68 Exhibits scherich - - 18 0.80 - - 18 0.63 Exhibits scherich - - 18 0.80 - - 10 0.65 12 12 12 18 0.63 - - 12 0.65 12 12 12 13 0.45 12 14 1.55 0.5 12 12 13 0.45 12 12 0 | Clerodendrum myricoides | 1 | 0.42 | 15 | 0.67 | - | - | 16 | 0.56 |
| Croin macrostachysis 4 1.69 32 1.42 - - - 36 1.20 Discopolium perminervium 4 1.69 33 1.47 1.4 3.4 51 1.70 Dobonase anguafolium perminervium 3 1.27 - - - - 3 0.11 Dovojati obysinica 3 1.27 20 0.89 - - 1.3 0.48 Exhings kehricho - - 1.8 0.80 - - 1.8 0.60 Enhesis achimperi 1 0.42 1.8 0.80 - - 1.9 0.47 Enhesis achimperi - - 4 1.69 49 2.18 - - 1.6 0.42 Enherbia achimperi 1 0.42 1.8 0.30 - - 4 1.59 Enherbia achimperi 1 0.42 1.9 - - 5 1.60 Enher | Clutia lanceolata | 2 | 0.85 | - | - | - | - | 2 | 0.07 |
| Cacanalis projectarum 1 0.42 - - - - - - - - 1 0.01 Dodonca argustifola 3 1.27 - - - - - - 3 0.11 Dodonca argustifola 3 1.27 20 0.89 - - 13 0.68 Echingis kebericho - - 18 0.60 - - 13 0.66 Elesteric foccifola 2 0.85 2.5 1.11 - - 27 0.95 Dired anbera - - 46 0.60 - - 19 0.65 Erichoria anphyla 5 1.22 39 1.74 - - - 10 1.80 0.03 1.80 Enchoria anphyla 5 1.21 39 1.74 - - - 1.30 0.40 Elestar 1.61 1.79 - - | Croton macrostachyus | 4 | 1.69 | 32 | 1.42 | - | - | 36 | 1.26 |
| Decognation permanerum 4 1.69 33 1.47 14 3.84 51 1.79 Doorneal angustifolia 3 1.27 - - - - 3 0.11 Dorolati angustifolia 3 1.27 20 0.89 - - 23 0.81 Exchanges kebrito - - 18 0.80 - - 18 0.63 Elashine faccifolia 2 0.85 25 1.11 - - 190 0.67 Erica arbora - - 46 2.05 25 6.85 71 2.49 Endphofia intraciti 1.69 49 2.18 - - 8 0.26 Endphofia intraciti 2 0.85 - - - - 4 1.55 Exphorbia intraciti 3 1.127 - - - 51 1.79 Galatinas angustifac 1.02 0.85 14 0 | Cucumis prophetarum | 1 | 0.42 | - | - | - | - | 1 | 0.04 |
| Domane infigural S 1.27 - 1 0 0 - - - 1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 1 0 0 1 | Discopodium penninervium | 4 | 1.69 | 33 | 1.47 | 14 | 3.84 | 51 | 1.79 |
| Dryman Lynamu J LD LD Cost - - - LD Cost | Douonaea angusujona Douvalis abyssinica | 3 | 1.27 | - 20 | - | - | - | 3 | 0.11 |
| Bib - - 18 0.80 - - 18 0.63 Elestin faccifolia 2 0.85 2.5 1.11 - - 2.7 0.95 Endial schuperi 1 0.42 18 0.80 - - 19 0.67 Ericat aborea - - - 46 2.05 2.5 6.85 71 2.49 Epythrin bruci 4 1.69 49 2.18 - - - 8 0.36 - - 4 0.15 Euphorbia mipulpila 5 2.12 39 1.74 - - - 4 1.55 Euphorbia mipulpila 1 1.69 40 1.78 - - - 13 0.11 Ficas ar 3 1.27 - - - 13 0.13 1.79 Galines ascinga quadrinchia 2 0.85 11 0.49 5 1.37 | Echinops kehericho | 5 | 1.27 | 13 | 0.59 | _ | _ | 13 | 0.81 |
| Identify Product of the second s | Ekebergia capensis | _ | _ | 18 | 0.80 | _ | _ | 18 | 0.63 |
| Induction 1 0.42 18 0.80 - - - 19 0.67 Driva arbora - - 169 49 2.18 - - 53 1.88 Euclypturs arbutas - - 8 0.36 - - 8 0.36 Eugharbia amplayfula 5 2.12 39 1.74 - - 44 1.55 Eugharbia amplayfula 3 1.27 - - - - 44 1.55 Galiners assrifting 5 2.12 40 1.78 - - - 13 0.46 Galiners assrifting 5 2.12 40 0.42 1.7 - - 1.37 1.7 0.60 Galiners assrifting 5 2.13 0.42 1.1 0.49 - - 1.37 1.7 0.60 Galiners assrifting - - 2.2 0.85 1.42 16 | Eleusine floccifolia | 2 | 0.85 | 25 | 1.11 | _ | _ | 27 | 0.95 |
| bria - - 46 205 25 6.85 71 2.49 Brachprins - - 8 0.26 - - 8 0.28 Brachprins - - 8 0.26 - - 8 0.28 Brachprins 1 0.85 - - - - 2 0.070 Ricts sar 3 1.27 - - - - 44 1.55 Galines 1.4 0.69 40 1.78 - - 1 1 0.40 1.55 Galines 0.85 1.1 0.49 - 1.37 1.70 0.60 Galines 0.85 1.4 0.62 7 1.92 2.3 0.81 Galines 1.40 0.49 5 1.37 1.37 1.50 0.60 Galines 1.6 0.28 1.42 16 0.38 1.23 1.23 | Embelia schimperi | 1 | 0.42 | 18 | 0.80 | _ | _ | 19 | 0.67 |
| Important base41.69492.1851.86Evalphoribla ampliphyla52.12391.7480.28Euphorbia ampliphyla52.12391.7441.55Euphorbia atrucall20.8520.07Ficus sur31.2730.11Ficus fibrai fibrai subro atrigit41.69401.78441.55Galinessa subrigating52.12462.051.310.46Galinessa subrigating20.85110.491.922.330.81Galinessa cubra10.42110.4951.37170.60Hagenia abysinica260.116260.91Halleria lucid164.38160.551.23< | Erica arborea | - | - | 46 | 2.05 | 25 | 6.85 | 71 | 2.49 |
| Luc options globulus80.3680.28Luphobia anrualli20.85441.55Luphobia tarualli20.8530.11Ficus thomingi41.69401.7830.11Ficus thomingi52.12462.05511.79Galineser quadrimulatu20.851.10.491.30.46Galinast quadrimulatu20.851.40.6271.922.30.81Guidanis and and antimus10.421.162.60.91Halleria duysinica321.421.64.381.60.56Hypoistes forskaolii20.851.40.621.60.55Hypoistes forskaolii20.851.40.621.60.55Hypoistes forskaolii20.851.40.621.60.55Haula conferifior341.5161.64401.40Jumigeris procea52.12662.942.36.30943.30Jungeris procea31.271.40.621.6480.28Jungeris procea31.271.40.221.7< | Erythrina brucei | 4 | 1.69 | 49 | 2.18 | - | - | 53 | 1.86 |
| Laphobia analpinylam52.12391.741007Ficas sur31.2720.007Ficas sur31.2730.11Ficas storning52.12462.051.30.46Galinsoga quadrivalitat20.85110.491.30.46Galinsoga quadrivalitat20.85140.6271.922.30.81Guidois schra10.42110.4951.37170.60Hagenia dixisia321.42164.38481.69Hallerina lucida261.140.62160.38131.23Hypeican revolutan301.3451.37351.231.23Hypeican revolutan341.5161.64401.40Jasmium obysnicum20.85190.85160.380.60Jasmium obysnicum20.8561.6480.28Jubita schimpertana31.27190.8261.64300.60 | Eucalyptus globulus | - | - | 8 | 0.36 | - | - | 8 | 0.28 |
| Luptopia trincalli 2 0.85 - - - - - - - - - 2 0.011 Ficas sur 3 1.27 - - - - 4 1.55 Galiness axtisfraga 5 2.12 46 2.05 - - 13 0.46 Galiness axtisfraga 2 0.85 11 0.49 - - 13 0.46 Galiness axtisfraga 1 0.42 11 0.49 5 1.37 17 0.60 Hageria abyssinica - - 32 1.42 16 4.38 48 1.69 Helicristam revolutum - - 30 1.34 5 1.37 35 1.33 1.23 1.24 Hypoists forkaolit 2 0.85 14 0.62 - - 16 0.34 1.31 0.34 1.40 1.40 Juniperus procera 5 2.12 </td <td>Euphorbia ampliphylla</td> <td>5</td> <td>2.12</td> <td>39</td> <td>1.74</td> <td>-</td> <td>-</td> <td>44</td> <td>1.55</td> | Euphorbia ampliphylla | 5 | 2.12 | 39 | 1.74 | - | - | 44 | 1.55 |
| International prices start 3 1.27 - - - - - - - - - - 3 0.11 Ficus storningi 4 1.69 40 1.78 - - 5 1.79 Galinesa quadriradita 2 0.85 11 0.49 - - 51 1.79 Galinesa quadriradita 2 0.85 11 0.49 - - 1.37 0.60 Hagenia dissinica - - 32 1.42 16 4.38 48 1.69 Halleris uni dissinica - - 32 1.42 16 4.38 48 1.69 Helicrysun disphanitum - - 32 1.42 16 4.38 16 0.56 Hyperistor forskali 2 0.85 14 0.62 - - 16 4.33 16 0.56 Izer mitis 4 1.69 60 2.67 - - 16 4.30 1.01 18 0.62 - - | Euphorbia tirucalli | 2 | 0.85 | - | - | - | - | 2 | 0.07 |
| International Caliner Galinessa quadriradita1109401.78441.23Galinessa Galinessa quadriradita20.85110.49130.46Galinessa Galinessa20.85140.6271.92230.81Galinessa Galinessa10.42110.4951.37170.60Hageria abyssinica Halleria lucida261.16260.91Helleria lucida Typericam roothum Hypericam roothum301.3451.37351.23Hypoistes forskaolii20.85140.62642.55Instand Jumipens procena51.21662.64160.56Invalia schimperiana31.27140.62170.60Leppa dosis | Ficus sur | 3 | 1.27 | - | - | - | - | 3 | 0.11 |
| Journal Subsyncy J L.1.2 HO L.03 - - - J.1 O.1.7 Galinosog quadriradiati 2 0.85 11 0.40 - 1.37 17 0.60 Galinosof quadriradiati - - 32 1.42 16 4.38 48 169 Hagenia abyssinica - - 26 1.16 - - 26 0.91 Helicrysmi dephantinum - - 26 1.16 - - 26 0.91 Helicrysmi dephantinum - - - 16 0.55 1.37 35 1.23 Hypoists forskolii 2 0.85 14 0.62 - - 16 0.55 Itex mitis 4 1.69 60 2.67 - - 17 0.60 Jastimum bysinicum 2 0.85 19 0.85 - - - 16 4.8 0.22 | Ficus inonningii Galipiera savisfraga | 4 | 1.09 | 40 | 1.78 | - | - | 44 51 | 1.55 |
| Column simense 2 0.85 14 0.62 7 1.92 23 0.81 Guizo di scabra 1 0.42 11 0.49 5 1.37 17 0.60 Halgenia dispsinica - - 32 1.42 16 4.38 48 1.69 Halleria lucida - - 26 1.16 - - 26 0.91 Helicrysum elephantinum - - - 16 4.38 46 0.56 Hypericam revolutum - - 30 1.34 5 1.37 35 1.23 Hypericam revolutum - - 30 1.34 5 - - 16 0.56 Ilex mits 4 0.62 - - 64 2.25 India confertiflora 2 0.85 19 0.85 - - 2 10.74 33 33 Jumipers procera 3 1.27 | Galinsoga ayadriradiata | 2 | 0.85 | 11 | 0.49 | _ | _ | 13 | 0.46 |
| Guizotia scabra10.42110.4951.37170.60Hagenia abyssinica321.42164.38481.09Helleria lucida-261.16260.91Helleriy sum dephantinum7164.38160.56Hypoitst Gyrskalii20.85140.62160.56Iler mitis41.69602.67642.25Inula confertifora341.5161.64401.40Jaminum abyssinicum20.85190.85210.74Jutipers procera52.12642.94236.30943.30Justita schimperiana20.85170.60Leonotis raineriana20.8561.6480.28Lippia daoensis31.27140.62131.86Maytenus abscura31.27311.38341.19Miletia ferruginea41.69351.56341.19Myrine asticifolia41.69410.6271.92230.63Myrine asticifolia60.851.440.6271.92230.63Myrine asticifolia6 <t< td=""><td>Galium simense</td><td>2</td><td>0.85</td><td>14</td><td>0.62</td><td>7</td><td>1.92</td><td>23</td><td>0.81</td></t<> | Galium simense | 2 | 0.85 | 14 | 0.62 | 7 | 1.92 | 23 | 0.81 |
| Hagenia abysinica321.42164.38481.69Halleria lucida261.16260.91Hellicryaun tephontinum261.3451.37351.33Hypericum revolutum301.3451.37351.23Hypoises forskaoli20.85140.62642.25Inula confertifiora341.5161.64401.40Jasminum abysinicum20.85190.852.120.74Junipens procera52.12662.942.36.30943.30Justitia schimperiana31.27140.62170.60Lepna doensis11.27291.2982.19401.40Lobeta rhynchopetalum61.6480.28Massa lanceolata41.69492.18311.86Maytems arbutifolia20.85391.74341.19Midetia ferruginea41.69351.56341.19Midetia ferruginea41.694.10.6271.922.30.81Myrien safulfolia20.851.56341.91 <td>Guizotia scabra</td> <td>1</td> <td>0.42</td> <td>11</td> <td>0.49</td> <td>5</td> <td>1.37</td> <td>17</td> <td>0.60</td> | Guizotia scabra | 1 | 0.42 | 11 | 0.49 | 5 | 1.37 | 17 | 0.60 |
| Helicria lucida261.160000Helicry sum elephantium164.38160.56Hypericum revolutum0.851.440.62160.56Ilex mitis40.692.67642.25Inula conferifiora341.5161.64401.40Jasminum abyssinicum20.85190.85210.74Juniperus procera52.12662.94236.30943.30Justia schimperiana31.27140.62170.60Lopoits rineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Maxeus abutifolia20.85351.56391.37Myrica schiftofia41.69351.56301.37Myrica schiftofia41.69411.831.922.30.61Myrica schiftofia41.69411.641.611.50.531.56Olea corposi62.54321.51 | Hagenia abyssinica | - | - | 32 | 1.42 | 16 | 4.38 | 48 | 1.69 |
| Helicrysum elephantium164.38160.56Hypoixes forskalti20.851.3451.37351.23Hypoixes forskalti20.851.420.62160.56Iter mitis41.69602.67642.25Inula confertiflora341.5161.64401.40Jaminum Abysinicum20.85190.85210.74Jaminum Abysinicum20.85190.85170.60Juniperus procera52.12662.94236.30943.30Justitia schimperiana31.27140.621680.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum16661.6480.28Maytenus arbutifolia20.85391.74391.371.37Myrica salicifolia41.69113.01150.53Myrica salicifolia41.69113.01150.53Myrica salicifolia41.69113.01150.51Olea capensis60.2541.9223 | Halleria lucida | - | - | 26 | 1.16 | - | - | 26 | 0.91 |
| Hypericum revolutum301.3451.37351.23Hypoistes forskaolii20.85140.62160.56Ilex mitis41.69602.67642.25Inula confertiflora341.5161.64401.40Jasminum abysinicum20.85190.85210.74Juniperus procera52.12662.94236.30943.30Justitia schimperiana31.27140.62170.60Leontis raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum411.44Lobelia rhynchopetalum20.85391.74331.86Maytenus arbutifolia20.85391.74341.1931Millettia ferruginea41.69351.56391.37350.53Myrsine africana20.851.440.6271.92320.81Ocimum lamitifolium241.0782.19350.53Myrsine africana20.851.66 | Helicrysum elephantinum | - | - | - | - | 16 | 4.38 | 16 | 0.56 |
| Hypoixtes forskaolii20.85140.62160.56Ilex mitis41.69602.67642.25Inula confertiflora341.5161.64401.40Jasminum abyssiniam20.85190.85210.74Juniperus procera52.12662.94236.3094330Justita schimperiana31.27140.6270.60Leonotis raineriana20.8561.6480.28Lippia adoensis31.27140.62164.38160.56Maesa lanceolata41.69492.18531.86Maytenus arbutifolia20.85391.74341.19Myriac salicifolia41.69351.56341.19Myriac salicifolia41.69113.01150.53Myrsine africana20.85140.6271.92230.81Ocimu Iamifolium113.01150.53Myrsine africana20.85140.6271.92230.81Olea capensis62.54113.01150.53 | Hypericum revolutum | - | - | 30 | 1.34 | 5 | 1.37 | 35 | 1.23 |
| Ilex mitis41.69602.67642.25Inula confertifora341.5161.64401.074Jasninum abysinicum20.85190.85210.74Juniperus procera52.12662.94236.30943.30Justitia schimperiana31.27140.62170.60Leonotis raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobeita rhynchopetalum164.38160.56Masa lanceolata41.69492.18341.19Miltetia ferruginea31.27311.38341.19Miltetia ferruginea41.691113.01150.53Myrsine africana20.85140.6271.92230.81Ociarum lamitifolium1.120.630.51Olea carensis62.5460.210.53Olea carensis62.5460.21Olea carensis62.5460.51Olea | Hypoistes forskaolii | 2 | 0.85 | 14 | 0.62 | - | - | 16 | 0.56 |
| Intal congrugand341.5161.64401.40Jasminum abyssinicum20.85190.85210.74Juniperus procera52.12662.94236.30943.30Justitia schimperiana31.27140.62170.60Leonois raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Maesa lanceolata41.69492.18531.86Maytenus obscura31.27311.38341.19Millettia ferruginea41.69351.56341.37Myrica salicifolia41.69113.01150.53Myrise africana20.85140.6271.92230.81Olea capensis62.5460.21Olea capensis62.54451.58Olinia rochetiana41.69441.9682.19561.97Osyris quadriparitia41.69291.29120.42 | llex mitis | 4 | 1.69 | 60 | 2.67 | - | - | 64 | 2.25 |
| Juniperus procera20.63190.63210.74Juniperus procera52.12662.94236.30943.30Justitia schimperiana31.27140.62170.60Leonotis raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Masa lanceolata41.69492.18411.44Maytenus arbutifolia20.85391.74341.19Millettia ferruginea41.69351.56391.37Myrica salicifolia41.69113.01150.53Myrise africana20.85140.6271.92230.81Olea capensis62.5460.21Olea capensis62.5460.21Olinia rochetiana41.69441.9682.19321.12Olea capensis62.5460.21Olinia rochetiana41.692.91.29451.58Olinia roc | Inuta conjertifiora | - 2 | - | 34 10 | 1.51 | 0 | 1.04 | 40 21 | 1.40 |
| Justitia schimperiana31.27140.62170.60Leonotis raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Massa lanceolata41.69492.18531.86Maytenus obscura31.27311.38411.44Maytenus obscura31.27311.38341.19Millettia ferruginea41.69351.56391.37Myrica salicifolia41.69113.01150.53Myrisne africana20.85140.6271.92230.81Olea europaea41.69411.8360.21Olea europaea41.69441.9682.19561.97Oyris quadriparitia41.69441.9682.19561.97Oyris quadriparitia41.69291.29331.16Otastegia integrifolia20.85100.45120.67Phytolacca dodecandra10.42130.5841.1018 </td <td>Juninerus procera</td> <td>_ 5</td> <td>0.00</td> <td>19 66</td> <td>0.65 2 Q4</td> <td>- 23</td> <td>- 6 30</td> <td>∠ı 94</td> <td>2 20</td> | Juninerus procera | _ 5 | 0.00 | 19 66 | 0.65 2 Q4 | - 23 | - 6 30 | ∠ı 94 | 2 20 |
| Leonotis raineriana20.8561.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum61.6480.28Lippia adoensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Masea lanceolata41.69492.18531.86Maytenus abstura31.27311.38411.44Maytenus obscura31.27311.38341.19Milletia ferruginea41.691113.01150.53Myrise aslicifolia41.691113.01150.53Myrise africana20.85140.6271.92230.81Olea capensis62.5460.21Olea capensis62.54451.58Olinia rochetiana41.69411.83451.58Olinia rochetiana41.69291.29331.66Olinia rochetiana41.69291.29331.66 <t< td=""><td>Justitia schimperiana</td><td>3</td><td>1.27</td><td>14</td><td>0.62</td><td>25</td><td>-</td><td>17</td><td>0.60</td></t<> | Justitia schimperiana | 3 | 1.27 | 14 | 0.62 | 25 | - | 17 | 0.60 |
| Lippia advensis31.27291.2982.19401.40Lobelia rhynchopetalum164.38160.56Maesa lanceolata41.69492.18531.86Maytenus arbutifolia20.85391.74411.44Maytenus obscura31.27311.38341.19Millettia ferruginea41.69113.01150.53Myrica salicifolia41.69113.01150.53Myrica salicifolia41.69113.01150.53Myrise africana20.85140.6271.92230.81Ocimum lamiifolium241.0782.19321.12Olea capensis62.54451.58Olinia rochetiana41.69411.83451.58Olinia rochetiana41.69291.29331.16Otostegia integrifolia20.85100.45120.42Peucedanum mattirolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Leonotis raineriana | 2 | 0.85 | _ | - | 6 | 1.64 | 8 | 0.28 |
| Lobelia rhynchopetalum164.38160.56Maesa lanceolata41.69492.18531.86Maytenus arbutifolia20.85391.74411.44Maytenus obscura31.27311.38341.19Milletia ferruginea41.69351.56301150.53Myrica salicifolia40.69113.01150.53Myrica salicifolia20.85140.6271.92230.81Ocimum lamiifolium241.0782.19321.12Olea capensis62.54451.58Olinia rochetiana41.69411.83451.58Olinia rochetiana41.69441.9682.19561.97Osyris quadripartita41.69291.29331.16Otostegia integrifolia20.85100.45331.46Otostegia integrifolia31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Lippia adoensis | 3 | 1.27 | 29 | 1.29 | 8 | 2.19 | 40 | 1.40 |
| Maesa lanceolata41.69492.18531.86Maytenus arbutifolia20.85391.74411.44Maytenus obscura31.27311.38411.44Maytenus obscura31.27311.38341.19Milletia ferruginea41.69351.56301150.53Myrica salicifolia40.697-113.011.92230.81Ocimum lamiifolium10782.19321.12Olea capensis62.5460.21Olea curopaea41.69411.83451.58Olinia rochetiana41.69441.9682.19561.97Osyris quadripartia41.69291.29120.42Peucedanum mattirolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Lobelia rhynchopetalum | - | - | - | - | 16 | 4.38 | 16 | 0.56 |
| Maytenus arbutifolia20.85391.74411.44Maytenus obscura31.27311.38341.19Millettia ferruginea41.69351.56391.37Myrica salicifolia41.69113.01150.53Myrsine africana20.851.40.6271.92230.81Ocimum lamiifolium241.0782.19321.12Olea capensis62.5460.21Olea europaea41.69411.83451.58Olinia rochetiana41.69291.29331.16Otsegia integrifolia20.85100.4520.42Peucedanum mattirolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Maesa lanceolata | 4 | 1.69 | 49 | 2.18 | - | - | 53 | 1.86 |
| Maytenus obscura31.27311.38341.19Millettia ferruginea41.69351.56391.37Myrica salicifolia41.69113.01150.53Myrsine africana20.85140.6271.92230.81Ocimum lamiifolium241.0782.19321.12Olea capensis62.5460.21Olea curopaea41.69411.83451.58Olinia rochetiana41.69291.29331.16Otsegia integrifolia20.85100.45331.16Peucedanum mattriolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Maytenus arbutifolia | 2 | 0.85 | 39 | 1.74 | - | - | 41 | 1.44 |
| Millettia ferruginea41.69351.56391.37Myrica salicifolia41.69113.01150.53Myrsine africana20.85140.6271.92230.81Ocimum lamifolium-241.0782.19321.12Olea capensis62.5460.21Olea europaea41.69411.83451.58Olinia rochetiana41.69291.29331.16Otostegia integrifolia20.85100.45331.16Peucedanum matriolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Maytenus obscura | 3 | 1.27 | 31 | 1.38 | - | - | 34 | 1.19 |
| Myrica satictyotia41.69113.01150.53Myrsine africana20.85140.6271.92230.81Ocimum lamitfolium241.0782.19321.12Olea capensis62.5460.21Olea europaea41.69411.83451.58Olinia rochetiana41.69291.29331.16Osyris quadripartita41.69291.29120.42Peucedanum mattirolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Millettia ferruginea | 4 | 1.69 | 35 | 1.56 | - | - | 39 | 1.37 |
| Myrsne arricana20.85140.6271.92230.81Ocimum lamiifolium241.0782.19321.12Olea capensis62.5460.21Olea europaea41.69411.83451.58Olinia rochetiana41.69291.29331.16Osyris quadripartita41.69291.29120.42Peucedanum mattirolii31.27100.4561.64190.67Phytolacca dodecandra10.42130.5841.10180.63 | Myrica salicifolia | 4 | 1.69 | - | - | 11 | 3.01 | 15 | 0.53 |
| Octman lannyouun - - - 24 1.07 8 2.19 32 1.12 Olea capensis 6 2.54 - - - - 6 0.21 Olea europaea 4 1.69 41 1.83 - - 45 1.58 Olinia rochetiana 4 1.69 29 1.29 - - 33 1.16 Osyris quadripartita 4 1.69 29 1.29 - - 33 1.16 Otostegia integrifolia 2 0.85 10 0.45 - - 12 0.42 Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | wyrsine africana | 2 | 0.85 | 14 | 0.62 | / | 1.92 | 23 | 0.81 |
| Olca cupielity 0 2.54 - - - - 6 0.21 Olea europaea 4 1.69 41 1.83 - - 45 1.58 Olinia rochetiana 4 1.69 44 1.96 8 2.19 56 1.97 Osyris quadripartita 4 1.69 29 1.29 - - 33 1.16 Otostegia integrifolia 2 0.85 10 0.45 - - 12 0.42 Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Olea capensis | - | - 2 54 | 24 | 1.07 | ō | 2.19 | 32 6 | 1.12 |
| Olinia rochetiana 4 1.69 44 1.96 8 2.19 56 1.97 Osyris quadripartita 4 1.69 29 1.29 - - 33 1.16 Otostegia integrifolia 2 0.85 10 0.45 - - 12 0.42 Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Оlea енгораеа | 4 | 2.34 1.69 | - 41 | - 1.83 | _ | _ | 45 | 1 58 |
| Osyris quadripartita 4 1.69 29 1.29 - - 33 1.16 Otostegia integrifolia 2 0.85 10 0.45 - - 12 0.42 Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Olinia rochetiana | 4 | 1.69 | 44 | 1.96 | 8 | 2.19 | 56 | 1.97 |
| Otostegia integrifolia 2 0.85 10 0.45 - - 12 0.42 Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Osyris quadripartita | 4 | 1.69 | 29 | 1.29 | - | _ | 33 | 1.16 |
| Peucedanum mattirolii 3 1.27 10 0.45 6 1.64 19 0.67 Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Otostegia integrifolia | 2 | 0.85 | 10 | 0.45 | _ | _ | 12 | 0.42 |
| Phytolacca dodecandra 1 0.42 13 0.58 4 1.10 18 0.63 | Peucedanum mattirolii | 3 | 1.27 | 10 | 0.45 | 6 | 1.64 | 19 | 0.67 |
| | Phytolacca dodecandra | 1 | 0.42 | 13 | 0.58 | 4 | 1.10 | 18 | 0.63 |

(continued on next page)

| Species name | Lowland | | Lower highland | | Upper highland | | Overall WWF | |
|--------------------------|-----------|------|----------------|------|----------------|------|-------------|------|
| | frequency | % | frequency | % | frequency | % | frequency | % |
| Piliostigma thonningii | 3 | 1.27 | _ | _ | _ | _ | 3 | 0.11 |
| Pinus patula | - | - | 30 | 1.34 | - | - | 30 | 1.05 |
| Pittosporum viridiflorum | - | - | 30 | 1.34 | - | - | 30 | 1.05 |
| Plantago lanceolata | 1 | 0.42 | 12 | 0.53 | 3 | 0.82 | 16 | 0.56 |
| Poa leptoclada | - | - | - | - | 28 | 7.67 | 28 | 0.98 |
| Podocarpus falcatus | 5 | 2.12 | 41 | 1.83 | - | - | 46 | 1.62 |
| Podocarpus falcatus | 6 | 2.54 | 61 | 2.72 | - | - | 67 | 2.35 |
| Prunus africana | 4 | 1.69 | 34 | 1.51 | - | - | 38 | 1.33 |
| Psydrax schimperiana | 3 | 1.27 | 17 | 0.76 | - | - | 20 | 0.70 |
| Ranunculus simensis | 3 | 1.27 | 16 | 0.71 | - | - | 19 | 0.67 |
| Rhamnus staddo | 2 | 0.85 | 18 | 0.80 | - | - | 20 | 0.70 |
| Rhiocissus Tridentata | 1 | 0.42 | 5 | 0.22 | - | _ | 6 | 0.21 |
| Rhus glutinosa | 2 | 0.85 | 15 | 0.67 | - | - | 17 | 0.60 |
| Rhus vulgaris | 4 | 1.69 | 41 | 1.83 | - | - | 45 | 1.58 |
| Ricinus comminus | 2 | 0.85 | 15 | 0.67 | 5 | 1.37 | 22 | 0.77 |
| Rosa abyssinica | 2 | 0.85 | 19 | 0.85 | 7 | 1.92 | 28 | 0.98 |
| Rubus steudneri | 1 | 0.42 | 16 | 0.71 | - | - | 17 | 0.60 |
| Rubus volkensii | - | - | - | - | 6 | 1.64 | 6 | 0.21 |
| Rumex abyssinica | - | - | 32 | 1.42 | - | - | 32 | 1.12 |
| Rumex nervosus | 1 | 0.42 | 14 | 0.62 | 10 | 2.74 | 25 | 0.88 |
| Salix subserrata | 4 | 1.69 | 40 | 1.78 | - | - | 44 | 1.55 |
| Solanecio gigas | 2 | 0.85 | 10 | 0.45 | 1 | 0.27 | 13 | 0.46 |
| Solanum indicum | 2 | 0.85 | 11 | 0.49 | - | _ | 13 | 0.46 |
| Sparmannia ricinocarpa | | 0.00 | 28 | 1.25 | 7 | 1.92 | 35 | 1.23 |
| Stephania abyssinica | 3 | 1.27 | 11 | 0.49 | 3 | 0.82 | 17 | 0.60 |
| Teclea nobilis | 2 | 0.85 | 28 | 1.25 | - | _ | 30 | 1.05 |
| Thymus schimperi | - | - | - | - | 27 | 7.40 | 27 | 0.95 |
| Urera pypsoledendron | - | - | 10 | 0.45 | 3 | 0.82 | 13 | 0.46 |
| Urtica Simensis | - | - | 15 | 0.67 | - | - | 15 | 0.53 |
| Verbascum sinaiticum | 3 | 1.27 | 17 | 0.76 | 3 | 0.82 | 23 | 0.81 |
| Vernonia amygdalina | 4 | 1.69 | 26 | 1.16 | - | _ | 30 | 1.05 |
| Vulpia bromoides | - | - | 30 | 1.34 | 11 | 3.01 | 41 | 1.44 |
| Ximenia americana | 1 | 0.42 | 10 | 0.45 | - | - | 11 | 0.39 |
| Zehneria scabra | 2 | 0.85 | 8 | 0.36 | 2 | 0.55 | 12 | 0.42 |
| Ziziphus spina–christi | 4 | 1.69 | 26 | 1.16 | - | - | 30 | 1.05 |
| Total | 236 | 100 | 2246 | 100 | 365 | 100 | 2847 | 100 |



Fig. 4. Diameter class distribution of species in WWF. DBH class: (1 = < 2.5 cm; 2 = 2.5 - 12.5 cm; 3 = 12.6 - 25 cm; 4 = 25.1 - 50 cm; 5 = 50.1 - 80 cm; 6 = > 80 cm).



Fig. 5. DBH class distribution of species in the plant communities of the forest. DBH class: (1 = < 2.5 cm; 2 = 2.5-12.5 cm; 3 = 12.6-25 cm; 4 = 25.1-50 cm; 5 = 50.1-80 cm; 6 = >80 cm.

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Fig. 6. Height class frequency distribution of species in WWF. Height class: $(1 \le 5 \text{ m}; 2 = 5.1-10 \text{ m}; 3 = 10.1-15 \text{ m}; 4 = 15.1-20 \text{ m}; 5 = 20.1-25 \text{ m}; 6 = 25.1-30 \text{ m}; 7 = >30 \text{ m}).$



Fig. 7. Height class distribution of species in WWF. Height class: $(1 \le 5 \text{ m}; 2 = 5.1-10 \text{ m}; 3 = 10.1-15 \text{ m}; 4 = 15.1-20 \text{ m}; 5 = 20.1-25 \text{ m}; 6 = 25.1-30 \text{ m}; 7 = >30 \text{ m}).$

 Table 8

 The most abundant tree and shrub species in each class of the three communities.

| Height classes | Midland | Lower highland | Upper highland |
|-------------------|-----------------------------|---------------------------|----------------------|
| Class 1 | Casuarina cunninghamiana | Podocarpus falcatus | Erica arborea |
| Class 2 | Rhus vulgaris | Allophylus abyssinicus | Erica arborea |
| Class 3 | Erythrina brucei | Ilex mitis | Juniperus procera |
| Class 4 | Prunus africana | Polyscias fulva | Juniperus procera |
| Class 5 | Casuarina cunninghamiana | Podocarpus falcatus | Juniperus procera |
| Class 6 | Celtis africana | Podocarpus falcatus | Juniperus procera |
| Class 7 | Podocarpus falcatus | Juniperus procera | - |

BA (m^2ha^{-1}) of top five tree species in each of the plant communities.

| Midland | | Lower highland | | Upper highland | |
|---------|--|---|--|--|--|
| BA | % | BA | % | BA | % |
| 16.56 | 18.6 | 9.43 | 13.1 | _ | _ |
| 8.81 | 9.9 | - | - | _ | - |
| 6.26 | 7.0 | - | - | _ | - |
| 6.19 | 6.9 | 5.37 | 7.5 | _ | - |
| 5.38 | 6.0 | 13.50 | 18.8 | 6.21 | 39.1 |
| - | - | 4.34 | 6.05 | - | - |
| - | - | 3.94 | 5.48 | - | - |
| - | _ | - | - | 2.11 | 13.3 |
| - | _ | - | - | 4.10 | 25.9 |
| - | _ | - | - | 1.37 | 8.6 |
| - | - | - | - | 0.88 | 5.6 |
| | Midland BA 16.56 8.81 6.26 6.19 5.38 - - - - - - - - - - | Midland BA % 16.56 18.6 8.81 9.9 6.26 7.0 6.19 6.9 5.38 6.0 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | Midland Lower H BA % BA 16.56 18.6 9.43 8.81 9.9 - 6.26 7.0 - 6.19 6.9 5.37 5.38 6.0 13.50 - - 3.94 - - 3.94 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | $\begin{tabular}{ c c c } $$ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ |

4. Discussions

4.1. Vegetation composition of the study area

In comparing the vegetation composition of WWF, relatively few species were recorded than other similar Afromontane forests of Kenya such as Kakamega forest (986) [28], Aberdare National Park (778) [29] and Lake Kivu (Rwanda) totally 722 vascular plants [30]; implying that WWF is floristically poorer than these forests (108 vascular plants). But, Kalfou Forest in Cameroon had fewer vascular plants (86) [31] than WWF. The differences in species composition among these forest sites could mainly be attributed to the dissimilarities of the sites in terms of location, altitude, human impact, rainfall, and other biotic and abiotic factors [32].

The vegetation composition of the lower highland plant community (87 species) shows relatively higher species number than midland (83 species) plant community of WWF. However, the vegetation composition of the upper highland plant community (37 species) was founded with very few species than the lower highland and midland plant communities. This variation might be due to the geographic locations of the communities, climatic and edaphic factors and the degree of the human disturbance they have been exposed to [33]. The midland plant community of WWF had also a very low number of plant species than the eastern escarpment of Wollo Ethiopia, situated between 750 and 1780 m.a.s.l in which 216 plant species were analyzed [34].

4.2. Species diversity and richness of the plant species

The altitude based classified plant communities were found different in species diversity which indicates the impact of altitude. The higher the species richness resulted in a high evenness which indicates that species richness and evenness were positively correlated. The possible reason for higher diversity and richness of the lower highland community could be it being situated in the inaccessible area for excessive human intervention. In contrast, the midland community of the forest was situated at the lower average altitude interval (2067 m.a.s.l.) which is relatively more

Plant species frequency, relative frequency, density, relative density, basal area and relative dominance of the top ten tree species of the WWF in descending order of IVI.

| Species name | BA/ha | RD0m | Frequency | RF (%) | Density/ha | RD (%) | IVI |
|--------------------------|-------|-------|-----------|--------|------------|--------|------|
| Juniperus procera | 9.43 | 16.85 | 94 | 5.93 | 52.83 | 7.95 | 30.7 |
| Podocarpus falcatus | 7.26 | 12.97 | 67 | 4.23 | 29.78 | 4.48 | 21.7 |
| Ilex mitis | 3.96 | 7.08 | 64 | 4.04 | 31.96 | 4.81 | 15.9 |
| Erica arborea | 0.89 | 1.59 | 71 | 4.48 | 46.52 | 7.00 | 13.1 |
| Hagenia abyssinica | 3.54 | 6.32 | 48 | 3.03 | 19.35 | 2.91 | 12.3 |
| Polyscias fulva | 2.38 | 4.25 | 46 | 2.90 | 32.17 | 4.84 | 12.0 |
| Allophylus abyssinicus | 1.19 | 2.13 | 62 | 3.91 | 32.61 | 4.91 | 11.0 |
| Euphorbiaampliphylla | 2.75 | 4.92 | 44 | 2.78 | 21.52 | 3.24 | 11.0 |
| Casuarina cunninghamiana | 3.11 | 5.56 | 42 | 2.65 | 17.17 | 2.59 | 10.8 |
| Buddeleja polystachya | 0.97 | 1.73 | 58 | 3.66 | 27.39 | 4.12 | 9.5 |

RDom-Relative Dominance; RF-Relative Frequency; RD-Relative Density; IVI- important value index.

Table 11

Multiple comparisons between each community in the forest.

| Dependent Variable | (I) Community | (J) Community | Mean Difference (I- J) | Std. Error | Sig. |
|-----------------------|--------------------|-------------------|------------------------------|---------------|-------|
| Shannon index | Midland | Lower highland | 320* | 0.048 | 0.001 |
| | | Upper highland | -1.560* | 0.057 | 0.000 |
| | Lower highland | Upper highland | -1.240* | 0.038 | 0.000 |
| Evenness | Midland | Upper highland | 176* | 0.010 | 0.000 |
| | Lower highland | Upper highland | 166* | 0.010 | 0.000 |
| | | Midland | -0.009 | 0.005 | 0.182 |
| Richness | Midland | Upper highland | 27.425* | 1.759 | 0.000 |
| | Lower high land | Upper highland | 17.040* | 0.503 | 0.000 |
| | | Midland | -27.425* | 1.759 | 0.000 |
| Abundance/ plot | Midland | Upper highland | 91.226* | 7.894 | 0.000 |
| | Lower highland | Upper highland | 5.251 | 5.531 | 0.612 |
| | | Midland | -85.974* | 6.583 | 0.000 |
| Density/ha | Midland | Upper highland | 785.935* | 25.84 | 0.000 |
| | Lower highland | Upper highland | -57.006* | 4.089 | 0.000 |
| | | Midland | -785.935* | 25.841 | 0.000 |
| Basal area | Midland | Lower highland | 025* | 0.007 | 0.001 |
| | | Upper highland | .018* | 0.007 | 0.034 |
| | Lower highland | Upper highland | .043* | 0.006 | 0.000 |
| Height of trees | Midland | Lower highland | -0.071 | 0.459 | 0.987 |
| | | Upper highland | 4.493* | 0.467 | 0.000 |
| | Lower highland | Upper highland | 4.564* | 0.259 | 0.000 |
| Diameter of trees | Midland | Lower highland | -2.380* | 0.921 | 0.027 |
| | | Upper highland | 3.284* | 1.062 | 0.006 |
| | Lower highland | Upper highland | 5.664* | 0.752 | 0.000 |

* The mean difference is significant at the 0.05 level.

favorable for growth and reproduction of a variety of species in the area. However, deforestation and forest degradation are extensively practiced for grazing and agricultural expansion due to the accessibility of the area, and which is closer to the local communities. Moreover, the upper highland plant community had the least species richness, evenness, and diversity that could be associated with growth at a relatively higher altitude in which only better-adapted species potentially grow better than the others. Other studies also revealed that species richness, evenness, and diversity is usually higher in less degraded than degraded sites [35]. The results of the present study are in agreement with the reports from other studies indicated that species richness and diversity tend to be higher at an intermediate altitude and decline at the lower and upper elevations [36].

4.3. Human disturbances along with the plant communities

The relationship between the degree of site disturbance and tree species richness is notable among the plant communities. The highly disturbed midland plant community had just 83 species, while the less disturbed site lower highland community had 87 species. These results support the supposition that total species diversity in the dry forest is normally reduced when the disturbance is severe and/or prolonged [37]. Thus the species paucity recorded in the midland forest community could be assigned to the high levels of anthropogenic disturbance (score 15). In several studies, the anthropogenic disturbance has significantly lowered the plant species richness of the dry evergreen forests [38, 39]. It is striking that the 87 species recorded in the moderately disturbed lower highland forest community among the three evergreen forest communities may support the intermediate disturbance hypothesis [40].

4.4. Analysis of vegetation structure

4.4.1. Density distribution of the plant species

Comparison of the results of this study with other studies in dry Afromontane forests of the country showed that the density of mature trees/shrubs in WWF is less than Angada forest (4964 individuals ha⁻¹) [41], Denkoro forest (811 individuals ha⁻¹) [42] and Dodola forest (1293 individuals ha⁻¹) [43]. The possible reason for this variation might be due to the presence of high-pressure anthropogenic disturbance as it has been reported by Barnes et al. [44], in which large and medium-size trees have been continuously removed.

4.4.2. Diameter at breast height (DBH) distribution

The general pattern of distribution of trees and shrubs in Wof-Washa forest along the different DBH classes indicates the predominance of small-sized individuals in the forest and similar distribution of tree and shrub species were reported by Fisaha et al. [19], in the same forest. The regular DBH pattern distribution of the midland and the lower highland forest community indicates that the vegetation had good reproduction and low recruitment which might have been due to the selective cutting of large tree individuals as has been stated by Tilahun [18]. However, the irregular DBH distribution (bell-shaped) in the highland community revealed more or less dissimilar vegetation distribution with relative to that of midland and lower highland plant communities.

4.4.3. Basal area of trees and shrubs

The overall basal area of all trees and shrubs in this forest is less than that of Tilahun [18] and Fisaha et al. [19], and, which were $64.32 \text{ m}^2\text{ha}^{-1}$

Jaccard's and Sorensen's similarity coefficient within the three communities of the forest.

| Plant communities | Jaccard's coeffi | Jaccard's coefficient | | | Sorensen's coefficient | | | |
|-------------------|------------------|-----------------------|----------------|---------|------------------------|----------------|--|--|
| | Midland | Lower highland | Upper highland | Midland | Lower highland | Upper highland | | |
| Midland | 1 | | | 1 | | | | |
| Lower highland | 0.65 | 1 | | 0.44 | 1 | | | |
| Upper highland | 0.20 | 0.27 | 1 | 0.25 | 0.31 | 1 | | |

and 360.07 m²ha⁻¹ respectively. This might be due to the removal of large-sized tree individuals for timber and other construction purposes and the dominance by small-sized trees and shrubs. Other possible reasons for this variation might be due to the difference in the number of sample plots taken and the distance between plots. Moreover, the comparison of the present result of the total basal area of Wof-Washa forest with other related forests shows that it has a lower basal area than Dodola forest (129 m² ha⁻¹) [43] and Angoda forest (79.8 m² ha⁻¹) [41], but higher than Denkoro forest (45 m² ha⁻¹) [42].

Unlike the two other plant communities of the forest, the basal area of trees and shrubs in the upper highland plant community was much less than the two communities and had very few trees and shrubs. For this study, only seven trees and shrub species were recorded in the upper highland community with the DBH and height. This could be due to its harsh environment since environmental variables like altitude, slope, and topography affect the vegetation distribution and excessive erosion was common during the summer season. *Juniperus procera* was the dominant tree species in this community comprising 39.1% of the total basal area followed by *Hagenia abyssinica* (25.9%) and *Erica arborea* (13.3%).

The distribution of plant communities is the manifestation of physical gradients like micro-climate, soil heterogeneity, elevation, biotic response to physical gradients and historical disturbances [11]. As it has been indicated by Tadesse [33], environmental factors such as slope, landscape pattern, and altitude also characterize the distribution of plant communities. Therefore, these environmental factors might influence the plant community formation of the present study in a similar manner.

4.4.4. Important value index (IVI)

The highest basal area of *Juniperus procera* made the species to have a large value of relative dominance and hence got the highest IVI in the forest. In the midland forest community the highest IVI value of *Podocarpus falcatus*, followed by *Prunus africana*, *Polyscias fulva*, *Erythrina brucei* and *Juniperus procera*, indicates that these species were the most dominant and frequent tree species in this community. However, the highest IVI in the lower highland plant community demonstrated by *Juniperus procera*, followed by *Podocarpus falcatus*, *Ilex mitis*, *Polyscias fulva* and *Allophylus abyssinicus* revealed that these species were the most dominant in the lower highland community in the forest.

4.4.5. Species similarity and difference among plant communities of the forest

The Games-Howell's test showed that there was a statistically significant mean difference among the three communities with regard to species diversity, richness and density since the P-value for each community was less than 0.05 alpha level. But in comparing the species evenness, there was no statistically significant mean difference between the midland and lower highland plant community of the forest (P = 0.182). Moreover, in comparing species abundance, there was a statistically insignificant mean difference between the upper highland and the lower highland plant community. This could be due to, the midland and lower highland plant community had similar species evenness yet human disturbance was more practiced in the midland plant community.

There was a statistically significant mean difference between the three communities with regard to basal areas of trees and shrubs (i.e. P = 0.001, less than 0.05). But in comparing the heights of trees and shrubs,

there was no statistically significant mean difference between the midland and lower highland community of the forest (i.e. P = 0.987, greater than 0.05). This could be due to species found in both communities may have similar growth and adaptation strategies, but in the midland community, wide-ranging trees were selectively removed illegally relative to the lower highland plant community. Whereas, in comparing the diameters of trees/shrubs, there was a statistical and significant mean difference between the three communities.

Jaccard's (Sj) and Sorensen's (Ss) similarity coefficients were also used to detect vegetation similarities between the three plant communities of the forest. The highest similarity coefficients (Sj = 0.65 and Ss = 0.44) observed between the midland and lower highland plant communities could be due to the fact that the two communities had plots adjacent to each other which indicate similar adaptation mechanisms and requirements of the vegetation. The lowest similarity coefficients (Sj = 0.2 and Ss = 0.25) were observed between the midland and the upper highland plant communities of the forest. The possible reason for this might be mainly due to altitudinal variation and environmental factors in which all plots of the upper highland forest community were located at a higher altitude than plots in the midland community in the forest.

5. Conclusions

The analysis of overall vegetation data in Wof-Washa forest indicated the presence of high species diversity, richness, and evenness. From the total species family recorded, *Asteraceae* was the most species-rich family followed by *Fabaceae, Euphorbiaceae,* and *Rosaceae.* The dominance of these families might be due to well-developed strategies and adaptations that would help them to effectively survive in the area. A significant difference regarding all variables in the plant communities along altitudinal gradients was observed. However, the lower highland plant community had the highest species diversity, richness, density, DBH and basal area of trees and shrubs. The variation of these variables could be due to the presence of strong anthropogenic disturbance in the midland plant community for agricultural expansion, selective cutting for charcoal, construction and timber production.

The analysis of vegetation difference among plant communities revealed that altitude had significant effects on species diversity, composition, and structure in Wof-Washa forest. In addition, the human disturbance was found highest in the midland community followed by lower highland and upper highland communities respectively. In the midland and lower highland communities: disturbance, species richness, and diversity were found negatively correlated. The high altitude resulted in a decline of all the variables, especially in the upper highland plant community in the forest. From the structural analysis, the overall diameter and height class distribution patterns of the individuals had a regular (inverted J-shape pattern), reflecting the dominance of small-sized individuals in the lower classes than in the higher classes and resulted in the rare occurrence of large individuals. This is an implication of the existence of excessive cutting of selected size classes in the area. As can be seen from the importance value index of tree species, Juniperus procera and Podocarpus falcatus were the most dominant tree species in Wof-Washa forest. The present study was delimited to the impacts of altitude and specific human disturbances on species diversity, composition, and structure of plant species and thus, further studies on regeneration

status and distribution of plants with respect to other environmental factors like temperature, soil type, and slope are recommended.

Declarations

Author contribution statement

Fikadu Yirga, Mequannt Marie, Sosina Kassa, Mebrahtu Haile: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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References

- [1] F. Martin, G. Georg, A. Lalisa, K. Thomas, I.M. Danie, R. Rosalaura, Mountain Forests in a Changing World - Realizing Values, Addressing Challenges, 2011, pp. 6–12.
- [2] E.O. Wilson, The current status of tropical biodiversity, in: E.O. Wilson (Ed.), Biodiversity, National Academy Press, Washington, 1988, pp. 1-18.
- [3] J.C. Lovett, Eastern tropical african center of endemism: a candidate for world heritage status, J. East Afr. Nat. Hist. 87 (1998) 359-366.
- [4] J.A. Coetzee, Phytogeographical aspects of the montane forests of the chain of mountains on the eastern side of Africa, Erdwiss. Forsch. 11 (1978) 482-494.
- [5] B. Tamrat, Studies on remnant Afromontane forests on the central plateau of Shewa, Ethiopia, Acta Phytogeogr. Suec. 79 (1993) 1-59.
- [6] Ethiopia Forestry Action Program (EFAP), Summary Final report, The Challenge for Development, Vol. III, Ministry of natural resource, Addis Ababa, Ethiopia, 2011.
- [7] F. White, in Natural Resources Research Report, Vegetation of Africa-Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa, vol. XX, United Nations Educational, Scientific and Cultural Organization, Paris, 1983, pp. 201-1356.
- [8] Conservation International, Biodiversity Hotspots, Arlington, USA, 2007.
- Institute of Biodiversity Conservation (IBC), Ethiopia: Second Country Report on [9] the State of PGRFA to FAO, Addis Ababa Institute of Biodiversity Conservation, Addis Ababa, 2008.
- [10] J.L. Vivero, E. Kelbessa, S. Demisew, Progress on the Red List of Plants of Ethiopia and Eritrea: Conservation and Biogeography of Endemic Flowering Taxa, Taxonomy and ecology of African plants their conservation and sustainable use, 2006, pp. 761–778.
- [11] E. Urban, L. Brown, A Checklist Birds of Ethiopia, Haile Selassie I university press, Addis Ababa, Ethiopia, 2002, pp. 38-43.
- [12] G. Tewoldeberhan, Vegetation and environment of the mountains of Ethiopia: implications for utilization and conservation, Mt. Res. Dev. 8 (2005) 211-216.
- [13] H. Winberg, Policy and demographic factors of deforestation patterns and socioecological processes, Southwest Ethiopia, J. Appl. Geogr. 54 (2010) 7-11.
- [14] B. Million, Forest Plantations and Woodlots in Ethiopia, vol. I, African Forest Forum, 2011, pp. 11-15.

- [15] Environmental Protection Authority of Ethiopia (EPAE), Deforestation Leaves Two Million Hectares of Land Barren in Ethiopia, January 12, Addis Ababa, Ethiopia, 2002, pp. 4-9.
- [16] R. Sayer, T. Shibru, Deforestation and land degradation on the Ethiopian highlands: a strategy for physical recovery, J. East Afr. stud. 8 (2003) 7-26.
- [17] Ministry of Environment, Forest and Climate Change (MEFCC), in: Situation Analysis, vol. I, National Forest Sector Development Program, Ethiopia, 2018, pp. 5–14.
- [18] A. Tilahun, Floristic Composition, Structure and Regeneration Status of Wof Washa forest in North Shoa Zone, In collaboration with SUNARMA Ethiopia, 2012, pp. 8–21.
- [19] G. Fisaha, K. Hundera, G. Dalle, Woody plants' diversity, structural analysis and regeneration status of Wof Waha Natural forest, North-East Ethiopia, Afr. J. Ecol. (2013) 4 - 9
- [20] Ethiopian wildlife and natural history society (EWNHS), Important Bird Areas of Ethiopia, Addis Ababa, 2010, pp. 181–182.
- [21] D. Teketay, T. Bekele, Floristic Composition of Wof-Washa Natural forest, Central Ethiopia: Implications for the Conservation of Biodiversity, vol. 106, 1995, pp. 127–147.
- [22] D. Mueller-Dombois, H. Ellenberg, Aims and Methods of Vegetation Ecology, Wiley, New York 1974
- [23] J. Caratti, Line Intercept (LI). Fire Effects Monitoring and Inventory System, Rep. RMRS-GTR-164-CD, U.S. Department of Agriculture. USDA Forest Service Gen. Tech. 2006.
- [24] A. Bekele, Useful Trees and Shrubs for Ethiopia, in: Identification, Propagation and Management for 17 Agro Climatic Zones, vol. VIII, ICRAF project, Nairobi, 2007.
- [25] R. Venkateswaran, N. Parthasarathy, Tropical Dry evergreen Forests on the Coromandel Coast of india: Structure, Composition and Human Disturbance, Society for Tropical Ecology, Pondicherry University, India, 2003, pp. 45-58.
- [26] A. Megurran, Ecological Diversity and its Measurement, Chapman and Hall. London, Priceton university press, Priceton, NJ, 1988.
- [27] R Core Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, 2018. https://www.R-project.org.
- [28] E. Fischer, K. Rembold, A. Althof, J. Obholzer, I. Malombe, G. Mwachala, J. Onyango, B. Dumbo, I. Theisen, Annotated checklist of the vascular plants of the Kakamega forest, western province, Kenya, J. East Afr. Nat. Hist. 99 (2010) 129-226.
- [29] K. Schmitt, The Vegetation of the Aberdare National Park Kenya, High Mountain Research, vol. 8, Universitätsverlag Wagner, Innsbruck, 1991.
- [30] M.K. Habiyaremye, Étude Phytocoenologique de la Dorsale Orientale du lac Kivu (Rwanda), Annales Science Économiques 24 (1997).
- [31] M. Froumsia, Z. Louis, M. Pierre, A. Bernard, Woody species composition, structure and diversity of vegetation of Kalfou Forest Reserve, Cameroon, J. Ecol. (2012) 4–6.
- [32] A. Girma, Plant Communities, Species Diversity, Seedling Bank and Resprouting in Nandi Forests, Kenya. PhD dissertation, 2011, pp. 68–72.
- [33] G. Tadesse, T. Bekele, S. Demissew, Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Wollo, Ethiopia, Ethiapia J. sci. 31 (1) (2008) 6-10
- [34] B. Tamrat, Vegetation and ecology of Afromontane forests on the central plateau of Shewa, Ethiopia, Acta phytogeorgr. Suec. 79 (1993).
- [35] H. Kirika, T. Tsegaye, Vegetation composition and structure of belete forest, Jimma zone, South western Ethiopia, J. Biol. Sci. 7 (2010) 1-15.
- [36] Z. Woldu, Forest in the vegetation types of Ethiopia and their status in geographical context, in: Proceeding the National Forest Genetic Resource Conservation Strategies Development Workshop, 1999, pp. 1-8.
- [37] L.R. Holdridge, Life Zone Ecology, vol. 29, Tropical Science Center, San Jose, Costa Rica, 1967, pp. 26-39.
- [38] C. Sabogal, Regeneration of tropical dry forests in Central America, with examples from Nicaragua, J. Veg. Sci. 3 (1992) 407-416.
- [39] J.M. Maass, Conversion of tropical dry forest to pasture and agriculture, in: S.H. Bullock, H.A. Mooney, E. Medina (Eds.), Seasonally Dry Tropical Forests, Cambridge University Press, Cambridge, 1995, pp. 399-422.
- [40] J.J. Armesto, S.T.A. Pickett, Experiments on disturbance in old field plant communities: impact on species richness and abundance, Ecology 66 (1985) 230-240
- [41] S. Alemu, Woody Species Composition, Diversity and Structural Analysis of Angada forest, Merti Wereda, Arsi Zone of Oromia Region, Ethiopia, Msc thesis, 2011, pp. 35–43.
- [42] A. Ayalew, A Floristic Composition and Structural Analysis of Denkoro forest, South Wollo, Ethiopia, Msc thesis, 2003, pp. 26-38.
- [43] K. Hundera, T. Bekele, E. Kelbessa, Floristics and Phytogeographic Synopsis of a Dry Afromontane Coniferous forest in the Bale Mountains: Implications to Biodiversity Conservation, Ethiopia, 2007.
- [44] B.V. Barnes, D.R. Zak, S.R. Denton, S.H. Spurr, Forest Ecology, fourth ed., Wiley, New York, 1998, pp. 639-649.