ORIGINAL ARTICLE

An analysis of vegetation structure of the moist evergreen Afromontane forests of Ethiopia

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ABSTRACT

This study presents an analysis of vegetation structure of moist evergreen Afromontane forests of Ethiopia, namely Berhane-Kontir, Bonga, Harenna, Maji, and Yayu. A quadrats of 20 x 20 m were laid down along transects to collect vegetation data. Importance Value Index, vegetation profiles and species population structures were used to analyze the forest structure. The moist evergreen Afromontane forests of Ethiopia support a high density of woody plants, which, however, differs between sites. The highest density of woody plants was recorded in Yayu (69,130 individuals/ha) and the lowest in Harenna (9,309 individuals/ha). Analysis of the diameter class distribution of some tree species, have exhibited abnormal population distribution that might be related to the removal of some classes of trees either by natural or human-related factors. In the studied forests, the basal area per ha ranged from 46 to 54 m^2 in the order of Berhane-Kontir > Maji > Harenna > Bonga > Yayu. In all forests, few species dominate the forest structure. Coffee is the only species with the highest relative frequency of occurrence in all forests. The vertical structures of the studied forests are generally similar, i.e., 2-3 strata: emergent/upper stratum (> 30 m tall), middle tree stratum (15-30 m tall) and small trees and shrubs layer (2-15 m tall). The forest of Berhane-Kontir had the highest species richness based on growth form compared to the other forests. The studied Afromontane rainforests revealed similar vegetation structures which could be attributed to similar historical events. Apparently, similar forest management schemes (e.g., thinning, harvesting level, etc.) can be employed in all forests.

Key words: Basal area, density, growth form, profile diagram, size class distribution, stratification,

INTRODUCTION

The vertical and spatial organization of species in a community is the outcome of the processes of recruitment, growth and competition in a physical landscape (Kohyama, 1992; Larsen and Bliss, 1998). For example, the structure of canopy heights plays a very important role in shaping different microenvironments that ultimately determine the conditions that limit underneath plant growth (Richards, 1952; Webb *et al*., 1976; Barkman, 1979; Bekele, 1994). These microenvironments strongly influence the competitive outcomes of different species living in the understory floor (Barkman, 1979; Kent and Coker, 1992). This leads to an understanding of how interactions among individuals, and between individuals and their environment shape the distribution, abundance, and diversity of organisms in a community.

An attempt to describe the vegetation structure and the associated underlying phenomena has been made by many authors (e.g., Richards, 1952; Webb *et al*., 1976; Barkman, 1979). According to Larsen and Bliss (1998) plant community structure can be characterized by composition, size, age, and spatial distribution, density of individuals and the history of disturbances that influence the population. Although a lot has been done in this regards, there are still disagreement among vegetation ecologists as to how to describe vegetation structure. Thus, more work is required in the area of vegetation structure analysis.

Studying the vegetation structure of moist evergreen Afromontane forests has therefore paramount importance for understanding the basic processes and to design appropriate forest management plans. Apparently, standardized approaches are required to characterize plant community structures in order to delineate guidelines for their management and conservation, and to assess their potential for maintenance of plant species diversity.

In the present study, the vegetation structure of five moist evergreen Afromontane forests was characterized using size-class distribution, density, basal area and stratification. Most plant communities consist of a large number of species and hence it is not possible to include all species in a survey. Woody plants only are therefore used for the present structural analysis. The objectives of the study were to assess the community structure of the woody vegetation, i.e., mainly vertical structure and size-class distribution, and to compare the similarities and/or dissimilarities of the different forests in terms of vegetation structure.

MATERIAL AND METHODS

Study sites

This study was carried out in five moist evergreen Afromontane forests (Figure 1), namely (1) Bonga (7^0 13′ N & 36^0 17′E), (2) Berhan-Kontir (7^0 N & 35^0 E), (3) Maji (6^0 N & 36^0 E) and (4) Harenna Forest (6^0 N & 39^0 E). For a comparison, Woldemariam (2003) dataset was used for Yayu (8^0 05′ N & 35^0 06′E). All forests are categorized as a moist evergreen Afromontane forest, according to Friis et al. (2010) vegetation classification.

The study sites are located within the altitudinal ranges between 950 and 2200 m a.s.l. There is a large variability over the study areas in total amount as well as time of arrival of rainfall with the mean annual rainfall ranges from 1200 mm to relatively over 2200 mm (NMSA, 1996). Temperatures generally vary little over the year and mainly controlled by elevation and cloud conditions; although maximum and minimum temperatures can be, vary somewhat with geographical location (Eklundh, 1996). According to FAO/UNESCO (1974) soil classification, the major dominant soil association in the moist evergreen Afromontane forest region is Dystric Nitosols. Additionally, Acrisols, Regosols, Vertisols, Fluvisols, and Cambisols are occasionally observed in the area. The majority of the soils in the study area are acidic having pH values below 6 and show significant lack of phosphorous. A detailed analysis of the soil of study area can be found in Murphy (1968).

Figure 1: Map of Ethiopia showing the location of study area

The study sites are distinguished for their high population flux because of their high production potential and of their conducive environment for living. Not only small-scale farmers are putting immense pressure but also a big commercial coffee and tea plantation projects are expanding in the area (Senbeta et al., 2013).

Dataset and analysis

The study was carried out between May 2003 and June 2010. Vegetation survey was carried out using 20 m x 20 m quadrat that laid down along transects; and the transects were spaced one kilometer apart. All data for Yayu forest is taken from Woldemariam (2003). Totally, 147 plots were distributed in relatively undisturbed part of the forest for the present analysis (Harenna, n = 24; Berhan-Kontir, n = 37; Yayu, n = 48; Maji, n = 10 and Bonga, n = 28).

Frequency and abundance of all woody plant species were recorded on a plot basis. The Importance Value (I.V.) index of Cottam and Curtis (1956) was used to describe and compare the species dominance of the forests. I.V. of a species is defined as the sum of its relative dominance (Rdom), its relative density (Rden), and its relative frequency (Rf). Relative dominance is the total basal area of a species/total basal area of all species ×100; relative density is the number of individuals of a species/total number of individuals' ×100, and the relative frequency is the frequency of species/sum frequencies of all species ×100. Vegetation profiles were drawn from transects of 61 m x 7.6 m following Richards (1952). All woody plants $\geq$ 2 m height and $\geq$ 2 cm diameter at breast height (dbh) were included in the drawing. The relative positions of the individual plants within the strip, their diameter, height, and crown shape were estimated visually. In total, six profiles were considered for the stratification analysis: Berhane-Kontir (2), Bonga (1), Harenna (2) and Maji (1).

Nomenclature followed the publications of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Hedberg and Edwards, 1995; Edwards et al., 1995; Edwards et al., 1997; Edwards et al., 2000; Hedberg et al., 2003).

RESULTS

Size class distribution

In all forests, a considerable number of individuals were found in the lower diameter classes (Figure 2). For example, 69% of the individuals in the Bonga forest and 46% in the Yayu forest were found in the dbh class between 2 and 5 cm. The number of individuals within the largest diameter class (> 47 cm) ranged between 1% (Bonga) to 3% (Yayu). The biggest diameter was recorded in the Harenna forest, i.e., 200 cm for *Podocarpus falcatus* (Harenna), followed by 187 cm for *Schefflera abyssinica* (Bonga), 150 cm for *Pouteria altissima* (Berhane-Kontir) and 143 cm for *Manilkara butugi* (Maji).

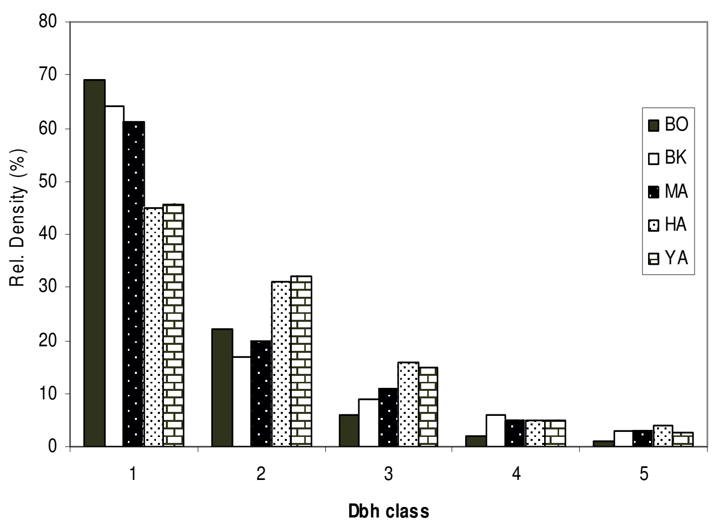

Figure 2: Diameter class frequency distribution of all woody plants within the studied forests of Ethiopia (Diameter at breast height (dbh) Class: 1 = 2-5 cm; 2 = 5- 11 cm; 3 = 11-23 cm; 4 = 23- 47 cm and 5 = > 47 cm; (*Abbreviation- BO: - Bonga; BK:- Berhane-Kontir; HA:-Harenna; MA:-Maji; YA:-Yayu)).

The evaluation of some the selected tree species reveals six main patterns of population distribution (Figure 3). These include 1) inverted J-shaped, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes e.g., *Blighia unijugata*, 2) broken inverted J-shaped, e.g., *Podocarpus falcatus*, 3) J-shaped, which shows a type of frequency distribution in which there is a low number of individuals in the lower diameter classes but increases towards the higher classes, e.g., *Syzygium guineense*, 4) broken J-shaped, e.g., *Pouteria altissima*), 5) U-shape, which shows a type of frequency distribution in which there is a high number of lowest and highest diameter classes but a very low number in the intermediate classes, e.g., *Olea welwitschii*, and 6) bell-shaped, which is a type of frequency distribution in which number of individuals in the middle diameter classes is high and lower in lower and higher diameter classes, e.g., *Celtis zenkeri*.

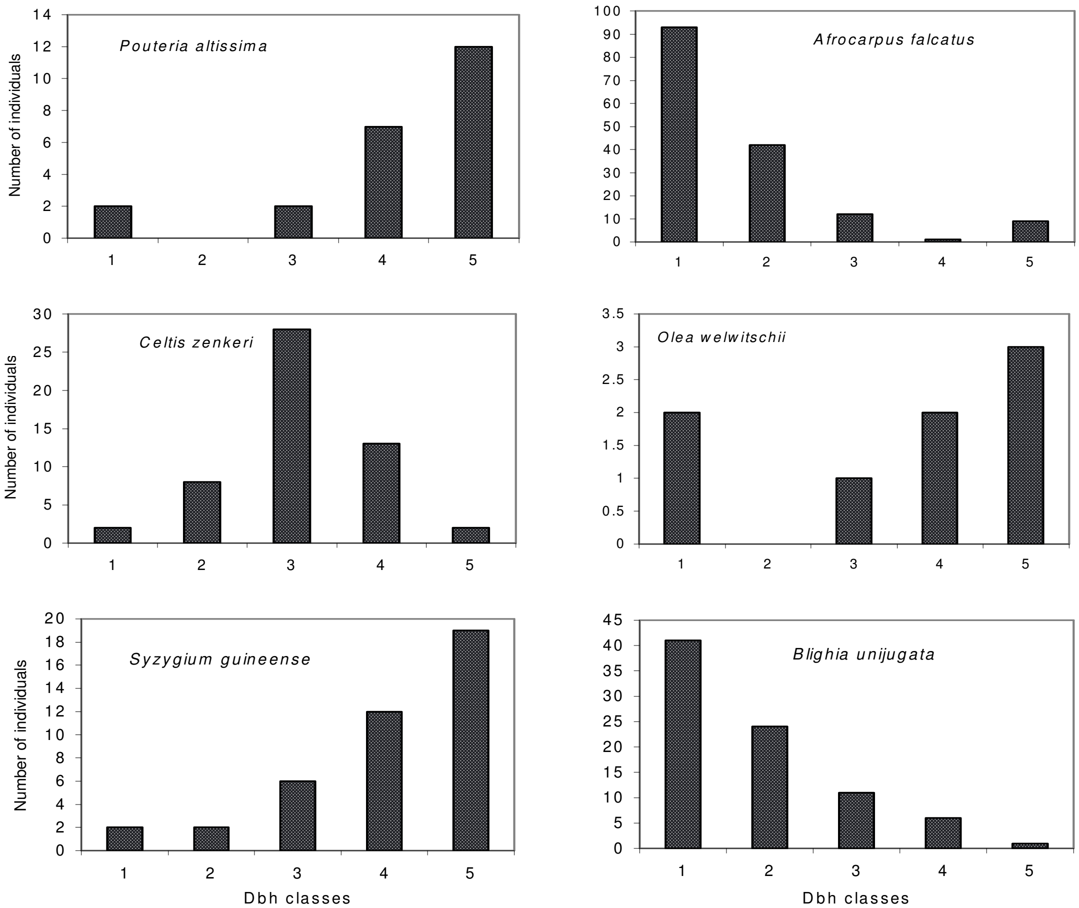

Figure 3: Diameter class frequency distribution of selected tree species in the studied Afromontane forests of Ethiopia (Dbh class: 1 = 2-5 cm; 2 = 5- 11 cm; 3 = 11-23 cm; 4 = 23- 47 cm and 5 = > 47 cm).

The patterns of height class distribution of the woody species reveals a high proportion of individuals in the lowest height class and few individuals in the largest height class (Figure 4). In Maji, for example, about 90% of individuals are represented in the height class of 0.5 to 5 m and only <1% reaches a height of more than 30 m. It is only in the Harenna forest that the higher height class, i.e., > 30 m, is relatively well represented (6%).

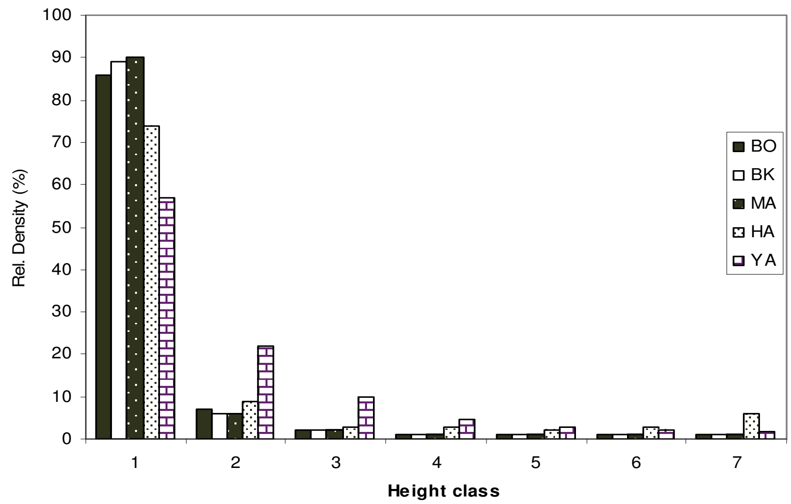

Figure 4: Height class frequency distribution of the woody plants in the studied Afromontane rainforests of Ethiopia. Class 1 =0.5-5 m; 2 = 5-10 m; 3 = 10-15 m; 4 = 15-20 m; 5 = 20-25 m; 6 = 25-30 m; 7 = > 30 m

Abundance and basal area

The total basal area per hectare and density of woody plants for each forest is shown in Table 1. The basal area ranged from 46 to 54 m^2 in the order of Berhane-Kontir > Maji > Harenna > Bonga > Yayu. The highest density of woody plants was recorded in Yayu (69130 individuals/ha) and the lowest in Harenna (9309 individuals/ha).

Table 1: Density and basal area of woody plants in the studied Afromontane forests of Ethiopia(*Abbreviation- BO: - Bonga; BK:- Berhane-Kontir; HA:-Harenna; MA:-Maji; YA:-Yayu).

Characteristics	BO	BK	HA	MA	YA
Total plots	28	37	24	10	48
Total density/site	21540	24296	8937	7273	132729
Min density/plot	169	303	89	432	955
Max density/plot	1459	1756	1980	1209	7684
Median of density/plot	777	570	178	665	2642
Density/ha	19232	18981	9309	18183	69130
Basal area (m^2/ha)	47	54	49	53	46

In each forest, the 10 most dominant species, i.e., species with the highest Importance Value are listed in Table 2. Coffee was the only dominant species occurring throughout all forests, and next to coffee four species, namely *Landolphia buchananii, Syzygium guineense, Dracaena fragrans* and *Diospyros abyssinica* are represented in the dominant list of at least two forests. The Maji and Harenna forests are dominated by a few species, whereas the other forests have a relatively comparable abundance of many species. Small-tree or shrub growth forms usually dominate the forests, although a few tall tree species such as *Olea welwitschii, Trilepisium madagascariense, Pouteria altissima,* and *Podocarpus falcatus* were observed in the dominance category of some forests. The tallest trees contribute the biggest share to the total relative dominance. Coffee is the only species with the highest relative frequency of occurrence in each forest.

Table 2: Importance Value (IV) of the 10 most common species in each Afromontane forest of Ethiopia. (Species are ranked in order of decreasing importance value (Rf-relative frequency; Rden- relative density; Rdom-relative dominance; T-tall trees; Tm-medium trees; Ts-small trees; S-shrubs and L- lianas)

Region	Species	Rf (%)	Rden (%)	Rdom (%)	IV (%)	Growth forms
Bonga	*Schefflera abyssinica* (Hochst. ex A. Rich.)Harms	1.20	0.09	29.79	31.08	Ts
	Olea welwitschii (Knobl.) Gilg & Schellenb.	1.88	0.34	22.96	25.19	S
	Coffea arabica L.	2.23	20.97	0.46	23.65	S
	Chionanthus mildbraedii (Gilg & Schellenb) Stearn	2.31	10.46	5.85	18.63	L
	Syzygium guineense (Willd.)DC	2.14	0.71	8.70	11.55	T
	Justicia schimperiana (Hochst. ex A.Rich.) T. Anders	1.03	9.82	0.02	10.87	Ts
	Galiniera saxifraga (Hochst.) Bridson	2.14	5.03	0.90	8.07	Tm
	Psychotria orophila Petit	2.40	5.50	0.10	8.00	L
	Vepris dainellii (Pichi-Serm.) Kokwaro	2.14	3.67	1.92	7.73	S
	Elaeodendron buchananii (Loes)Loes.	2.05	1.18	3.73	6.96	Ts
	Total other species (108)	80.48	42.22	25.57		
	Total	100	100	100		
Berhane -Kontir	*Argomuellera macrophylla* Pax.	2.68	31.04	0.57	34.29	S
	Coffea arabica L.	2.76	20.62	0.81	24.19	Ts
	Diospyros abyssinica (Hiern) F. White	1.70	0.30	19.02	21.03	Tm
	Whitfieldia elongata (Beauv.) De Wild. & T. Dur	2.92	4.23	6.24	13.39	S
	Rothmannia urcelliformis (Hiern) Robyns	1.38	0.12	10.58	12.08	Ts
	Blighia unijugata Bak.	1.70	0.89	9.33	11.92	Tm
	Pouteria altissima (A.Chev.) Baehni	2.51	5.6	0.12	8.24	T
	Dracaena fragrans (L.) Ker-Gawl	1.54	6.46	0.10	8.10	S
	Eugenia bukobensis Engl.	0.49	0.05	7.16	7.70	Ts
	Strychnos mitis S. Moore	2.11	5.16	0.1	7.36	Tm
	Total other species (179)	80.21	25.53	45.97		
	Total	100	100	100		
Harenna	*Coffea arabica* L.	2.31	49.06	1.45	52.82	Ts
	Podocarpus falcatus(Thunb) C.N.	2.99	6.63	18.67	28.29	T
	Landolphia buchananii (Hall.f.) Stapf	2.99	2.75	0.38	6.13	L
	Celtis africana Burm.f.	2.72	1.54	4.97	9.23	Tm
	Jasminum abyssinicum Hochst. ex Dc	2.86	1.72	0.04	4.62	L
	Oxyanthus speciosus (K. Schum) Bridson	2.72	1.54	0.96	5.22	Ts
	Bersama abyssinica Fresen	2.72	0.88	0.09	3.69	Ts
	Syzygium guineense (Willd.)DC	2.18	0.45	15.14	17.77	Tm
	Lepidotrichilia volkensii Nees ex Steud.	2.59	2.69	0.35	5.63	Ts
	Cassipourea malosana (Baker) Alston	2.59	1.33	0.94	4.85	Tm
	Total other species (127)	73.33	31.42	57.00		
	Total	100	100	100		
Maji	*Coffea arabica* L.	3.74	70.30	3.99	78.02	Ts
	Trilepisium madagascariense DC.	2.59	2.30	29.82	34.71	T
	Celtis africana Burm.f.	3.16	0.50	12.97	16.64	Tm
	Dracaena fragrans (L.) Ker-Gawl	2.87	10.50	0.00	13.37	Ts
	Manilkara butugi Chiov.	1.72	0.15	9.13	11.00	Tm
	Trichilia dregeana Sond.	2.87	0.25	6.49	9.62	Tm
	Millettia ferruginea (Hochst.) Bak.	2.59	0.63	6.06	9.28	S
	Pouteria altissima (A.Chev.) Baehni	2.30	0.14	6.21	8.65	Tm
	Vepris dainellii (Pichi-Serm.) Kokwaro	3.45	2.07	1.39	6.91	Ts
	Trichilia prieuriana A. Juss.	3.16	0.33	3.11	6.60	Tm

	Total other species (86)	71.55	12.85	20.82		
	Total	100	100	100		
Yayu	*Dracaena fragrans* (L.) Ker-Gawl	3.28	17.49	-	20.76	S
	Coffea arabica L.	3.00	15.99	-	18.99	Ts
	Landolphia buchananii (Hall.f.) Stapf	3.28	7.30	-	10.58	L
	Diospyros abyssinica (Hiern) F. White	3.28	4.88	-	8.15	Tm
	Albizia grandibracteata Taub.	3.21	2.77	-	5.98	Tm
	Canthium oligocarpum Hiern	3.00	2.06	-	5.06	Ts
	Rhus ruspoli Engl.	3.00	1.78	-	4.78	S
	Paullinia pinnata L.	2.86	5.84	-	8.70	L
	Maytenus gracilipes (Welw. Ex Oliv.) Exell	2.79	2.89	-	5.68	S
	Trichilia dregeana Sond.	2.72	0.92	-	3.64	Tm
	Total other species (84)	69.58	38.08	-		
	Total	100	100	-		

Stratification

The vertical structures of the Bonga, Berhane-Kontir, Harenna, Maji, and Yayu forests are generally similar, i.e., 2-3 strata: emergent/upper stratum (> 30 m tall), middle tree stratum (15-30 m tall) and small trees and shrubs layer (2-15 m tall). A few trees of the upper stratum, which are not in lateral contact, are raised well above the middle tree stratum and have a large number of branches. The middle tree stratum is often narrow and may be either discontinuous or continuous. The lower tree stratum usually forms a dense canopy. The herb layer is usually sparse and consists of forest grasses and ferns. Lianas and strangling epiphytes are abundant.

The profile diagram of the Bonga forest reflects the upper canopy of an *Olea welwitschii* stand at 1970 m a.s.l. (Figure 5). Except for a few 30-40 m emergent trees (mostly *Olea welwitschii*, sometimes *Pouteria adolfi-feridericii*), the height of the canopy varies between 15 and 20 m. The most characteristic species of the middle stratum include *Elaeodendron buchananii, Polyscias fulva, Millettia ferruginea,* and *Syzygium guineense.* The understory layer consists of small trees and shrubs with dense crowns between 2 and 15 m, with mainly *Coffea arabica*, *Dracaena afromontana, Chionanthus mildbraedii, Psychotria orophila* and *Galineria saxifraga*. The herb layer is patchy and the patches are variable in size and density.

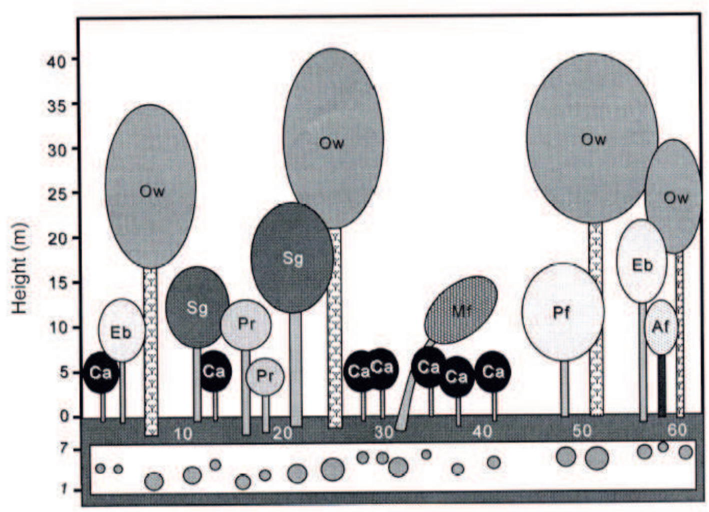

Figure 5: Profile diagram of an *Olea welwitschii* stand (61 m x 7.6 m) in the Bonga forest at 1970 m a.s.l. Ca = *Coffea arabica*; Eb = *Elaeodendron buchananii*; Ow = *Olea welwitschii*; Da = *Dracaena afromontana*; Pr = *Phoenix reclinata*; Mf = *Millettia ferruginea*; Pf = *Polyscias fulva*; AF = *Podocarpus falcatus*; Sg = *Syzygium guineenese*

The profile diagram of the Berhane-Kontir forest (Figure 6a,b) shows the upper canopy stands of *Pouteria* and *Manilkara butugi* at 1100 m and 1750 a.s.l., respectively, which comprises various species i.e., *Pouteria altissima*, *Milicia excelsa*, *Antiaris toxicaria*, *Olea welwitschii* and *Manilkara butugi* depending on the altitude. The middle stratum is relatively dense as compared to the emergent layers, and is composed of species like *Celtis spp.*, *Morus Mesozygia*, *Baphia abyssinica, Blighia unijugata, Diospyros abyssinica* and others. The shrub and small tree layer is occupied by *Argomuellera macrophylla, Rungia grandis, Whitfieldia elongata, Dracaena fragrans, Alchornea laxiflora* and *Coffea arabica.* Tree seedlings and herbaceous layers are generally sparse.

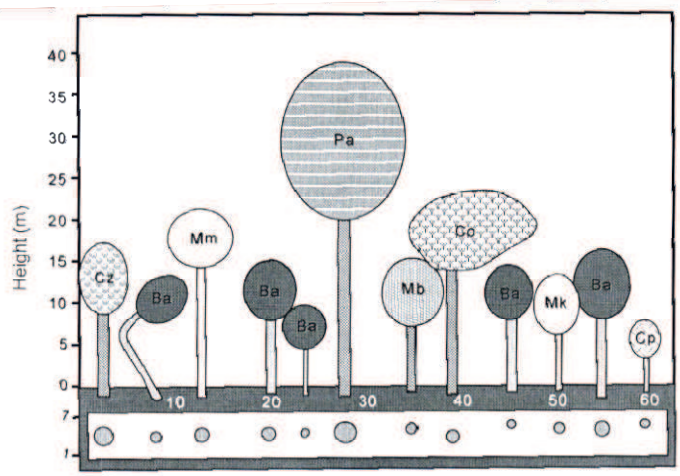

Figure 6a: Profile diagram of a *Pouteria altissima* stand (61 m x 7.6 m) in the Berhane-Kontir forest at 1100 m a.s.l. Ba = *Baphia abyssinica*; Co = *Cordia africana*; Cp = *Celtis philippensis*; Cz = *Celtis zenkeri*; Mb = *Manilkara butugi*; Mm = *Morus Mesozygia*; Pa = *Pouteria altissima*

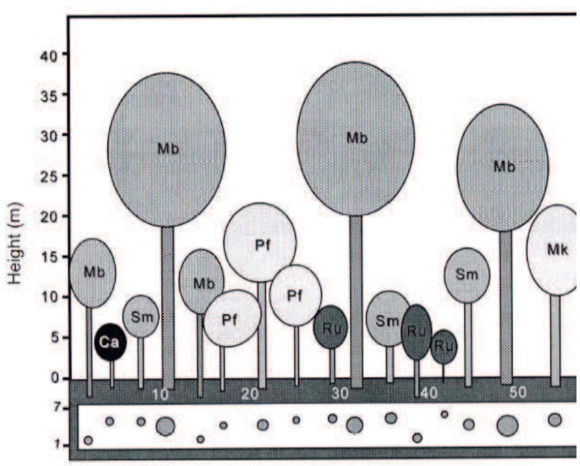

Figure 6b: Profile diagram of a *Manilkara butugi* stand (61 m x 7.6 m) in the Berhane-Kontir forest at 1750 m a.s.l. Mb = *Manilkara butugi*; Mk = *Mimusops kummel*; Pf = *Polyscias fulva*; Ru = *Rothmannia urcelliformis*; Sm = *Strychnos mitis* Ca = *Coffea arabica*

Figure 7a and b show the profile diagrams of the *Podocarpus* stands in the Harenna forest at 1670 and 1470 m a.s.l., respectively. Both profiles show the dominance of *Podocarpus* in the upper canopy and mixed species in the lower canopy. The middle stratum of this forest mainly dominated by *Ehretia cymosa*, *Diospyros abyssinica*, *Cassipourea malosana*, *Chionanthus mildbraedii*, *Alangium chinense*, *Strychnos mitis*, *Celtis africana* and *Ocotea kenyensis.* The shrub and small tree layer is sparse and composed of *Coffea arabica, Acanthus eminens, Suregada procera, Lepidotrichilia volkensii* and *Phyllanthus sepialis.* Very few tree seedlings and herbaceous were observed.

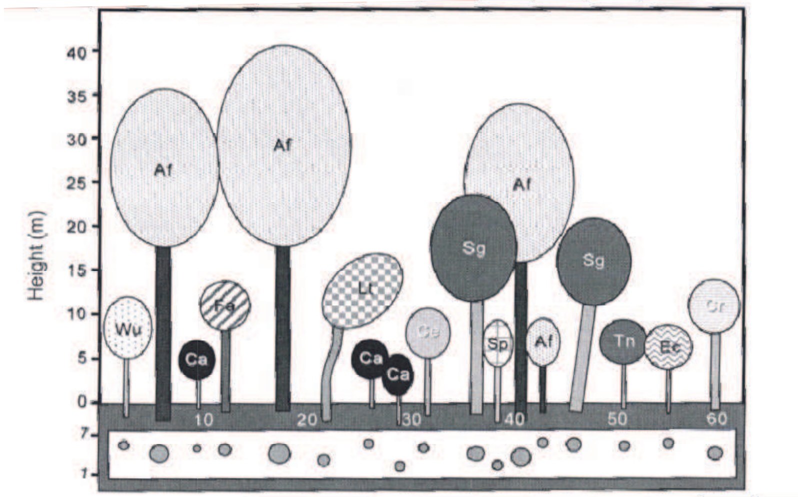

Figure 7a: Profile diagram of a *Podocarpus falcatus* stand (61 m x 7.6 m) in the Harenna forest at 1670 m a.s.l. Af = *Podocarpus falcatus*; Ca =*Coffea arabica*; Ce = *Celtis africana*; Cr = *Croton macrostachyus*; Ec = *Ehretia cymosa*; Fa = *Fagaropsis angolensis*; Lt = *Lepidotrichilia volkensii*; Sg = *Syzygium guineenese*; Sp = *Suregada procera*; Tn = *Teclea nobilis*; Wu = *Warburgia ugandensis*

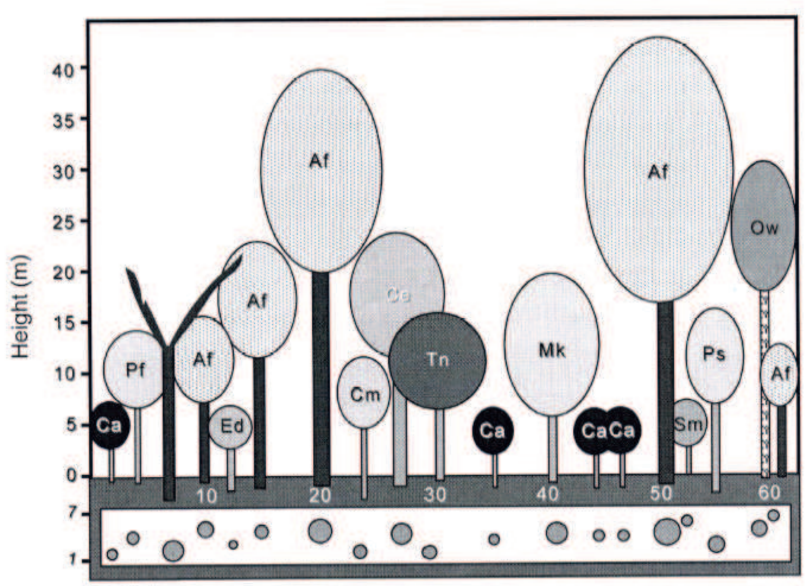

Figure 7b: Profile diagram of a *Podocarpus falcatus* stand (61 m x 7.6 m) in the Harenna forest at 1470 m a.s. l. Af = *Podocarpus falcatus*; Ca = *Coffea arabica*; Ce = *Celtis africana*; Cm = *Cassipourea malosana*; Fd = *Filicium decipiens*; Mk = *Mimusops kummel*; Ow = *Olea welwitschii*; Ps = *Psydrax schimperiana*; Tn = *Teclea nobilis*; Sm = *Strychnos mitis*

The profile diagram of the *Trilepisium* stand in the Kassi-Bero (= Maji) forest is shown in Figure 8. The upper canopy layer is occupied by the discontinuous tree species *Trilepisium madagascariense*. Because of over harvesting of emergent species, the understorey trees (e.g., *Diospyros abyssinica, Millettia ferruginea, Celtis africana,* and *Mimusops kummel*) sometimes form the main canopy. The shrub and small tree layers are dominated by *Tricholcladus ellipticus, Clausena anisata, Argomuellera macrophylla, Maytenus gracilipes* and *Dracaena fragrans*. The ground layer is discontinuous and forming patchy at different sites in the forest.

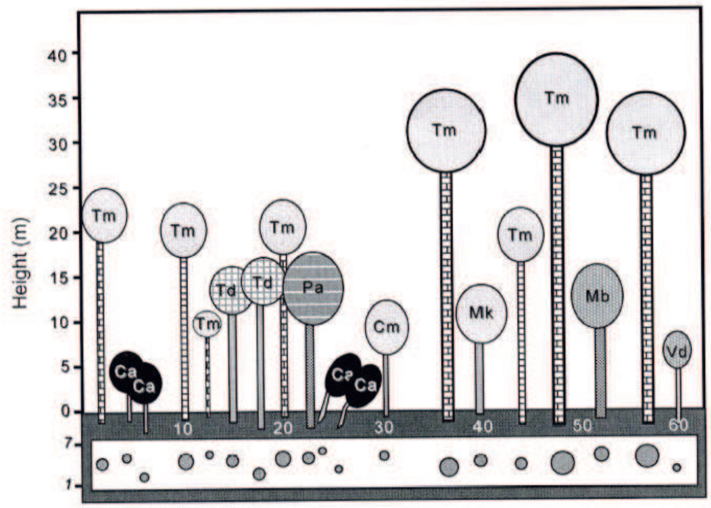

Figure 8: Profile diagram of a *Trilepisium* stand (61 m x 7.6 m) in the Kassi-Bero forest (Maji) at 1610 m a.s.l. Td = *Trichilia dregeana*; Tm=*Trilepisium madagascariense*; Ca = *Coffea arabica*; Cm = *Cassipourea malosan*a; Pa = *Pouteria altissima*; Vd = *Vepris dainelii*; Mb = *Manilkara butugi*; Mk = *Mimusops kummel*

Growth forms

A total of 651 vascular plant species was recorded from all forests. All species are categorized into five major growth forms (Table 3). This classification is based on information from the fieldwork and from the Flora of Ethiopia and Eritrea. The growth forms classification adapted for the present analysis is very simple and general as compared to other classifications (e.g., Raunkiaer, 1934; Hedberg, 1964). Analysis of the growth form data shows that herbs accounted for almost 35% of the total number of species followed by trees and climbers. Altogether, trees, climbers, and shrubs accounted for about 56% of the total species richness, while the epiphytes, which are a very prominent growth form, actually accounted for around 9% of the total species richness. Except for shrubs, all growth forms are common in the Berhane-Kontir forest but not so in the Maji forest.

Table 3: Species diversity according to growth forms in the studied Afromontane forests of Ethiopia (Abbreviation as Table 1).

	Total species		No. of species/ Site				
Growth forms*	No.	%	BO	BK	HA	MA	YA
Trees	139	22	69	106	83	56	76
Shrubs	85	13	33	35	44	23	29
Climbers	136	21	58	88	52	33	35
Herbs	231	35	88	96	81	23	60
Epiphytes	60	9	37	49	27	11	5

DISCUSSION

In most forests, the overall pattern of population structure was an inverted J-shaped type. This pattern is an indicator of healthy regeneration of the forest and species, and shows a good reproduction and recruitment capacity of the forest. On the contrary, some tree species reveal different distribution patterns of their diameter class (Figure 2). The J-shaped patterns show poor reproduction and hampered regeneration of the species/forest due to either most trees is not producing seeds due to age or there have been losses due to predators after reproduction (e.g., *Syzygium guineense*). In addition, *Syzygium* fruits are usually used as food by many animals and also humans, which might also be a reason for this pattern. A bell-shaped follows a Gauss distribution pattern. This pattern indicates a poor reproduction and recruitment of species, which may be associated with the over harvesting of seed bearing individuals (e.g., *Celtis zenkeri*). A U-shaped pattern indicates selective cutting and removal of medium-sized trees (e.g., *Olea welwitschii*) probably for house construction or farm tools. Broken J-shaped and inverted J-shaped, exhibit a distribution pattern where individual plants are removed from different classes by natural or human-related factors.

In Ethiopia, logging has been extremely selective and mostly confined to a few highly valuable timber tree species. It could be due to this logging effect that some tree species in the moist evergreen Afromontane forests have a distorted population structure. Bekele (1994), Teketay (1997), Woldemariam et al. (2000), and Tesfaye et al. (2002) have reported similar results from the different Afromontane forests of Ethiopia.

Moist evergreen Afromontane forests have a high density of individuals, which, however, differs between sites. These differences may be explained by the complex interactions of the different historic factors in each respective site. For example, the high plant densities in the Yayu forest might be attributed to the successional stage of the forest. Many natural disturbances, such as fire, may affect the succession processes of a forest. The Yayu forest probably has been subjected to some disturbance in the past. During early successional development, many pioneer species may establish and grow together in high density until they reach the climax stage where many individuals are eliminated due to competition (Ewel, 1983). The low density in the Harenna forest is related to heavy human-related disturbance.

The high dominance and/or abundance of a few species (e.g., *Coffea arabica*) in each forest could be attributed to a number of factors, such as over harvesting of the desired species, disturbance factors, successional stage of the forest, and/or survival strategies of the species. For instance, the high dominance of *C. arabica* in the Harenna and Maji forests compared to other sites are indicative of human influence via selective removal of other plant species to promote coffee productivity. On the other hand, some plant species may have a wide range of dispersal mechanisms and/or rapid reproduction strategies. Species able to survive and flourish after disturbance tend to be those that reproduce rapidly and abundantly (McKinney, 1997) and are dispersed widely.

There was little difference among the studied Afromontane forests concerning the basal area per hectare. Site productivity, competition, and/or density affect the basal area of the forests and stands. All studied forests showed comparable density of tree individuals per hectare except Yayu forest, which contributed to the total basal of the forest stand. However, the present basal area values are slightly higher than those of reported for tropical forests (Phillips *et al*., 1994). This might be due to a high density of individuals in the Afromontane forests. According to Gentry (1988) reports the density of woody plants in the montane forests of Africa is relatively high as compared to other tropical montane forests. This may have contributed to the high basal area in the studied Afromontane forests.

The vertical structure shown in the profile diagrams illustrates the general vegetation stratification in the studied Afromontane forests. In all forests, there were 2-3 strata of tree layers, i.e., the emergent, middle and lower canopy layers. Nevertheless, in each forest the upper canopy layer was occupied by different tree species, which probably explains the difference in climatic, edaphic and/or historical factors in each forest. Two-layer stratification is common in species-poor forests in Ecuador (Grubb *et al*., 1963). A similar result was reported from dry Afromontane forests of Ethiopia (Bekele, 1994). The degree of canopy stratification within a community related to the degree of 'functional' stratification (e.g., canopy density) in the canopy (Mitchley, 1988; Collins and Wein, 1998; Liira *et al*., 2002), the character of physical environment (Kent and Coker, 1992), and the microclimate (Grubb *et a*l., 1963; Stoutjesdijk and Barkman, 1992).

In addition to physical environments, human factors can modify the vertical stratification of the forest. For example, the low density and/or abundance of upper canopy trees in the Bonga and Maji forests compared to the other studied forests indicate the human-related influence during the past. Logging has occurred in most forests of Ethiopia in the past (Bekele, 1994; Tesfaye *et al*., 2002). In particular, there is a long history of human settlements in the Bonga area and surroundings. These human activities must have contributed to the reduction of the upper canopy trees, as most of these species were used for timber, e.g., *Pouteria adolfi-friederici*, and *Olea welwitschii*.

There have been attempts to classify plant species not only into a natural system according to similarities in their reproductive parts and assumed relationship but also into growth forms according to similarities in general physiognomy or in form and function of their vegetative parts (Raunkiaer, 1934; Hedbeg, 1964; Mitchley and Willems, 1995 and others). The growth form composition of communities may greatly affect the processes that are responsible for the vertical structuring in the canopies (Givnish, 1982; Kohyama, 1992). According to Raunkiaer (1934), growth forms of vascular plants represent a complex of characteristics closely linked to the ecological behavior of the species and their site conditions. However, factors causing variation in species richness may differ between growth forms.

The forest of Berhane-Kontir had the highest species richness based on growth form compared to the other forests. For instance, a high richness of tree species in this forest may be related to the presence of environmental gradients (e.g., altitudinal variation, soil types) across the forest (Senbeta , 2007); and as a result, there is a greater local diversity of tree species than in the other forests. In a similar way, the altitudinal gradient in the Harenna forest probably promoted the richness of tree species. Epiphytic growth form is rich in the Berhane-Kontir forest indicating high rainfall and/or humidity gradients in the region. This corresponds with the findings of Zotz *et al*. (1999), who report epiphyte richness as an indicator of moisture gradients in tropical rainforests. Diversity and abundance of epiphytes are recognized as an indicator of disturbance trends in tropical montane rainforests (Barthlott *et al*., 2001). Generally, herbaceous growth forms are abundant in all studied moist evergreen Afromontane forests indicating a diversity of local habitats due to the difference in moisture regimes, disturbance and edaphic gradients across the different regions (Whittaker *et al*., 2001).

CONCLUSIONS

The studied moist evergreen Afromontane forests revealed similar vegetation structures, i.e., size-class distribution, basal area, growth forms and vertical stratification. This could be attributed to similar historical events (e.g., human uses) and/or environmental factors. However, there is a variation in the density of the upper canopy trees indicative of the past logging or disturbance differences between and among the studied forests. It can be concluded that similar forest management schemes (e.g., thinning, harvesting level, etc.) can be employed in all forests. The physiognomic similarities could be the reason why the studied forests support wild populations of *Coffea arabica* in a similar way.

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