ECOLOGICAL ASSESSMENT OF WOODY PLANT DIVERSITY AND THE ASSOCIATED THREATS IN AFROMONTANE FOREST OF AMBERICHO, SOUTHERN ETHIOPIA

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ABSTRACT

Mountainous ecosystems provide social, economic, and environmental services at different scales. Nonetheless, currently, they have been exposed to environmental degradation risks. This study was conducted to investigate woody plant species diversity and threats to the study forest. Systematic sampling was employed to collect vegetation data from fifty 400 m^2 sample plots along five transect lines. Vegetation and the environmental variables were recorded from each plot. Eighty randomly sampled households were selected for socioeconomic data. Descriptive statistics and ranking exercises were employed. The vegetation classification was performed using the R program version 2.15.2. The species diversity, richness, and evenness were computed. The result showed that five plant communities were recognized. A total of 99 woody plants belonging to 87 genera and 50 families were identified, of which 13 % were endemic. The total basal area of the study forest was 3.40 m2ha^{-1}, and the forest was characterized by a bell-shaped population structure identified by poor regeneration and recruitment. With increasing altitude, there was a significant decrease in human impacts, grazing, and the number of plant species. About 90 % of the informants disclosed deforestation as the major threat to forest cover change, whereas 84 % of them recommended forest restoration as a tangible measure. There was a high deforestation rate of the selected woody species (e.g., *Arundinaria alpina*) and high expansion of agriculture at the fringes of the forest. This requires promoting forest land rehabilitation activities, nature tourism, establishing partnerships with communities on the forest management, consolidating village-level institutions and developing livelihood alternatives for communities at the local governments and the community level to restore the degraded forest.

Keywords: Afromontane Forest; biodiversity; ecological assessment; Ethiopia; woody species

INTRODUCTION

Ethiopia is a mountainous country with varied topographies and diverse climate conditions that resulted in diverse ecosystems (EBI, 2014). There is a high rate of change in altitudinal gradients, temperature, rainfall, and drainage in mountainous ecosystems. As a result, the diversity of plants changes within a short distance (Lovett, 1990; Bhattarai *et al*., 2014). Accordingly, Ethiopia has 12 potential vegetation types (Friis *et al*., 2010), which were classified based on a number of parameters: precipitation, altitude, soil types, and other factors such as drainage system and salinity. This places it as the fifth largest flora in tropical Africa with vegetation types that range from highly varying desert to Afro- alpine (Friis *et al*., 2010; Soromessa *et al.*, 2004), with over 6000 species of higher plants, of which about 10 % are endemic (Kelbessa & Demissew, 2014). A substantial quantity of the Ethiopian highlands have been covered by forests in the past (Friis *et al*., 2010; Tesfaye *et al.,* 2014). Most of the remaining forests are confined to the south and southwestern parts (Amogne, 2014). Reports depicted that the forest sector in Ethiopia contributes about 13 % of the measured value of GDP (Smith *et al.*, 2016).

Mountainous forest ecosystems provide diverse services such as sources of globally notable rivers and suppliers of freshwater, hotspots of biodiversity, and centers of diverse culture (FAO, 2002), and sequester carbon (Watson, 2013). Forest ecosystems are chief sources of livelihood (Yirdaw *et al*., 2014), including food, wild edible spices, traditional medicines, and fodder (Simane, 2013). According to (FAO, 2003), forests shield the land from wind and water erosion, and protect lakes and dams from silting. Likewise, the Afromontane forest of Ambericho of Kambatta Tembaro (KT) Zone in Southern Ethiopia of the current study area provides rich cultural, ecological, and environmental services to the local community (Zewude, 2018) that ranges from the provision of food, clean water, and natural medicine to tremendous cultural uses.

Land-use change is more rapid in the tropics due to a high disproportion between deforestation and regrowth (Lovett, 1990). According to MEFCC (2018), the deforestation rate in Ethiopia is, 92000 ha/yr, but the net gain is about 19000 ha/yr. The primary sources of natural forest destruction in Ethiopia include agricultural expansion, and overgrazing (Wassie, 2020), large-scale investment, and expansion of resettlement (Amogne, 2014). Moreover, forest fire, over-exploitation, invasive species (Amogne, 2014; Friis, 1992), and weak legal enforcement were cited as factors for forest loss (Temesgen *et al*., 2015). Consequently, the degradation of forest ecosystems in Ethiopia has resulted in the loss of habitat for biodiversity, soil fertility, wood of construction, among others (Amogne, 2014; MEFCC, 2018).

Various pieces of evidence on forest resources showed that the Ethiopian government has been employing various conservation strategies like ecosystem restoration (EFCCC, 2018), watershed management, afforestation, and reforestation programs (Temesgen *et al*., 2015) to lessen the impacts of the aforementioned threats. These practices were aimed to achieve better ecosystem sustainability, including improved the livelihoods (Tefera *et al*., 2011; FDRE, 2011). There are many traditional institutions in Ethiopia involved in biodiversity conservation and sustainable use such as the Geda system for rangeland resource management, Konso cultural landscape management, and the Kobo system of Sheka forest management (MEFCC, 2018). In addition, the Ethiopian Climate Resilient Green Economy (CRGE) strategy was aimed to reduce pressure on forest resources, and land degradation (FDRE, 2011).

The Afromontane forest of Ambericho is the typical secondary forest that has been threatened by agricultural expansion. Secondary forests are forests regenerating primarily through natural processes after significant human and/or natural disruption of the earlier forest vegetation or over an extended period, and displaying modification in forest structure and/or canopy species composition, in relation to immediate primary forests on similar sites (Chokkalingam & De Jong, 2001). Some main disturbances leading to secondary forest formation in the tropics include logging, swidden cultivation, and fallowing (Mery *et al*., 2010). Secondary forests also supply forest products such as firewood, timber, protect water catchments, regulate soil erosion and function as a habitat for the forest-dependent flora and fauna (Corlett, 1995), and act as refugia for biodiversity, and enhance carbon sequestration (Mery *et al*., 2010). Despite their importance, in Africa, secondary forests are frequently eliminated as swiftly as they become a set-up to make room for other land uses. If secondary forests are to be conserved and managed productively, the local communities managing them must receive benefits. They own some ecological characteristics that improve their management, including (i) the existence of natural regeneration, (ii) relatively homogeneous species composition, and (iii) speedy initial tree growth (ITTO, 2002).

The removal, cultivation, and abandonment of tropical forest lands have resulted in a rapid increase in the areas of tropical secondary forests (Corlett, 1995). Moreover, the extent of primary forests has been radically decreased except for effectively protected forests. Consequently, the area of secondary forests is constantly increasing with accelerated global population growth-escalating land resources to secure agricultural production (Mery *et al*., 2010). According to Adrian *et al*. (2018), activities commenced with the intent of increasing the productivity per unit area of rural land use is termed land intensification, which includes four broad types: land-use conversion, increased inputs, crop or product change, and mixed intensification.

The high density of human and livestock population causes secondary forest destruction that affects habitat loss and floristic elements, which reduces biodiversity, and, subsequently, worsens the livelihoods of rural people (Mery *et al*., 2010). The major impacts have been clearance for agriculture and cutting of trees for timber or firewood (Corlett, 1995). When a forest is cleared and cultivation lasts for several years, most or all forest species are eliminated from the site, and regeneration of forest must start from scratch (Corlett, 1995). The specific objectives of secondary forest management will depend on the needs, and capacities of forest owners, and other external factors, including markets for forest products (Mery *et al*., 2010).

Ambericho Afromontane ecosystem is iconic for Kambatta ethnic group in Southern Ethiopia. It is a holy place where people worship, seat for the Kambatta king in the past, a strategic site against intruding enemy, a source of water and wood for the Zonal Capital as well as medicinal and other edible plants for the local poor people (Zewude, 2018). Nonetheless, the aforementioned ecosystem services are not fully provided today, mainly due to anthropogenic impacts (Mery *et al*., 2010), and the current ecological condition of the Afromontane forest is not studied scientifically. The scientific study of the Afromontane forest indicates the socioeconomic conditions of the area, which in turn supports to recommend appropriate forest management approaches to enhance the sustainability in general and for the livelihood of the Afromontane dependent communities. Although it is a very attractive ecotourism site, there were no ecological and socioeconomic studies conducted so far in the area. Therefore, this study attempted to i) investigate ecological conditions of the Afromontane forest of Mt. Ambericho by studying the status of woody plant species, ii) study the perception of the local community on the Afromontane forest, and iii) generate baseline data intended for the management and sustainable utilization of the forest ecosystem.

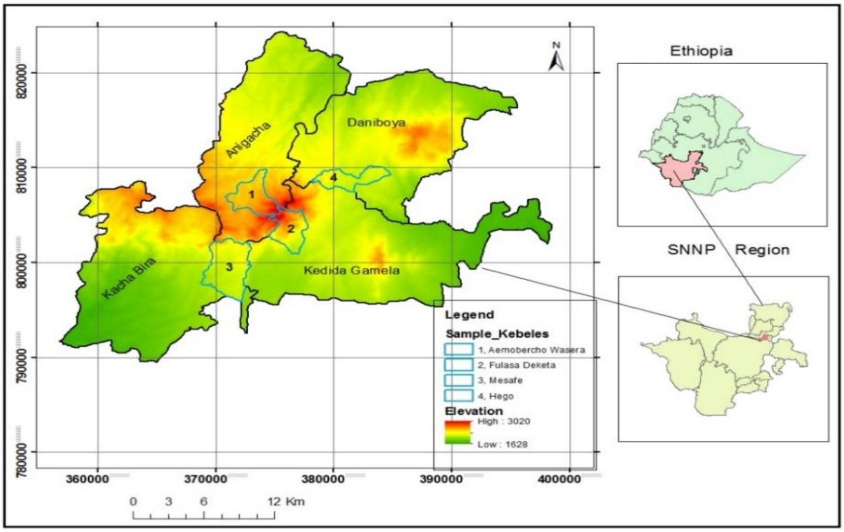
MATERIALS AND METHODS

Study area

The Afromontane Forest of Ambericho is located in the Kambatta Tembaro (KT) Zone in the south of Durame town (Fig. 1). The total area of the Afromontane is 650 hectares, with an altitude of 3038 m asl. It is 350 km distance away from the south of Addis Ababa, located at

$7^{0}\,17'\,15''$ N and $37^{0}\,52'18''$E longitude and latitude, respectively. KT Zone covers a total area of 1523.6 sq km and has an altitude range from 501 to 3037m a.s.l.

Fig. 1: Location map of study area



The study Zone has different agroclimatic zones consisting of 25% *Dega* (high land), 67 % *Woyna Dega* (midland), and 8 % *kola* (lowland). The annual average temperature ranges from 12.6-27.5^{0}C, and the annual average rainfall is 1144 mm on the Durame side, whereas its average is 1507 mm on the Angacha side. Out of its total land, 74.2 % is cultivated, and 89 % of the land is covered by bush and forest (Maryo, 2020).

Sampling design

A systematic sampling technique was employed to collect vegetation data for the current study (Kent & Coker, 1992) from the altitudinal range of 2373- 3026 m asl. Sampling sites for vegetation data collection, were along transects from the base to the peak of the Ambericho Afromontane forest in two directions (East and West). Along each transect, the tropical woody forest plants sampling method was carried out (van der Maarel, 2005) to sample plots of fifty 20 m x 20 m (400 m^2) at a distance of 50 m from each other. The distance between each transect line was 200 m. To investigate all the available tree/shrub species composition of the forest, species found outside the sample plots were considered. Socio-economic data sampling took place at four geographic sites of the study area, namely Fulassa Deketa, Mesafe, Hego, and Ambericho Wasera *kebeles* (lower administrative divisions in Ethiopia) (Fig. 1). These *kebeles* were selected based on their proximity to the Afromontane forest ecosystem. Households from *kebeles* in proximity to the Afromontane forest were selected randomly. Twenty sample household heads (HHs) per each *kebele* (80 HHs) were selected for the interview, and 5 HHs from 20 sampled HHs per *kebele* were selected for the focus group discussion (FGD).

Ethical clearance for social aspect of the study

Ethical clearance and approval letter to conduct the study were obtained from Dilla University Research Ethics Committee. Then, the support letter was written by the KT Zonal Agriculture and Rural Development Office, and given to the respective Kebele administration to communicate to individuals/ households at the village level. Then, verbal consent was obtained from peasant interviewees under study, and the confidentiality of the information given by the respondent was maintained.

Vegetation data collection

Woody plant species composition, plant diversity, vegetation structure, and plant community types of the study area were investigated. Plant species composition was used to detect the change in the ecological area. Nevertheless, species diversity as the measure of community complexity was considered as a function of species richness and species evenness (van der Maarel, 2005). DBH (diameter at breast height) was measured at 1.3 m at breast height for shrubs and trees that had a DBH ≥ 2cm. The height of trees and shrubs ≥ 2 m was measured (Bongers *et al*., 1998). A clinometer was used to measure woody species height, and visual estimates were employed when found difficult to measure. Moreover, visual estimates of percent cover for each woody plant were recorded within the 400 m^2 quadrat (Muller-Dombois & Ellenberg, 1974). The vertical stratification of trees in the study area was examined using the IUFRO classification scheme following Lamprecht (1989). Specimens of all woody plant species were collected, pressed, and dried. The voucher specimens were identified and deposited at the National Herbarium of Ethiopia, Addis Ababa.

Socio-economic data collection

The interview questionnaires were distributed to the HHs whose ages ranged from 25 - 80 years old, following Martin (1995). Eighty participants (50 males and 30 females) were interviewed using semi-structured questionnaires of > 20 in number. Twenty key informants, people who know more about what is happening in the community at the local condition, were selected from among 80 HHs selected in consultation with the Agriculture Office of the Woreda, local elders, and development agents of Kebeles. FGDs were held to verify facts gathered from surveys in order to validate the local people’s consensus. An average of 5 people were involved following Liswanti *et al*. (2012). Thus, the number of discussants who participated in the meeting from the four study sites were 5, 5, 5, and 5, respectively. Each meeting started with a discussion by asking major questions such as the changes that have occurred in the Afromontane forest over the past 4 decades, the associated challenges, impacts, and the most likely management means for the sustainability of the Afromontane ecosystem.

Environmental data collection

Environmental data collected include altitude, slope, aspect, human interference, and grazing effect. The state of human interference at each quadrat was estimated following Kidane *et al* (2010). A 0-3 subjective scale was taken into consideration to record the presence or absence of stumps, logs, and signs of fuelwood collection. Therefore, the magnitude of human impacts was quantified as follows: 0 = nil; 1= low; 2 = moderate, and 3 = heavy (Kidane *et al*., 2010). Grazing intensity was estimated following previous Works (Woldu & Backeus, 1991; Tekle *et al*., 1997): 0= nil; 1= slight; 2= moderate and 3 = heavy. Altitude and slope were recorded, and the aspect was determined. The aspect was codified as a possible indicator of total solar energy following Woldu *et al.* (1989) where N=0; E=2; S=4; W=2.5; NE=1; SE=3; SW=3.3 and NW=1.3.

Method of data analysis

Both socioeconomic and vegetation data collected were summarized using Microsoft Office Excel 2016 spreadsheet. The association of altitude with plant communities, and the impact of environmental disturbance on plant communities was examined to assess the plant-community environment relationship. Plant community as well as multivariate data, were analyzed using R-program ver. 2.14. The vegetation classification of the study area was done by agglomerative hierarchical cluster analysis (Whittaker, 2006) using similarity ratio as a resemblance index and Ward's linkage method to identify distinct vegetation assemblages (R Core Team, 2012). Following the classification, distinct plant community types were determined and named as "types" by the dominant species with the highest indicator values.

Shannon -Wiener diversity index (H') was employed to measure species diversity (Kent & Coker, 1992; Krebs, 1999). H' was calculated using a Formula, $H' = -\Sigma (Pi \ln Pi)$, where "Pi" is the ratio of a species average to the total species average (ni /N), "ln" the natural logarithm. The species evenness "J", measures the relative abundance of different species in the same area and was calculated using a formula $J = H'/Hmax$ where "Hmax" is lnS, where S is the number of species. The value of the evenness index falls between 0 and 1 which shows a divergence from evenness and perfect evenness, respectively.

The structure of vegetation was described based on the analysis of species density, DBH, height, basal area, frequency, and index (IVI). IVI depicts the structural importance of particular species within the stand of diverse species, and it was calculated as the sum from (i) the relative density; (ii) the relative frequency; and (iii) the relative dominance. The ranges between 0 and 300. DBH and tree height were classified into DBH classes and height classes, respectively. The percentage frequency distribution of individuals in each class was calculated. The tree or shrub density and basal area values were computed on a hectare basis. The vegetation data, particularly frequency, relative frequency, density, relative density, basal area, and the index (IVI) were analyzed using the previous formulae (Muller-Dombois & Ellenberg, 1974; Kent & Coker, 1992).

RESULTS

Vegetation diversity and structure

Floristic composition

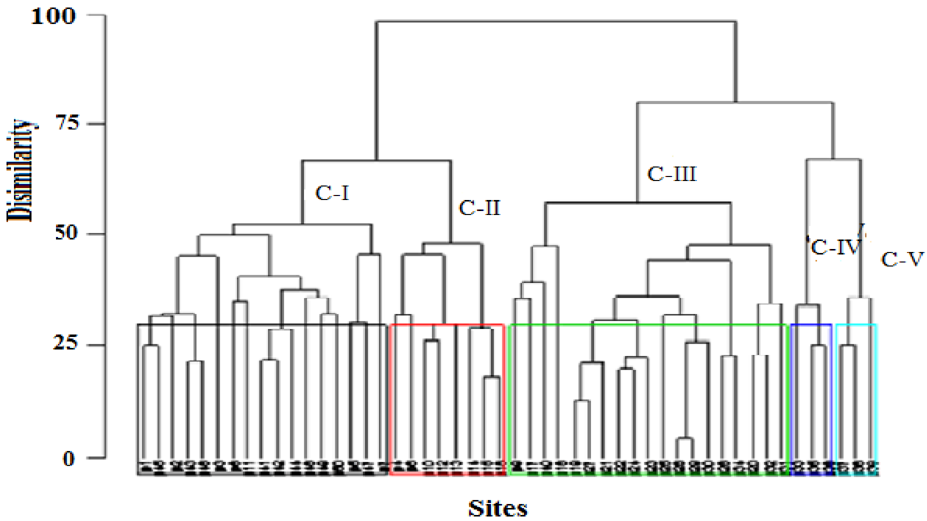
A total of 99 woody species belonging to 87 genera and 50 families were identified from the study site (see Appendix I). There was a variation in woody plant species richness and abundance of sample plots between the eastern and western aspects of the mountain. The eastern side of the woody forest consists of over 66 % of the woody species of Ambericho Afromontane forest, whereas the western side of the forest consists of about 33 % of sample plots. The ratio of woody plant species abundance in the western to the eastern side of the mountain was nearly 1:2. The dominant life forms of the identified forest species were shrubs (44 %), followed by trees (24 %), trees/shrubs (20 %), and woody lianas (12 %). Of the total identified species, 13 % were endemic to Ethiopia. The dominant family of the study area was Fabaceae (12 % of the species), followed by Asteraceae (9 %) and Euphorbiaceae (6 %).

Plant community classification.

Five plant community types were identified at 50 and 75 % dissimilarity levels (Fig. 2) with one or two species with the highest indicator values which are statistically significant ($P<0.05$) for each cluster (Appendix II). Accordingly, *Arundinaria alpina- Dombeya torrida* (Community type I), *Olinia rochetiana-Pittosporum viridiflorum* (Community type II), and

Clutia lanceolata - Helichrysum schimperi (Community type III), *Erica arborea* (Community type IV), and *Brucea antidysentrica- Discopodium penninervium* (Community type V) represented the identified communities, respectively. The community types are described as follows:

Fig. 2: Dendrogram showing plant community types of the study area



<u>*Arundinaria alpina- Dombeya torrida* community type</u> - this community is situated at an altitudinal range of 2469-2906m asl where human settlement is located, and subjected to anthropogenic influences, and represented by 17 plots and 48 species (Table 3). *Dracaena steudneri*, *Hypericum revolutum*, *Combretum molle*, and *Galinieria saxifraga* were important species in the tree/shrub layer. *Clutia lanceolata, Pentas schimperiana*, *Canthium oligocarpum*, *Asparagus africana*, *Lobelia gibberoa*, *Rubus steudneri*, *Vernonia auriculifera*, *Maesa lanceolata*, *Discopodium penninervium, and Brucea antidysentrica* were shrub species of this community. The most common lianas (climbers) of this community were *Urera hypselodendron*, *Helichrysum schimperi*, *Mikaniopsis clematoides,* and *Clematis hirsuta*, *Pergularia daemia* and *Mimulopsis solmsi.*

<u>*Olinia rochetiana-Pittosporum viridiflorum* community type</u> - located at an altitudinal range of 2837-2909m asl was represented by 8 plots and 32 species (Table 3). *Arundinaria alpina*, *Vernonia amygladina*, *Ilex mitis* and *G. saxifraga* were the dominant species in the tree layer of the community. *R. steudneri*, *E. arborea*, *Combretum molle*, *Trichocladus ellipticus, Maytenus arbutifolia*, *Schefflera abyssinica* and *Myrsine africana* were important species in the shrub layer. The most common climbers of the community were *U. hypselodendron*, *C. hirsuta*, *Smilax aspera*, and *Pentarrhinum baleens.*

<u>*Clutia lanceolata- Helichrysum schimperi* Community type</u> – found at altitudinal range from 2385-3026m asl that was represented by 19 plots and 40 species (Table 3). *Hagenia abyssinica*, *Cupressus lusitanica*, *A. alpina*, *Dombeya torrida*, *G. saxifraga*, *H. revolutum*, *Trichocladus ellipticus*, *I. mitis*, *Olinia rochetiana*, *Cassipourea malosana,* and *Ficus sur* were the dominant species in the tree layer of the community. The shrub layer was dominated by *B. antidysentrica*, *Osyris quadripartita*, *Lippia* adoensis, *A. africana*, *M. africana*, and

Inula confertiflora. *P. daemia*, *Smilax aspera*, *C. hirsuta*, and *P. baleens were* widely occurring climbers in the community.

Erica arborea Community type was located at an elevation of 2922-2926m asl and constituted of 3 plots and 4 species (Table 3). *M. lanceolata*, *V. auriculifera* and *O. quadripartita* were shrub species of the community, whereas woody climbing species diversity was very limited since it was situated at the high most altitude of the study area.

Brucea antidysentrica-Discopodium penninervium Community type situated at the elevation of 2373-2397m asl that was denoted by 3 plots and 12 species (Table 3). *G saxifraga*, *H. abyssinica*, and *Erythrina brucei* were important tree species of the community. *Inula confertiflora*, *M. lanceolata*, *V. auriculifera*, *Phytolacca dodecandra*, and *L. adoensis* represented a useful shrub layer of the community. The major climber of the community was *U. hypselodendron.*

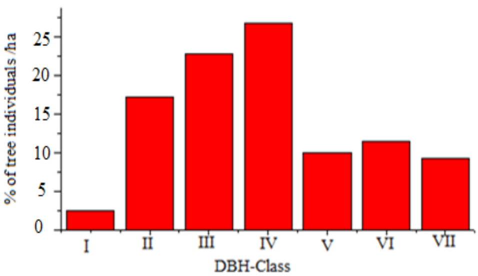
Vegetation structure

Diameter at breast height (DBH)

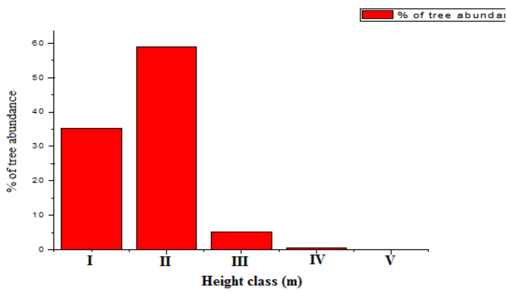
Seven DBH classes were identified. DBH class I (2-5 cm), II (6-10 cm), III (11-15 cm), IV (16-20 cm), V (21-25 cm), VI (26-30 cm), and VII (>30 cm). The DBH class interval used for this study was small because individuals found to be measured were few. The total number of tree/shrub species of Ambericho forest in DBH class increased from DBH classes I to IV, and decreases from DBH classes V-VII with increasing DBH and tended to form a bell-shaped structure (Fig. 3a). DBH analysis of Ambericho Afromontane secondary forest indicated 619. Individuals/ha.

Fig. 3: a) DBH classes and percentage of the number of individuals per hectares

Note: DBH class I represents 2-5 cm, II (6-10 cm), III (11-15 cm), IV (16-20 cm), V (21-25 cm), VI (26-30 cm), and VII (>30 cm)., and **b).** Percent distributions of trees/shrubs in the height classes, and **c)** Percent basal area distribution over DBH classes of the forest



a)



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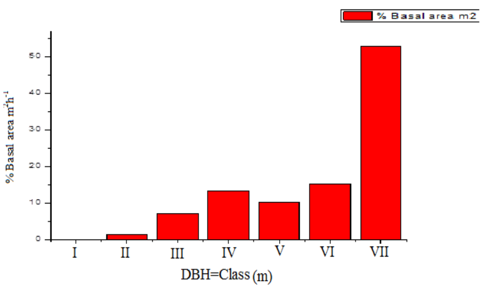


c).

Tree height

There are five tree height classes sampled, namely class I (2-5 m), II (6-10 m), III (11-15 m), IV (16-20 m), and class V > 20 m (no individual in this class) (Fig. 3b). Woody species in height classes II and I constitute 584/ha (94.4 %) of the forest, whereas woody species in height classes III and IV comprise 32/ha (5.11 %) and 3/ha (0.49 %), respectively.

Basal area

The total basal area of all tree /shrub species of the forest was 3.40 m^2/ha. About 49 % of the total basal area was covered by seven species, namely *I. mitis, Croton macrostachyus*, *H. abyssinica*, *F. Sur*, *E. brucei*, *O. rochetiana* and *C. lustanica*. From the identified woody species, 25.2 % of the total basal area consisted of *I. mitis*, followed by *A.* alpina (10.3 %), H. *abyssinica* (10 %), *G. saxifraga* (9 %), and *M. arbutifolia* (7 %.). DBH class I with a basal area of 0.06 % $m^{2/}$h was the smallest, composed of *I. confertiflora* and *M. arbutifolia* (Fig. 3C).

Index (IVI)

Of the total species identified, *Ilex mitis* was with the highest IVI (30.27), followed by *Arundinaria alpina* (27.53), *Erica arborea* (18.86), *Galinieria saxifraga* (16.06), *Maytenus arbutifolia* (15.86), *Hypericum rivolutum* (14.25), *Vernonia auriculifera* (13.71) and *Hygenia abyssinica* (10.94), *Dombeya torrida* (6.44) and others all comprises (124.43) respectively (Table 1).

Table 1: The importance value index of woody species of Ambericho Forest
(RF = Relative frequency, RD = Relative density, RDO=Relative Dominance, and IVI = Importance value index)

Botanical name	Family	RF	RD	RDO	IVI
Arundinaria alpina	Poaceae	4.24	12.97	10.32	27.53
Dombeya torrida	Stericulariaceae	2.31	0.75	3.38	6.44
Erica arborea	Ericaceae	4.95	11.38	2.53	18.86
Galinieria saxifrage	Rubiaceae	3.30	3.97	8.79	16.06
Hagenia abyssinica	Rosaceae	0.71	0.14	10.09	10.94
Hypericum revolutum	Hypericaceae	5.12	5.95	3.18	14.25
Ilex mitis	*Aquifoliaceae*	3.53	1.56	25.18	30.27
Inula confertiflora	Asteraceae	4.06	5.79	0.18	10.03
Maytenus arbutifolia	Celestraceae	4.80	3.91	7.12	15.83
Olinia rochetiana	Olinaceae	2.47	2.65	6.53	11.65
Vernonia auriculifera	Asteraceae	5.48	5.76	2.47	13.71
Others	-	59.03	45.17	20.23	124.43
Total		**100**	**100**	**100**	**300**

Woody species with lower IVI measure were *Lepidotrichilia volkensii (*0.45), *Flacourtia inidca (*0.50), and *Canthium oligocarpum (*0.92) from smallest to the largest.

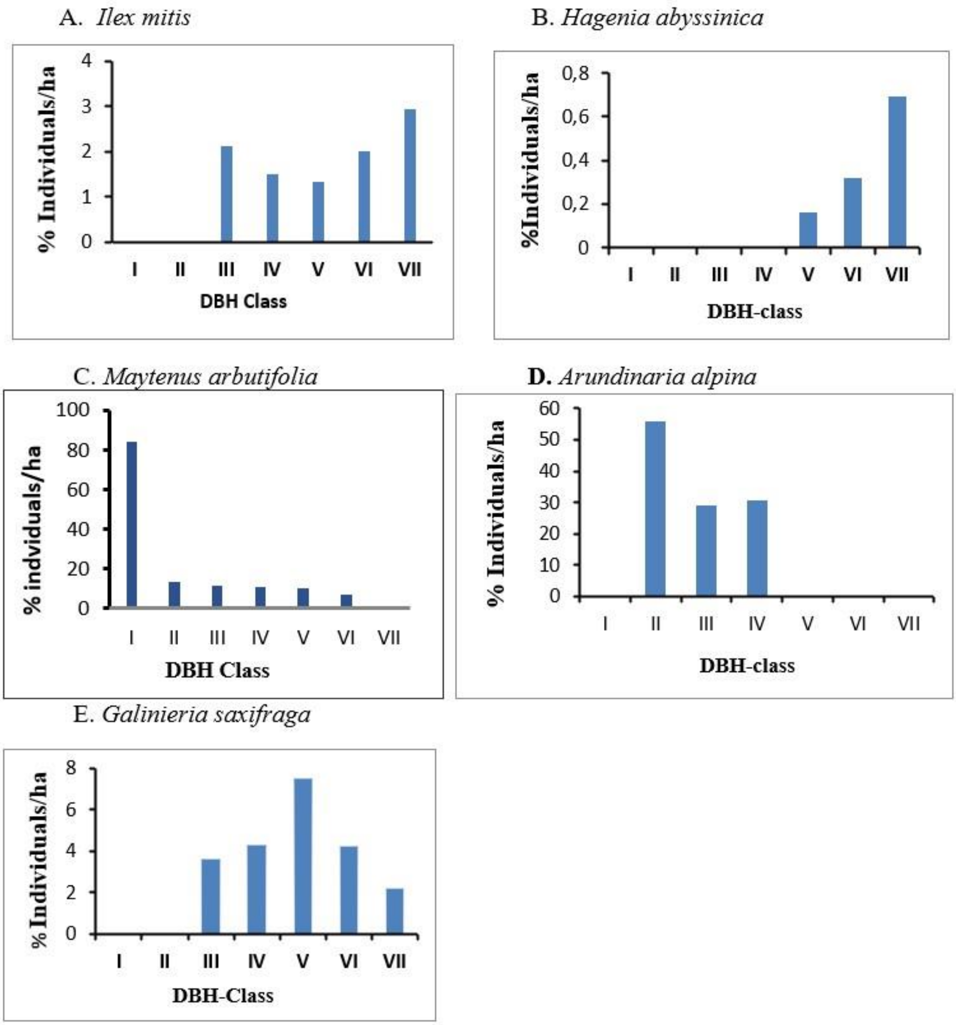
Population structure of representative woody species

The population structure of the Ambericho forest can be represented by the five woody species that had higher IVI, namely *I. mitis, H. abyssinica, M. arbutifolia, A. alpina,* and *G. saxifraga*. Five different patterns of plant population structure have been identified from the current forest, namely irregular, broken J- shaped, inverted J-shaped, broken inverted J-shaped, and broken bell-shaped patterns.

The first pattern was irregular, characterized by *I. mitis* (Fig. 4 A). Then the remaining DBH classes III- VII formed almost a U- shaped pattern. The second was a broken J- shaped configuration represented by *H. abyssinica* (Fig. 4B) where there were no individuals at the lower DBH classes (Class I-IV). The third pattern was an inverted J- shape illustrated by *M. arbutifolia* (Fig. 4C). *D. torrida, D. steudneri*, and *V. auriculifera* were woody species. Another pattern was a broken inverted J- shaped denoted by *A. alpina* (Fig. 4D) where individuals were missed at lower DBH (class I). The last pattern was a broken bell-shaped as shown by *G. saxifraga* (Fig. 4E).

Fig. 4: Five representative patterns of population structure (A_E) of tree species in Ambericho forest.

Note that DBH classes are: I) 2-5 cm, II) 6-10 cm, III) 11-15 cm, IV) 16-20 cm, V) 21-25 cm VI) 26-30 cm, VII)>30 cm.



Vertical stratification

The vertical stratification indicated that the species with the highest height was *E. brucei*, 20 m. Based on this, trees with height > 13m represented the upper storey (layers), which consisted of *E. brucei, H. abyssinica, C. lustanica,* and *F. sur*. The upper canopy layer constituted about 6 % of the woody species. Woody plant species with the height range of 7-12m represented a middle storey and contributed to about 365/ha (59.0 %) of the tree/shrub species of the height class. Species with the height < 7m constituted 218.94/ha (35.4%) of the lower storey.

Plant Community-Environment Relationship

The box plot (Fig. 5a) shows variation in plant communities along the altitudinal gradient. Plant community III represented by *C. lanceolata- H. schimperi* was recorded at the highest altitude (2385-3026m asl) whereas plant community five epitomized by *B. antidysentrica-D. penninervium* was located relatively at the lowest altitude (2373-2397m asl). Community IV (*Erica arborea* community type) was noted at the altitudinal range of 2922-2926m asl which was represented by few species.

Fig. 5: a) Box plot for the association of altitude with plant Communities, and b) the impact of disturbance on plant communities. Note that Community 1- 5, represent community I-V of Figure 4).

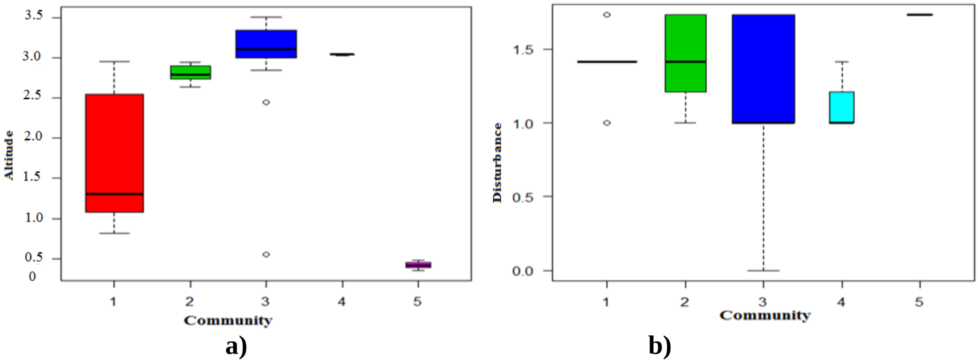


Fig. 5b shows that plant community I is located relatively at mid altitude that faced less disturbance than plant community V, and situated at the lowest altitude subjected to human disturbance.

The result of Pearson's product-moment correlation of environmental parameters is shown in Table 2. Altitude was negatively correlated to human impact, grazing, and plant species richness. Human impact was positively correlated with grazing intensity.

Table 2: Pearson's product-moment correlation coefficient for correlations between environmental variables

	Alt	Himp	Asp	Slop	Graz	No.sp
Alt	1					
Himp	-.509**	1				
Asp	-.203	.149	1			
Slop	-.158	.155	.095	1		
Graz	-.0423**	.495**	.080	-.174	1	
No.sp	-.313*	-.023	.015	.174	-.047	1

Note: *. Correlation is significant at 0.05 level (2-tailed).
**. Correlation is significant at 0.01 level (2-tailed).

Key: Alt- refers to altitude, Himp – human impact, Asp- aspect. Slop- slope, Graz- grazing by hervibores, and No.sp- number of species.

Diversity and Similarity analysis of plant communities

The outcome of the Shannon-Weiner diversity index (H') analysis shows that community type III had the highest species diversity, followed by community I. The highest species richness and evenness were recorded from community types III and I, respectively (Table 3).

Perception of local people on threats to Ambericho Afromontane forest

Informants disclosed that major threats for forest cover change include deforestation, agricultural expansion, and climate change (Table 4).

Ambericho forest represents the tropical secondary forest. Eighty-nine percent of informants confirmed that deforestation of the study forest is the top possible threats for forest cover change (Table 4). They explained that the Afromontane forest has been dwindling due to the use of forest resources for farm tool making, construction and fencing, firewood (Fig. 6A-D), and agricultural expansion (Fig. 6E-F), among others factors.

Table 3: Total plots examined, Species richness, Shannon - Wiener index, and evenness of the plant communities

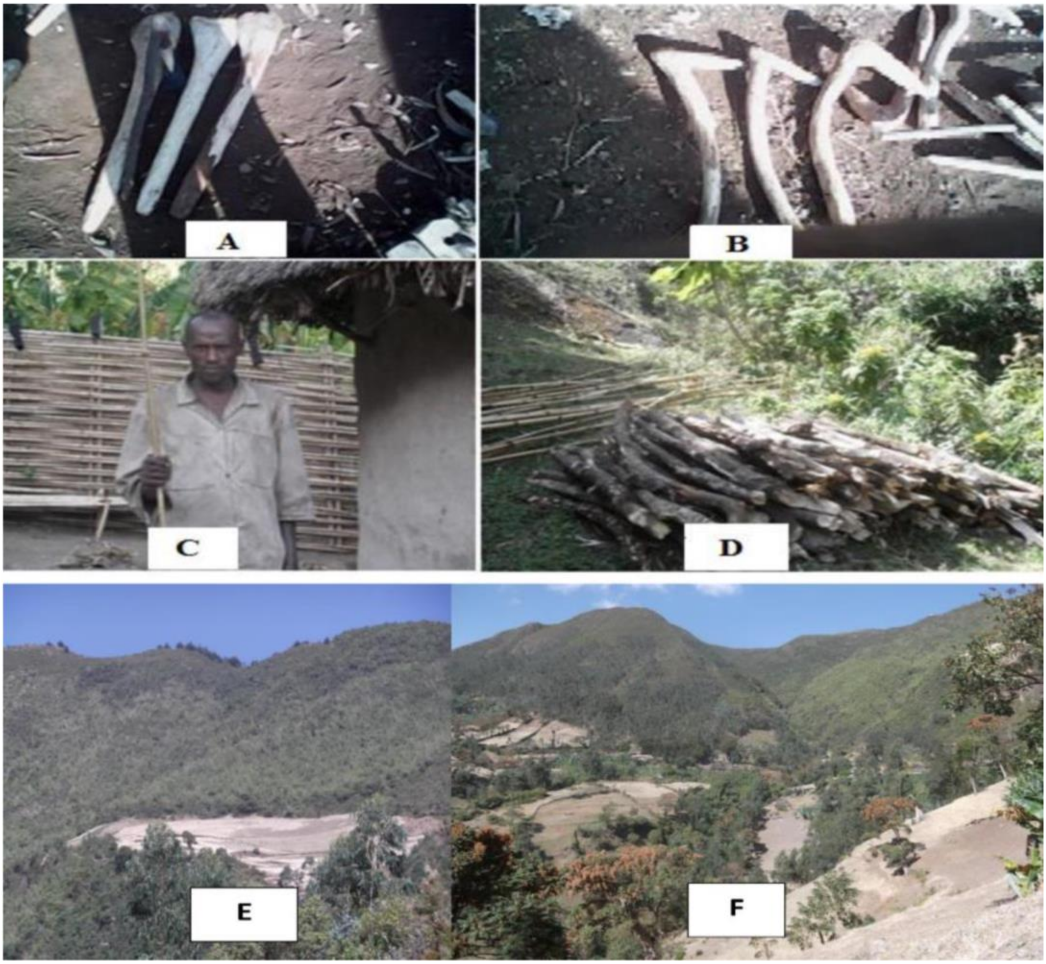
Community	Total plots	Species richness	Diversity index(H')	H' max	Species evenness(J)
I	17	48	2.77	3.87	0.72
II	8	32	2.02	3.47	0.58
III	19	40	2.92	3.69	0.79
IV	3	4	0.96	1.39	0.69
V	3	12	1.08	2.48	0.44

Table 4: Threats and possible solutions to Afromontane forest (N= 80)

S.No	Questions		Response		
1	**Is there any forest cover change over years?**		**Frequency**	**%**	
	a.	Yes,	68	85	
	b.	No,	12	15	
2	**What were possible threats for the forest cover change (you may Select > 1 choices)**				
			Freq.	**%**	**RO**
	a.	Deforestation	23	88.8	1
	b.	Climate change	11	73.8	3
	c.	Agricultural expansion	15	78.8	2
	d.	Impact of exotic species	9	31.3	4
	e.	Browsing effect	3	3.8	6
	f.	Firing	7	8.8	5
	g.	Other (list. If any)	0	0	
3	**What were happened due to forest cover change**		**Freq.**	**%**	**RO**
	a.	Soil erosion (by water & wind)	21	86.3	1
	b.	Lack of potable clean water	18	72.5	3
	c.	Climate change	20	55	2
	d.	Extinction (loss) of wild animals	15	78.8	4
	e.	Reduction of agricultural product	13	66.3	5
	f.	Other(Lis if any)	3	3.8	6
4	**Possible means to sustain Afromontane forest diversity**		**Freq.**	**%**	**RO**
	a.	Awareness raising among the local community	29	86.3	1
	b.	Establishing community bylaws and participatory conservation approach	10	52.5	3
	c.	Restoring the degraded forest area	35	83.8	2
	d.	Other (List, if any)	5	6.3	4

Key: Freq. = Frequency, Ro= Rank order.

Fig. 6: Degradation of Afromontane forest due to various purposes:
A and B) farm tools, C) construction, D) firewood collection, and E-F) agricultural expansion



About seventy-nine percent of the informants confirmed that agricultural expansion is the second important threat to the study forest. Researchers observed in the field that those farmers whose land located at the edge of the forest (Fig. 6E & F) aggravated forest degradation by encroaching into the natural forest.

About seventy-four percent of the informants believed that climate change has modified the existing forest biodiversity as well as the livelihoods of the local people, which in turn forced poor local people to harvest available resources illegally. They also disclosed the top effect of forest cover change to be soil erosion (86 %) (Table 4). Similarly, when informants were asked about the leading possible means to sustain the forest, they suggested awareness raising among the local community on the role of forest biodiversity conservation (86 %) (Table 4).

DISCUSSION

Vegetation diversity and structure

Woody species composition

Ambericho Afromontane forest was represented by a large number of species (99) record from the degraded secondary forest in tropics. For instance, 66 forest species of Guraferda (Hundera & Deboch, 2008), 41 species of Gedam (Gedafaw & Soromessa, 2014), 95 species of Boda dry evergreen montane (Erenso *et al*., 2014), 51 species of Tara Wotagisho (Unbushe & Tekle, 2016), and 76 woody forest species of Ethiopian (Boz & Maryo, 2020). This shows that Ambericho forest has relatively large number of woody forest species. Of the total species identified in the forest, > 13 % were found to be endemic to Ethiopia (see Appendix I), which are medicinally important elsewhere in Ethiopia (Maryo, 2020) besides other ecosystem services.

Some informants reported that there were few common woody climber species in the plant communities due to human harvesting undertakings for farm tool construction and other craft activities. Human interventions also cause a change in species composition in the plant community (Mery *et al*., 2010). For instance, community IV situated at the altitude range where human settlement located was represented by very few species due to anthropogenic disturbances. Similar findings were reported from Ethiopia (Temesgen *et al*., 2015; Teketay, 2005). Environmental factors such as slope, soil, physical and chemical features have sound effects on patterns of plant communities (Wana & Woldu, 2005; Danu, 2006).

In the current study, low species evenness was observed in plant community type V that is probably attributed to imprudent environmental disturbances, mainly by anthropogenic exploitation, elevation variation, and inapt conditions for plant species regeneration (Wana & Woldu, 2005; Manuel & Molles, 2007). High plant species diversity and evenness in communities III, II, and I could be related to the fair forest management, differences in the number of plots, and the level of species abundance per plant community. One study (Wana & Woldu, 2005) indicated that the species richness and diversity tend to peak at an intermediate altitude and decline at the lower and upper elevations. Similarly, the result of the present study more or less agrees with this finding, where there is more anthropogenic impacts at the lower, and less conducive environmental condition at the upper elevation, respectively.

The elevation and aspect of the study area are considered as factors that determine the woody species abundance and distribution, by determining the climate and agro ecology of the area. Therefore, the finding of this study agrees with White (1983) who explains that aspect of hilly slopes significantly influence the horizontal distribution of vegetation within the elevation range. As to Wana & Woldu (2005), altitude directly influences temperature, and moisture similarly in this study eastern side (windward side) is greater than the western side (leeward side) where high condensation of clouds takes place. Accordingly, the western side of the mountain consisted of a few woody forest species. Furthermore, most informants disclosed that agricultural expansion and deforestation are major factors for the observed differences in the forest. The high anthropogenic disturbances on natural forests tend to challenge the succession process, species richness, agricultural productivity, and the livelihood of people (Mery *et al*., 2010).

Most informants confirmed that four decades ago, Ambericho Afromontane forest was almost covered by native woody species. The major forest part was deforested since the “Derge” regime in Ethiopia (i.e., 1974-1991, the period when the military government was ruling the country) aimed to extract firewood and expand the cropland. Furthermore, the chief native woody species of the forest were replaced by exotic tree species like Eucalyptus and Cupressus sp. focusing on the temporary economic importance of these species than biodiversity conservation (Mehari, 2012; Yirefu *et al.*, 2016). Nonetheless, an expansion of such fast-growing tree species continued as a threat to the forest species composition since they could alter the Afromontane forest structure (Awoke & Mewded, 2019), chiefly by replacing native plant biodiversity.

Vegetation stand structure

A. alpina occurred in 75 % of the quadrats on the eastern side of the mountain, indicating its dominance. The whole regeneration profile of the forest vegetation based on woody species density, DBH, height, frequency, basal area, and IVI of the species form a vertical structure (Boz & Maryo, 2020). Greater frequency may show the woody species ability to regenerate in the wider area, whereas smaller frequency could suggest clustered distribution of the species (Ayanaw & Dalle, 2008). The species distribution can be attributed to their ecological adaption to the area, including their biological strategy to perpetuate.

Diameter class distribution of the selected woody species of various patterns of the population structure suggests differences in population dynamics among species (Manuel & Sher, 2019. Individuals of *I. mitis*, *H. abyssinica*, *E. brucei*, *F. sur*, and *C. macrostachyus* were recorded in the higher DBH classes. Out of these species, *I. mitis*, *E. brucei*, *H. abyssinica* and *F. sur* had DBH > 100 cm. The most abundant DBH class was class IV (16-20 cm), which might have been associated with the low preference of the aforementioned species at this stage by the local community. On the other hand, a decrease in the percentage of individuals among DBH classes (V-VII) seems to be the exploitation of forest for various socio-economic purposes, chiefly construction and firewood collection. Correspondingly, the decrease in the percentage of the number of individual woody species within larger DBH classes was found to be illegal cutting for construction and fuelwood consumption (Tesfay *et al*., 2019; Boz & Maryo, 2020) as well as charcoal making (Tefera *et al*., 2011). Our finding depicted the structure of the DBH class to be a bell shape. This indicates a higher number of individuals in the middle diameter classes (EFCCC, 2018; Tesfay *et al*., 2019). This could be associated with factors like demand for fuelwood and pole, selective wood harvesting as well as clearing for agriculture (Boz & Maryo, 2020). According to Senbeta *et al*. (2007), a bell-shaped pattern indicates a poor reproduction and recruitment of species.

In general, the pattern of the DBH class depicted that the study forest is a dying type unless quick restoration and proper management actions are put in place. Nonetheless, studies from the northern part of Ethiopia showed an inverted bell-shaped distribution, which depicts a good potential for reproduction and recruitment of the forest (Ayanaw & Dalle, 2008). The highest number of individual trees/shrubs was found to be 365/ha, which comprises 59 % of the total woody species of Ambericho forest. The low percentage of species density at lower DBH class, which could be linked to poor regeneration of the forest. The height of a tree can be used as an indicator of the age of the forest (Kebede *et al*., 2016). Old trees are found at the height class > IV that are economically important but constitute only 0.49 % of the woody species distribution. Therefore, continuous anthropogenic forest disturbances (Yirdaw *et al*., 2014) made the Afromontane forest of Ambericho to be a characteristic secondary forest (Chokkalingam & De Jong, 2001). Thus, it demands more efforts to reverse the negative impact on it.

The study on basal areas denoted that very few species have large basal areas. The percentage of tree individuals with the lowest DBH class almost had negligible basal area/ha whereas species with a lower percentage of individual tree/shrub density and higher DBH had a high basal area. The forest species with high basal area were reported to be economically important for construction, timber, and farm tool, primarily composed of

I. mitis, *M. arbutifolia*, *E. brucei*, *C. macrostachyus*, *H. abyssinica*, and *F. sur*. When compared with other Afromontane forests of Ethiopia, Ambericho forest has the lowest basal area/ha (3.40 m2/ha) than 142.6 of Masha (Assefa *et al*., 2013), 129 of Bale Mountains (Hundera *et al*., 2007), 94.2 of Mana Angetu (Kidane *et al*., 2010), and 6.81 basal area of Afar region (Tefera *et al*., 2011). On the other hand, the lowest basal area (1. 3) was reported from the Kota dry forest in India (Sagar *et al*., 2003). In short, the lower basal area of the study forest shows low forest productivity. The lower basal area in Ambericho forest could also provide an opportunity for the decreased tree competition, and growth of grasses and other tree species, which in turn could support wildlife biodiversity provided that the forest is properly managed.

Population structure

Out of the five different patterns of population structure identified, the irregular pattern is associated with poor regeneration and recruitment or damage by domestic animals. Domestic and wild animals browse almost all species in this group. The number of individuals of broken J- shaped pattern in this study increased with increasing DBH classes. A similar pattern was reported from moist Afromontane forests (Senbeta, 2016) where the J-shaped pattern was displayed by *Syzygium guineense* with a low number of individuals in the lower diameter classes but increased towards higher classes. According to the author, this pattern exhibited poor reproduction and hindered regeneration. *H. abyssinica* is one of the most useful medicinal plants in this pattern where the female flower part is used as a remedy for tapeworm infestation. This may affect the production of viable seeds to germinate and enhance seedling (Negash, 2010). Accordingly, *H. abyssinica* tree became the most endangered woody species that requires special conservation priority at the country level.

The inverted J- shaped pattern shows numerous individuals at a lower DBH-class that decreases to some DBH-classes and slightly shows increasing and decreasing pattern at higher DBH-class. All species in this category show good reproduction. According to Boz & Maryo (2020), such pattern exhibits healthy populations that substitute themselves naturally through recruitment. Nonetheless, not all members of this group may reach to a maximum DBH limit through maturity, such as *M. arbutifolia* due to its natural limit.

The forest species with the highest IVI in Ambericho forest was *I. mitis*, followed by *A. alpina*, and *E. arborea*. This index divulges a comparison of species in a given location and reveals the incidence of a given species in relation to other associated species in the area. It enables ecologists to rank the species for management and conservation priority based on its features in the vegetation (Boz & Maryo, 2020). In the current finding, *D. torrida*, *I. confertiflora* and *H. abyssinica* had lower IVI. Accordingly, these species require higher conservation priority (Lamprecht, 1989; Awoke & Mewded, 2019). The high IVI of the study of woody species perhaps related to conservation effort as in the case of medicinal plant by the local people, rapid regeneration capacity and the multipurpose utility by a local people (e.g., *A. alpina*).

Vertical stratification

Our finding showed that some species like *E. brucei* and *H. abyssinica* were located only in the middle and upper storey whereas other species like V. auriculifera and I. confertiflora were limited only to the lower storey. On the other hand, there was a large number of individuals in the middle story. This could be linked with poor recruitment at the lower stratum and high disturbance of the upper story class by human exploitation. Similarly, a report depicted only few species' abundances at the upper storey (Senbeta, 2016), and the structure of upper story height plays a substantial role in shaping different microenvironments that eventually determine conditions that limit beneath plant growth (Bekele, 1994). On the other hand, numerous individuals in the lower story (97 %) reported from SW Ethiopia (Boz & Maryo, 2020). They showed that the physical environment and anthropogenic factors shaped the vertical stratification of the forest. Recruitment and growth of tree/shrub species, as well as the competition for environmental factors, can cause the vertical organization of the plant community. In general, the low density of the canopy tree species could be linked with anthropogenic influences other than the climatic condition of the current study area.

Relationship between plant communities and environmental factors

Our finding depicted that the number of forest species is negatively correlated with increasing altitude, grazing, and human impact. Woody species richness and altitude had a negative correlation, where species richness decreased with increasing altitude (Awoke & Mewded, 2019). The species diversity, richness, and abundance is highly influenced as human impact and grazing increase. Human impact, grazing, and aspect are positively correlated to each other. The finding is consistent with Kidane *et al*. (2010). There was relatively a high level of disturbance in community I than in communities II and III due to its closeness to human settlement. The high level of forest disturbance is associated with human interference where agriculture expands, and people collect firewood from the forest. Human impact has increased the intensity of grazing and aggravated deforestation, which in turn may lead to the expansion of agriculture as well as biodiversity loss. This type of land-use conversion is a typical example of land-use intensification, which could lead to biodiversity loss and ecosystem degradation (Adrian *et al*., 2018). Furthermore, it was reported that the plant species diversity of the dry evergreen forests has been significantly reduced by anthropogenic disturbance (Sabogal, 1992).

Threats to Ambericho Secondary Afromontane forest

Authors field observation and the informants' discussion depicted that local people used to burn the forest to 1) remove wild animals that attack their field crops, and domestic animals, and 2) to get better grass and or fodder for their livestock. The rate of deforestation seems the highest for natural *A. alpina*. Its deforestation was aggravated due to its demands for construction, beehive, household furniture, and the short logs (sissaa for chopping pseudostem) to scrap the enset crop). As a result, crafts men deforest it illegally from different sides of the study forest. Deforestation continued at alarming rate in the tropics due to extreme levels of disturbance (Manuel & Sher, 2019). Even though, threats to *A. alpina* is the highest, other forest species like *M. arbutifolia*, *O. rochetiana*, and *C. malosana* were also under threat because of firewood collection, farm tool making, and house construction. As to Mery *et al*. (2010), ongoing secondary forest destruction will result in biodiversity loss, reduces agricultural productivity and worsen the livelihoods, which in the long run may cause ecosystem imbalance.

Seventy-nine percent of the respondents agreed that degradation of the forest cover resulted in the loss of wildlife biodiversity such as civets, gazelle, and leopard. Some animal species became extinct, namely Walia Ibex (endemic to Ethiopia). Afromontane areas of Ethiopian mountains are among the unique centers of biodiversity, hosting varied endemic flora and fauna, also became sources of many transboundary Rivers, and holding amazing sociocultural significance that links people with nature and to the provision of material goods and services. Studies on Afromontane areas of Ethiopian ecosystems indicate a declining trend caused by anthropogenic and non-anthropogenic changes on the land use and land cover system, mainly due to the expansion of agricultural land and settlement areas (Lemessa *et al*., 2022).

Informants substantiated that fire wood is an important energy source for rural people for coking and backing which is obtained from forest cut or by price so that, one donkey load of the firewood on average equals about 400 Ethiopian Birr (≈ 10 USD), which is sold in the market This contributes much to forest species loss. Forestland intensification is more marked in the study area by land conversion and product change (Adrian *et al*., 2018), which has been driven by the population pressure.

Informants have reported awareness-raising, restoration of degraded ecosystems with full community participation, enhancement of law enforcement, and the establishment of effective participatory forest management as methods to sustain the current study forest, which are scientifically supported solutions (Amogne, 2014). Furthermore, ecosystem restoration, including, afforestation, reforestation programs, and watershed management (EFCCC, 2018; Temesgen *et al*., 2015) are good initiatives still taking place by the government of Ethiopia. Informants also discussed encouraging experiences that were carried out by KMG-Ethiopia (NGO) on soil and water conservation activities with the aim to restore degraded forest areas, by planting indigenous forest species such as *H. abyssinica*, *Syzygium guineense*, *A. alpina* as well as few exotic tree species. According to key informants, restoration activities are believed to restore animal diversity besides rehabilitation of natural bamboo (*A. alpina*) and other ecologically important woody forest species. Therefore, Ambericho secondary forest can be managed effectively by involving local communities by reducing grazing, firing, and, changing it into farmland if aimed to ensure secondary forest's sustainability (ITTO, 2002).

Many traditional institutions in Ethiopia that currently support for biodiversity and ecosystem conservation include Geda system, Gedeo agroforestry, Konso cultural landscape management, and the Kobo system of forest management (EFCCC, 2018). Informants of the present study showed that the forest of Ambericho was considered as a sacred (holy place) where people from the Kambatta ethnic group in Southern Ethiopia used to worship the traditional God “Abba Sarecho” once yearly in September (about 50 years before), a month for the beginning of a new year. This has enabled better conservation of the forest, including medicinal plants, wild life and the forest ecosystem at large (Zewude, 2018). Nonetheless, informants confirmed that such tradition has already abandoned by the young generation and others due to modernization and the expansion of protestant Christianity in the area.

CONCLUSION

The Ambericho Afromontane forest represents secondary forests where intense land-use intensification was observed due to a large population of both human and livestock. The local community confirmed that in the Afromontane forest both biodiversity resources, and ecosystem services, are declining. Both land-use intensification and land use change became the characteristic of the study forest area, which is causing negative impacts on the forest ecosystem as well as on the livelihood of the local community. This study indicated relatively rich woody plant diversity, of which about thirteen percent of the identified species were endemic to Ethiopia, and almost all have been previously reported to have a medicinal value. Afromontane areas of Ethiopian mountains are among the unique centers of biodiversity, hosting varied endemic flora. The study forest area is also a source of the Omo River, transboundary Rivers, and hold prodigious cultural values for linking people with nature and serving the purposes of recreation and tourism besides material goods and services.

Nonetheless, the mountain ecosystem has entered a declining phase as manifested by shrinkage of coverage due to ongoing human-driven land-use and land-cover changes with increasing agriculture and settlement, as well as vulnerability to climate change, which calls for grand attention to forest conservation.

Five different population structures have been described where the forest forms a bell-shaped structure, which is characterized by poor reproduction and recruitment of the species. The analysis of population structure depicted reduction in the abundance of tree species like *H. abyssinica* and *O. europea sub. sp cuspidata*, and the high rate of exploitation of *A. alpina* for diverse uses, which calls for the need for conservation of such priority plant species. From informants' discussion and researchers' field observation different anthropogenic practices in the forest were identified, namely deforestation and agricultural expansion that influenced the biodiversity and ecosystem services of the Ambericho Afromontane forest. Accordingly, the following points were recommended:

- Introducing participatory forest management for the conservation of locally threatened and economically useful species such as *H. abyssinica, A. alpina and O. europea sub.sp cuspidata.*
- Ambericho Afromontane forest is a tower of potable water source for many surrounding and neighboring communities, including boundary-crossing rivers, including the Omo River. Thus, the restoration of the degraded forest using native trees/shrub species should involve the local people to enhance and recuperate the availability of water.

It is recommendable to establish partnerships with communities for community empowerment on the forest, and consolidating village-level institutions/associations to promoting forest land rehabilitation activities, and nature tourism that involves conservation of the environment and improves the welfare of local people.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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