Ecological and Floristic Study of Hirmi Forest, Tigray Region, Northern Ethiopia

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Abstract

Background: The Dryland area in Ethiopia contributes large vegetation resources. However, the landmass has received less attention even if it has high ecological, environmental and economic importance. The present study was conducted in Hirmi forest, which is one of the dry forest in Northwestern, Ethiopia; to study the floristic composition, plant community types, community-environment relation, vegetation structure and regeneration status of the forest.

Method: Vegetation and environmental data were collected from 80 sampling plots having equal size of 25m×25m were designated as the main plots. Within the main plot, five 2m×2m subplots were laid to record seedlings, saplings, and herbaceous species. Furthermore, within each subplot, soil samples were collected to analyze the relationship of edaphic parameters with the plant community. DBH, height, BA, density, vertical structure and frequency were computed. Floristic diversity and evenness were computed using Shannon diversity and Evenness indices. The plant community types and vegetation-environment relationships were analyzed using classification and ordination tools in R package (ver. 3.6.1), respectively.

Result: A total of 171 vascular plant species belonging to 135 genera and 56 families were recorded. About 5.85% of the species were endemic/near endemic to Ethiopia. Woody species

(48%) were dominant over herbs (45.6%) and liana (6.4%). The highest number of species was recorded in plant families of Fabaceae (16.37%) and Poaceae (11.7%) followed by Asteraceae (7.02%) and Combretaceae (3.5%). Five plant communities were identified and positively correlated with altitude, slope, sand, silt, soil organic matter, total Nitrogen and disturbance. Vegetation structure reveals that, large number individual species were categorized in the lower class of DBH, BA, frequency and height. The highest Shannon diversity index and evenness values of the study area were 4.21 and 0.95, respectively. *Anogeissus leiocarpa*, *Combretum hartmannianum*, *Ziziphus mucronata*, *Terminalia macroptera*, *Acacia polyacantha* were the species with high important value.

Conclusion: the study shows Hirmi forest has high species diversity, richness, and endemism. However, due to various disturbances, it is under poor regeneration status that requires urgent conservation measures. Integrated forest management, monitoring, applying restoration techniques by considering the significant environmental factors associated with the species diversity, IUCN threat and regeneration status of the species is recommended to preserve the study forest.

Keywords: Diversity, Dryland, Ecological Data, Hirmi forest, Plant Communities

Background

Terrestrial biodiversity is highest in the tropics and near to the equator (Gaston 2000), which seems to be the result of the warm climate, high primary productivity and diverse topography (Field et al. 2009). About 40% of the global tropical forest area is covered by the dryland ecosystem (Mayaux et al. 2005) and 14% of the total African land surface that contribute 25% of the natural vegetation (Eshete et al. 2011). Though the dryland area has high ecological, environmental and economic importance, currently the vegetation resources inside the landmass are facing serious problems because of human intervention and less attention than moist forests (Muys *et al.*, 2006). Deforestation and habitat degradation on that area bring several socio-economic and environmental challenges that have strongly affect the capacity of forests to provide ecosystem services (Nyssen et al. 2007). Recently conservation of biodiversity in the dryland ecosystems has been receiving greater international attention (CBD 2006). Environmental determinants such as soil properties, elevation, habitat suitability and diversity, species interaction, disturbance are critical and need to be considered in the design of hotspot biodiversity conservation programs. The hotspot concept is based on species richness, endemism, and threat (Reid 1998).

Ethiopia is a tropical country that shares more than 50% of the Afromontane regions land areas above 1500m of Africa (Bekele 1994) as well as extensive dryland landmass (Teketay 2001). According to a study conducted by Teketay (2001), about 65% of the Ethiopia landmass is covered by dryland ecosystems, where 12% of human and 20% of livestock populations reside. It is the center for biodiversity, endemism and grazing (Mengistu et al. 2005).

The wide range of agro-ecologies in northern Ethiopia covered dryland with woody dry forests (Georgis 2010). Following the long history of land degradation, many land rehabilitation and

conservation programs have been carried out in northern Ethiopia in general, Tigray region in particular. However, inadequate investigation of ecological baseline information makes the effectiveness of biodiversity conservation policy and strategy to fall in a challenge for its implementation as it intends (EFAP 1994; Teketay 2001).

Hirmi forest is one of the dryland forest with remnant climax vegetation found in North Ethiopia, Tigray region, north to Tekeze rift valley (Hagos *et al.*, 1999). An assessment conducted by Ethiopian REDD+ (MEF 2015) secretariat reveals Hirmi forest is identified as one of the potential areas that require forest ecosystem restoration and conservation by the participation of the local community and other relevant approaches. However, ecological conservation is efficient and feasible when the plant community in relation to environmental and anthropogenic drivers are well investigated (Pimm and Raven 2000; Brooks et al. 2002). The plant diversity, composition, structure, threats and regeneration status of Hirmi forest is not studied yet. Therefore, this study was conducted to fill the existing gap for conservation and sustainable utilization of the forest and might also be applied in other parts of the country.

The objectives of the research were to:

1. Examine the floristic composition and plant community types of Hirmi forest.
2. Assess the population structure and regeneration status of the study forest.
3. Examine the relationship between selected environmental determinants with the patterns of community formation in Hirmi forest.
4. Identify threats associated with the vegetation in the study area.
5. Suggest appropriate methods of ecological conservation and management for sustainable utilization of the study forest.

MATERIALS AND METHODS

Study area

Hirmi forest is found stretched within three districts of North Western-Tigray Zone at a distance of approximately 1100 km from Addis Ababa (Ethiopian Capital) at of 13°49'– 14°04' North latitude and of 38°14' – 38°25' East longitude; along the altitude ranges from 900-2002m (Fig. 1A). The total area coverage of the study is 240 km² (Gerben 2013; Gebrelibanos & Assen 2015; Agriculture & Natural Resource Bureau of North-Western Zone of Tigray 2017). The studied forest dominated with *Combretum–Terminalia* and *Acacia-Commiphora* woodland forest type found in northern Tekeze rift valley of Tigray region (MEF 2015; Girma 2014). There are two climatic zones in the study area namely lowlands (800-1500m) and middle altitude ranging from 1501-2002m (NMSAE 2018). To describe the climate of the study area twenty years (1998-2017) climatic data were taken from the nearest Endabaguna metrological station. Analysis of the meteorological data shows the study area has a maximum and minimum monthly mean temperature of 31.9 °C and 13.1 °C respectively, with an average annual rainfall of 888 mm. The mean annual temperature in Endabaguna was 21.6⁰C. The highest precipitation was recorded in August (302.9 mm) & lowest precipitation in February (1.45mm) (Fig. 1B).

Figure 1 A) Map of the study area; B) Climate diagram of Hirmi Forest (from Endabaguna Meteorological Station)

Method of collection

Vegetation data

Preferential sampling design technique with a flexible systematic model was used for data collection following Mueller-Dombois and Ellenberg (1974) and Smartt (1978). A flexible systematic transect was laid within distance from 300-500m apart each other along with altitudinal drop. Vegetation data were gathered from eighty (80) plots 50 m far each and ten (10) transects. For the collection of woody species plots of 25 m x 25 m (625 m²) were laid. Herbaceous species, seedlings and saplings of all woody plants (shrubs and trees) were recorded in a 2 m x 2 m (4 m²) subplot inside each main plot, four from each corner and one at the center following Bekele (1993), Woldemariam (2003) and Kidane (2015). Plants with a height of ≥ 2 m and DBH ≥ 2 cm was considered as shrub or tree whereas plants less than 2 m long were considered as a sapling or seedlings (Senbeta and Teketay 2001; Tuxill and Nabhan 2001; Tadesse 2015). Vegetation cover-abundance was estimated based on the Van der Maarel scale (1979).

Plant specimens were collected, pressed, dried properly during the data collection period at the field site and brought to the National Herbarium (ETH), Addis Ababa University for identification and verification. An attempt was made to record the vernacular names of species encountered in the study during collection whenever possible.

Environmental data collection

Terrain variables such as altitude, aspect, slope and geographical coordinates were taken and recorded for each sample plot. Altitude and geographical coordinates were measured using GPS and the slope of each plot was measured using Clinometer. Soil samples were taken from five points (four from each corner and one from the center) measuring 15 x 15cm, at a depth of 0-

30cm (Tenkir 2006; Tadesse et al. 2008) of the main plot laid for vegetation data collection. These samples were mixed to form a composite sample and about a kilo of the sample was taken for analysis. The soil samples were air-dried by spreading on plastic trays crushed and sieved with a mesh size of 2 mm to remove root particles and other organic debris before chemical analyses. Finally, measurements and analysis for soil texture (sand, silt, and clay), pH, Electrical conductivity (EC), Cation Exchange Capacity (CEC), soil organic matter (SOM), total Nitrogen (N) and available phosphorus (P) were done at Shire agricultural research center, soil laboratory Department following the standard procedures outlined in Landon (1991); Sertsu and Bekele (2000).

Ecological disturbances were noticed and recorded as present or absent in the sampled plots. The magnitude of disturbance was rated from 0 to 4 following Yeshitla and Bekele (2002) and Senbeta et al. (2007) with slight modification; based on visible signs of forest disturbance parameters such as tree cutting, debarking, grazing, firing and charcoal production signs. Values were coded as follows: 0: no disturbance; 1: if any one of the above-mentioned factors was present (slightly disturbed); 2: if any two of the above-mentioned factors were present (moderately disturbed); 3: if any three of the above-mentioned factors were present (highly disturbed); 4: if all of the above-mentioned and other associated factors such as tree stumps due to natural factors and landslide/degradation, were present (extreme disturbed).

Data Analysis

Multivariate and diversity analysis

Agglomerative cluster analysis methods were used to group the collected species data into a sort of group (community types) based on their similarity using free packages R programs, Version 3.6.1 (R Development Core Team 2019). The plant community types from the cluster analysis

were further analyzed in a synoptic table based on cover-abundance values (van der Maarel et al. 1987). The community was named after the dominant tree or shrub species in that specific community with higher synoptic values. In each plant community type the significance of synoptic value of each species were further tested in order to find significant indicator value of the species in the identified community types performed in R using package labdsv.CCA was used to correlate the identified plant community types with selected environmental and disturbance factors (Woldu 2016; Kent 2012). Shannon-Wiener index was used to compute species diversity, richness and evenness of Hirmi forest using the free statistical software R version 3.6.1 (R Development Core Team 2019) as indicated below:

Shannon diversity index (H') is calculated from the equation: $H' = -\sum_{i=1}^s p_i \ln p_i$

Shannon evenness index (J) was calculated using the equation: $J = \frac{H'}{H_{\max}} = \frac{H'}{\ln s}$

Where: H' = Shannon-Wiener Diversity Index; Σ = Summation symbol; p_i = the proportion of individuals or the abundance of i^{th} species expressed as a proportional of total cover in the sample and $\ln$ = log base (natural logarithms); J' = evenness; $H_{\max} = \ln S$; S = total number of species. $H=0$ if there is only one species in the sample and H' is maximum (ranges from 1.5 up to 3.5 rarely up to 4.5) when all species are represented by the same number of individuals (Kent 2012; Woldu 2016). The values of J ranges normally between 0 and 1, where 1 represents a situation in which all species are equally abundant (Magurran 1988).

Vegetation structure

Diameter at Breast Height (DBH), vertical structure, basal area, density, frequency, height and important value index was used for the description of vegetation structure. These parameters were calculated to determine the vegetation structure as described below:

Diameter at Breast Height (DBH): DBH measurement was taken at about 1.3 m from the ground using a measuring tape for those woody plants having circumferences greater than 6 cm. For tree/shrub species that branch at breast height or below, DBH of each branch was measured separately and the average was taken and then treated as a single individual for the basal area calculation. There is a direct relationship between DBH and basal area (Kent 2012).

Vertical structure: The vertical structure of the woody species was analyzed using the International Union for Forestry Research Organization (IUFRO) classification scheme (Lamprecht 1989). The IUFRO classification scheme classifies story into upper, where the tree/shrub height is greater than 2/3 of the top height; middle, where the tree/shrub height is in between 1/3 and 2/3 of the top height and lower where the tree/shrub height is less than 1/3 of the top height.

Basal area (BA): Basal area of a woody species was calculated from diameter at breast height

(d) as follows: $BA = \pi \left(\frac{d}{2}\right)^2$ where; $\pi=3.14$

First, all measurements were in a square centimeter, latter it was converted into m² per hectare.

Calculating of basal area of species to sampled area gives dominance of species.

Frequency: is defined as the probability or chance of finding a species in a given sample plot. It is dependent on quadrat size, plant size and patterning in the vegetation (Kent 2012). Frequency

is calculated with this formula: $Frequency = \frac{\text{Number of plots where a species occur}}{\text{Total plots examined}} \times 100$

Density: is the count of individuals per unit area and calculated using the following formula:

$$Density = \frac{\text{Total number of stems of a given species}}{\text{sample size in hectare}} \times 100$$

Importance Value Index (IVI): is useful to compare the ecological significance of species and to take a measurement on conservation priority (Kent 2012). The Importance Value Index is the

cumulative value of the three parameters (i.e. relative frequency, relative density and relative dominance), which was calculated using the following formula:

$$IVI = \text{Relative frequency(RF)} + \text{Relative dominance(RDO)} + \text{Relative density (RD)}$$

$$\text{Where, Relative Frequency} = \frac{\text{Frequency of single species}}{\text{Frequency of single species}} \times 100$$

$$\text{Relative density (RD)} = \frac{\text{density of a single species}}{\text{total density of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Basal area of a single species}}{\text{Total basal area of all species}} \times 100$$

Regeneration status:

Regeneration status was estimated based on the composition and density of seedling and sapling of all woody species recorded in each sample plot (Khan et al. 1987). The density of seedlings and saplings were calculated using the following formula:

$$\text{Density of sapling/ seedling} = \frac{\text{the number of sapling/seedling}}{\text{area of sample in a hectare}}$$

Woody species of the study forest were grouped into four categories, based on the density of seedlings. These are category I: species with the no seedlings, category II: species with no saplings, category III: species with no saplings and seedling; category IV: species with high saplings and seedlings density.

Result

Floristic Composition

A total of 171 plant species belonging to 138 genera and 58 families were recorded and identified in Hirmi forest. Regarding the habit of species; herbs, shrubs and trees were most dominant represented by 78(45.6%), 44(25.7%) and 38(22.2%) species respectively. The highest number of species was recorded in plant families of Fabaceae (28 species, 16.37%), Poaceae (20 species, 11.7%) followed by Asteraceae (12 species, 7.02%), Combretaceae (7 species, 3.5%) and Moraceae (7 species, 3.5%). The rest 51 families were represented by ≤ 3 species. Out of the total plant species identified from the study area, 10 (5.85%) species were endemic and near endemic to Ethiopia according to the flora of Ethiopia and Eritrea and Friis et al. (2010). Plant species such as *Acacia venosa*, *Acanthospermum hispidum*, *Bidens macroptera*, *Boswellia papyrifera*, *Lippia adoensis*, *Maytenus arbutifolia*, *Phragmanthera macrosolen* and *Urtica simensis* were endemic and *Combretum hartmannianum* and *Combretum rochetianum* were near endemic species. Based on the IUCN criteria of level of threat; one species (*Acacia venosa*) was endangered, two species (*Combretum hartmannianum* and *Combretum rochetianum*) were vulnerable and the rest of them were least concerned and not evaluated.

Plant community types

Five plant community types were identified from the agglomerative hierarchical cluster analysis based on the abundance data of the species on the study plots (Fig. 2). Two species with relatively high synoptic values in the group were used to name the corresponding communities (Table 1). In each plant community type the significance of synoptic value of each species were further tested in order to find significant indicator value of the species in the identified community types performed in R using package labdsv.

Accordingly the first community was named by *Ziziphus mucronata* - *Acacia polyacantha*, community two = *Combretum.hartmannianum* - *Terminalia macroptera*, community three= *Anogeissus leiocarpa*- *Ozoroa insignis*, community four = *Euclea racemosa*-*Acacia abyssinica* and community five = *Dodonaea angustifolia*- *Flueggea virosa*

Figure 2: Dendrogram showing plant community types in Hirimi forest

Table 1: Species list with synoptic cover-abundance values for species having a value of ≥ 1 at least one in community type.

Community name	C1	C2	C3	C4	C5	
community size	19	11	24	12	14	P-value
<i>Ziziphus mucronata</i>	3.37	0.27	0.21	0	1.29	0.004
<i>Acacia polyacantha</i>	3.21	0.73	0	0	0	0.001
<i>Bidens pilosa</i>	2.11	2	1.5	0.67	0.29	0.12
<i>Achyranthes aspera</i>	1.89	0	0.17	0	0	0.012
<i>Ziziphus spina.christi</i>	1.74	0.27	0.62	0.17	0.93	000
<i>Trifolium campestre</i>	1.84	0	0	0.33	1.43	0.6
<i>Chamaecrista mimosoides</i>	1.68	0	0.33	0	1.14	000
<i>Dichrostachys cinerea</i>	1.26	0.73	0	0	0.36	000
<i>Combretum hartmannianum</i>	0.84	5.64	0.92	0	0.71	0.01
<i>Terminalia macroptera</i>	1.32	4.09	0.42	0	0	000
<i>Setaria megaphylla</i>	0.84	4	0.33	0	0.57	000
<i>Oplismenus burmannii</i>	0.63	3.27	0.83	0	0	000
<i>Ficus ingens</i>	1.05	2.64	0	0	0	0.61
<i>Senna obtusifolia</i>	1.05	2.55	0	0	0	0.05
<i>Lannea fruticose</i>	0.53	1.45	0.33	0	0.36	000
<i>Acanthospermum hispidum</i>	0.84	1.09	0.33	0	0.29	000
<i>Eleusine africana</i>	0.79	1.09	0.96	0	0	0.01
<i>Anogeissus leiocarpa</i>	1.58	2.64	2.96	0	0	000
<i>Ozoroa insignis</i>	0	0	2.79	0	2.29	000
<i>Bidens macroptera</i>	0.42	0	2.33	1.33	0.86	0.378
<i>Guizotia scabra</i>	0.21	0	2.12	0.33	0.86	000
<i>Terminalia catappa</i>	0	0	1.46	0	0.79	000
<i>Vangueria madagascariensis</i>	0	0	1.17	0.42	0.14	0.23
<i>Rhus. retinorrhoea.</i>	0.32	0	0.58	1.67	0	000
<i>Diospyros abyssinica</i>	0.26	0	0.54	1.33	0.43	0.01
<i>Combretum molle</i>	0.32	0	0.46	1	1.14	000
<i>Entada abyssinica</i>	1.21	0	0.21	0	0.36	000
<i>Eucle racemosa</i>	0	0	0.21	3.17	0.71	000

<i>Acacia abyssinica</i>	0	0	1.75	2.83	1.21	000
<i>Galiniera saxifraga</i>	0	0	0.42	2.25	0.79	0.01
<i>Acokanthera schimperi</i>	0.37	0	0.29	2.08	0	000
<i>Acacia seyal</i>	0	0	0.75	1.83	1.21	000
<i>Balanites aegyptiaca</i>	0.11	0	0	1.75	0	0.81
<i>Mimusops kummel</i>	0.26	0	0.42	1.5	0.36	000
<i>Acacia lahai</i>	0	0	0.25	1.42	0.79	000
<i>Desmodium intortum</i>	0	0	0.17	1.08	0	000
<i>Dodonaea angustifolia</i>	0	0	0	1.33	3.71	0.01
<i>Flueggea virosa</i>	1.68	0.91	0	0	1.36	0.02
<i>Hyparrhenia cymbaria</i>	0	0	0	0	1.71	0.612
<i>Hyparrhenia rufa</i>	0	0	0.17	0	1.43	000
<i>Capparis tomentosa</i>	0.21	0	0.21	0.17	1.07	000
<i>Arthraxon micans</i>	0	0	0.17	0	1.43	000
<i>Dactyloctenium aegyptium</i>	0	0	0.83	0.33	1.14	000
<i>Grewia ferruginea</i>	0.26	2.18	0.29	0	0.71	1.00
<i>Combretum.adenogonium.</i>	1.11	0	0	0	0	4.23
<i>Stereospermum kunthianum</i>	0.26	1.09	0	0	0	0.84
<i>Lonchocarpus laxiflorus</i>	0.11	2	0	0	0	0.145
<i>Combretum rochetianum</i>	0	2.18	0	0	0	0.15

* Bold= species score high cover-abundance and significant values used for community types

1. *Ziziphus mucronata*- *Acacia polyacantha* community type

The altitudinal ranges of this community were from 1170-1565 m.a.s.l. At the edge and lower altitude of the forest, high disturbance such as cutting, debarking, grazing was documented. In contrast to other community types, this community is situated at a moderate slope, which ranges from 2-35%. More than 60% of the total species were found within < 10% slope. Totally, 19 plots and 64 species were associated in this community. *Ziziphus mucronata*, *Acacia polyacantha*, *Ziziphus spina.christi*, *Flueggea virosa*, and *Chamaecrista mimosoides* were the most icon and high significant values (Table 1).

2. *Combretum hartmannianum*-*Terminalia macroptera* community type

This community has 40 plant species, found in the south of the study forest within an altitude of 1098-1300 m.a.s.l. It was the most disturbed community. At the steepest area, highly dense *Oxytenanthera abyssinica* was recorded. *Combretum hartmannianum*, *Terminalia macroptera*, *Anogeissus leiocarpa*, *Ficus ingens*, *Dichrostachys cinerea*, *Lannea fruticosa*, *Lonchocarpus laxiflorus*, *Sterculia setigera*, *Senna obtusifolia*, *Setaria megaphylla*, *Oplismenus burmannii*, were among the common species recorded in this community.

3. *Anogeissus leiocarpa*- *Ozoroa insignis* community type

This community was found within an altitudinal range of 1400-1840 m.a.s.l with average slopes of the community were 41%. It was the highest number of species (100 species) in contrast to the rest community. The dominant tree species in this community were *Anogeissus leiocarpa*, *Ozoroa insignis*, *Acacia seyal*, *Diospyros abyssinica*, *Mimusops kummel*, *Acacia lahai*, whereas the shrub layer was dominated by *Vangueria madagascariensis*, *Rhus retinorrhoea* and *Acokanthera schimperi*. In the herb layer *Chamaecrista mimosoides*, *Setaria pumila*, *Achyranthes aspera*, *Oplismenus burmannii*, were recorded.

4. *Euclea racemosa* - *Acacia abyssinica* community type

A total of 75 species were recorded in 12 plots in this community. At the bottom of the altitude plant species such as *Balanites aegyptiaca*, *Ximenia Americana*, and *Ficus salicifolia* were recorded. At the upper altitude (>1800 m.a.s.l) plant species such as *Rhus retinorrhoea*, *Olea europaea*, *Acacia lahai*, *Acacia seyal*, *Croton macrostachyus*, *Erythrina abyssinica* and *Solanum incanum* were recorded.

5. *Dodonaea angustifolia*- *Flueggea virosa* community type

A total of 75 species were recorded from 14 plots in this community type. This community is dominated by shrub species such as *Dodonaea angustifolia*, *Flueggea virosa*, *Ziziphus mucronata*, *Capparis tomentosa* and *Ziziphus spina.christi*. The tree species associated with this community were *Ozoroa insignis*, *Acacia seyal*, *Combretum molle*, and *Entada abyssinica*, whereas *Hyparrhenia cymbaria*, *Trifolium campestre*, *Arthraxon micans*, *Hyparrhenia rufa*, *Chamaecrista mimosoides*, *Dactyloctenium aegyptium*, *Setaria pumila*, *Bidens pilosa* and *Acanthospermum hispidum* among the common herbs in the community. *Oreosyce africana* and *Dioscorea schimperiana* were among the liana species in this community.

Ordination

CCA ordination was employed to examine the effect of environmental variables on the patterns of variation in the floristic composition of Hirmi forest. Altitude, Slope, Soil pH, Electrical Conductivity, soil texture (sand, silt, clay), Available phosphorus, soil organic matter (SOM), Total Nitrogen (N), Cation Exchange Capacity (CEC) and disturbance (tree cutting, debarking, grazing, firing and charcoal production sign) were among the selected environmental variables used to investigate their association with plant community types in this study. Total of nitrogen, disturbances and sand were associated with community type one and two. Community type three was found in scattered form and affected by different factors. However, slope, soil organic matter and silt were strongly associated with the plant community. Community four occurred in high altitude, slope, soil organic matter and silt; while community five is highly associated with silt and disturbance (Fig. 3).

Figure 3: CCA biplot of environmental variables and sampling plots (communities)

Species richness, evenness and diversity of the five community types

The Shannon-Wiener diversity result for the identified five community types are shown in Table 2. In terms of the actual number of species per community; community III was the most species-rich followed by community V, IV, and I respectively. Community II was the most species poor community. Similarly, community V had the highest species diversity and community II had the lowest. In terms of evenness community, V had the highest evenness index (0.95) and community II and III had the highest similar species or lowest evenness of species (0.90 each) relatively with the rest community types.

Table 2: Showing the Shannon-Wiener Diversity and Evenness Indices for the Five Communities

Community	Elevation	Species richness (S)	Shannon-Wiener Diversity Index (H')	Shannon's Evenness index (J)
1	1170-1565	64	3.83	0.93
2	1098-1300	40	3.25	0.90
3	1400-1840	100	4.07	0.90
4	1405-2002	75	3.96	0.93
5	1285-1790	75	4.21	0.95

Vegetation structure

DBH and height distribution

Species were classified into seven DBH (cm) classes as: 1≤10; 2=10.1-20; 3=20.1-30; 4=30.1-40; 5= 40.1-60; 6=60.1-80; 7>80 cm. As the DBH class size increases, the number of individuals gradually decreases towards the successive higher DBH classes (Fig. 4). *Sterculia setigera*, *Ficus vasta*, *Ficus palmata*, *Adansonia digitata* and *Terminalia catappa* were found to be the dominant large-sized DBH trees in Hirmi forest. *Anogeissus leiocarpa* *Ziziphus mucronata*, *Combretum hartmannianum* were among the species contribute highest cumulative proportion of DBH (contribute >14%), whereas *Buddleja cordata* and *Clerodendrum myricoides* contributed least to the total DBH (accounts <0.06% both).

Figure 4: DBH class distributions of trees and shrubs in Hirmi forest

Individuals of woody species with height $> 2\text{m}$ and DBH $> 2\text{cm}$ were classified into seven height classes and density per hectare was calculated. More than 72% of the height class was accounted in the first height class whereas only 28% height class was contributed by the rest of the five classes. Hirmi forest has an inverted J-shape of height class, indicates that a decline in the density of woody plants with increasing height classes (Fig.5).

Figure 5: Height class distribution of woody species of Hirmi forest

Vertical structure:

The top height for trees in the study forest was 25 m. According to the IUFRO classification scheme classification 65.2% of the species were in the lower storey (< 8.3 m). The cumulative vertical structure of Hirmi forest was an inverted J-shape (Fig. 6). This indicates that the lower storey contains the highest individual species but the upper storey was represented by the lowest individual of stems. Woody species in lower storey were; *Acokanthera schimperi*, *Calpurnia aurea*, *Dichrostachys cinerea*, *Dodonaea angustifolia*, *Flueggea virosa*, *Maytenus arbutifolia* and *Ximenia Americana*. Woody species in the middle storey of the forest (8.3-16.6m), contributed about 28.6% of the total individuals in the forest. The tree species that occupied the middle storey in Hirmi forest include: *Albizia malacophylla*, *Ziziphus mucronata*, *Entada abyssinica*, *Diospyros mespiliformis*, *Entada abyssinica*, and *Euclea racemose*. The Upper storey also contains 6.2% of the total individuals in the forest. The tree species that occupied the upper storey in Hirmi were *Acacia albida*, *Combretum hartmannianum*, *Stereospermum kunthianum*, *Acacia abyssinica*, *Anogeissus leiocarpa*, *Combretum adenogonium*, *Ficus vasta*, *Sterculia setigera* and *Terminalia macroptera*.

Figure 6: Percent density of trees in lower, middle and upper storey

Density of trees and shrubs

A total of 2642 species/5 hectare were recorded from 80 plots of Hirmi forest. As indicated in table 3, only 10 species accounted for 40.4% of the total density. On the other hand, the remaining 70 woody species altogether accounted for 59.6% of the total density in the forest.

Table 3: Density and percentage contribution of ten woody species in Hirmi forest

Species name	Density ha ⁻¹	%
<i>Dodonaea angustifolia</i>	31.2	5.9
<i>Flueggea virosa</i>	29.2	5.53
<i>Diospyros mespiliformis</i>	28	5.3
<i>Anogeissus leiocarpa</i>	25.8	4.88
<i>Ziziphus mucronata</i>	18	3.44
<i>Combretum hartmannianum</i>	18	3.4
<i>Maytenus arbutifolia</i>	18	3.4
<i>Ximenia americana</i>	16	3.03
<i>Acokanthera schimperi</i>	14.4	2.73
<i>Acacia polyacantha</i>	12.8	2.43
Sub-total density of 8 species	211.4	40.4
other 70 species	317	59.6
Total density h⁻¹	528.4	100

Basal area (BA) and frequency

The total basal area of Hirmi forest was 14m² ha⁻¹. About 7.10 (>50%) of the total basal area was contributed by large large-sized tree species such as *Anogeissus leiocarpa*, *Acacia polyacantha*, *Combretum hartmannianum*, *Terminalia macroptera*, *Ziziphus mucronata*, *Terminalia catappa*, *Diospyros abyssinica*, *Ficus ingens*, *Ozoroa insignis* and *Diospyros mespiliformis*.

Frequency is obtained by dividing the number of plots in which the species occurred by the total number of the plots from which all the species sampled in the area under the study. The computed frequency values of species were classified into five frequency classes as: 1=0-10; 2=10.1-20; 3=20.1-30; 4=30.1-40; 5>40 (Fig. 7). The result showed that 59 % of the total woody species were distributed in frequency class one. The grand frequency distribution of woody species in Hirmi forest showed that higher proportions of species were found to be distributed in the first frequency classes followed by a rapid decline in the distribution of species across successive higher frequency classes. *Anogeissus leiocarpa* was the most highly frequent species (40.5%), followed by *Terminalia macroptera* (28.5%) and *Ziziphus mucronata*, *Combretum hartmannianum* (26.25% each) where as *Acacia nilotica*, *Buddleja cordata*, *Olea europaea*, *Otostegia fruticose*, *Phoenix reclinata*, *Phytolacca dodecandra* and *Syzygium guineense* were species with low frequency (2.5% each) in the study forest.

Figure 7: Frequency distributions of trees and shrubs in Hirmi forest

Importance Value Indices (IVI) of the three plant communities

The first top ten woody species which contributed 37.78% of the IVI in decreasing order were; *Anogeissus leiocarpa*, *Combretum hartmannianum*, *Ziziphus mucronata*, *Terminalia macroptera*, *Acacia polyacantha*, *Flueggea virosa*, *Dodonaea angustifolia*, *Diospyros abyssinica*, *Ozoroa insignis* and *Diospyros mespiliformis* respectively (Table 4). The remaining 62.22% of the IVI was contributed by the remaining 70 species.

Table 4: The top ten species with the highest IVI value in Hirmi forest

No.	Spp Name	RF	RD	RDO	IVI
1	<i>Anogeissus leiocarpa</i>	5	4.86	10.69	20.55
2	<i>Combretum hartmannianum</i>	3.22	3.81	6.05	13.08
3	<i>Ziziphus mucronata</i>	3.22	5.24	4.28	12.74
4	<i>Terminalia macroptera</i>	3.52	2.66	5.24	11.42
5	<i>Acacia polyacantha</i>	2.45	2.36	6.42	11.23
6	<i>Flueggea virosa</i>	2.3	5.46	1.92	9.68
7	<i>Dodonaea angustifolia</i>	1.53	5.84	2.21	9.58
8	<i>Diospyros abyssinica</i>	1.53	3.35	4.13	9.01
9	<i>Ozoroa insignis</i>	2.76	1.83	3.61	8.2
10	<i>Diospyros mespiliformis</i>	1.99	2.4	3.47	7.86
Total		27.52	37.81	48.02	113.35

*RF=Relative frequency, RD= Relative density, RDO= Relative dominance, IVI= Importance

Value Indices

Regeneration status of Hirmi forest

Regeneration status of Hirmi forest was characterized by recording and counting of seedlings, saplings and adults of eighty (80) trees/shrubs. The total density of seedlings, saplings and mature tree and shrub species were 2750 ha⁻¹, 3025 ha⁻¹ and 528.4 ha⁻¹ respectively, (Fig. 8).

Figure 8: Density per hectare of seedlings, saplings, Mature of woody species (trees/ shrubs).

For the sake of conservation priority, the regeneration status of woody species recorded in the study area was grouped into four categories based on the density of seedling, sapling and mature of trees and shrubs. These are category I: species with the no seedlings, category II: species with no saplings, category III: species with no saplings seedling and category IV: species with high saplings and seedlings density (Table 5).

Table 5: Classification of woody species in the different conservation priority classes

	Category I	Category II	Category III	Category IV
1	<i>Acacia nilotica</i>	<i>Acacia nilotica</i>	<i>Acacia nilotica</i>	<i>Ziziphus mucronata</i>
2	<i>Adansonia digitata</i>	<i>Buddleja cordata</i>	<i>Clerodendrum myricoides</i>	<i>Diospyros abyssinica</i>
3	<i>Balanites aegyptiaca</i>	<i>Clerodendrum myricoides</i>	<i>Cordia africana</i>	<i>Anogeissus leiocarpa</i>
4	<i>Clerodendrum myricoides</i>	<i>Cordia africana</i>	<i>Justicia schimperiana</i>	<i>Ziziphus spina-christi</i>
5	<i>Cordia africana</i>	<i>Ficus vasta</i>	<i>Phoenix reclinata</i>	<i>Flueggea virosa</i>
6	<i>Croton macrostachyus</i>	<i>Justicia schimperiana</i>	<i>Phytolacca dodecandra</i>	<i>Lannea fruticosa</i>
7	<i>Erythrina abyssinica</i>	<i>Lannea schimperi</i>		<i>Terminalia macroptera</i>
8	<i>Justicia schimperiana</i>	<i>Maerua angolensis</i>		<i>Ximenia americana</i>
9	<i>Phoenix reclinata</i>	<i>Phoenix reclinata</i>		<i>Combretum hartmannianum</i>
10	<i>Phytolacca dodecandra</i>	<i>Phytolacca dodecandra</i>		<i>Ozoroa insignis</i>
11	<i>Piliostigma thonningii</i>	<i>Sterculia setigera</i>		
12	<i>Rumex nervosus</i>			

DISCUSSION

Floristic composition and diversity of Hirmi forest

The forest was composed of *Acacia- Commiphora* woodland, *Combretum–Terminalia* woodland and dry evergreen Afromontane forest species within 1098m-2002m of elevation. The existence of high species richness in the study site was due to the fact of heterogeneity within the forests community (Murphy and Lugo 1986), altitude difference (Bekele 1993), anthropogenic impacts (disturbance) (Lyaruu *et al.* 2000) and soil properties (Kooch *et al.* 2009). The species richness of Hirmi forest is higher than some dryland forest studied in Ethiopia such as in Metema with 87 species (Adamu *et al.* 2012), Kimphe Lafa (West Arsi) with 130 species (Aliyi *et al.* 2015) and in Grat-Kahsu 64 species (Atsbha *et al.* 2019) but less than the study conducted in Benshangul Gumuz regional state with 1102 species (Awas 2007).

High richness of herbaceous species may be attributed due to the open canopy cover of the forest patch enables to grow freely and diversely in the study area. This was in agreement with Murphy and Lugo (1986), which reported that an abundance of herbs has an inverse relation with canopy cover. Anthropogenic impacts such as exploiting plant products and selective cutting of trees (Lulekal *et al.* 2008; Yineger *et al.* 2008) and shrub species in dryland forest (Lemenih and Bongers 2011) increased the growth of herbaceous species. More than half of the total sampled (54.5%) of the plant family was represented by one species indicates the richness of families and great diversity in the area. The highest number of species recorded from Hirmi forest was Fabaceae and Poaceae followed by Asteraceae and Lamiaceae proves the fact that they are species-rich families in the flora Ethiopia and Eritrea (Tadess 2004). Out of the recorded 10 endemic species; *Acacia venosa* and *Lippia adoensis* have been included in the IUCN red data list of Ethiopia and Eritrea (Vivero, *et al.* 2005). This was in association with existing significant disturbance in the study forest. The threat status of the endemic species in Hirmi forest reveals

that, the need for conservation prioritization. The dryland forest type in Ethiopia is currently under strong environmental stress (Friis et al. 2010). The ecosystem approach of biodiversity conservation and participatory forest management provides an opportunity to conserve large numbers of species that are rare and endemic (Aynekulu 2011; Lemenih and Bongers 2011).

The Shannon diversity index of the study forest was range from 3.25 to 4.21 (with mean value 3.73) and evenness was from 0.90-95 (with mean value 0.93). The higher value of Shannon diversity index and evenness indicates that the study forest has high species diversity with more evenly distributed of the species within the study plots. Community type V had the highest species diversity and evenness whereas community II was with the lowest species diversity and evenness. The variation in species diversity is associated with environmental and disturbance factors. This was in line with a study conducted by Suratman (2012) reported, the difference in terrain, gradient and slope direction causes differences in the soils, water, and microclimate conditions which cause differences in species diversity and adaptability.

Plant community and Environmental variables relationship (Ordination)

The relationship between plant communities and environmental variables is important in understanding the plant communities in a given ecology (McCune and Grace 2002). Patterns of species community is associated with environmental factors such as climate, topography, and soil as well as anthropogenic and livestock disturbances (Whittaker et al. 2003). Ecological study conducted in Ethiopia by Woldu et al. (1989), Friis (1992), Bekele (1994), Aynekulu (2011), Kelbessa and Girma (2011) and Gebrehiwot et al. (2019) reported importance of environmental variables (altitude, slope, landscape, disturbances, and soil physical and chemical properties) in separation of forest communities.

CCA analysis shows that environmental variables such as altitude, slope, silt, sand, soil organic matter, total Nitrogen and disturbances were associated with species compositions of plant communities in Hirmi forest. However, all those environmental determinants have different effects for the five identified communities from the Agglomerative clustering algorithm. Community one (*Ziziphus mucronata*- *Acacia polyacantha*) and community two (*Combretum hartmannianum*-*Terminalia macroptera*) of the present study area were strongly influenced by sand and total Nitrogen. Nitrogen content of a soil is suitable for species growth and diversity (Brown 2003). Similarly, disturbances (cutting, debarking and grazing) were common and significantly associated in both communities. This can be plots of these communities were from a small difference of environmental gradients and near human settlement which is easily accessible by local people (edge effect). A study by Condit et al. (2002) reports that there is a high probability species composition similarity in a community with small environmental determinants differences and taken from adjacent plots. Disturbance such as selective cutting and grazing is high at the edge of the forest ecosystem (Daniel et.al. 2006) is also agreed with the present result.

Least disturbance and high species composition in community three (*Anogeissus leiocarpa*-*Ozoroa insignis*) was due to most plots were sampled from the center or far from the edge of the forest. This community was positively correlated with soil organic matter, silt and slope. Soils having high organic matter and moisture holding capacity of the silt loam of soil are suitable for species growth and diversity (Brown 2003; O'Geen 2006). Furtherly, species found in strong slope are less disturbed and would be rich in species composition (Tilahun et al. 2011; Gebrehiwot et al., 2019). The longest arrow of altitude in the ordination axis was positively correlated with community type four (*Euclea racemosa* - *Acacia abyssinica*) than the other

community types. Longest arrows environmental determinant in the ordination diagram indicates its strong influence on species composition of plant community diversity (ter Braak 1987). The highest elevation difference (1405-2002) was recorded in this community. Altitudinal difference did not bring only species richness and diversity, but also it affects the soil texture, atmospheric pressure, moisture and temperature that directly affect species distribution and composition (Bekele 1994; Lovett and Wasser 1993). The existence of high species richness as well as high Shanon diversity ($H'=4.21$) and evenness ($J=0.93$), in community five (*Dodonaea angustifolia-Flueggea virosa*) was positively associated with silty loam soil and disturbances in the study area. Silty loam soil contains the perfect combination of sand, silt and clay particles and moisture holding capacity that supports the growth of virtually all forms of plant life (Sheunesu 2018). The disturbed dryland of Ethiopia areas are covered by shrubs like *Dodonaea angustifolia* and secondary forests (Lemenih and Bongers 2011; Woldu et al. 2019).

Generally, the identified community types in the study forest have either positive or negative with the selected environmental and disturbance factors. Forest community has its distribution area with a specific combination of environmental variables (Brinkmann et al. 2009). Hence, conservation techniques should implement based on the species composition and diversity of the community types in relation to the associated environmental gradients.

Vegetation structure of Hirmi Forest

Analysis of vegetation structure was implemented by considering species; DBH class, Vertical structure, density, basal area, frequency, height and Important Value index.

DBH: the overall height and DBH class distribution of all individuals in different size showed an inverted J- shape distribution. In the lower class of DBH (DBH=2-20cm), high number of species were existed. The existences of high number of species at the lower the DBH with

gradual decrease towards high DBH indicates, healthy regeneration of the forest (Silvertown and Doust 1993). Similar result was reported in Abergele dry woodlands (Eshete et al. 2011), Dawsura – Tembien woodlands (Woldu et al. 2019) and Ilu Gelan of *Combretum-Terminalia* and *Acacia* vegetation (Tadesse et.al. 2018). In addition the study forest was dominated by small-sized species (shrubby and secondary vegetation) but a large number of individual species such as *Dodonaea angustifolia*, *Flueggea virosa*, *Maytenus arbutifolia*, *Acokanthera schimperi*, *Bersama abyssinica*, *Ziziphus mucronata*, *Ximenia americana*.

Vertical structure: based on on the Lamprecht (1989) scheme of classification highest proportion of species was concentrated in the lower storey followed by the middle and upper storey. This confirms the dominance of small-sized individuals and secondary developmental stage of the forest. A similar result was reported in other dryland forest by Debissa Lemessa (2009) in Taltalle woodland area and Tadesse et.al (2018) in Ilu Gelan *Combretum-Terminalia* and *Acacia* vegetation. Physical environments, human factors can modify the vertical structure of the forest (Kent, 2012). More than 53.7% of woody species of Hirmi forest comprises shrubs layer. According to White (1983), shrubby layer forest is mostly dominated by lower undifferentiated woody species. Similar result was also reported in another dryland forest of Ethiopia by Aliyi et al. (2015). Besides a study in Metema and Abergele by Eshete et al. (2011) reports that the replacement of large size (height) of woody species by small-sized species (shrubs) was associated with the intensity of human/livestock intervention in the natural vegetations and the regeneration of secondary young plants.

Density: the overall density of woody species in Hirmi forest was 528.4 individuals per hectare. This was greater than density reported from dryland forest studied in Metema (18.8 stems/ha, Adamu et al. 2012) and Kimphe Lafa Forest (515.7 stems/ha, Aliyi et al. 2015). However, it was

less than the study in other dryland forests in Abobo–Gog forest (1579 stems/ha, Bareke 2018) and Shai Hills dryland in Ghana (959/ha, Swaine et.al 1990). Such variation could be attributed to variations in topographic gradients and habitat preferences of species forming the forest, and the degree of anthropogenic disturbances (Whittaker *et al.* 2003).

Basal area: The total basal area of Hirmi natural forest for plant species with DBH >2 cm was 14m²/ha. This result was higher than the study conducted in Grat-Kahsu (5.32 m²/ha; Atsbha et al. 2019) and Taltalle woodland area (0.44 m²/ha; Lemessa 2009). However, it was smaller than the other dry woodland forest studied in Abobo–Gog forest (Gambella Regional State) (29.3 m²/ha; Bareke 2018) and the normal basal area value for virgin tropical forests in Africa is (23-37 m²/ha; Lamprecht 1989). More than 50% of the total basal area of Hirmi natural forest was contributed by large large-sized tree species such as *Anogeissus leiocarpa*, *Acacia polyacantha*, *Combretum hartmannianum*, *Terminalia macroptera*, *Ziziphus mucronata*, *Terminalia catappa*, *Diospyros abyssinica*, *Ficus ingens*, *Ozoroa insignis* and *Diospyros mespiliformis*. However, the number and diversity of the above tree species were far less than the shrub species in Hirmi forest. Small DBH of plant species in a forest covered by the shrub layer would have a small total basal area in contrast to tree species (Murphy and Lugo 1986; Lemenih and Bongers 2011). The lower and higher DBH class contributed to the total basal area was also supported by other studies such as Bekele (1993) and Daniel et.al. (2006).

Frequency: frequency is an indicator for the homogeneity and heterogeneity of given vegetation (Kent, 2012). The number of species decreased as the rate of frequency class was increases. Based on the Lamprecht (1989) frequency of analysis; high value in the lower frequency classes shows the heterogeneous species composition of Hirmi forest. *Anogeissus leiocarpa*, *Combretum hartmannianum*, *Terminalia macroptera*, *Ziziphus mucronata* and *Ziziphus spina-christi* were

among the species with high-frequency value whereas *Phoenix reclinata*, *Phytolacca dodecandra*, *Olea europaea*, *Acacia nilotica*, and *Cordia africana* had small frequency value. High frequency of a species always depends on factors that relate to habitat preferences, adaptation, degree of exploitation and availability of suitable environmental conditions for regeneration (Rey et al. 2000). According to (Friis et al. 2010), most of the above species are frequently revealed in *Acacia-Commiphora woodland* and *Combretum-Terminalia woodland* and wooded grassland vegetation type around Tekeze valley, north-western Ethiopia.

Important Value Index (IVI): *Anogeissus leiocarpa*, *Combretum hartmannianum*, *Ziziphus mucronata*, *Terminalia macroptera*, *Acacia polyacantha*, *Flueggea virosa*, *Dodonaea angustifolia*, *Diospyros abyssinica*, *Ozoroa insignis* and *Diospyros mespiliformis* were the top ten species with the highest IVI value in decreasing order in Hirmi forest. High value of basal area, frequency and density of these species were the factor to have a high value of IVI. High density and frequency coupled with high Basal area indicate the overall dominant or high important species of the forest (Lamprecht, 1989). Species with high IVI in the present study were different from other dryland studied in Kimphe Lafa Forest (Aliyi et al. 2015), Abobo–Gog forest (Bareke 2018); but there was small similarity with a study done in Benshangul Gumuz regional by Awas (2007) and Dawsura-Temben by Woldu et al. (2019). Species IVI of the study forest varies from 0.35 to 20.55. This in turn implies the importance of conservation priority for the existing species in the dry forest land according the species frequency, density and dominace status. IVI is a good index for summarizing vegetation characteristics and ranking species for management and conservation practices (Kent 2012).

Regeneration status of Hirmi forest

Density of sapling was higher than seedling and mature trees/shrubs. According to Khan et al. (1987) regeneration analysis, Hirmi forest is categorized under poor status. The ordination result shows disturbance was significantly associated with the vegetation diversity of Hirmi forest. Dry forests of Ethiopia are characterized by poor and fluctuating patterns of regeneration status due to periodic disturbances (Yebeyen 2006; Tesfaye 2008; Lemenih and Bongers 2011). A study conducted by Kelbessa and Girma (2011) reported that human caused disturbances such as intensive grazing, firing and removal of trees are the common threats for the dryland forest regeneration. Frequent sign of disturbances were recorded in plant communities near to the settlement and edge of the study forest. A study conducted by Girma (2014); Gebrelibanos and Assen (2015) reveals, previously human settlements around the study area were restricted to afro-montains landmasses. However, rapid human population growth imposes to settle in lowland areas for the demanding of large farmland as well as plant and plant product. Thus, a human and livestock intervention in that area leads to be poor in the regenerating of species. As a result, there were plant species either with no seedling, sapling or both. Hence, this study suggests that high conservation priority is required to the species either with no both seedling and sapling (considered as priority one) and species either with sapling or seedling (considered as priority two). Besides recoding and studding these species will help to rescue from extinction.

CONCLUSION

The result of this study shows, Hirmi dryland forest is one of the remnant forest in Northern Ethiopia with high floristic composition and diversity. The largest part the forest was covered with undifferentiated floristic composition belongs to *Acacia- Commiphora* and *Combretum–Terminalia* forest type. At the elevated part of the forest, floristic composition similar to the DAF species was documented. The variation in diversity and floristic composition of the study forest structure was associated with the topographic variation and heterogeneity of the forest community. The presence of endemic and near endemic species (some of them categorized in IUCN threatened list) in the study forest indicates the area's potential of plant diversity and conservation priority.

The multivariate analysis result revealed that, the identified five plant communities in the study were influenced by; altitude, slope, total Nitrogen (N), soil organic matter, sand, silt and disturbance. Community 1 and 2 were strongly influenced by similar affinity of sand, total Nitrogen and disturbances. Community three was the most species-rich community associated with high content of soil organic matter and silt loam. The location of this community was in a strong slope and less disturbed site also contributes to the species richness. The longest arrow of altitude in the ordination axis was positively correlated with community type four indicate as it strongly affects the community and found at high elevations isolated from the others. The existence of high Shanon diversity and evenness ($J=0.93$), in community was associated with the availability of high silty loam soil in the community which is sutabel for the growth of all species.

The vegetation structure of Hirmi forest reveals that, large number of individual species was categorized in the lower class of DBH. The hight class of the forest has an inverted J-shape

indicates that, the decline in density of woody plants with increasing height classes. High density of species at the lower DBH class and high class is due to the dominance shrubs or/and developments secondary vegetation species in the forest. *Dodonaea angustifolia*, *Anogeissus leiocarpa*, *Flueggea virosa* and *Ziziphus mucronata* were among the species with high density whereas species such as *Anogeissus leiocarpa*, *Acacia polyacantha*, *Combretum hartmannianum*, *Terminalia macroptera*, *Ziziphus mucronata*, *Diospyros abyssinica*, *Ficus ingens*, *Ozoroa insignis* and *Diospyros mespiliformis* are species with high basal area which accounts more than 50% of the total BA of the study forest. High value in lower frequency classes of the study forest indicates that, the existence of a high degree of floristic heterogeneity in the forest. The result from the assessment for the regeneration status of the study forest shows, the population of sapling was higher than seedling and mature trees/shrubs. This indicates the forest is under poor regeneration stage. This was associated with disturbance events such as selective harvesting/cutting, debarking, grazing and charcoal production. As a result of these threats, there were plant species either with no seedlings, saplings or both seedling and sapling.

Generally, the study concludes conservation measurement in the study forest should consider the significant environmental factors associated with the species diversity, IUCN threat status and regeneration status of the species.

Abbreviation

CBD: Convention on Biological Diversity; CCA: Canonical Correspondence Analysis; DAF: Dry evergreen Afromontane forest; DBH: Diameter at breast height; EFAP: Ethiopian Forestry Action Program; IUCN: International Union for the Conservation of Nature; m.a.s.l: meter above sea level; MEF: Ministry of Environment and Forest; m: meter; mm: mili meter; NMSAE:

National Metrological Service Agency of Ethiopia; REDD+: Reduced Emission from Degradation and Deforestation.

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Authors' contributions

The first author collects and analyzes the data, and wrote the manuscript. All authors read, edit and approved the manuscript.

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Not applicable

Consent for publication

All authors have an agreement to publish this manuscript.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Reference

- Adamu H, Bekele T, Dalle G (2012) Plant community and ecological analysis of woodland vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *J Forestry Res.* 23(4): 599–607.
- Agriculture and Natural Resource Bureau of North-Western Zone of Tigray, Ethiopia Annual report; 2017.
- Aliyi K, Hundera K, Dalle G (2015) Floristic Composition, Vegetation Structure and Regeneration Status of Kimphe Lafa Natural Forest, Oromia Regional State, West Arsi, Ethiopia. *J.Life Sci* 5(1).
- Atsbha T, Belayneh A, Zewdu T (2019) Woody species diversity, population structure, and regeneration status in the Grat-Kahsu natural vegetation, southern Tigray of Ethiopia. *Heliyon* 5(1120).
- Awat T (2007). Plant diversity in western Ethiopia: Ecology, Ethnobotany and Conservation. Ph.D. Thesis, University of Oslo, Norway.
- Aynekulu E (2011) Forest diversity in fragmented landscapes of northern Ethiopia and implications for conservation. *Doctoral Dissertation*, University of Bonn.
- Bareke T (2018) Lowland semi-evergreen forest of Ethiopia. Holeta Bee Research Center, Oromia Agricultural Research Institute, Ethiopia. *Forestry Res and Eng Int J* 2(5):244–248. DOI: 10.15406/freij.2018.02.00057
- Bekele T (1994) Phytosociology and ecology of a humid Afromontane forest on the central plateau of Ethiopia. *J Veg Sci* 5: 87–98.
- Bekele T (1993) Vegetation ecology of remnant Afromontane forests on the central plateau of Shewa, Ethiopia. *Acta Phytogeographica Suecica* 79: 1–64.

- Brinkmann K, Patzelt A, Dickhoefer U, Schlecht E, Buerkert A (2009) Vegetation patterns & diversity along an elevational & a grazing gradient in the Jabal al Akhdar mountain range of northern Oman. *J Arid Env* 73:1035–1045.
- Brooks TM, Mittermeier RA, Mittermeier CG (2002) Habitat Loss and Extinction in the Hotspots of Biodiversity. *Conservation Biology* 16(4):909-923.
- Brown RB (2003) Soil Texture. University of Florida, Institute of Food and Agriculture Science;. Available online: <http://edis.ifas.ufl.edu/SS169>.
- CBD (2006) Report of the eighth meeting of the Parties to the Convention on Biological Diversity UNEP/CBD/COP/8/31, Curitiba.
- Condit R, Hubbell SP, Lafrankie JV, Sukumar R, Manokaran N, Foster RB, Ashton PS (2002) Species-area and species-individual relationships for tropical trees: a comparison of three 50-ha plots. *J of Ecology* 84:549-562.
- Daniel L, Aldicir S, Karen D (2006) Effects of Habitat, Cattle Grazing and Selective Logging on Seedling Survival and Growth in Dry Forests of Central Brazil. *BIOTROPICA* 39(2):269-274
- Debissa Lemessa (2009) Woody plant species Diversity of Taltalle woodland (*Acacia–Commiphora* woodland Ecosystem), Oromia, Ethiopia. Forest Genetic Resources Conservation, Institute of Biodiversity Conservation, Addis Ababa, Ethiopia.
- EFAP (1994) The Challenge for Development, Volume II. Ethiopian Forestry Action Program, Addis Ababa, Ethiopia.
- Field R, Hawkins BA, Cornell HV, Currie DJ, Diniz-Filho J, Alexandre F, Guégan JF, Kaufman DM, Kerr JT, Mittelbach GG, Oberdorff T, O'Brien EM, Turner JR (2009) Spatial species-richness gradients across scales: a meta-analysis. *J Biogeography* 36 (1): 132–147. doi:10.1111/j.1365-2699.

- Friis I, Demissew S, von Breugel P (2010) Atlas of Potential Vegetation of Ethiopia. The Royal Danish Academy of Science and Letters, Copenhagen.
- Friis I (1992) Forests and forest trees of northeast tropical Africa: Their natural habitats and distribution patterns in Ethiopia, Djibouti and Somalia. Her Majesty's Stationery Office, London.
- Eshete A, Stercka F, Bongersa F (2011) Diversity and production of Ethiopian dry woodlands explained by climate- and soil-stress gradients. *J Else: Forest Ecology and Management* pp1-11.
- Gaston KJ (2000) Global patterns in biodiversity. *Nature* 405 (6783): 220–227. doi:10.1038/35012228. PMID 10821282.
- Gebrehiwot K, Demissew S, Woldu Z, Fekadu M, Desalegn T, Teferi E (2019) Elevational changes in vascular plants richness, diversity, and distribution pattern in Abune Yosef mountain range, Northern Ethiopia. *Plant Diversity* 41:220-228.
- Gebrelibanos T, Assen M (2015) Land use/land cover dynamics and their driving forces in the Hirmi watershed and its adjacent agroecosystem, highlands of Northern Ethiopia, *J Land Use Sci* 10:1, 81-94.
- Gerben van Ek (2013) Participatory Forest Management Socio-Economic Baseline Study. Assessment of the economic and social values of forests on rural households in and adjacent to SLMP project areas. Addis Ababa-Ethiopia.
- Georgis K (2010) Agricultural based Livelihood Systems in Drylands in the Context of Climate Change. Inventory of Adaptation Practices and Technologies of Ethiopia. Food and Agriculture Organization of the United Nations, Rome. PP5-57

- Girma A (2014) Land use land cover mapping of PFM (participatory forest management) project areas and adjacent SLMP watersheds in three regions of Ethiopia. Mekelle University and GIZ.
- Hagos F, John P, Gebreselassie N (1999) Land degradation in the Highlands of Tigray and Strategies for Sustainable Land Management. Socioeconomic and Policy Research Working Paper 5:2-12.
- Khan ML, Rai JP, Tripathi RS (1987) Population structure of some tree species in disturbed and protected sub-tropical forests of north-east India. *Acta Oecologia: Oecologia Applicata.*; 8: 247-255.
- Kelbessa E, Girma A (2011) Forest types in Ethiopia; Status, Potential Contribution and Challenges . Forum for Environment, Addis ababa Ethiopia 7: 4-158
- Kent, M. (2012)Vegetation description and data analysis: a practical approach. 2nd ed. John Wiley & Sons, New York 2:1-30.
- Kidane L (2015) Vegetation ecology and plant diversity of Hugumburda-Gratkhassu National Forest Priority Area, Northeastern Ethiopia: habitat fragmentation in time and space. PhD Dissertation. Addis Ababa University, Ethiopia;.
- Kooch Y, Jalilvand H, Bahmanyar MA, Pormajidian MR (2009) Differentiation of ecosystem units of Caspian lowland forests and its relation with some soil characteristics.
- Lamprecht H (1989) Silviculture on the Tropics.Tropical forest ecosystems and their tree species – Possibilitiesand methods for their long term utilizations.
- Landon JR (1991) Tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. pp 474.

- Lemenih M, Bongers F (2011) Dry Forests of Ethiopia and Their Silviculture. *Tropical Forestry*. pp8-17.
- Lovett JC, Wasser SK (1993) Biogeography and ecology of the rain forests of eastern Africa. Cambridge University Press, Cambridge, UK.
- Lulekal E, Kelbessa E, Bekele T, Yineger H (2008) Plant species composition and structure of the Mana Angetu moist montane forest, Southeastern Ethiopia. *J east African Natural History* 97(2): 165-185.
- Lyaruu HV, Eliapenda S, Backeus I (2000) Floristic, structural and seed bank diversity of a dry Afromontane forest at Mafai, central Tanzania. *Biodiversity and Conservation* 9:241-263.
- Magurran AE (1988) Ecological diversity and its measurement. Chapman and Hall, London.
- Mayaux P, Holmgren P, Achard F, Eva H, Stibig H, Branthomme A (2005) Tropical forests cover change in the 1990s and options for future monitoring. *Philosophical Transactions of the Royal Society* 360:373–384.
- McCune B, Grace, JB (2002) Analysis of Ecological Communities. MjM Software Design, Oregon, USA. pp3-13
- MEF (2015) Pilot Redd+ Sites Visit Report. Federal Democratic Republic of Ethiopia, Addis Ababa.
- Mueller – Dumbois and Ellenberg, H. (1974) *Aims and Methods of Vegetation Ecology*. John Willey and Sons, New York.
- Murphy PG, Lugo AE (1986) Ecology of tropical dry forest. *Annu. Rev. Ecol. Syst* 17:67-88
- Muys B, Gebrehiwot K, Aerts R, Haile M, Deckers J (2006) Perspectives for the rehabilitation of dryland forests in Ethiopia. *J Drylands* 1(2): 217-220.

- NMSAE (2018) Data of Rainfall and Temperature of 20 years (1998-2017). Addis Ababa, Ethiopia.
- Nyssen J, Unro M, RN, Haile M, Poesen J, Descheemaeker K, Haregeweyn N, oeyersons J, Govers G, Deckers J (2007) Understanding the environmental changes in Tigray: a photographic record over 30 years. Tigray Livelihood Papers No. 3, VLIR – Mekelle University IUC Programme and Zala-Daget Project 3:2-82.
- O'Geen AT, Elkins R, Lewis D (2006) *Erodibility of agricultural soils, with examples in Lake and Mendocino counties*. Oakland: University of California Division of Agriculture and Natural Resources publication 8194. <http://anrcatalog.ucdavis.edu>
- Pimm L, Raven P (2000) Extinction by numbers. *Nature* 403:843-845.
- R Development Core Team. R (2019) A Language and Environment for Statistical Computing URL. <http://www.r-project.org/>.
- Reid, WV (1998) Biodiversity hotspots. *Tree* 13:275-280.
- Rey PJ, Julio M, Alcantara M (2000) Recruitment dynamics of a fleshy-fruited plant (*Olea europaea*): Connecting patterns of seed dispersal to seedling establishment. *J Ecology* 88(4): 622-633.
- Senbeta F, Teketay D (2001) Regeneration of indigenous woody species in native and exotic tree plantations in central Ethiopia. *Tropical Ecology* 42(2): 175-185.
- Senbeta F, Woldemariam T, Demissew S, Denich M (2007) Floristic diversity and composition of Sheko forest, southwest Ethiopia. *Ethiopian Journal of Biological Science* 6(1):11-42.
- Sertsu S, Bekele T (2000) Procrdures for soil and plant anlysis. National Soil Research Centre, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

- Sheunesu R (2018) The Edge Effect on Plant Diversity and Soil Properties in Abandoned Fields Targeted for Ecological Restoration. *Journal of sustainability*. pp1-12.
- Silvertown JW, Doust JL (1993) *Introduction to Plant Population Biology*. Oxford, UK: Blackwell.
- Smartt PF (1978) Sampling for vegetation survey: a flexible systematic model for sample location. *Journal of Biogeography*. 5(1): 43-56.
- Suratman MN (2012) Tree Species Diversity and Forest Stand Structure of Pahang National Park, Malaysia. In: *Biodiversity Enrichment in a Diverse World*, A.G. Lameed (ed.), *Vegetation Science* 19: 45-56.
- Swaine MD, Lieberman D, Hall JB (1990) Structure and dynamics of a tropical dry forest in Ghana. *Vegetation* 88: 31-51.
- Tadesse G, Bekele T, Demissew S (2008) Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Wolo, Ethiopia. *Ethiop. J. Sci*31(1): 43-54.
- Tadesse M, Hedberg, I, Friis, I.B. and Edwards, S (2004) *Flora of Ethiopia and Eritrea Volume 4, part 2.*; The National Herbarium, Addis Ababa University, Ethiopia, Uppsala, Sweden.
- Tadesse Z (2015) *Floristic Composition and Structural Analysis of Woodland Vegetation in Ilu Gelan District, West Shewa Zone of Oromia Region, Central Ethiopia*. MSc thesis in Biology (Botanical Science), Addis Ababa University, Addis Ababa.
- Tadesse Z, Kelbessa E, Bekele T (2018) Structural analysis of Combretum-Terminalia mixed Acacia vegetation in Ilu Gelan District, West Shewa Zone, Oromia Region, Central Ethiopia. *Tropical Plant Research* 5(1): 61–76]

- Mengistu, Demel Teketay, H. Hultenc, Y (2005) Yemshaw. The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments* 60: 259–281.
- Teketay D (2001) Deforestation, wood famine, and environmental degradation in Ethiopia's highland Ecosystems: urgent need for action. *Northeast African Studies* 8(1):53-76.
- Tenkir E (2006) Soil seed bank study and natural regeneration assessment of woody species in Dodola dry afromountain forest and Bale Mountains. MSc thesis in Biology (Botanical Science), Addis Ababa University, Addis Ababa.
- ter Braak, C.J.F. (1987) The analysis of vegetation-environment relationships by canonicalncorrespondence analysis. *Vegetation* 69: 69-77.
- Tesfaye G (2008) Ecology of regeneration and phenology of seven indigenous tree species in a dry tropical afromontane forest, southern Ethiopia. PhD dissertation, Addis Ababa University, Addis Ababa, Ethiopia.
- Tilahun A (2011) Soromessa T, Kelbessa E and Dibaba A. Floristic composition and community analysis of Menagesha Amba Mariam forest (egdu forest) in central shewa, Ethiopia. *Ethiopian Journal of biological science* 10(2): 111-136.
- Tuxill J, Nabhan GP (2001) People, plants and protected areas. Earthscan publication Ltd, London and Sterling. pp248
- Van der Maarel, E (1979) Transformation of cover-abundance values in phytosociology and its effects in community similarity. *Vegetation* 39: 97-114.
- Vivero JL, Kelbessa E, Demissew S (2005) The Red List of Endemic Trees & Shrubs of Ethiopia and Eritrea. Fauna & Flora International, United Kingdom.pp 28.

- White F (1983) The Vegetation of Africa: A descriptive memoir to accompany the vegetation map of Africa. UNESCO, Switzerland pp 353.
- Whittaker RJ, Willis KJ, Field R (2003) Climatic–energetic explanations of diversity: a macroscopic perspective. In: *Macroecology: concepts and consequences*, Blackburn, T.M. and Gaston, K.J. (eds.), Cambridge University Press; Cambridge. pp107-129.
- Yebeyen D (2006) Population status of *Acacia senegal* (linne) willd and its gum quality in the central Rift Valley of Ethiopia. MSc. thesis, Wondo Genet College of Forestry, Ethiopia.
- Yeshitla K, Bekele T (2002) Plant community analysis and ecology of afro-montane and transitional rainforest vegetation of Southwestern Ethiopia. *Ethiopian J of Sci* 25(2): 155-175.
- Yineger H, Kelbessa E, Bekele T, Lulekal E (2008). Floristic Composition and Structure of the Dry Afro-montane Forest at Bale Mountains National Park. *SINET: Ethio Journal Sci* 31(2): 103-120.
- Woldemariam T (2003) Vegetation of the Yayu forest in Southwest Ethiopia: Impacts of human use and Implications for In situ Conservation of Wild *Coffea Arabica* L. populations. Ecology & Development Series No. 10. Center for Development Research, University of Bonn.
- Woldu Z, Feoli E., Nigatu L (1989) Partitioning an elevation gradient of vegetation from southeastern Ethiopia by probabilistic methods. *Veg* 81: 189–198.
- Woldu Z (2016) *Comprehensive analysis of vegetation and ecological data: Basics, concepts and methods*. Addis Ababa University Press, Addis Ababa, pp1-40.
- Woldu G, Solomon N, Hishe H, Gebrewahid H, Amha M, Birhane E (2019) Topographic variables to determine the diversity of woody species in the enclosure of Northern Ethiopia. *Heliyon*; 6: 1-6