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Research article

Plant community along age and disturbance gradients of dry Afromontane forest patches of Wombera district, Benshangul Gumuz, Ethiopia

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Abstract: Plant community's distributions are determined by topographic factors, soil composition, and physical factors. This study intended to investigate plant community assembly along topography, age, and disturbance gradients. The higher altitude forest patches of the wombera district were classified into pioneer, intermediate, and climax based on age gradients, canopy height, and layer. Each age classes ranked into disturbance gradients: Intact, medium, and highly disturbed based on intensity, frequency, and severity of disturbances. Every 150–300 meters, transact lines were laid along altitudinal gradients, and plots were laid every 100–150 m along transects. Woody plants' cover abundance, height, and DBH were measured from 54 (20 × 20 m each) nested sampling plots. In five (5 m × 5 m) quadrates nested in the larger quadrates, shrubs, seedlings, and saplings were recorded. In 5 (1 m × 1 m) quadrates nested in the 5 m × 5 m quadrates, herbs and grass species were collected. Agglomerative hierarchical cluster analysis and nested ANOVAs with R software were used to identify plant communities and analyze the relationship between plant richness and diversity along age and disturbance gradients. Woody (85) and herbaceous (65) species were classified into three plant communities. Age (Succession) and disturbance gradients were also determinates of pant communities. Plant species diversity and richness significantly varied along age and disturbance gradients. The RDA result showed that the variation of species distribution and plant community formation was related to age, altitude, and disturbance. The maximum species diversity was found in patches of moderately disturbed forest, followed by intact and highly disturbed forest patches along with disturbance gradients.
Keywords: Community - Pioneer - Climax - Diversity - Species richness.

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INTRODUCTION

Ethiopian owns extreme altitudinal ranges from lowland below sea level (Danakil Depression 110 m.a.s.l) to top mountains (Ras Dashen, 4532 m.a.s.l) (Woldu *et al*. 1999). The Great Rift Valley is also the other landscape that runs from northeast to southwest of the country and separates the country into Northwestern and Southeastern highlands enables to own semi-arid lowlands to the east, south, and west of the country (Friis 1986, Bekele 1993). These diversified landscapes and altitudinal range makes to own a diversified range of agro-ecological zones, temperature, rain full, soil structure, and wind patterns in Africa (Friis *et al.* 2010). The diversified environmental conditions and landscapes resulted in diversified flora and fauna (Bekele *et al*. 1999, Woldu 1999), and hence Ethiopia is believed to be home to about 6500 species of higher plants with approximately 12% endemism, and hence, one of the six plant biodiversity-rich countries of Africa (UNEP 1995). Ethiopia also shelters two of the 34 global biodiversity hotspots, namely the Eastern Afromontane and Horn of Africa biodiversity hotspots (Myers *et al*. 2000). Ethiopia is a regional centre for biological diversity

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due to its wide range of altitudes, its great geographical diversity with high and rugged mountains, flat-topped plateaus and deep gorges, incised river valleys and rolling plains (Woldu 1999, Kelbessa *et al*. 2000).

Dry Evergreen Montane forest (DAF) is a part of Afromontane vegetation characterized by a very complex vegetation type and a complex system of succession relating widespread grasslands rich in legumes on heavy black clay soils that are periodically inundated areas, shrubs, and small to large size trees to the closed forest with a canopy of several strata on slopes (Friis *et al*. 2011). The vegetations of DAF are dominated by *Juniperus procera* Hochst. ex Endl., *Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don.) Cif, *Podocarpus falcatus* (Thunb.) R.B. ex Mirb., and *Prunus africana* (Hook. f.) Kalkam. Grass vegetation types are *Hyparrhenia hirta* (L.) Stapf, *Eragrostis schweinfurthii* Chiov., *Sporobolus africanus* (Poir.) Robyns and Tournay and *Pennisetum thunbergii* Kunth whereas legumes include species of *Trifolium simense* Fresen., *Indigofera rothii* Baker, *Tephrosia interrupta* Hochst.,and Steud. ex Engl. and *Crotalaria laburnifolia* L. sub sp. *laburnifolia* (Friis *et al*. 2011). Lianas comprise of *Urera hypselodendron (*A.Rich.) Wedd., *Ebelia schimperi* Vatke and *Jusminum abyssinicum* Hochst. ex DC (IBC 2009). Dry evergreen montane forests experience long dry seasons (4–8 months) and the rainy period is unreliable. During the dry season, not only moisture stress, but also temperature increases and daytime humidity are reduced. The Ethiopian high land encompasses over 50% of the African land area covered by Afromontnae vegetation (Bekele 1993) of which dry Afromontane forests comprise a large part (Teketay 2005). According to Friis (1992) and Woldu (1999), vegetation at an altitude of 1350–3550 m above sea level with an average annual temperature and rainfall of 14°C and 700–1100 mm, respectively, represents a complex system of successions that includes extensive grasslands rich in legumes, shrubs, small to large trees, and closed forests. In Ethiopia, different researchers have studied the genera vegetation pattern in different agro-ecologies however, the objective of this study focus: on vegetation diversity, structure, compositions, and community type, along with age (maturity) and disturbance gradients and (b) Forest, Patches dynamics in terms of species composition and structural variation along age and disturbance gradients. The study addressed the following questions: (a) what were the impact of anthropogenic disturbance (socio-economic values) on vegetation structure and species composition, (b is or are there a significant difference in species diversity, abundance, along age and disturbance gradients.

METHODS

Descriptions of the study area

The Study area, Wombera district, is 658 km from Addis Ababa, the capital city. Wombera is in the Metekel administrative zone of Benishangul Gumuz regional state in the northwestern part of Ethiopia. Wombera is one of the largest districts in the Metekel administrative zone. It shares a boundary with Guba and Dangur in the north, Bullen in the east, Agallometi and Yaso in the south and Serba Abbay, and Sherkole in the west. The latitudinal and longitudinal extension of the woreda ranges between 9°57′ 30″ to 11° 08′ 45″ N and 35° 09′ 09″ to 35° 50′ 25″ E (Fig. 1).

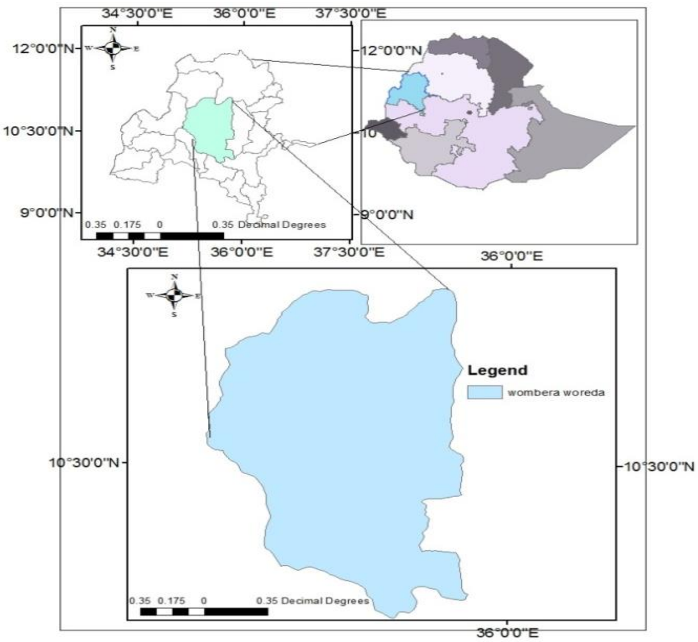

Figure 1. Map of study area.

The topography is undulating and has few plains. The altitudes of the wombera district range from 576 to 2615. The aspects vary and are complex in all of the three agro-ecological zones. This study was conducted in higher agro-ecology. The Annual temperatures range between a minimum of 7.2°C and a maximum of 26°C with an average of 15.9°C. The average annual rainfall was 1942 mm (Fig. 2).

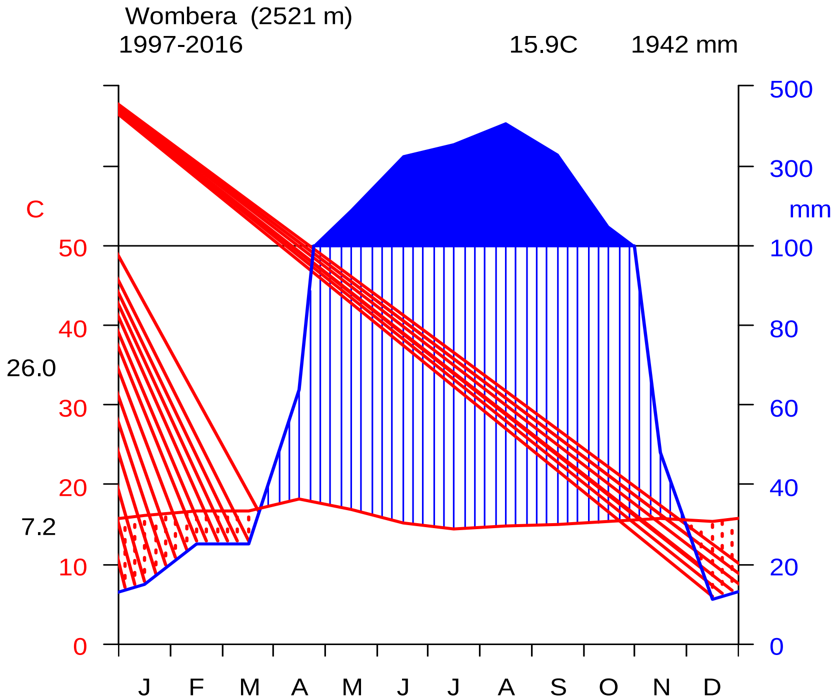

Figure 2. Climate diagram of wombera district.

Forest patches selection

Three forest patches had selected on their accessibility and distance from roads and residents. Gesengesa-Tumi forest patch (GTFP), Senkora-lopi patch (SLFP), and Menesibu-Babo patch (MBFP) were selected. Each forest patch was delineated into three age gradients: Pioneer (10–30 years), intermediate or transitional (30–50 years) and Climax (above 50 years). Each age class were defined as 1= pioneer, 2 = intermediate and 3 for a climax. Each age class was classified into three levels based on the degree, frequency, intensity, extent, and severity of disturbance following (Pickett & White 1985). The disturbances were assessed and ranked following (Althof 2005). Based on disturbance levels, forest patches were classified into intact, moderately disturbed and highly disturbed. The magnitude of disturbance was rated from 0 to 3 following (Senbeta *et al.* 2007, Aynekulu 2011). Forest patches were defined based on degree of disturbance as very low disturbances = Zero, lower =one, Medium =two, and very severe a value of three. The frequency and events of grazing were assessed by interview and further confirmed by the scene left behind on the damaged plant species. The degree of disturbances was defined based on their severity. It was defined as high = 3, Moderate =2, Low=1 and No at all =0. The distance of forest patches from water bodies was measured by taking GPS points on the plots and superimposing them on Arc map and Google map.

The environmental variables were measured for every plot along the transects line of each stratum. Altitude was measured using Garmin GPS. The slope was recorded using clinometers. Aspect (exposure) was determined using Suunto compass or GIS analysis as a possible indicator of total solar energy, and the percentage was converted following (Woldu *et al*. 1989); which defined as North = 0; East = 2; South = 4; West = 2.5; North-East = 1; South-East = 3; South-West = 3.3 and North-West =1.3.

Vegetation data

From the classified forest patches of age or maturity level (pioneer, intermediate and climax) and disturbance level (intact, disturbed and highly disturbed), plant samples were taken during the end of the rainy season, from November to December in tree forest patches. Nested quadrates were laid down 100–150 m following (Stohlgren *et al*. 1995) intervals along transects. The transects were laid parallel at a distance of 300–500 m. Trees with stem diameter at breast height (DBH) >2.5 cm were sampled in 20 by 20 plots. The canopy cover of each tree was calculated by measuring side branches of trees at right angles. The side branches were taken as the side of the square. The canopy cover for each tree species in a lot was computed to 400 m^2. The layer of trees was classified based on height into the lower canopy (2.5–10.0 m), middle layer canopy (10.5–25.0 m) and Upper canopy (above 25 m), following (Feyera 2006). The visual inspection was adopted from (Rahman *et al*. 2009). In 5 m × 5 m quadrates nested in the larger quadrates seedlings, saplings were counted. In 1 m × 1 m quadrates nested in the 5 m × 5 m quadrates, herbaceous and grass were sampled. Thus, vegetation was collected from 54 plots (3 patches, three age classes and disturbance levels with two repetitions). The percentage of cover occupied by each woody plant (400 m^2), shrub (25 m^2) and herbaceous (1 m^2) were computed.

The percentage cover of each herbaceous species was also estimated in each plot and the mean cover was computed. All plant specimens were collected, temporarily tagged with plot numbers), pressed and brought to the National Herbarium (ETH) for identification and storage. Unidentified species in the field were identified and confirmed at the National Herbarium (ETH) of Addis Ababa University using the various volumes of the Flora of Ethiopia and Eritrea (Hedberg 1989, Edwards *et al*.1995, Phillips 1995, Edwards *et al*.1997, Hedberg & Hedberg 2003, Hedberg *et al*.2006, Hedberg *et al* 2009a, Hedberg *et al* 2009b). Botanical names and authorities were verified using the species and family lists in Volume 8 of the Flora of Ethiopia and Eritrea (Hedberg *et al*. 2009b).

Data analysis

Vegetation diversity, richness, evenness, abundance along age gradients (pioneer, intermediate and climax) and disturbance gradients (intact, moderately disturbed, and highly disturbed) of forest patches were computed by nested ANOVA using R Package version 3.4.3. Nested two Way ANOVA is used when there is one measurable variable and two or more nominal variables (Woldu 2017).

Cluster analysis is a multivariate technique that is widely used to group a set of observations (plots or vegetation samples) based on their attributes or floristic composition (Kent & Coker 1992, McCune & Grace 2002). In ecology, cluster analysis is used to classify sites, species or variables based on their similarities (Jongman *et al.* 1987). In this study, hierarchical (agglomerative) cluster analysis was performed using the free statistical software R version 3.4.3 (Team 2017) to classify the vegetation into plant community types.

Vegetation-environment relationship (Ordination)

The ordination method was employed to understand the relationship between the plant communities and the environment. The ordination method (unimodal or linear model) is often selected based on the length of the first DCA axis in various ecological studies (Feyera 2006). Accordingly, a gradient length exceeding four implies a strong unimodal response between the Species and environmental variables (Berhanu *et al*. 2017). On the other hand, if the Length is less than four, the data are homogeneous, and a linear response would happen. RDA is suitable where linear relationships among response variables and between response and predictor variables are expected/demonstrated. RDA enables the use of standardized/non-standardized analyses; by standardization by samples, we can separate differences in total cover from the differences in species composition. RDA assumes that response variables are linearly related to predictors (McCune & Grace 2002).

RESULTS

Taxonomic composition

A total of 37 woody, 30 shrubs, 15 lianas and 62 herbs were identified (Appendix 1). They were under the category of 52 families. Among the identified species, 140 were inside and 14 were outside the plot. Asteraceae, Poaceae, Fabaceae, and Polygonaceae were the dominant family. Asteraceae had the highest species (22 species, 15.83 %), followed by Poaceae (12 species, 8.63%) and Fabaceae. Polygonaceae and Solanaceae had an equal number (6 species, 4.32%)**.**

Classification of plant communities

The hierarchical classification analysis resulted in three plant community types in the study area (Fig.3). Indicator species were named after two or more indicator species (P < 0.001) (Table 1).

*Nuxia congeta-Maesa lanceolata (*C1*)*

Indicator species were *Nuxia congeta* R.Br. ex Fresen, *Maesa lanceolata* Forssk., and *Acacia abyssiniea* Hochst. ex Benth. were significantly varied P < 0.001). This community is in the dry Afromontane forests occur in three forest patches. These woody species were twisted by *Clematis simensis* Fresen., *Rosa abyssinica* Lindely, *Jusminum abyssinicum* Hochst. ex DC., and *Stephania abyssinica* Dillin and A.Rich.) Warp. The ground layer is covered by grasses *Achyrospermum schimperi* (Hochest. ex Briq.) Perkins, *Cyperus fischerianus* A.Rich., *Digitaria abyssinica* (Hochst. ex A.Rich.) Stapf, *Pennisetum clandestinum* Chiov. and Herbs: *Carduus schimperi* Sch. Bip. ex. A. Rich, *Sporobulos pyramidalis* P.Beauv. and *Trifolium multinerve* A.Rich.

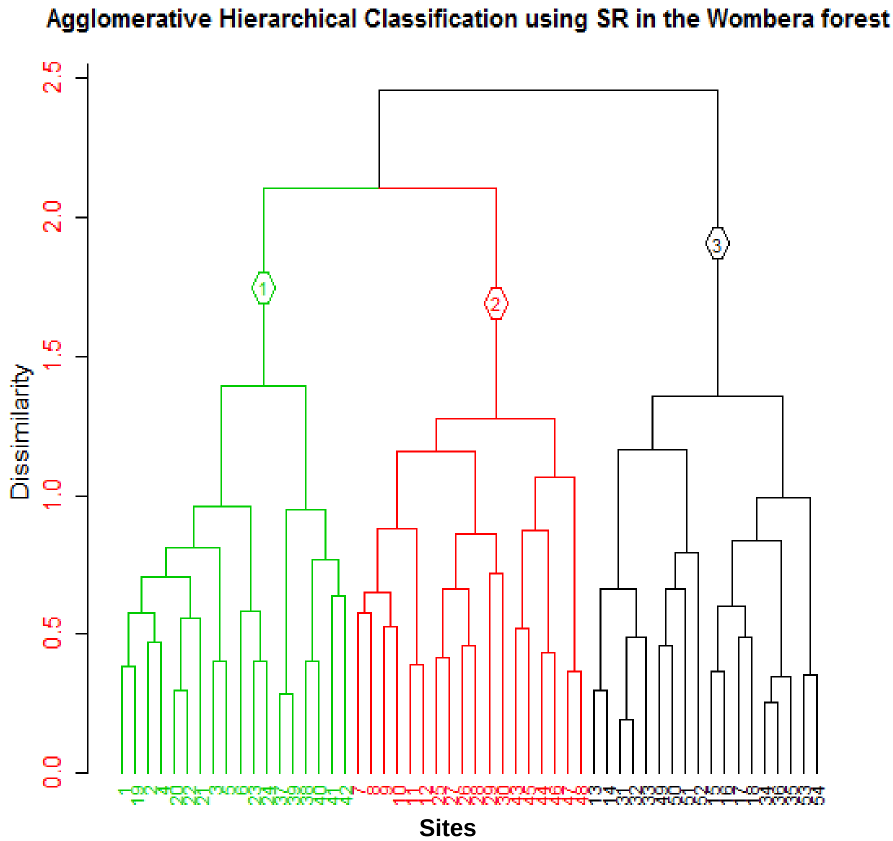

Figure 3. Dendrogram of plant community analysis indicate three communities: *Nuxia congeta* - *Maesa lanceolata* community; *Allophyllus abyssinicus* - *Hagenia abyssinica* and *Dombeya torrida* community; and *Prunus africana* - *Apodyte dimiditata* community.

Table 1. Synoptic and indicator values of species in each community type (C1-C3).

Species	Synoptic value*			Indicator value %**			P Value
	C1	C2	C3	C1	C2	C3	
Nuxia congeta	5.33	0.78	0	76.8	2.6	0	0.001
Maesa lanceolata	5.22	1.11	0	65.3	57	0	0.001
Allophyllus abyssinicus	0.83	5.44	1.67	0	73.7	9.3	0.001
Dombeya torrida	1	4.83	0	5.7	68.5	0	0.001
Hagenia abyssinica	1	3.33	0	5.8	57	0	0.001
Apodytes dimidiata	1.44	1.39	4.83	10.5	70	54.7	0.001
Prunus africana	1	1.44	4.67	5.5	7.9	52.5	0.001
Nuxia congeta	5.33	0.78	0	76.8	2.6	0	0.001

Note: * The mean values of the species cover-abundance in each community.
** The product of the relative frequency and relative cover-abundance values in each Community.

Allophyllus abyssinicus -Hagenia abyssinica *(C2)*

Indicator species are *Allophyllus abyssinicus* (Hochest.) Radlk., *Hagenia abyssinica* (Brace) J.F. Gmel and *Dombeya torrida* (J.F. Gmel.) Bamps. This plant community exists on the same forest patches as community one. It is older than community one and younger than community three. This community is the intermediate between the two communities. Community one is decreasing and, community three was on increasing by species composition. The indicator woody species were *Allophyllus abyssinicus* (Hochest.) Radlk., *Hagenia abyssinica* (Brace) J.F. Gmel and *Dombeya torrida* (J. F. Gmel.) Bamps which significantly varied ($P < 0.001$). These woody species are twisted by *Lagenaria siceraria* (Molina) Standley, *Urera hypselodendron* (A.Rich.) Wedd., *Kalanchoe petitiana* A.Rich. near the river and by *Clematis simensis* Fresen., *Rosa abyssinica* Lindely, *Jusminum abyssinicum* Hochst. ex DC. and *Stephania abyssinica* Dillin and A.Rich.) Warp., far away from the riverbank. In intact forests, the ground layer cover by a few types of grass and herbs, and the disturbed patches are covered with herbs and grasses. Community two was mainly dominated by sapling and lower DBH plants of *Syzygium guineense* (Wild.) DC., *Ficus sur* Forssk., and *Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don.) Cif, and nearer to the river border and *Prunus africana* (Hook. f.) Kalkam and *Apodytes dimidiata* E. Mey. ex Arn., and *Ekebergia capensis* Sparrm.,are away from the riverside.

Apodyte dimiditata- Prunus africana community (C3)

It exists in the same forest patches with community one and community two. Indicator species were *Prunus africana* (Hook. f.) Kalkam and *Apodytes dimidiata* E. Mey. ex Arn. They were significantly varied (P < 0.001). The community was dominated by the most upper canopy tree such as *Syzygium guineense (*Wild.) DC., *Ficus sur* Forssk. and *Olea europaea* L. subsp. *cuspidata* near the river border and *Prunus africana* (Hook. f.) Kalkam and *Apodytes dimidiata* E. Mey. ex Arn., and *Ekebergia capensis* Sparrm. were away from the river bank. In intact climax forest, there were no middle layer, lower layer and ground layer species, however where there are disturbances, the lower layer was dominated by *Maytenus arbutifolia* (A.Rich) Wilezek, and *Teclea nobilis* Del.*;* the shrub layer was covered by *Brucea antidysenterica* J.F. Mill., and sapling of upper and lower canopy trees. In highly disturbed climax forests, the *Schefflera abyssinica* (Hochst. ex A.Rich.) and *Croton macrostachyus* Huchst. ex Del. united upper canopy trees and the ground layer was dominated by: *Solanecio gigas* (Vatke) *C*.Jeffrey, *Echinops ellenbeckii* O.Hoffm., *Solanecio mannii* (Hook.f.) C. Jeffrey, *Solanecio tuberosus* (Sch.Bip.) C. Jeffrey and *Solanum anguivi* Lam., *Echinops giganteus* A.Rich., *Eriosema scioanum* Avett*a*, *Cyathula uncinulata* (Schrad.) Schinz., *Impatiens aethiopica* Grey-Wilson, *Nicandra physaloides* (L.) Gaertn., *Pavonia procumbens* (Wight & Arn.) Walp., *Solanum anguivi* Lam., and *Urtica simensis* Steud.

Species diversity

Species diversity significantly varied along age gradients (pioneer, intermediate and climax) in GTFP (P>0.0000939), SLFP (P>0.000022) and MBFP (P>0.000049). Species diversity also varied significantly along disturbance (intact, moderately disturbed and highly disturbed) in GTFP (P>0.0000109), SLFP (P>0.00000512), and MBFP (P>0.0000710). The interactions of age and disturbance also varied significantly in GTFP (P>0.00000601), SLFP (P>0.0000415) and not significantly varied in MBFP (P>0.0724) (Table 2).

Table 2. Statistical test Diversity along age, disturbance and their interaction.

Factors	GTFP				Pr(>F)	Sig
	Df	**Sum sq**	**Mean sq**	**F value**		
Age	2	2.15715	1.07858	316.712	0.0000939	***
Disturbance	2	0.30271	0.15136	44.444	0.0000109	***
Age:Disturbance	4	0.5809	0.14523	42.644	0.00000601	***
Residuals	18	0.0613	0.00341			
	SLFP					
Age	2	3.2647	1.63233 5	41.459	0.000022	***
Disturbance	2	0.1558	0.0779	25.841	0.00000512	***
Age:Disturbance	4	0.5384	0.13461	44.652	0.0000415	***
Residuals	18	0.0543	0.00301			
	MBFP					
Age	2	2.18915	1.09457	116.8214	0.000049	***
Disturbance	2	0.31886	0.15943	17.0158	0.0000710	***
Age:Disturbance	4	0.09672	0.02418	2.5808	0.07238.	
Residuals	18	0.16865	0.00937			

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
GTFP= Gesengesa-Tumi forest patch, SLFP= Senkora-lopi patch, and MBFP= Menesibu-Babo forest patch.

Species richness

Species richness significantly varied along age gradients (pioneer, intermediate and climax) in GTFP (P>0.0000549), SLFP (P>0.0000022) and MBFP (P>0.000667). Species Richness also varied significantly along disturbance gradients (intact, moderately disturbed and highly disturbed) in GTFP (P>0.0000511), SLFP (P>0.0000383) and MBFP (P>0.00266). The interactions of age and disturbance also varied significantly at GTFP (P>0.00000229), SLFP (P>0.000493) and not significantly varied in MBFP (P>0.2289) (Table 3).

Richness and diversity along age and disturbance gradients

Along with age gradients, species diversity was highest in intermediate forest patches: GTFP, MBFP and SLFP; followed by the pioneer forest patches: GTFP, MBFP and SLFP, and climax forest patches: GTFP, MBFP and SLFP. Along disturbance gradients, Species richness was highest in moderately disturbed intermediate forest patches: MBFP, GTFP, and SLFP followed by the pioneer (GTFP, MBFP and SLFP, and climax GTFP, MBFP and SLFP. Species evenness was highest in pioneer forests, followed by intermediate and climax forests (Table 4).

Table 3. Statistical test of diversity on age, disturbance and their interaction.

Factors	GTFP				Pr(>F)	Sig
	Df	Sum sq	Mean sq	F value		
Age	2	1426.07	713.04	437.546	0.0000549	***
Disturbance	2	215.41	107.7	66.091	0.0000511	***
Age:Disturbance	4	413.93	103.48	63.5	0.0000229	***
Residuals	18	29.33	1.63			
	SLFP					
Age	2	1508.96	754.48	496.854	0.0000022	***
Disturbance	2	154.96	77.48	51.024	0.00000383	***
Age:Disturbance	4	265.48	66.37	43.707	0.000493	***
Residuals	18	27.33	1.52			
	MBFP					
Age	2	1085.63	542.81	148.0404	000667	***
Disturbance	2	146.74	73.37	20.0101	0.00266	***
Age:Disturbance	4	22.81	5.7	1.5556	0.2289	
Residuals	18	66	3.67			

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
GTFP= Gesengesa-Tumi forest patch, SLFP= Senkora-lopi patch, and MBFP= Menesibu-Babo forest patch.

Table 4. Species diversity and richness along age and disturbance gradients.

Forest Patches	Index	Forest age and disturbances gradients								
		Pioneer forest			Intermediate forests			Climax forests		
		PINT	PMDIS	PHDIS	IINT	IMDIS	IHDIS	CINT	CMDIS	CHDIS
GTFP	Richness	32	33	39	55	57	31	18	25	23
	H	3.26	3.31	3.43	3.86	3.88	3.25	2.65	3.11	3.01
	Sh. Evenness	0.95	0.95	0.94	0.96	0.97	0.95	0.91	0.97	0.96
SLFP	Richness	39	43	31	53	53	40	13	24	23
	H	3.49	3.59	3.27	3.79	3.79	3.60	2.38	2.97	2.92
	S. Evenness	0.98	0.953	0.95	0.96	0.95	0.98	0.93	0.94	0.93
MBFP	Richness	50	45	31	52	55	35	23	26	16
	H	3.77	3.647	3.27	3.76	3.85	3.45	3.01	3.14	2.71
	Sh. Evenness	0.96	0.958	0.95	0.95	0.96	0.97	0.96	0.97	0.98

Note: PINT= Pioneer intact, PMDIS= pioneer moderately disturbed, PHDIS= Pioneer highly disturbed, IINT= Intermediate intact, IMDIS= Intermediate moderately disturbed, IHDIS= Intermediate highly disturbed, CINT= Climax intact, CDIS= Climax disturbed and CHDIS= Climax highly disturbed.
GTFP= Gesegesa-Tumi forest patch, SLFP= Senkora-Lopi forest patches, and MBFP= Menesibu-babo forest patch.

Richness along age gradients

The average total plant species abundances decline along age gradients in the tree forest patches: GTFP, SLFP and MBFP(y =31–14x and r^2 = 0.431) (Fig. 4A). The Abundance of Lower canopy trees also declines along age gradients regression (y =16–0.15x, r^2 = 0.431 (Fig. 4B). The Middle canopy trees decrease along age gradients by regression(y= 10–0.085x, r^2=0.473) (Fig. 4C). However, the upper canopy trees increase along age gradients by regression y=2.2+0.21x, r^2=0.882 (Fig. 4D).

RDA for higher altitude

All environmental factors significance test of a backward and forward selection of seven variables indicate that all are significant (P<0.001–0.009) except moisture (P<0.143) (Table 5). Among environmental variables, Age (0.34) had the highest strength followed by Altitude (0.25), Disturbances (0.20), Grazing (0.19), Aspect (0.14), slope (0.11) and moisture (0.09) respectively.

RDA with coloured clusters constrained with species score Eigenvalues using library vegan as shown in figure 5. Community three was constrained highly by age and aspect. However, Community one and community three are constrained by Slope, disturbance, and altitude.

Correlation of environment at higher altitude

In higher altitudes, environmental factors, Disturbance, and Grazing were positively correlated followed by Age and Aspect, and Age and grazing. Age and Disturbance were negatively correlated followed by Moisture and Disturbance, and aspect and Grazing (Table 6).

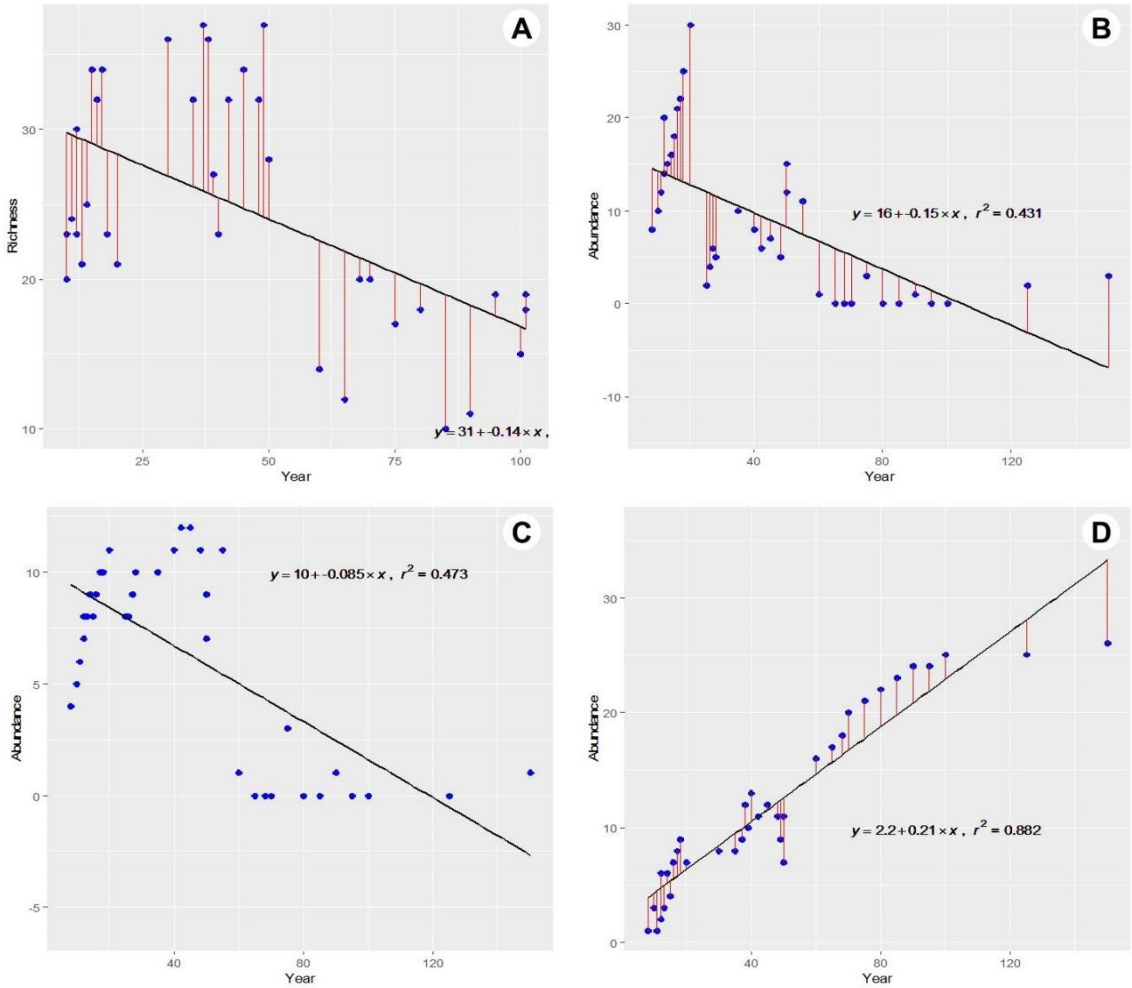

Figure 4. A, Species richness along age gradients; **B**, Lower canopy trees along age gradients; **C**, Abundance of middle canopy trees along age gradients; **D**, Abundance upper canopy trees along age gradients.

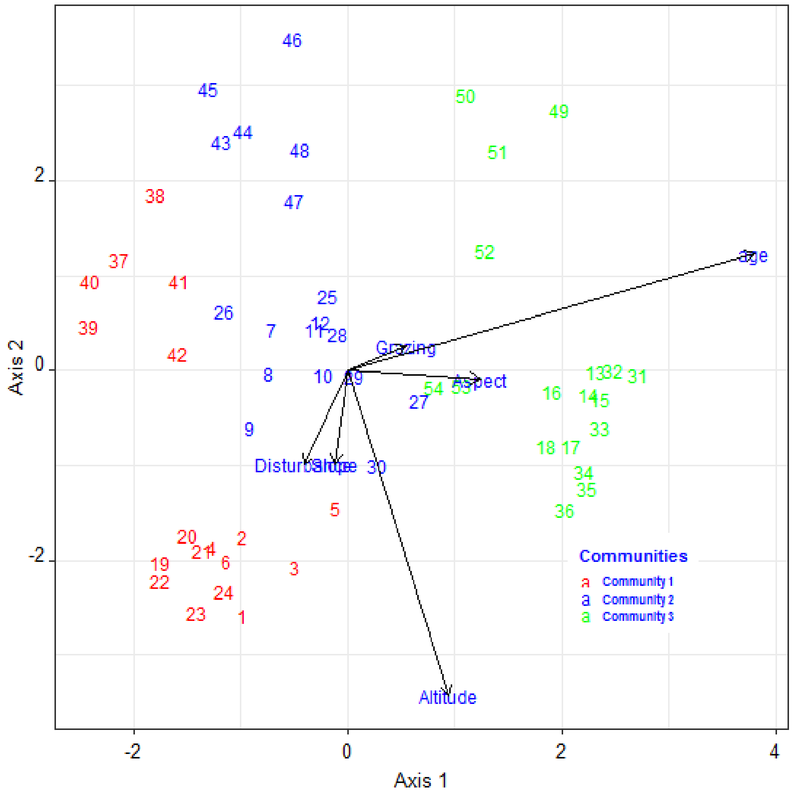

Figure 5. RDA display of sites with environmental and geographic factors.

Table 6. The correlations of environmental variables.

	Slope	Aspect	Grazing	Disturbance	Moisture	Age
Aspect	0.01					
Grazing	-0.15	-0.25				
Disturbance	-0.14	0.037	0.58			
Moisture	0.078	0.12	0.29	-0.31		
Age	-0.057	0.38	0.32	-0.4	-0.13	
Altitude	-0.014	-0.15	-0.04	-0.05	-0.21	0.01

DISCUSSIONS

The total numbers of woody species recorded from the three forest patches GTFP, SLFP, and MBFP are similar to the dry Afromontane, Awi zone forest Forest (Berhanu *et al*. 2017). Wombera district and Awi zone share boundaries. The altitudinal ranges of wombera dry Afromontane forest patches range from 1765–2650 (current study) m.a.s.l, and Awi zone altitudes range from 1830–2660 m.a.s.l; This similarity contributes to vegetation similarity. The highest number of Asteraceae, Poaceae, and Fabaceae species recorded in wombera forest patches was similar to the flora of Ethiopia and Eritrea Volumes records. The result is also similar to other studies (Tadesse 2004, Lulekal *et al* 2008, Yineger *et al*. 2008, Gurmessa *et al*. 2012). According to Gebrehiwot *et al*. (2020) Asteraceae and Poaceae families are the most widely distributed vascular plants standing first and the six in the world. Asteraceae, Fabaceae and others were among the top 10 species-rich families in many Neotropical forests (Gentry 1995). These are also widely distributed families, ranked third and second following Fabaceae, in Ethiopia (Kelbessa & Demissew 2014). Asteraceae inflorescence and the diverse pollination mechanism probably made the family widely distributed (Judd *et al*. 2008). These families are also the top species-rich families distributed worldwide (Stevens 2018).

Most plant communities were determined by altitude, aspect, slope, moisture, and soil type discussed by different authors. However, in the Wombera district, higher altitude forest patches Age or maturity level, and disturbance gradients were also determinates of pant communities. There are different criteria and systems for classifying vegetation or plant communities (Mueller-Dombois & Ellenberg 2002). However, other studies in Ethiopia studied plant communities based on topographic and soil physical and chemical characteristics (Bekele 1994, Yeshitela & Bekele 2002, Assefa *et al*. 2013).

Community one (C1) is grown in pioneer forests mainly dominated by shrubs and lower layer canopy trees: *Nuxia congeta* R.Br. ex Fresen, *Maesa lanceolata* Forssk. and *Acacia abyssiniea* Hochst. ex Benth. These species can invade grasslands, farmlands, bare land, abandon lands and form Pioneer forests. They are fast-growing, light-demanding and seeds only germinate in full sunlight and seedlings not surviving in the shade (Peters 1996). Similarly, many of the enclosures on the degraded hillsides are occupied with pioneer shrubs (Kidane *et al*. 2010). They are well-known soil layer builders for the coming species of middle and upper canopy trees. It is partly in line with the Facilitation idea "when later species can become established and grow after earlier species have suitably modified the environment"(Connell & Slatyer 1977).

Community two (C2) is in the intermediate stage of the three forest patches. It grows on the ecology of community one. In intermediate or transitional forests or community two, middle-layer canopy trees are dominant. It exists on the same forest patches with community one and community three. It is more mature than community one and younger than community three.

Plant species are dependent on their environment and influence one another and modify their environment (Connell & Slatyer 1977). Community three are a successor of plant community two which, are dominated by upper canopy trees: *Prunus africana* (Hook. f.) Kalkam and *Apodytes dimidiata* E. Mey. ex Arn.., *Syzygium guineense* (Wild.) DC., *Ficus sur* Forssk. and *Olea europaea* L. subsp. *cuspidata*, and *Ekebergia capensis* Sparrm. It is similar to the finding of different scholars (Friis 1986, Bekel 1993, Woldu *et al*. 1999, Friis *et al*. 2010) which elaborate upper canopy trees dominate in climax dry Afromontane forests. In intact climax forests, middle layer trees, grasses, herbs, and lower layer canopy trees do not found. It is partly similar to the idea of inhibition (Mueller-Dombois & Ellenberg 1974) *i.e.* “togetherness eliminates the role of tolerance”. However, where disturbances were high, lower layer strata were dominated by *Maytenus arbutifolia* (A.Rich) Wilezek, *Teclea nobilis* Del., *Brucea antidysenterica* J.F. Mill., *Bersama abyssinica* Fresen., and sapling of upper canopy trees.

The similarity of lower canopy trees, middle and upper layer canopy trees in the three forests patches are in line with the Community-unit theory, which states communities are highly structured, repeatable and identifiable associations of species controlled by environmental gradients (Clements 1936). on the other hand, the association and replacement of lower by and middle, and middle by upper layer canopy trees along age gradients: pioneer, intermediate, and climax forests in the three forest patches correspondingly support continuum theory which states that plant communities change gradually along complex environmental gradients, such that no distinct associations of species can be identified (Curtis 1959, Whittaker 1953).

The highest Floristic richness of intermediate, pioneer and climax forest patches respectively is related to soil layer and shades suitability through time. The Transitional forest patches consist of more Herbs, climbers, seedlings and saplings of upper canopy trees. The highest species richness is moderately disturbed intermediate forests of GTFP (57), SLFP (53) and MBFP (55); followed by intermediately disturbed pioneer forests of GTFP (33), SLFP (43), and MBFP (45). The species richness varied significantly along the disturbance gradients (intact, moderately disturbed and highly disturbed) in three forest patches. It is also elaborated (Gebrehiwot *et al*. 2020) Anthropogenic disturbances such as livestock grazing and logging have changed the richness, diversity, distribution pattern, and vegetation structure in an ecosystem.

In moderately disturbed forest patches, the free space formed by disturbances allows the entry of other species. Moderate forest disturbances may give the possibility for less adaptive species to coexist together (Connell & Slatyer 1977). These, in turn, may add to the high evenness and diversity of the community types. Relatively, the climax forest consists of a few understory trees. Following moderately disturbed forest patches, more species exist in intact forest patches of intermediate, pioneer and climax forests. Highly disturbed forest patches were the least in species composition because of over-extraction by humans, the dominance of a few invasive species and overgrazing by animals.

The species diversity of moderately disturbed Intermediate forests was higher than in moderately disturbed pioneer and climax forests. Diversity is generally lower in later successors, disturbances before the late successor can prevent species diversity (Mueller-Dombois & Ellenberg 1974). In moderately disturbed intermediate forest patches, a plant Species diversity (H) ranges from 3.85 to 3.87, followed by moderately disturbed Pioneer (H) ranges from 3.31 to 3.647, and in climax forests (H) ranges from 2.975 to 3.144. Variations in species diversity along age gradients: intermediate, pioneers and climax forest patches is the related maturity level of the forest patches. Frequent disturbances that maintain early-succession conditions reduce diversity, leading to dominance by fast-growing species.

Ordination methods, which use environmental variables in the construction of the ordination, are called constrained ordination or direct ordination since the positions of the samples in the ordination are determined by the environmental variables (Van Tongeren 1995). The species abundance and environmental matrices containing elevation (m.a.s.l), slope (%) and aspect are used for ordinations (Kebede *et al*. 2013). All seven variables had a significant impact on vegetation distribution except moisture ($P<0.143$). Aspect ($P<0.001$), Age ($P<0.001$) and altitude ($P<0.001$) were highly significant. Slope ($P<0.004$), Grazing ($p<0.009$) and Disturbance ($P<0.003$) were moderately significantly varied, and Moisture was not significant. Plant species were constrained by the first RDA axis. Amongst the variables, Age -class or maturity level highly correlated with axis one, thus maturity was the major variable in explaining variations in plant species distribution and patterns of plant community formation in the higher altitude, dry Afromontane forest patches. Because of the highest severity and intensity of anthropogenic impact on the higher altitudes of vegetations, age or maturity becomes the highest determinant of vegetation distribution. Administrative fluctuation and conservation cultures established age gradients.

CONCLUSION

Along vegetation age classes and disturbance gradients, there are differences in plant species composition. Pioneer species encroach on grasslands, abandon lands and wilderness, and prepare the soil for subsequent generations of plants. All plant species are present in the middle phase or middle age of the forest. In the intermediate phase, climax forests are predominating while the pioneer species are declining. The maximum species diversity was found in intermediate, pioneer, and climax forest sections, respectively, along age gradients. The maximum species diversity was found in patches of moderately disturbed forest, followed by intact and highly disturbed forest patches, along disturbance gradients. Compared to middle and higher canopy trees, lower layer trees may survive and rejuvenate in low-nutrient soil. Middle canopy trees were the predominant species in intermediate forests.

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Appendix I: Floristic composition of GTFP, SLFP and MBFP with their habit type (life form), local name and collection code.

Species	**Family**	**Habit**	**Local Name**	**Code**
Acacia abyssiniea Hochst. ex Benth.	Fabaceae	Tree	Doota	GSM91
Acanthus pubescens (Oliv.) Engl.	Acanthaceae	Shrub	Kossoru	GSM67
Achranthes aspera L.	Amaranthaceae	Herb		GSM111
Achyrospermum schimperi (Hochest. ex Briq.) Perkins	Laminaceae	Herb	Kusayee	GSM22
Allophyllus abyssinicus (Hochest.) Radlk.	Sapindaceae	Tree		GSM92
Amaranthus spinosus L.	Amaranthaceae	Herb	Iyassu	GSM23
Ampelocissus bombycina (Bak.) Planch.	Vitaceae	Herb		GSM115
Apodytes dimidiata E. Mey. ex Arn.	Icacinaceae	Tree		GSM93
Arisaema schimperanum Schott	Araceae	Herb	Boqoolo Or	GSM24
Asparagus africanus Lam.	Asparagaceae	Herb	Sariiti	GSM25
Bidens prestinaria (Sch.-Bip.) Cuf.	Asteraceae	Herb	Keloo	GSM26
Bersama abyssinica Fresen.	Melianthaceae	Shrub		GSM116
Bidens biternata (Lour.) Merr.& Sherff	Asteracea	Herb	Qamate Keloo	GSM27
Bidens ghedoensis Mesfin	Asterace	Herb	Keloo	GSM28
Bidens pilosa L.	Asteraceae	Herb	Maxxanne	GSM29
Bothriocline schimperi Oliver & Hiern ex Bentham	Asteraceae	Herb	Tufoo	GSM117
Brucea antidysenterica J.F. Mill.	Simaroubaceae	Shrub	Qomanyo	GSM68
Buddleja polystachya Fresen.	Loganiaceae	Tree		GSM118
Caesalpinia decapetala (Roth) Alston	Fabaceae	Climber	Harangama	GSM10
Canthium oligocarpum Hiern	Rubiaceae	Shrub		GSM119
Carduus schimperi Sch. Bip. ex. A. Rich	Asteraceae	Herb	Qoratti Hare	GSM30
Clematis simensis Fresen.	Ranunculaceae	Climber	Fiiti	GSM01
Croton macrostachyus Huchst. ex Del.	Ephorbiaceae	Tree	Bakkanniisa	GSM120
Cyathula uncinulata (Schrad.) Schinz	Amaranthaceae	Herb	Qamate	GSM31
Cynodon dactylon (L.) Pers.	Poaceae	Herb	Coqorsa	GSM45
Cynoglossum geometricum Baker & Wright	Boraginaceae	Herb	Maxxanee	GSM32
Cyperus digitatus Roxb.	Cyperaceae	Herb	Caffee	GSM46
Cyperus fischerianus A.Rich.	Cyperaceae	Herb	Qunii	GSM17
Cyperus longus L.	Cyperaceae	Herb	Qunni	GSM47
Cyperus richardii Steud.	Cyperaceae	Herb	Qunni	GSM48
Cyphostemma cyphopetalum (Fresen.) Desc. ex Wild & Drummond	Vitaceae	Herb		GSM121
Datura stramonium L.	Solanaceae	Herb	Asaangira	GSM49

Species	Family	Type	Local Name	Code
Digitaria abyssinica (Hochst. ex A.Rich.) Stapf	Poaceae	Herb	Margaa	GSM18
Dombeya torrida (J. F. Gmel.) P. Bamps	Sterculiaceae	Tree	Adanissa	GSM138
Dracaena steudneri Engl.	Dracaenaceae	Tree		GSM95
Ebelia schimperi Vatke	Myrsinaceae	Climber	Anquu	GSM03
Echinops ellenbeckii O.Hoffm.	Asteraceae	Shrub	Sokoruu	GSM86
Echinops giganteus A.Rich.	Asteraceae	Herb	Koshoshila	GSM33
Ekebergia capensis Sparrm.	Meliaceae	Tree		GSM112
Eleusine jaegeri Pilg.	Poaceae	Herb		GSM124
Eragrostis paniciformis (A. Br.) Steud	Poaceae	Herb	Marga	GSM50
Eriosema scioanum Avetta	Fabaceae	Herb		GSM34
Erythrina brucei Schweinf.	Fabaceae	Tree	Welensuu	GSM126
Euphorbia abyssinica Gmel.	Euphorbiaceae	Tree		GSM125
Euphorbia candelabrum Kotschy	Euphorbiaceae	Tree	Adamii	GSM96
Ficus sur Forssk.	Moraceae	Tree		GSM140
Guizotia schimperi Sch. Bip. ex Walp.	Asteraceae	Herb		GSM35
Hagenia abyssinica (Brace) J.F. Gmel	Rosaceae	Tree	Hetoo	GSM97
Heteropogon contortus L.	Poaceae	Herb	Marga	GSM51
Hibiscus flavi folius Ulbar.	Malvaceae	Herb	Hincinni	GSM36
Hibiscus macranthus Hochst.	Malvaceae	Herb	Hincinni	GSM52
Hygrophila auriculata (Schumach.) Heine	Acanthaceae	Herb	Bale	GSM53
Hyparrhenia rufa (Nees) Stapf	Poaceae	Herb	Daggala	GSM54
Impatiens aethiopica Grey-Wilson	Balsaminaceae	Herb	Ansosila	GSM38
Jusminum abyssinicum Hochst. ex DC.	Oleaceae	Climber	Echilbee	GSM04
Justicia schimperiana (Hochst. ex Nees) T.Anders	Acanthaceae	Shrub	Dhumuuga	GSM72
Kalanchoe petitiana A.Rich.	Crassulaceae	Climber	Bosoqee	GSM05
Lagenaria abyssinica (Hook.f.) C. Jeffrey	Cucurbitaceae	Climber	Sexanaa	GSM06
Lagenaria abyssinica (Hook.f.) C. Jeffrey	Cucurbitaceae	Climber		GSM07
Lagenaria siceraria (Molina) Standley	Cucurbitaceae	Climber	Buqqe	GSM12
Laportea alatipes Hook.f.	Uriticaceae	Herb	Dobbii	GSM39
Lippia javanica (Burm.f.) Spreng.	Verbenaceae	Herb		GSM40
Maesa lanceolata Forssk.	Myrsinaceae	Tree	Abayii	GSM129
Maytenus arbutifolia (A.Rich)Wilezek	Celestraceae	Tree	Kombolcha	GSM130
Maytenus undata (Thunb.) Blackelock	Celestraceae	Tree	Kokolfaa	GSM113
Medicago laciniata L.	Fabaceae	Herb	Sidisaa	GSM66
Mikania capensis DC.	Asteraceae	Herb	Hiddaa Reffaa	GSM132
Mikania sagittifera B. Robinson	Asteraceae	Herb		GSM133
Myrica salicifolia A. Rich.	Myricaceae	Tree	Jimmaa	
Myrsine africana L.	Myrsinaceae	Shrub		GSM72
Nicandra physaloides (L.) Gaertn.	Solanaceae	Herb	Hawwixii	GSM41
Nicotiana tabacum L.	Solanaceae	Herb	Tamboo Nyaata	GSM42
Nuxia congeta R.Br. ex Fresen	Loganiaceae	Tree		GSM134
Olea europaea L. subsp. *cuspidata* (Wall. ex G. Don.) Cif	Oleaceae	Tree	Ejerrsa	GSM98
Osyris arborea Wall. ex. Wight	Santalaceae	Tree	Wattoo	GSM99
Osyris quadripartita Decne	Santalaceae	Shrub	Waatoo	GSM90
Panicum monticola Hook.f.	Poaceae	Herb	Marga-Gogorri	GSM55
Pavonia procumbens (Wight & Arn.) Walp.	Malvaceae	Herb	Doobi	GSM56
Pavonia urens Cav.	Malvaceae	Climber	Maxxanne	GSM13
Penisetum schimperi A. Rich.	Poaceae	Herb	Megera	GSM19
Pennisetum clandestinum Chiov.	Poaceae	Herb	Serdoo	GSM20
Pennisetum sphacelatum Th.Dur. and Schinz	Poaceae	Herb	Migira	GSM21
Periploca linearifolia Quart.Dill. & A.Rich.	Asclepiadaceae	Climber	Hidda Dimaa	GSM08
Phoenix reclinata Jacq.	Arecaceae	Tree	Meexxi	GSM100
Phytolacca dodecandra L'Herit.	Phytolaccaceae	Shrub	Andoode	GSM73
Pittosporum viridiflorum Sims	Pittosporaceae	Tree	Solee	GSM111
Plantago lanceolata L.	Plantaginaceae	Herb	Qorxobi	GSM57
Podocarpus falcatus (Thunb.) R.B.ex Mirb.	Podocarpaceae	Tree	Birbirsa	GSM114
Premna schimperi Engl.	Lamiaceae	Tree	Urgeessa	GSM106
Prunus africana (Hook. f.) Kalkam	Rosaceae	Tree	Oomi	GSM107

Species	Family	Type	Local Name	Code
Rhamnus prinoides L' Her.	Rhamnaceae	Tree		GSM101
Rhamnus staddo A. Rich	Rhamnus	Tree	Qaddidaa	GSM102
Rhoicissus tridentata (L.f.) Wild & Drummond	Vitaceae	Shrub	Hidarefa	GBS66
Rhus glutinosa A.rich.	Anacardiaceae	Tree		GSM136
Rhus ruspolii Engl.	Anacardiaceae	Shrub		GSM74
Rhus vulgaris Meikle	Anacardiaceae	Shrub		GSM84
Ricinus communis L.	Euphorbiaceae	Shrub	Qobo	GSM75
Rosa abyssinica Lindely	Rosaceae	Climber	Qaqii	GSM11
Rothmannia urceliiformiis (Hiern.) Robyns	Rubiaceae	Shrub	Bururi	GSM76
Rubia cordifolia L.	Rubiaceae	Herb	Maxxannee	GBS29
Rubus apetalus Poir.	Rosaceae	Shrub	Gora	GSM77
Rubus steudneri Schweinf.	Rosaceae	Shrub	Goraa	GSM88
Rumex abyssinicus Jacq.	Polygonaceae	Herb	Dhangago	GSM58
Rumex abyssinicus Jacq.	Polygonaceae	Herb	Moqmooqii	GBS45
Rumex nepalensis Spreng	Polygonaceae	Herb	Timiji	GSM59
Rumex nervosus Vahl	Polygonaceae	Shrub		GSM87
Rytigynia neglecta (Hiern.) Robyns	Rubiaceae	Shrub	Mixo	GSM85
Salix mucronata Thunb.	Salicaceae	Tree	Alaltuu	GSM103
Salix subserrata Willd.	Salicaceae	Tree	Alaltu	GSM110
Schefflera abyssinica (Hochst. ex A. Rich.) Harms	Araliaceae	Tree	Gatamaa	GSM108
Snowdenia polystachya (Fresen.) Pilg.	Poaceae	Herb	Muuja	GSM60
Solanecio gigas (Vatke) C.Jeffrey	Asteraceae	Shrub	Bosoqa	GSM89
Solanecio mannii (Hook.f.) C. Jeffrey	Asteraceae	Shrub		GSM69
Solanecio tuberosus (Sch.Bip.) C. Jeffrey	Asteraceae	Shrub		GSM70
Solanum anguivi Lam.	Solanaceae	Herb	Hiddi-Sare	GSM61
Solanum incanum L.	Solanaceae	Shrub		GSM71
Solanum marginatum L.f.	Solanaceae	Shrub	Hiddi-Warabessa	GSM78
Sonchus asper L.	Asteraceae	Herb	Qoraattii Haree	GSM43
Sonchus bipontini Asch.	Asteraceae	Herb		GSM44
Spermacoce sphaerostigma (A.Rich.) Vatke	Rubiaceae	Herb		GSM65
Sporobulos pyramidalis P.Beauv.	Poaceae	Herb	Muri	GSM62
Stephania abyssinica Dillin & A.Rich.) Warp.	Menispermaceae	Climber	Kalalaa	GSM14
Syzygium guineense (Wild.) DC.	Myrtaceae	Tree	Badessa	GSM139
Teclea nobilis Del.	Rutaceae	Tree	Hadheesa	GSM105
Toddalia asiatica (L.) Lam.	Rutaceae	Climber	Harangaamaa	GSM09
Trifolium burchellianum Ser.	Fabaceae	Herb		GSM137
Trifolium multinerve A.Rich.	Fabaceae	Herb	Siddisa	GSM63
Urera hypselodendron (A.Rich.) Wedd.	Urticaceae	Climber	Lanqessa	GSM15
Urera hypselodendron (A.Rich.)Wedd.	Urticaceae	Climber	Lanqessaa	GBS53
Urtica simensis Steud.	Urticaceae	Herb	Gurgubbe	GSM64
Usnea africana Motyka	Lichen	Herb	Harrii Mukaa	GSM16
Vernonia adoensis Sch. Bip. ex Walp.	Asteraceae	Shrub	Sooyyama	GSM79
Vernonia amygdalina Del.	Asteraceae	Shrub	Eebicha	GSM80
Vernonia auriculifera Hiern.	Asteraceae	Shrub	Reeji	GSM81
Vernonia brachycalyx O.Hoffm.	Asteraceae	Shrub	Sooyyama	GSM82
Vernonia filigera Oliv.& Hiern.	Asteraceae	Shrub	Sooyyama	GSM02
Vernonia ruppellii Sch. Bip. ex Walp.	Asteraceae	Shrub	Sooyyama	GSM83
Warburgia ugandensis Sprague	Canellaceae	Tree	Biifti	GSM109