

Woody species diversity, productivity and carbon stock potential of dry deciduous woodland in Alitash National Park, North West Ethiopia

Amsalu Abich^{1*}, Asmamaw Alemu¹, Tadesse Mucheye², Mequanent Tebikew¹ and Yohanns Gebremariam¹

¹ Department of General Forestry, College of Agriculture and Rural Transformation, University of Gondar, P.O. Box 196, Gondar, Ethiopia

² Department of Natural Resource Management, College of Agriculture and Rural Transformation, University of Gondar, P.O. Box 196, Gondar, Ethiopia

Abstract

Dry woodlands provide multifunctional benefits which grouped socioeconomic and ecological values. Despite these advantageous while recently threatened, the status of dry woodland attribute is not well understood, particularly Alitash National Park (ANP). Hence, woody species diversity, productivity and carbon stock potential of ANP were studied. Based on the collected data, a total of 24 woody species were identified. The computed Shannon-Wiener's diversity and evenness index were 2.11 and 0.66, respectively which indicated that moderate diversity and individual species were sparsely distributed horizontally. The study site was dominated by few individuals of woody species that exhibited the highest value of IVI. Population structure pattern of woody species showed F shape indicates the first class exhibited good regeneration. Whereas, species in the second classes interrupted the seedling establishment phase and transformation to sapling stage as a result of disturbance caused by anthropogenic, grazing and frequent firing. Stand basal area, volume and AGB were 8.57 m²ha⁻¹, 48.15 m³ha⁻¹ and 49.06 ton ha⁻¹, respectively. The estimated carbon stock of the stand was 27.7 ton ha⁻¹. In conclusion, the results of woody vegetation attributes showed ANP is affected negatively caused by different disturbance indicate the need of appropriate intervention and management system although ANP is protected.

Keywords: Dry woodland; Diversity; Population structure; Productivity; Carbon stock

Introduction

Ethiopia is the fifth largest flora diversity in tropical Africa (Eshetu, 2001). This is due to the country has diverse geographical configuration that has given rise to the development of wide diversities of flora and fauna rich with endemic elements. However, these biological rich resources are diminishing at an unprecedented rate resulted population growth driven agricultural land expansion, dependency of biomass energy and overgrazing (Lemenih and Teketay, 2006; Teketay, 1992; 2004-2005; Wassie, 2007). In addition, land-grabbing, biological invasive, and climate change have emerged as a new threats for forest destruction in the country. Current policy framework such as Growth and Transformation Plan in 2010 promoted large scale land leases to foreign and domestic investors in the agricultural sectors, particularly for the production of export crops and biofuels. In line with this, 1.2 million hectare of forest vegetation was converted to agricultural land between 2004 and 2008 (Stebek, 2011). These land use change contribute for shrinking of forest resources leads to affect ecosystem services negatively including biodiversity loss and climate change.

Ethiopian flora have been classified in to twelve major vegetation types (Friis *et al.*, 2010). Among others, Combretum-Terminalia woodland vegetation type is characterized by small to moderate size with fairly large deciduous leaves and dominated by the family Combretaceae, Fabaceae and Burseraceae (Demissew and Nordal, 2010; Eshete *et al.*, 2011; Wale *et al.*, 2012). This vegetation provides socioeconomic and

ecological services at local and national level. Some of the benefits are livelihood diversification, create job opportunity, for livestock production, fight against desertification, biodiversity conservation, improve soil fertility and carbon sequestration (Lemenih and kassa, 2011). Furthermore, it is characterized by rich floristic composition (Wale *et al.*, 2012). However, this ecosystem is under threatened due to natural and anthropogenic challenges. Empirical evidence indicated that change of climate variability (Eshete *et al.*, 2011; Lemenih and kassa, 2011); socioeconomic activities such as wood extraction for construction and energy source, livestock production, land use change and frequent firing (Eshete *et al.*, 2011; Lemenih and kassa, 2011; Wale *et al.*, 2012); and government initiated resettlement (Lemenih and kassa, 2011) have been identified as major challenges for dry deciduous woodland ecosystem in North west Ethiopia. Eventually, these factors are influenced the dry deciduous woodland attributes, productivities and alters species composition negatively (Eshete, 2011).

National parks, a part of dry deciduous woodlands, safeguard habitats for vast range of indigenous flora and fauna. They maintain biodiversity and endangered endemic species or serves as *in situ* conservation to ensure the capacity of ecosystem service and goods. However, these protected area are faced by several challenges in meeting human and wildlife needs (Tessema *et al.*, 2007). These challenges are human triggering including grazing, settlement, agricultural expansion, fishing, fire and improper collection of non-timber forest products (Menale and Jungmeier, 2011). These anthropogenic disturbances have brought substantial negative changes on the woodland attributes leading to deteriorate woodland ecosystem functions (Eshete *et al.*, 2011). In Alitash National Park (ANP), few researches focused on investigations of challenges and opportunities (Menale and Jungmeier, 2011) and habitat association of rodents and insectivores (Hatamu and Bekele, 2008) have conducted. However, woody species attributes of this woodland ecosystem have not sufficiently understood. Generally, the attributes of dry forests and woodlands have received little attention in terms of research (Chidumayo and Gumbo, 2010).

Although anthropogenic disturbances are investigated by few researches the woody species attributes (Wale *et al.*, 2012) and productivity of dry woodlands (Eshete *et al.*, 2011; Sisay *et al.*, 2017) in north west Ethiopia, the impact of these human induced factors and utilization on woody species diversity, productivity and carbon stock has not been well studied in ANP. This is because of harsh environmental conditions, inaccessibility, remoteness, inhospitability and instability, Ethio-Sudan border, in and round area. Moreover, these scholars information was inadequate for describing the productivity of vast dry land deciduous woodlands. Therefore, assessments of these woodland vegetation attributes are crucial for effective conservation planning, and the presence of rare or threatened indigenous woody plant species to be determined. Consequently, this information is used for preparing protected area management plan and designing conservation strategies. Thus, the objective of this study was to assess woody species diversity, productivity and carbon stock of ANP dry deciduous woodlands. Hypotheses of this study is protected area including national parks enhance woody species diversity, productivity and biomass production (Angassa and Oba, 2010; Mengistu *et al.*, 2005; Wassie *et al.*, 2009a; Yayneshet *et al.*, 2009).

Materials and Methods

Description of the study site

The study was undertaken in Alitash National Park which is found in Quara, Amhara National Regional State, North West Ethiopia. It is located between 11°47'5.4" to 12°31'3.6"N latitude and 35°15'48" to 35°48'51" E. longitude in north western flat plain part of Ethiopia bordered with Sudan. ANP was established legally in 20th February 2006 published in regional legal issues publication news letter 'Zekere Heg'' by regional council with Regulation act No 38/2005. The total area of the ANP is more than 2.666 x 10⁵ hectares. The annual rainfall of the area goes up to 800 mm. Mean monthly temperature are ranged 13.6 to 19.2°C minimum and 34.0°C to 41.1°C maximum (Cherie Enawugaw et al, 2006). The mean altitude ranges from 500 masl around (Alga) in the northern flat plain to 900 around (Tsequa) hills in Southern part. The dominant soil types physically observed are vertisoles, fluvisols and alluvial deposits around River course dominated by sandy texture.

The vegetation cover of the park is characterized by five vegetation types. The dominant vegetation type is - mixed woodland vegetation where Combretum and Terminalia species are abundant. There are also other vegetation types which include Riverine vegetation, - Seasonal wetland vegetation and -open wooded grass

land vegetation types, and hilly area woodland areas. Although few fragmented research exist, comprehensive scientific studies on the vegetation type, biodiversity composition and current status have not been undertaken in the ANP.

The community surrounding ANP is mainly dependant on Agriculture, crop and livestock production, and some related activities. The park is also served as routine which connected to Sudan for Illegal traders. Gumiz ethnic group is the only native residence round the park but recently most of the dwellers are settled by government. This national park is used as a grazing land for these local communities and 'Felata' nomads.

Sampling design for woody vegetation inventory

Reconnaissance survey was carried out from May to June 2016 in the park. Three sites were selected based on species composition, distance, accessibility, safety, and resource with park manager and experts. Systematical random sampling approach and transect line method was applied for surveying woody species. The first transect was aligned randomly at one side of the forest using a compass; then the others was laid at 500 m intervals from each other. Along each transect, minimum size sample quadrats measuring 20 m x 20 m (for trees) was laid down (Kent and Coker, 1992) at 500 m interval. Sub-quadrats measuring 10 m x 10 m was set up in the center of each quadrat for recording of sapling. For regeneration assessment, sub-quadrats measuring 3 m x 3 m were laid down one in the center and four from each corner of the quadrat for counting of seedling. A total of 60 (20 from each site) quadrats were sampled. Individuals were classified in a series of Diameter at Breast Height (DBH) classes at specific intervals, ≥ 10 cm DBH, 3.5 to 10 cm DBH and DBH less than 3.5 cm are considered as tree, sapling and seedling respectively following (Dhaukhandi *et al.*, 2008; Tiwari *et al.*, 2010). We measured stem diameter using forest calliper at breast height (1.3 m above the ground). In each of these quadrats, local species name, number and DBH of individuals of all woody species were determined and recorded. Plant specimen identification was conducted with knowledgeable local farmers and using Bekele (2007) field manual book.

Data analysis

Woody plant species diversity

Woody species diversity of ANP was analyzed using Shannon–Wiener Diversity Index (Magurran, 2004). The Shannon- Wiener diversity (H') and evenness (E') indices are calculated as a measure to incorporate both species richness and species evenness (Magurran, 1988). Species richness is the number of species in a sample of standard size (Whittaker, 1972). Species i comprises proportion p_i of the total individuals in a community of S species,

$$\text{Shannon – Wiener diversity index is } H = - \sum_{i=1}^S p_i \ln p_i \quad \text{Eq. (1)}$$

$$\text{Species evenness is } E = \frac{H}{H_{\max}} \quad H_{\max} = \ln s \quad \text{Eq. (2)}$$

Where E = Pielou evenness (Pielou, 1966); H' =the observed value of Shannon-wiener diversity index; $H_{\max} = \ln S$, and S =Total number of species

Population structural diversity

Woody species structure in ANP were analysed in terms of mean basal area (calculated from individuals with $DBH \geq 3.5$ cm), dominance and size class distribution. Dominance is described in terms of Importance Value Index (IVI) (Kent and Coker, 1992) which is the sum of relative basal area, relative density and relative frequency in the sample plots for each species (Curtis and McIntosh, 1950; Pascal and Pelissier, 1996). Woody species that has the highest value of IVI were selected for population structure analyses. Tree size class distributions were formed with 4.9 cm increment based on tree diameters for selected woody species. Population dispersion pattern were also analysed through abundance to frequency ratio following (Whitford, 1949). IVI can be computed as:

$$IVI_i = R_{D_{oi}} + R_{D_i} + R_{f_i} \quad \text{Eq.(3)}$$

Woody species dominance is calculated by dominance of species i in the sample (m^2) divided by total dominance of all individual species j in the sample (m^2). It can be computed as:

$$R_{D_{oi}} = \left(\frac{D_{oi}}{D_{oj}} \right) \times 100 \quad \text{Eq. (4)}$$

Density of woody species can be computed as the number of individuals of species i in the sample (D_i) divided by total number of individuals of all species j in the sample (D_j):

$$R_{D_i} = \left(\frac{D_i}{D_j} \right) \times 100 \quad \text{Eq. (5)}$$

Frequency is defined as the probability or chance of finding a plant species in a given Sample area or quadrant. It is calculated with the formula; Relative frequency is the number of plots in which species i occur (f_i) divided by total number of plots j (f_j) and it can be computed as:

$$R_{f_i} = \left(\frac{f_i}{f_j} \right) \times 100 \quad \text{Eq. (6)}$$

Regeneration status

Regeneration status of woody species in the Park was analyzed based on population size of seedlings, saplings and matured trees (Dhaulkhani *et al.*, 2008; Tiwari *et al.*, 2010). Good regeneration if seedlings > saplings > adults; fair regeneration, if seedlings > saplings \leq adults; poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults). If a species is present only in an adult form it is considered as not regenerating.

Volume, height and biomass

Individual stem volume, basal area and aboveground biomass were computed. Then these estimated individual variables were summed and converted to stand level. Aboveground biomass was estimated using Eq. 9 and 10 developed by Abich *et al.* (2018) for our study woodland vegetation (accepted for publication). An average 56.4% of carbon content (Abich *et al.*, 2018) was used for estimating carbon stocks of the stand. Individual total trees heights were predicted using height – diameter relationships (Eq.7) (Abich *et al.*, 2018). Individual tree variables were calculated as follows:

$$\ln(H) = 0.740 + 0.521 \ln(DBH) \quad \text{Eq. (7)}$$

$$\ln(AGB) = -2.109 + 2.422 \ln(DBH) \quad \text{Eq. (8)}$$

$$\ln(AGB) = -2.965 + 1.820 \ln(DBH) + 1.157 \ln(H) \quad \text{Eq. (9)}$$

Where H is total height; DBH is diameter at breast height; AGB is aboveground biomass; and ln is natural logarithm.

Result

Woody species composition, diversity and richness

In ANP, a total of 24 woody species were recorded in the 60 quadrats. Twenty one woody species belonging to 17 genera under 13 families, 2 unidentified and 1 unknown species were identified in the park. The two dominant families were Combretaceae, comprising five species in 3 genera, and Fabaceae, comprising six species in 4 genera. The computed Shannon-Wiener's diversity and evenness index were 2.11 and 0.66, respectively.

Population structural analyses

Density of trees/shrubs, sapling and seedling

Total stem density of matured trees, saplings and seedling were 290.4, 220 and 8295 individual ha^{-1} , respectively. The highest woody species densities were observed for species *Combretum collinum* ($97.5 ha^{-1}$), *Combretum molle* ($65 ha^{-1}$), *Terminalia laxiflora* ($27.5 ha^{-1}$), *Anogeissus leiocarpa* ($15 ha^{-1}$), *Dalbergia melanoxylon* ($14.6 ha^{-1}$), and *Combretum harotomannianum* ($13.8 ha^{-1}$). The highest sapling densities were observed in decreasing order: 76.7, 65, 25, 18.3, 11.3 and 8.3 ha^{-1} individuals for *C. Collinum*, *C. Molle*, *A*,

seyal, *T. Laxiflora*, *C. harotomannianum*, and *Zonbelit* (unidentified) species, respectively. The lowest trees/shrub densities were observed ranged from 0.42 to 10.8 individual's ha⁻¹ for species *Stereospermum kunthianum*, *Dichrostachys cinerea*, *Acacia Polyacantha*, *Sterculia setigera*, Fola (unidentified), *Lanchocarpus laxiflora*, *Unknown*, *Pterocarpus lucens* *Balanites aegyptiaca*, *Zonbelit* (unidentified), and *A. seyal* in descending order (Table 2).

The density of sapling and seedling were dominated by few species. Of the total woody species, 45.8% were not represented by their sapling. Out of the total seedlings, 84.3% of the seedlings were dominated by five species including *C. Collinum* (2114.7 ha⁻¹), *T. Laxiflora* (2022.7 ha⁻¹), *C. Molle* (1072 ha⁻¹), *Dalbergia melanoxylon* (958.7 ha⁻¹) and *Dichrostachys cinerea* (822.7 ha⁻¹). The lowest seedling densities were observed in *Grewia bicolor*, *Lonchocarpus laxiflorus*, *Stereospermum kunthianum* which represented only 0.016% of each. *Pterocarpus lucens* and Fola (unidentified) species seedlings were not recorded in all studied quadrats.

Basal area, IVI and DBH class distribution of trees and saplings

The most frequent species in the study area was *Combretum collinum* species covering 16.6% of relative frequency in the total sampled quadrats followed by *Dalbergia melanoxylon* (12.7%), *C. molle* (9.7%), *T. Laxiflora* (9.4%) and *Lannea fruticosa* (9.1%). The estimated total basal area of matured trees and saplings were 7.910 and 0.656 m² ha⁻¹, respectively. *Combretum collinum*, *Combretum molle*, *Anogeissus leiocarpa* and *Terminalia laxiflora* were accounted 32.67, 16.30, 12.21 and 9.90 % of relative dominance among the recorded woody species, respectively (Table 1). DBH class distribution of individual species, grouped in to nine classes, was revealed F shape distribution pattern (Fig.1).

Importance value index was determined for each species which provides information about ecological significance of the species in a given ecosystem. Based on IVI, eight top woody species were selected for analysis of population structure such as *Combretum collinum* (75.3%), *Terminalia laxiflora* (42.7%), *Combretum molle* (39.6%), *Dalbergia melanoxylon* (28.1%), *Lannea fruticosa* (18.4%), *Anogeissus leiocarpa* (17.7%), *Combretum harotomannianum* (12.0%) and *Zonbelit-unidentified* (11.3%) which present in Table 1. *Combretum collinum*, *Terminalia laxiflora*, and *Combretum molle* were the most dominated woody species in the study site. Diameter class population structure distribution of selected woody species showed similar shapes except *Anogeissus leiocarpa*. "F" shape type of distribution is demonstrated on all population, when the first class exhibited highest individuals; the second and third class had absent/few individuals; the intermediate class (4, 5 and 6) had relatively higher individuals and with gradual decreased towards the larger classes. *Anogiossus leocarpa* was formed "E" shape. "E" shape is formed when few numbers of individuals are found at the lower (2, 3 and 4 class) diameter class and higher at the intermediate diameter class (5, 6 and 7 class). In this type of shape, the number of individuals decreased at 8 and 9 diameter class and again individuals increased as diameter size increase (Fig.2).

Species distribution patterns

Abundance to frequency ratio values indicates the pattern of plant species distribution which receives the attention of ecologist and forester. Woody species distribution pattern in the study area were revealed contagious. The computed values of abundance to frequency ratio of all individuals were greater than one which is presented in Table 1.

Regeneration status of woody species

In the current study, 22 wood species were represented in the seedling class which DBH less than 3.5cm. In the total recorded woody species, seedlings can be comprised 94.2%. Matured trees/shrub and saplings were comprised 3.3% and 2.5%, respectively. Nine woody species depicted good regeneration status and eleven species showed fair regeneration. Two species showed poor regeneration. Whereas, *Pterocarpus lucens* and Fola (unidentified) did not shows regeneration (Table 2). Most woody species seedling emerged from the soil seed bank but *C. collinum*, *T. laxiflora* and Zombelit (unidentified) regenerated through soil seed and sprouting from the scared stump (field observation).

Stand productivity, aboveground biomass and carbon stocks

Individual stem basal area, volume and aboveground biomass were computed, summed and converted to stand variables. The result of computed stand variables is presented in Table 3. The total stand basal area, volume and aboveground biomass were 8.57 m²ha⁻¹, 48.15 m³ha⁻¹ and 49.06 ton ha⁻¹ respectively. The estimated carbon stock of the stand was 27.7 ton ha⁻¹.

Discussion

Species composition, richness and diversity

A total of 24 woody species were recorded. Of these, 21 woody species comprising 13 families, two unidentified and one unknown woody species were represented the site. This woodlands are characterized by Combretum - Terminalia woodland vegetation (Friis *et al.*, 2010). The most species rich families were Combretaceae and Fabaceae in this study site. It was consistent with the finding of Savadogo *et al.* (2007) they found these two families were dominated the Sudanian Savanna woodlands. In Metema similar woodland vegetation formation, higher woody species composition ranged 36 -39 woody species (Eshete *et al.*, 2011; Wale *et al.*, 2012) were identified few distance apart from our study site. This difference in species composition among the two sites might be due to the difference in climatic variability-moisture (Eshete *et al.*, 2011), soil characteristics and altitudinal gradients (Yeshitela and Bekele, 2002), altitudinal gradients (Lieberman *et al.*, 1996) and soil attributes (Awas, 2007; John *et al.*, 2007; Zhang and Chu, 2011). In addition, Grazing pressure (Hanke *et al.*, 2014; Khatri *et al.*, 2016) and frequent firing (Peterson and Reich, 2008; Teketay, 2005b) altered species composition. In our study site, anthropogenic activities including selective logging; increased grazing intensity; and frequent firing might be the responsible causes for changing woody species composition.

Species diversity, plant community attribute, measurement play crucial role in biodiversity conservation and ecological studies (Maguran, 2004). Shannon- Weiner diversity and evenness index were 2.11 and 0.66, respectively in the present study. Our results of woody species diversity and evenness value were similar compared with reports from studies in the Botswana dry woodland (Neelo *et al.*, 2013), Alabama woodlands in southeast US (Khatri *et al.*, 2016), Metema dry deciduous woodlands in North west Ethiopia (Eshete *et al.*, 2011) but lower than Miombo woodlands in Tanzania (Giliba *et al.*, 2011), Sudanian Savanna woodlands in Burkina Faso (Savadogo *et al.*, 2007), woodland savanna in Uganda (Nangendo *et al.*, 2006) and woodlands in Ethiopia (Dibaba *et al.*, 2014; Worku *et al.*, 2012). The value of Shannon-Weiner diversity index is ranged 1.5 – 3.5 and rarely exceed 4.5 (Kent and Coker, 1992) which comprise both species richness and evenness (Manguran, 1988). Cavalcanti and Larrazábal (2004) also nominated this index value as high when it is exceed 3, medium when the value lay between 2-3 and low when the value is ranged 1-2. Whereas, if the value of H' of a given community less than 1 it is considered as poor diversity. Based on this analysis, woody species diversity value in the present study falls at the medium diversity range indicates the presence of disturbance in this dry deciduous woodland. However, woody species evenness value (E = 0.66)

more or less comparable with that was reported in Ethiopia (Didita *et al.*, 2010; Eshete, 2011), suggests the recorded individual species exhibited moderately evenly distributed in the area.

Environmental factors and anthropogenic disturbance have influenced the attributes of dry forest and woodlands. Several studies pointed out increasing fire frequency, common problem in dry woodlands, declined woody species diversity of dry woodlands (Bullock *et al.*, 2009; Chidumayo and Gumbo, 2010; Peterson and Reich, 2008; Teketay, 2005b). This might be described by the presence of large fuel load, dry mass of litters, herbs and grasses on the ground which facilitate ignition. So, dry deciduous woodland vegetations are called fire prone ecosystem and the stem bark gradually changed to thick. In addition, despite intermediate grazing intensity can promote plant species diversity (Naveh, Z. & Whittaker, R.H. 1980), empirical evidence indicated that plant species diversity negatively affected by grazing intensity (Angassa and Oba, 2010; Mengistu *et al.*, 2005; Pueyo *et al.*, 2006; Wassie *et al.*, 2010). It also might be altered the woodland conditions and interrupts the resource regulatory process (Yates *et al.*, 2000) and changed to Savanna grassland (Bullock *et al.*, 2009). Generally, plant species diversity in the terrestrial ecosystem is influenced by various factors including species interaction, disturbance processes and environmental factors (Connell, 1978; Huston, 1994; Whittaker, 1975). In our study, frequent human induced fire for preventing wild animal attacks, particularly by illegal traders, and heavy livestock grazing pressures by 'felata' ethnic groups and inhabitants are observed as a major disturbance. These indicating the ANP have not well designed fire break and has weak management system that received the attention of decision and policy makers.

Population structure

Population structure analyses of forest provide substantial evidence for quantifying seedling recruitment, population status and monitoring the indicators of stability, trends and rate of population change. The total stem density and basal area (DBH \geq 3.5 cm) were estimated to be 510.4 ha⁻¹ and 8.57 m² ha⁻¹, respectively. Compared to similar woodland vegetation formation, woody species density is higher compared with that was reported in earlier study (Eshete, 2011; Wale *et al.*, 2012) in Ethiopia, semi arid zone woodlands in Senegale (Ndiaye *et al.*, 2014) and Sudanian Savanna woodlands in Burkina Faso (Savadogo *et al.*, 2007). Whereas, our result is lower compared to earlier study undertaken Miombo woodland in Tanzania (Giliba *et al.*, 2011). Despite ANP protected area, the result clearly shows there is sign of illegal selective wood removal in the park for construction and energy source. In addition, almost all quadrats were fired and we tried to find fire free places but couldn't be found. Hence, the density of saplings, DBH ranged 3.5 -10 cm was influenced and underestimated which is not expected result (Fig. 3). This might be suggested that fire is damaged the lower diameter class (Peterson and Reich, 2001) that interrupted the progressive growth of sapling to mature trees (Fig 1).

Population structure and density analyses of major tree species can be provided better understanding of species regeneration status, past and present conditions and ecology of the forests or woodlands (Senbeta *et al.*, 2007; Teketay, 2005a; Teketay, 2005b). In the present study, the overall basal area higher than the findings of Worku *et al.* (2012) but lower compared with the finding of Eshete (2011) suggests soil water stress and moisture availability (Eshete, 2011), climatic and edaphic conditions (Bullock *et al.*, 2009) are influenced growth features of dry woodland. Basal area analyses of individual woody species revealed the area was dominated by few species (Table 1). *Combretum collinum*, *Combretum molle*, *Anogeissus leiocarpa* and *Terminalia laxiflora* were the most dominance woody species in descending order. This indicates the aforementioned species have more adaptive and resistance capability to harsh environmental conditions and human disturbance.

Several ecological studies demonstrated the contribution of individual species IVI value determination in relation to ecological significance of the species in a given vegetation formations (Girma *et al.*, 2011; Kent and Coker, 1992; Neelo *et al.*, 2013; Worku *et al.*, 2012; Zegeye *et al.*, 2006). In the present study, the dry deciduous woodlands dominated by few woody species that had greater than 11.3% of IVI value. This might be suggested that these woody species can be considered as the most ecologically important species contributed by their relative frequency, density and dominance. More than 50% of woody species had less than 5% IVI value suggests several woody species had lower abundance due to environmental factors,

disturbance and ecological requirement. Thus, these species should be prioritised for applying conservation efforts.

Analyses of population structure using diameter size class provides an understanding of structural diversity, regeneration status, disturbance response and changes of population structure of woody species (Bekele, 1993; Senbeta *et al.*, 2007; Teketay, 2005a; Teketay, 2005b). The overall and individuals diameter class distribution of the sampled area was formed similar F shape distribution (Fig. 1 and 2). This type of population structure shows early good recruitment and establishment of seedlings following the rainy season. However, dry woodlands are characterized by long dry season, frequent firing, moisture stressed and poor soil nutrient availability (Bullock *et al.*, 2009; Chidumayo and Gumbo, 2010) leads to interrupt the progress of succession from these seedling in the first class to sapling stage, in our case, the 2nd and 3rd class. Relatively higher individuals were presented in the intermediate class (4, 5, and 6) indicate the ability of species competitiveness and resistance to past disturbance in the area. Whereas, the number of individuals decreased towards the larger class due to human induced disturbance including selective tree harvesting (Pueyo *et al.*, 2006; Teketay, 2005a; Wassie *et al.*, 2010; Wassie *et al.*, 2009a), inability to cop up frequent firing, disease, (particularly, *T. laxiflora*, *C. molle* and *C. harotomannianum*), wind throw, and may be ecological process. For instance, pole sized (DBH ranged 10-20 cm) and matured woody species including, *C. collinum*, *C. molle*, *C. harotomannianum*, *P. lucens* and *D. melanaxylon* have been used for various purposes in the study area. This is because of their good characteristic in terms of termite resistant, strengthens and durability, particularly *Dalbergia melanaxylon* species. Eventually, the combination of livestock-induced disturbances (Pueyo *et al.*, 2006; Wassie *et al.*, 2010); interspecific competition, herbivory, predation and mutualism (Tilman, 1986) and frequent firing are influenced vegetation structure.

Regeneration status

In this study, cumulative population structure, by grouping seedling, sapling and matured, of woody species exhibited reverse J shaped distribution (Fig. 3). This type of distribution is widely acknowledged and showed healthy regeneration, recruitment capacity and stable population structure (Aleign *et al.*, 2007; Dibaba *et al.*, 2014; Didita *et al.*, 2010; Teketay, 2005a; Wassie *et al.*, 2010; Zegeye *et al.*, 2006) of a given forest or woodland. A total of 8805.1 individuals ha⁻¹ were recorded in our study. Of these, seedlings were comprised 94.2% contributed by seven woody species such as *T. laxiflora*, *C. collinum*, *C. molle*, *D. Melanaxylon*, *D. cinerea* Zonbelit and *C. Harotomannianum* in descending order (Table 2). On the other hand, six woody species seedlings were absent / few ranged 0 - 4 individuals ha⁻¹. Whereas, both saplings and matured were comprised 5.8% of individuals ha⁻¹. Out of the recorded saplings, five species had relatively higher individuals but 70.8% of the recorded woody species sapling densities were represented by few (absent) individuals (Table 2). However, much higher seedling and sapling density were recorded in our study compared with the reports of Wale *et al.* (2012) in similar dry woodland vegetation. Seedling and saplings of *Lonchocarpus laxiflorus*, *Pterocarpus lucens*, *Fola-identified*, *Stereospermum kunthianum*, *Anogeissus leiocarpa* and *Balanites aegyptiaca* were poorly represented. It was consistent with the findings of Wale *et al.* (2012). Regeneration status of the dry woodland are characterised as 37.5, 45.8, 8.3 and 8.3% of woody species were showed good, fair, poor and no regeneration, respectively. However, the transition of woody species regeneration and seedling establishment to sapling stage or higher class is hampered/ takes a long time due to heavy grazing pressure, moisture availability, competition with other vegetation, frequent firing, and tree harvesting (Bullock *et al.*, 2009; Gnüter *et al.*, 2011; Teketay, 2005a; Teketay, 2005b).

Species distribution patterns

Spatial distribution patterns of plant species are associated with different factors including competition for limiting resources and light (Tilman, 1986); variation in soil attributes (Thomas and Packham, 2007); stages of succession and seed dispersal mechanism (Whitford, 1949); and dispersal modes, altitude and disturbance (Senbeta *et al.*, 2005). In our study, Abundance to Frequency ratio (A/F) values of all the recorded woody species were > 1 (Table 1). According to Whitford (1949) the value of A/F ratio is ranged 0.025 – 0.05. If the computed value of A/F is < 0.025 indicates the species are distributed regularly; the value lies between 0.025 – 0.05 the species shows random distribution; and the value is > 0.05 it shows a contagious or clumped distribution. Contagious dispersion pattern is mostly common in natural vegetation (Venna *et al.*, 1999) but it was also found in both secondary forest and plantation (Kumar *et al.*, 2006). In our study,

woody species distribution patterns were exhibited contagious distribution suggesting the number of seedling density decreased with increasing the distance away from the mother trees. This implies the parent trees create micro-climate including moderate temperature fluctuation; moisture due to shading and nutrient accumulation through nutrient pumping and addition of organic matter under the canopy or dispersal limitation.

Productivity and aboveground carbon stock

Generally, the growth and productivity of dry woodland is less due to severe climatic variability, soil moisture availability, anthropogenic disturbance and low quality of soil attributes (Bullock *et al.*, 2009; Chidumayo and Gumbo, 2010; Gnüter *et al.*, 2011; Thomas and Packham, 2007). In the present study, the estimated basal area and volume were 8.57 m²ha⁻¹ and 48.15 m³ha⁻¹, respectively (Table 3). In similar dry woodland vegetation, the computed mean basal area was 12.19 m²ha⁻¹ and 9.55 m²ha⁻¹ for Metema and Averegele dry woodland, respectively; and the mean stand volume was 38.6 m³ha⁻¹, and 15.38 m³ha⁻¹ for Metema and Averegele dry woodland, respectively (Eshete *et al.*, 2011). Sisay *et al.* (2017) also showed that mean volume of Mahibereselassie dry woodland was 27.6 m³ha⁻¹. In another ways, lower basal area and higher volume were found in our study site compared with the aforementioned reports. This difference in stand productivity might be explained by variation in climate variability (Eshete *et al.*, 2011), resource availability and environmental factors (Balvanera and Aguirre, 2006; Condit *et al.*, 2013; Pausas and Austin, 2001) and human disturbance (Eshete *et al.*, 2011; Pueyo *et al.*, 2006; Wassie *et al.*, 2010; Worku *et al.*, 2012) across the site. These factors can be reduced tree growth, stem density and the number of large diameter tree in dry woodland vegetations suggesting lower productivity compared to dry Afromontane forests (Bullock *et al.*, 2009; Gnüter *et al.*, 2011).

Aboveground biomass of dry woodlands was 49.06 ton ha⁻¹ (Table 3). Carbon stock potential of this dry woodland was 27.7 ton ha⁻¹ higher than that was reported by Sisay *et al.* (2017) and (Vreugdenhil *et al.*, 2012) in similar dry woodland vegetation, North west Ethiopia. This variation might be associated with the difference in site condition, disturbances and environmental factors (Chave *et al.*, 2005; Henry *et al.*, 2011; Přemyslovská *et al.*, 2007) and model selection (Abich *et al.*, 2018; Salis *et al.*, 2006; Sileshi, 2014). Generally, aboveground carbon stock potential of Alitash National Park dry deciduous woodland was 7.4 Mega tone which serve as climate change mitigation.

Conclusion and recommendation

The result indicated that Alitash dry deciduous woodland house 24 different woody species which provide various goods and services. Combretaceae and Fabaceae were the most dominant families in this study site. Woody species composition and diversity index value were medium which indicates the need of conservation from human disturbance although ANP is protected area. The frequency of woody species was relatively low with the exception of a few species indicating that environmental factors might be influenced horizontal distribution of individual wood species. This is also confirmed from the computed value of medium evenness value and higher abundance to frequency ratios (contagious distribution) in the study site. Population structure analyses result revealed that population structures negatively affected which hampered each stage of woody species succession. This indicate human disturbance including livestock grazing (browsing and trampling), recurrent firing and long dry season affect ecological succession of woody vegetation negatively which requires attentions and appropriate management intervention.

The result revealed that most of the woody species exhibited low value of density, basal area and IVI value and unstable population structure. Population structure of the whole population and selected woody species, particularly those grouped in population structure class 2 and 3, showed individuals species were few or absent in the lower diameter class. This indicates unable to transform from seedlings to saplings and saplings to intermediate diameter size class. The assessment of regeneration status based on seedling, sapling and matured tree count exhibited some woody species showed good to fair regeneration status but many woody species were poor or not regenerating. This indicates intensive livestock grazing, illegal tree harvesting, recurrent fire and long dry season affect dry woodland ecosystem attributes negatively. Despite human and natural disturbance affect the productivity of dry woodland ecosystem, ANP stored 7.4 Mt of carbon that mitigate climate change and prevent desertification. Generally, the result indicates the need of urgent conservation and appropriate management intervention in order to maintain and sustain

multifunctional benefits of this dry deciduous woodland. We suggested that plant community attributes study at ecosystem level warrant further investigation rather than fragmented research on the natural dynamics of dry woodland vegetation, i.e. causes, mechanisms and factors which drive the rate of this ecosystem process.

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Table 1. List of woody species recorded in ANP dry deciduous woodland: Densities (individuals ha⁻¹), RD = relative densities (%), F = frequencies (%), RF = relative frequencies (%), BA = basal area (m².ha⁻¹), RBA = relative basal areas (%), IVI = importance value indices and A/F = abundance to frequency ratios

Table 2. Regeneration status of woody species in ANP dry deciduous woodland with their densities (individual ha-1)

Scientific name	Family name	Abu.	Density	F	RF	RD	BA	RBA	IVI	A/F	
<i>Acacia polyacantha</i> Willd. subsp.	Fabaceae	26	33.25	5.00	1.51	0.38	0.03	0.38	2.26	5.20	
<i>Acacia seyal</i> Del. var. <i>Fistula</i>	Fabaceae	133	158.50	10.00	3.02	1.80	0.23	2.74	7.56	13.30	
<i>Acacia sieberiana</i> Dc.	Fabaceae	8	10.67	3.00	0.91	0.12	0.00	0.00	1.03	2.67	
<i>Anogeissus leiocarpa</i> (DC.) Guill. & Perr.	Combretaceae	46	28.67	17.00	5.14	0.33	1.05	12.21	17.67	2.71	
<i>Balanites aegyptiaca</i> Del.	Balanitaceae	33	33.00	10.00	3.02	0.37	0.25	2.96	6.35	3.30	
<i>Combretum collinum</i> Fres.	Combretaceae	1862	2285.92	55.00	16.62	25.96	2.80	32.67	75.25	33.85	
<i>Combretum harotomannianum</i> Schweinf.	Combretaceae	285	352.08	19.00	5.74	4.00	0.20	2.28	12.02	15.00	
<i>Combretum molle</i> R.Br. ex G.Don	Combretaceae	1000	1202.42	32.00	9.67	13.66	1.40	16.30	39.62	31.25	
<i>Dalbergia melanoxylon</i> Guill. & Perr.	Leguminosae	754	973.25	42.00	12.69	11.05	0.37	4.32	28.06	17.95	
<i>Dichrostachys cinerea</i> (L.) Wight & Arn	Fabaceae	618	823.08	25.00	7.55	9.35	0.00	0.04	16.94	24.72	
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	Ebenaceae	16	21.33	3.00	0.91	0.24	0.00	0.00	1.15	5.33	
<i>Fola</i> -unidentified	-	5	2.08	2.00	0.60	0.02	0.04	0.49	1.11	2.50	
<i>Gardenia ternifolia</i> Schumach. & Thonn.	Rubiaceae	10	13.33	4.00	1.21	0.15	0.00	0.00	1.36	2.50	
<i>Grewia bicolor</i> Juss.	Tiliaceae	2	3.00	1.00	0.30	0.03	0.01	0.08	0.41	2.00	
<i>Lanea fruticosa</i> (Hochst. ex A. Rich) Engl	Anacardiaceae	237	277.50	30.00	9.06	3.15	0.53	6.17	18.38	7.90	
<i>Lonchocarpus laxiflorus</i> Guill. & Perr.	Fabaceae	9	5.92	7.00	2.11	0.07	0.09	1.11	3.29	1.29	
<i>Pterocarpus lucens</i> Guill & Perr.	Fabaceae	10	4.17	4.00	1.21	0.05	0.37	4.31	5.57	2.50	
<i>Sterculea setigera</i> Del.	Sterculiaceae	8	7.92	4.00	1.21	0.09	0.08	0.90	2.19	2.00	
<i>Stereospermum kunthianum</i> (Cham, Sandrine. Petit)	Bignoniaceae	3	3.42	3.00	0.91	0.04	0.01	0.09	1.03	1.00	
<i>Strychnos innocua</i> Del.	Loganiaceae	3	4.00	1.00	0.30	0.05	0.00	0.00	0.35	3.00	
<i>Terminalia laxiflora</i> Engl. Ex Diels	Combretaceae	1594	2068.50	31.00	9.37	23.49	0.85	9.89	42.75	51.42	
Unknown	-	19	21.08	4.00	1.21	0.24	0.06	0.67	2.12	4.75	
<i>Ziziphus spina-christi</i> (L.) Willd.	Rhamnaceae	46	61.67	5.00	1.51	0.70	0.00	0.02	2.23	9.20	
<i>Zonbelit</i> -unidentified	-	323	410.33	14.00	4.23	4.66	0.21	2.40	11.29	23.07	
Scientific name	Seedling	Sapling	Matured	Rege. status							

<i>Acacia polyacantha</i> Willd. subsp.	25.3	6.7	1.3	Good
<i>Acacia seyal</i> Del. var. <i>fistula</i>	122.7	25.0	10.8	Good
<i>Acacia sieberiana</i> Dc.	10.7	0.0	0.0	Good
<i>Anogeissus leiocarpa</i> (DC.) Guill. & Perr.	12.0	1.7	15.0	Fair
<i>Balanites aegyptiaca</i> Del.	28.0	0.0	5.0	Good
<i>Combretum collinum</i> Fres.	2114.7	75.0	96.3	Fair
<i>Combretum harotomannianum</i> Schweinf.	326.7	11.7	13.8	Fair
<i>Combretum molle</i> R.Br. ex G.Don	1072.0	65.0	65.4	Good
<i>Dalbergia melanoxylon</i> Guill. & Perr.	958.7	0.0	14.6	Fair
<i>Dichrostachys cinerea</i> (L.) Wight & Arn	822.7	0.0	0.4	Fair
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	21.3	0.0	0.0	Good
<i>Fola</i> -unidentified	0.0	0.0	2.1	Not regenerated
<i>Gardenia ternifolia</i> Schumach. & Thonn.	13.3	0.0	0.0	Good
<i>Grewia bicolor</i> Juss.	1.3	1.7	0.0	Poor
<i>Lannea fruticosa</i> (Hochst. ex A. Rich) Engl	260.0	0.0	17.5	Fair
<i>Lonchocarpus laxiflorus</i> Guill. & Perr.	1.3	1.7	2.9	Poor
<i>Pterocarpus lucens</i> Guill & Perr.	0.0	0.0	4.2	Not regenerated
<i>Sterculea setigera</i> Del.	6.7	0.0	1.3	Fair
<i>Stereospermum kunthianum</i> (Cham, Sandrine. Petit)	1.3	1.7	0.4	Fair
<i>Strychnos innocua</i> Del.	4.0	0.0	0.0	Good
<i>Terminalia laxiflora</i> Engl. Ex Diels	2022.7	18.3	27.5	Fair
Unknown	17.3	1.7	2.1	Fair
<i>Ziziphus spina-christi</i> (L.) Willd.	60.0	1.7	0.0	Good
<i>Zonbelit</i> - unidentified	392.0	8.3	10.0	Fair

Table 3. Summary of the stand variables of dry deciduous woodland in ANP

Variables	Mean DBH	Mean Hpre.	Basal area m ² ha ⁻¹	Volume m ³ ha ⁻¹	AGB - Eq. (9) kgha ⁻¹	AGB - Eq. (10) kgha ⁻¹	C stocks kgha ⁻¹ Eq. (10)
	15.18	8.38	8.57	48.15	48930.49	49062.55	27671.28
SD	8.15	2.24	0.012	0.1	96.06	96.38	54.36
N	831	831	831	831	831	831	831

SD: standard deviation; N: number of sample trees and Hpre: predicted total height

Figures

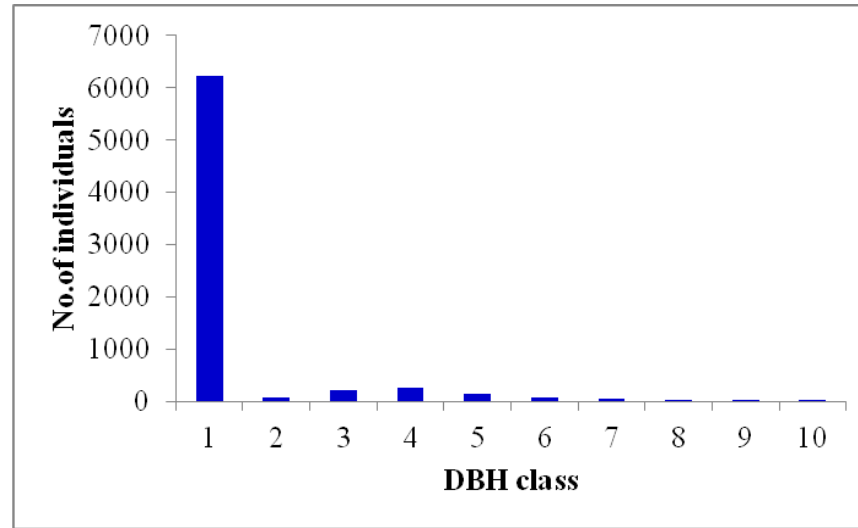
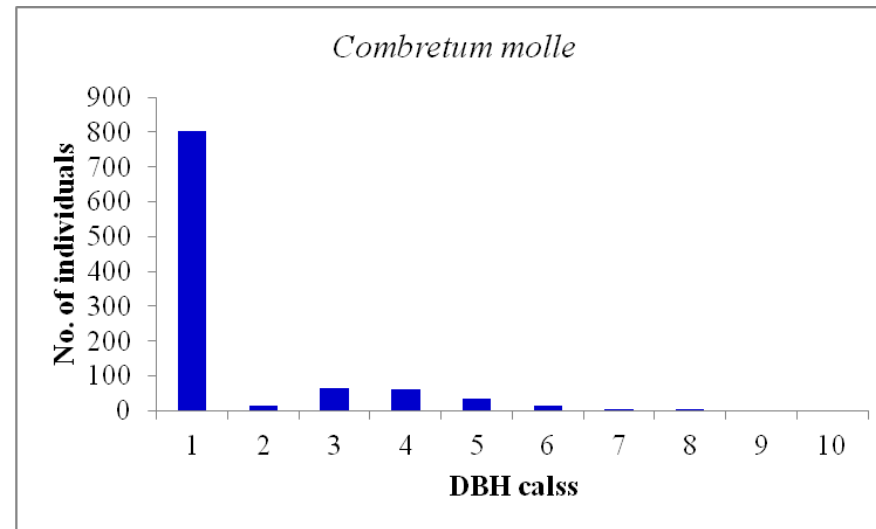
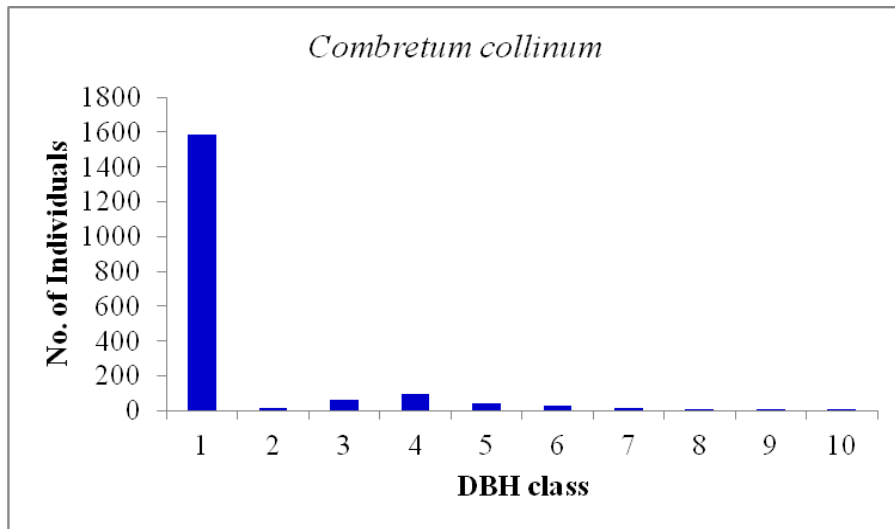
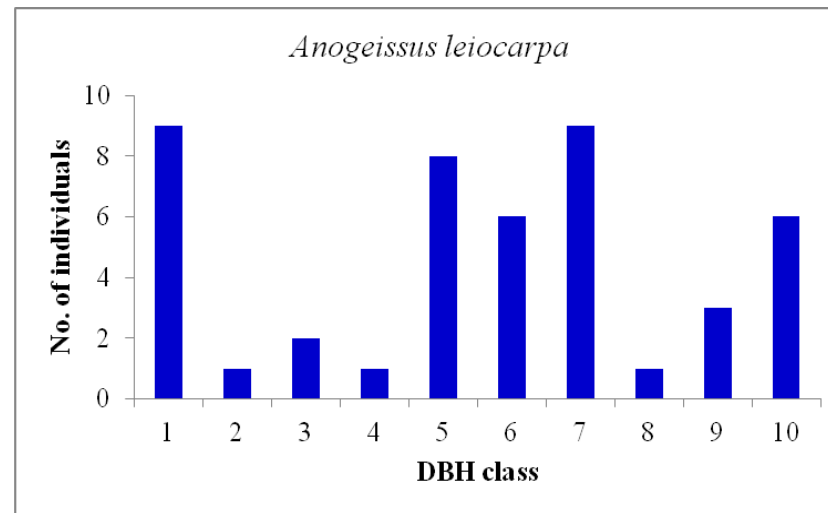
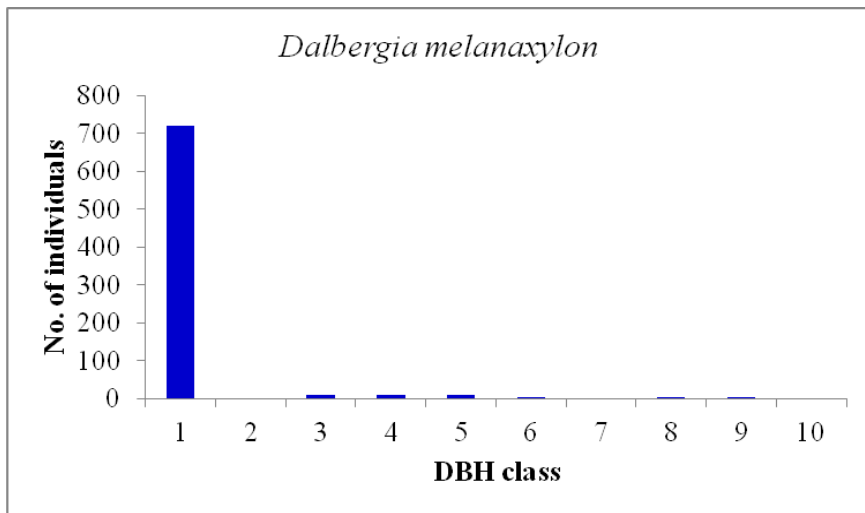
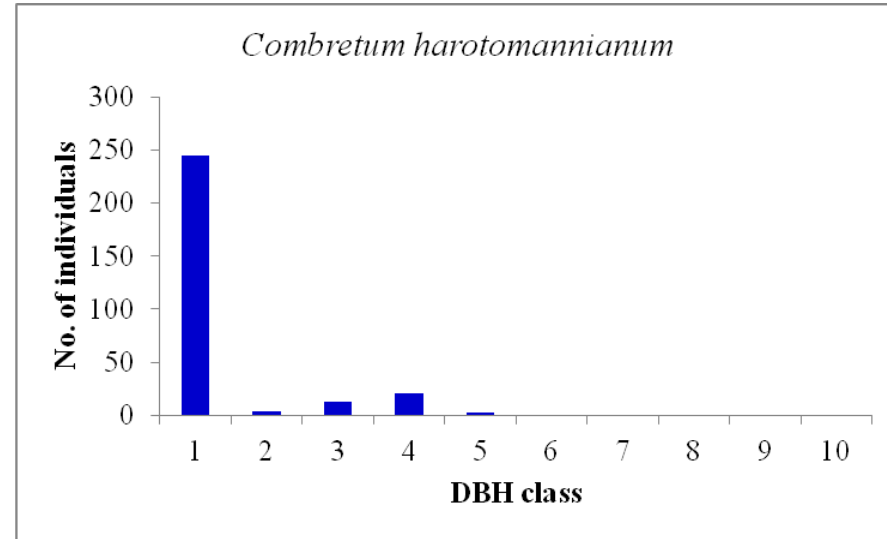
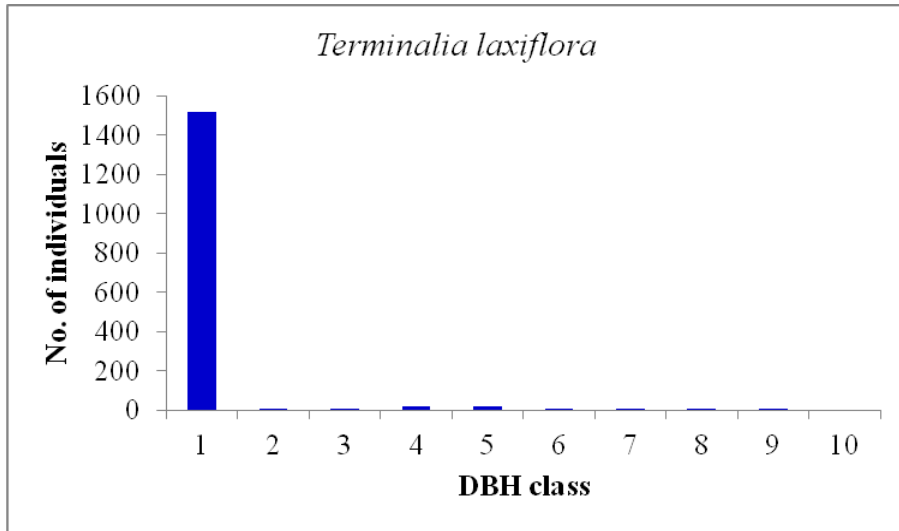


Figure 1. Diameter class distribution of dry deciduous woodland in ANP, North West Ethiopia (1 < 3.5; 2 = 3.5-5.9 cm; 3 = 6-10.9 cm; 4 = 11-15.9 cm; 5 = 16-20.9 cm; 6 = 21-25.9 cm; 7 = 26-30.9 cm and 8 = 31-35.9 cm; 9 = 36-40.9 cm and 10 > 41 cm DBH classes)





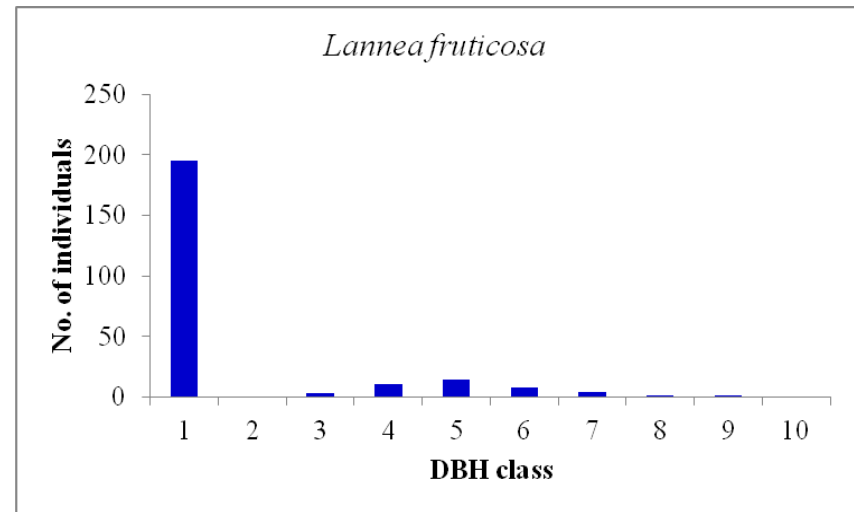
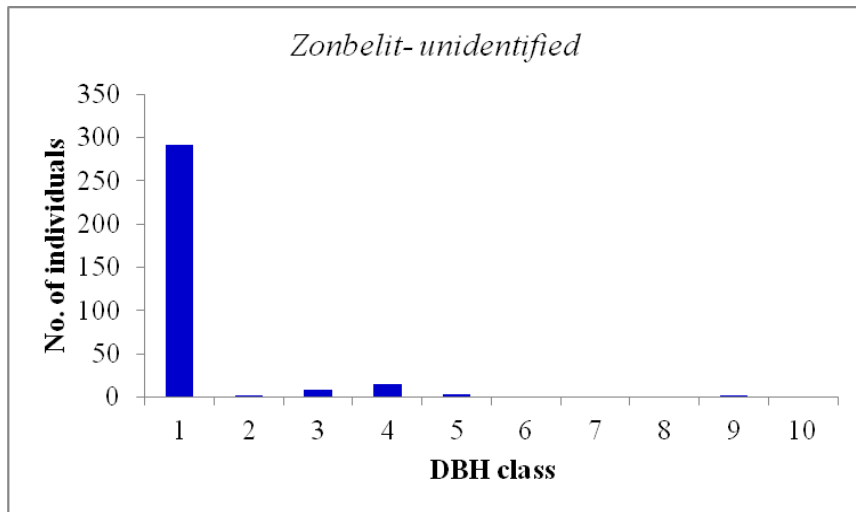


Figure 2. Population structure of selected woody species in ANP dry deciduous woodlands, North West Ethiopia

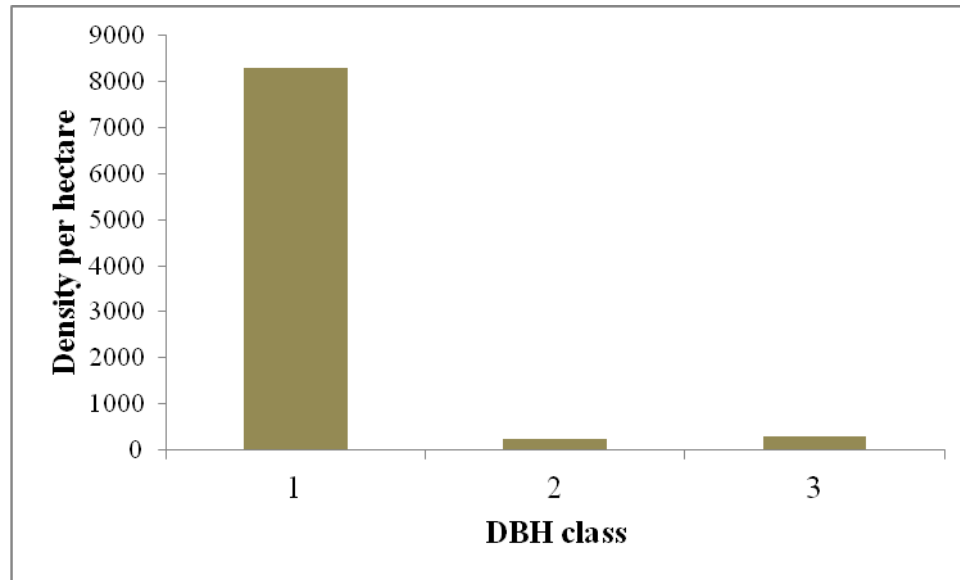


Figure 3. Regeneration status of dry deciduous woodland in ANP, North West Ethiopia (1: diameter < 3.5 cm (seedling); 2: diameter between 3.5 and 10 cm (sapling) and 3: diameter \geq 10 cm (matured trees))

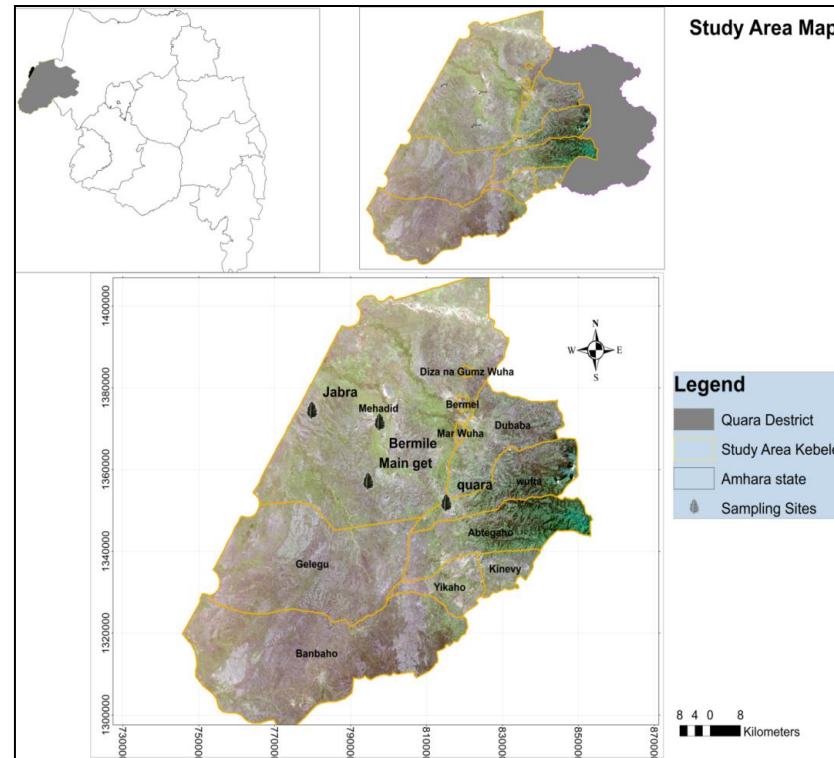


Figure 4: Map showing the study site, Alitash National Park, North west Ethiopia