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Diversity and regeneration of native woody plant species as indicators of sustainable ecosystem service provisioning in Menagesha Suba Forest, Central Ethiopia

G. Kewessa*, **, M. Tolera*

*Hawassa University, Shashemene, Ethiopia
**Ambo University, Ambo, Ethiopia

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Wondo Genet College of Forestry and Natural Resources, Hawassa University, Shashemene P.O. Box 128, Ethiopia. Tel.: +251-913-240-574. E-mail: gonfa.kewessa@gmail.com

Department of Forestry, Guder Mamo Mezemir Campus, Ambo University, P.O. Box 19, Ambo, Ethiopia.

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Biodiversity loss poses significant threats to forest ecosystem services (FES) and human well-being. Despite their critical importance, understanding FES dynamics in developing countries like Ethiopia remains limited due to a lack of comprehensive data on biodiversity, vegetation structure, and their relationships with FES. This study aimed to address these gaps by investigating the diversity, structure, regeneration status, and FES provision of woody plant species in Menagesha Suba Forest, one of Ethiopia's oldest dry Afromontane forests. A vegetation inventory conducted across 94 systematically sampled plots (20 × 20 m) identified 71 woody species, comprising 42.3% trees, 46.5% shrubs, and 11.3% woody climbers, belonging to 56 genera and 43 families. Dominant species included *Juniperus procera* (IVI = 86.5%) and *Olea europaea* (IVI = 28.2%). Diversity indices indicated high species richness (H' = 3.06), moderate evenness (0.72), and high biodiversity (D = 0.93). Household surveys (n = 145) revealed that 43 woody species were utilized for nine key uses. Fuelwood was the most common use (26 species), followed by fences (22 species), farming tools (21 species), house construction (17 species), and household utilities (16 species). Apart native woody species, exotic species, including *Eucalyptus globulus*, *Cupressus lusitanica*, and *Grevillea robusta*, were among the most utilized. Despite disturbances such as illegal fuelwood collection and grazing, the forest remains a critical biodiversity hotspot and an essential provider of ecosystem services. Strengthening landscape multifunctionality through assisted regeneration, targeted reforestation, and afforestation is imperative to balance biodiversity conservation with FES provision. Future research should integrate biodiversity and ecosystem service data to guide evidence-based conservation strategies, fostering socioecological resilience in Ethiopia and similar regions.

Keywords: forest ecosystem services; biodiversity conservation; useful tree species; human disturbance.

Introduction

Forests form the foundation of terrestrial ecosystems, and play a vital role in maintaining ecological balance, supporting biodiversity, and contributing to human well-being (Malik et al., 2014; Bhat et al., 2020; Shumi et al., 2021; Duguma et al., 2023). Among these, tropical forests stand out for their unique biodiversity, hosting the majority of the world's biodiversity hotspots and approximately 60% of known vascular plant species (Pillay et al., 2022), despite covering less than 20% of Earth's terrestrial surface (Dinerstein et al., 2017). These forests not only provide vital ecosystem services for approximately 1.5 billion people but also play an indispensable role in regulating the Earth's climate (Lewis et al., 2015).

Forest ecosystems offer diverse ecosystem services categorized into provisioning, regulating, supporting, and cultural services. Native tree species, in particular, provide greater ecosystem service value due to their adaptation to local environmental conditions (Solorio et al., 2017). The ecosystem service framework links biodiversity with human well-being, underscoring the role of biodiversity in supporting ecosystem functions such as nutrient cycling, climate regulation, and provisioning of food, fuel, and timber (Brander et al., 2024; Costanza et al., 2014). However, the relationship between biodiversity and ecosystem services remains underexplored, particularly in tropical regions including Ethiopia where inappropriate land-use intensity adversely influences biodiversity and ecosystem functionality (Shumi et al., 2021; Jeldu et al., 2023). Biodiversity loss and ecosystem degradation disproportionately affect smallholder farmers, who heavily depend on forest resources for their livelihoods (Tadesse et al., 2014; Gebreselassie et al., 2015; Tekalign et al., 2017).

Over the past decades, Ethiopian forests have faced significant threats, including deforestation, forest degradation, and unsustainable resource extraction, leading to biodiversity loss and a decline in ecosystem services (Ethiopian Biodiversity Institute, 2022). In Ethiopia's central highlands, Menagesha Suba Forest exemplifies these challenges. As one of the country's oldest national forest priority areas, over 500 years old, this forest has been subjected to intensive human activities, including agricultural expansion, open grazing, fuelwood collection, and illegal logging, resulting in shifts in species composition and biodiversity loss (Duguma et al., 2009; Benti, 2011; Tekalign et al., 2017; Tolessa et al., 2017; Deyessa & Emana, 2024; Workneh & Wasie, 2024). These pressures jeopardize the forest's ecosystem services, which are essential for local livelihoods and ecological resilience.

A comprehensive approach to understanding and measuring forest ecosystem services includes understanding key ecosystem service providers, factors influencing the ability of providers to deliver services of interest, and measuring spatial and temporal scales over which providers operate and ecosystem services are available (Garbach et al., 2014). The relationships between biodiversity and ecosystem function are also important for understanding the provision of ecosystem services (Garbach et al., 2014). For instance, species richness measured as the number of species in a given area is associated with enhanced ecosystem services (Balvanera et al., 2006). Therefore, understanding the diversity, species richness, and regeneration potential of native woody plant species is fundamental for assessing forest community structure and designing conservation strategies. Native woody species play a dominant role in shaping forest ecosystems by forming habitat structures (Ishii et al., 2004), and providing resources for numerous animal species (Pillay et al., 2022). Assessing native woody species diversity and regeneration is a critical step for evaluating the availability of provisioning ecosystem services. Such species-site specific information is crucial for evidence-based conservation planning and to improve forest resilience, and ensure the provision of critical ecosystem services to surrounding communities (Duguma et al., 2024). Integrating and maintaining native tree species create multifunctional landscapes that balance ecological and socio-economic goals, promoting biodiversity conservation and sustaining local livelihoods (Solorio et al., 2017; Tekalign et al., 2017; Shumi et al., 2021).

With this context, this study focuses on Menagesha Suba Forest, one of Ethiopia's oldest forest remnants (over 500 years old), to investigate native woody plant species diversity and regeneration as indicators of sustainable ecosystem services. The specific objectives were to: (i) quantify native woody plant species diversity, regeneration potential, and ecosystem service supply across natural and mixed plantation forests; and (ii) explore the relationship between woody plant species diversity and ecosystem service diversity. The study hypothesizes that different forest types provide distinct ecosystem services and that ecosystem service diversity is positively correlated with woody plant species diversity (Shumi et al., 2021). These findings will provide critical insights for up-to-date species-site-specific information on native woody species and will serve as input for devising conservation planning and contribute to enhancing ecosystem service provisioning in the study area and beyond.

Materials and methods

The study area. This study was carried out in the Menagesha-Suba dry Afromontane Forest, situated 50 km southwest of Addis Ababa between 8°56' – 9°02' N and 38°28' – 38°36' E, with an elevation ranging from 2200 to 3000 m (Fig. 1). The forest encompasses an isolated mountain surrounded by low-lying plains, covering approximately 2500 ha, of which 800 ha is man-made plantation forest and the remaining area is natural forest. The topography is highly dissected, characterized by alternating ridges and valleys, while the soil varies with altitude, being shallow and rocky at higher elevations and deep, reddish-brown, and less gravelly at lower altitudes. The mean annual rainfall is 1056 mm, and the mean minimum and maximum monthly temperatures are 6 °C and 22 °C, respectively. The area has a bimodal rainfall pattern, with the main rainy season occurring from mid-June to the end of September and a short rainy season occurring between mid-April and mid-May.

Over the past decades, the forest has been degraded due to excessive timber exploitation and agricultural encroachment (Senbeta & Teketay, 2001). Rehabilitation efforts began in the mid-20th century, with plantations established on deforested or degraded areas using both indigenous species such as *Juniperus procera* and exotic species like *Eucalyptus globulus*, *Pinus radiata*, *Pinus patula*, and *Cupressus lusitanica*. During the field observations, it has been observed that huge reforestation and afforestation activities were undertaken, aligned with Ethiopia's Green Legacy Initiative and the 10-year development plan (2020–2030), as outlined in the updated Nationally Determined Contributions. These efforts aim to rehabilitate deforested and degraded sites, potentially enhancing forest coverage in the area. The forest cover is concentrated on the northwestern and southwestern slopes, while the eastern slope has largely been converted to farmland. Menagesha-Suba forest is a vital habitat for diverse wildlife, including baboons, colobus monkeys, bushbucks, spotted hyenas, caracals, wildcats, and various bird species, reflecting its ecological importance (personal communication with forest rangers and field observation).

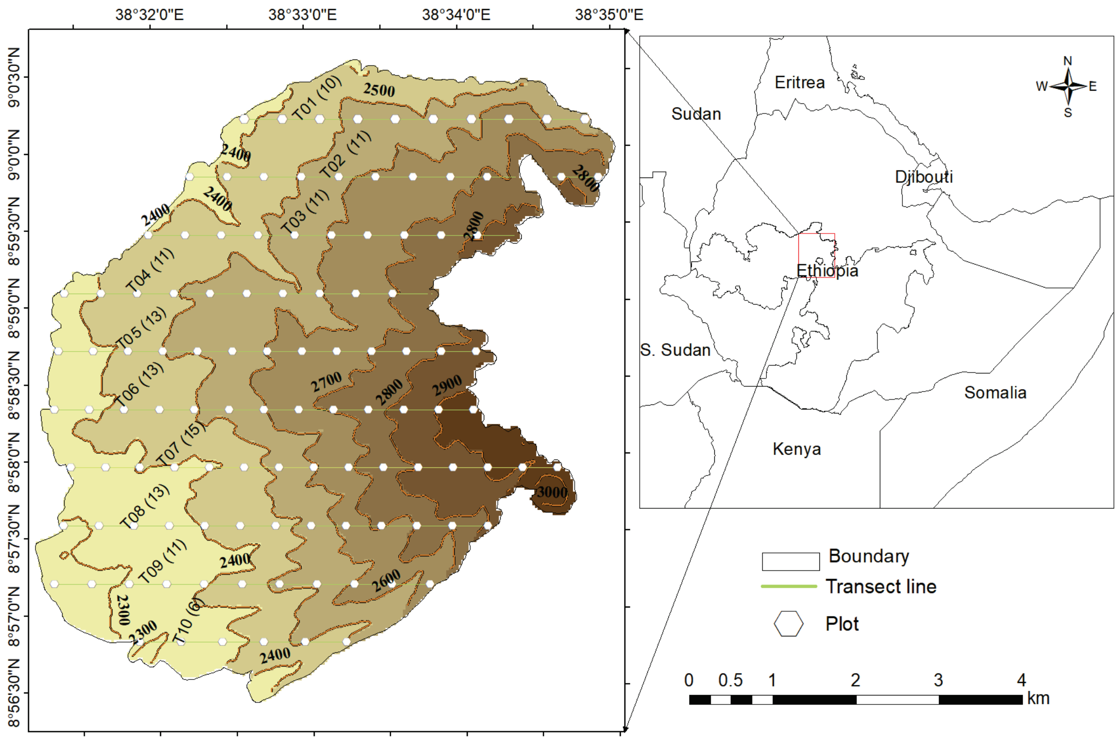

Fig. 1. The location of the study area and sampling schemes for the vegetation inventory in Menagesha Suba Forest, Central Highlands of Ethiopia

Menagesha Suba Forest is encircled by approximately 15 kebeles, with an estimated population of 27,000 residents. It is estimated that approximately 31% of households reside within the forest boundaries, while the remainder live on its periphery (Duguma et al., 2009). The average landholding per household ranges from 0.5 to 1.5 hectares, and the mean family size is 5. Agriculture serves as the primary livelihood, with crops such as teff (*Eragrostis tef*), wheat (*Triticum aestivum*), beans (*Vicia faba*), and peas (*Pisum sativum*) being cultivated. However, the community faces challenges due to low agricultural productivity, stemming from land degradation after decades of intensive farming and inadequate soil management practices. Beyond the protected forest, there is limited woodland in the area, and few trees are present on individual farm plots, rendering households unable to meet their wood needs. This scarcity compels the community to depend on Menagesha Suba Forest for forest products in the area.

Vegetation sampling. A multistage sampling technique was employed to assess woody species diversity and regeneration to compare natural forests and adjacent mixed plantation forests. Before the actual field data collection, a reconnaissance survey was conducted to identify study sites, vegetation patterns, and forest types. Using Google Earth Pro and ArcGIS, forest areas were delineated, and representative transects and plot spacing were determined (Fig. 1). Stratified purposive sampling was applied for site selection, following previous techniques used for woody species assessments (Senbeta & Teketay, 2001; Senbeta et al., 2002; Froumsia, 2012; Kewessa et al., 2019; Ayele et al., 2024).

Systematic line transect sampling, of areas stratified by natural and mixed plantation forest, was conducted to collect data on woody species diversity. Transects were established following methodologies from Mekuria & Veldkamp (2012) and Tsechoe et al. (2014). A total of 94 plots, each measuring 20 × 20 m (0.04 ha), were located at 200 m intervals along line transects, spaced 300 m apart. Within each main plot, five 5 x 5 m plots for saplings and five 1 x 1 m subplots for seedlings were used (Fig. 2), following procedures described in studies (Senbeta & Teketay, 2001; Shrestha & Moe, 2015; Ayele et al., 2024). The starting points of transects were randomly located, and all plots were positioned at least 50 m from edges or roads, to minimize edge effects (Senbeta & Teketay, 2001). The number of plots was determined with sample sizes proportional to forest strata based on area coverage, as illustrated in equation 1. This stratification ensured representativeness across forest types, enabling comparative analyses of species diversity, floristic composition, and regeneration status.

$$n = \frac{(N*S)^2}{\frac{N^2*E^2}{t^2} + N*S^2} \qquad \text{equation 1}$$

where, E – allowable error or the desired half-width of the confidence interval; t – the sample statistic from the t-distribution for the 95% confidence level; S – standard deviation derived from the previous study; N – maximum possible number of sampling units in the population that was determined following a previous study, equation 2:

$$\mathrm{N} = \frac{\mathrm{A}}{\mathrm{AP}} \qquad \text{equation 2}$$

where, A – the total forest area selected for this study is approximately 3300 ha; AP – sample plot size in ha (0.04 ha).

Accordingly, a total of 94 sample plots were used for the vegetation survey. These total sample plots are proportionally allocated for each forest type in Menagesha Suba Forest.

Woody species data collection. Within each plot, all woody species were identified and categorized into seedlings (height ≤ 1.0 m), saplings (height 1–3 m), and trees (height > 3 m) (Ayele et al., 2024; Senbeta & Teketay, 2001). Vegetation data, including species name, diameter at breast height (DBH), tree height, crown cover, and regeneration status, were recorded using vegetation assessment field formats. Height and DBH measurements were taken with a hypsometer and caliper, respectively. The diameter was measured using a caliber and/or diameter tape at 1.3 m aboveground (Ditt et al., 2010) for all trees and shrubs. Trees forking below 1.3 m were measured and recorded separately, while those forking above 1.3 m were measured at breast height as a single stem. Trees on the border of the sample plots were included if greater than 50% of their basal area was within the plot and were excluded otherwise. Trees outside of the plot but overhanging into the plot were excluded, and those trunks inside the sampling plot and branches outside the plot were included following previous studies. Vegetation data were classified into three different growth stages (habits) to determine the status of regeneration: adult trees (DBH ≥ 5 cm and height greater than 2 m), saplings (DBH 1–5 cm and height less than 2 m), and seedlings (DBH < 1 cm and height less than 1 m), as described in Tadesse Woldemariam (2003). Additional variables such as aspect, altitude, and plot coordinates were also recorded.

Floristic identification and nomenclature. Plant species identification followed standard taxonomic references, with the help of local informants and referring from identification keys and other publications (Bekele-Tesemma, 2007), Interactive Suitable Tree Species Selection and Management Tool for East Africa-Ethiopia (https://doi.org/10.34725/DVN/ZTT9EF). Besides, the researcher's botanical knowledge, a botanist from the Ethiopian Biodiversity Institute and Ambo University was involved in identifying tree species on the spot. Also, currently accepted botanical names of tree species and their respective families have been verified in the Flora of Ethiopia, Global Plants on Jostor (http://plants.jostor.org/compilation) as well as in the World Checklist of Vascular Plants, a continuously updated resource for exploring global plant diversity (Govaerts et al., 2021) and using the website at Plants of the World (Kew) (https://powo.science.kew.org).

Household survey. In addition to the vegetation assessment, we assessed household use of woody plants from Menagesha Suba Forest using a two-phase mixed-methods approach. In June 2022, an exploratory pilot study was conducted to gain a foundational understanding of woody plant utilization and sources. Open-ended questionnaires were administered to 30 households across six kebeles located within and on the forest periphery. Insights from the pilot study informed the design of the main survey. From January to March 2023, we conducted the main study using a structured questionnaire with primarily closed-ended questions. The questionnaire was divided into four sections: (i) household background information; (ii) uses and preferences for woody plant species; (iii) household dependency on forest resources; and (iv) perceived challenges and opportunities for sustainable forest management in the area. Woody plant uses were classified into 10 major categories, based on pilot findings and literature (Shumi et al., 2019). A total of 145 households were randomly selected, ensuring proportional representation across kebeles, a detailed procedure available in (Kewessa and Tolera, unpublished). Respondents were household heads or their spouses, chosen for their in-depth knowledge of household resource use. Anonymity was maintained to protect respondent privacy. Before each interview, we clearly explained the study objectives and emphasized the voluntary nature of participation, fostering trust and transparency.

Data analysis. The study assessed tree species diversity, structure, and regeneration using key diversity indices and structural parameters, including Shannon diversity (H), Simpson diversity (D), and Simpson evenness (E), which were calculated to quantify tree species diversity, as described in Kent et al. (2011).

The evenness index (E) was calculated as the ratio of observed diversity to maximum diversity using the following equation (Magurran, 2005).

The importance value index (IVI) for each woody species was calculated as follows:

IVI = Relative density + Relative frequency + Relative dominance

$$\text{Relative Density} = \frac{\text{Density of spps}}{\text{Total density of all spps}} \text{ x 100}$$

$$\text{Density of spps} = \frac{\text{Number of trees in a s spps}}{\text{Total area sampled}}$$

$$\text{Relative Dominance} = \frac{\text{Dominance of tree spps}}{\text{Total cover of all spps}} \text{ x 100}$$

$$\text{Dominance of tree spps} = \frac{\text{Total basal area of a spps}}{\text{Total area sampled}}$$

$$\text{Relative Frequency} = \frac{\text{Frequency of a spps i the sample}}{\text{Total frequency of a spps in the sample}} \text{ x 100}$$

$$\text{Frequency of a spps} = \frac{\text{Area of plots in which a spps occur}}{\text{Total area sampled}}$$

Structural parameters, including stem density, basal area, and diameter and height class distributions, provided insights into stand composition. Accordingly, we classified diameter classes and the height classes-based field on the mean distribution of each class and graphed. Regeneration status was evaluated by comparing seedlings, saplings, and mature individuals, categorized as "good" (seedlings > saplings > mature), "fair" (seedlings > saplings < mature), "poor" (mature > saplings > seedlings), "none" (absent saplings and seedlings but present mature trees), or "new" (saplings/seedlings present without mature individuals) (Gebrehiwot & Hundera, 2014).

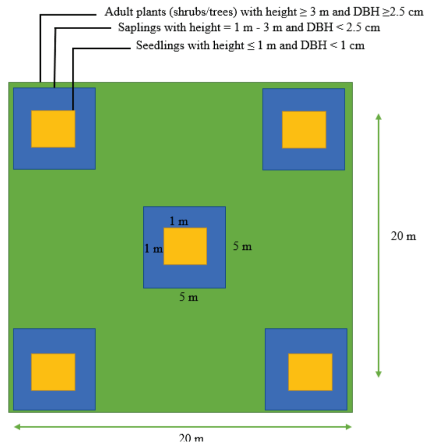

Fig. 2. The sampling design where trees and shrubs were sampled in a 20 x 20 m plot, saplings within a 5 x 5 m plot, and seedlings in 1 x 1 m subplots, following procedures described in previous studies (Ayele et al., 2024; Senbeta & Teketay, 2001; Shrestha & Moe, 2015)

Furthermore, household survey data were analyzed using descriptive and inferential statistical methods. Descriptive statistics, including means, percentages, and frequency distributions, were used to summarize household characteristics and woody plant usage patterns. Preference rankings for woody plant species were evaluated using weighted averages and proportion scores. To identify dominant woody plant use categories and their relative importance, we calculated the proportion of households utilizing each category and analyzed the data by kebele and forest use values.

Results

Woody species composition of Menagesha Suba Forest. The inventory analysis of woody species in Menagesha Suba Forest revealed significant insights into the role of remnant dry Afromontane forests in biodiversity conservation, emphasizing their importance as an indicator of forest provisioning ecosystem services and as a conservation priority forest. A total of 71 woody species belonging to 56 genera and 43 families, were identified from 94 surveyed plots (Table 1).

Table 1
List of woody plant species recorded in all 94 surveyed plots across the two forest types (natural forest and mixed plantation forest) in Menagesha Suba Forest, Ethiopia (the table includes their scientific family, local name, habit, the number of sites where they occurred, and their abundance

Scientific name	Family	Afan Oromo	Habit	Abundance and occurrence of species by forest type			
				natural forest		mixed plantation forest	
				occurrence	abundance	occurrence	abundance
Acacia abyssinica	Fabaceae	Laaftoo	Tree	1	1	2	2
Acacia decurrens	Fabaceae	–	Tree	1	3	1	3
Acacia saligna	Fabaceae	–	Tree	–	–	1	2
Albizia coriaria	Fabaceae	Muka erba	Tree	16	22	2	2
Albizia gummifera	Fabaceae	Muka arba	Tree	1	2	1	3
Apodytes dimidiata	Icacinaceae	Oda-badda	Tree	4	5	–	–
Asparagus africanus	Asparagaceae	Saariitii	Climber	2	3	4	6
Aspilia africana	Asteraceae	Hadaa adii/Hidaa adii	Climber	3	5	1	1
Bersama abyssinia	Melianthaceae	Lolchiisaa	Shrub/tree	31	167	16	63
Brucea antidysenterica	Simaroubaceae	Qomanyoo	Shrub/tree	5	12	1	2
Buddleja polystachya	Scrophulariaceae	Bulchaana/qawisa	Shrub	5	8	–	–
Calpurnia aurea	Fabaceae	Cheekaa	Shrub	4	5	13	101
Carissa edulis	Apocynaceae	Agamsa	Shrub	29	149	25	202
Clematis hirsuta	Ranunculaceae	Hidda	Climber	–	–	1	1
Clematis simensis	Ranunculaceae	Hiddaa fiitii	Climber	15	35	1	3
Croton macrostachyus	Euphorbiaceae	Bakaniissa	Tree	6	12	13	75
Cupressus lusitanica	Cupressaceae	Gaatiraa faranjii	Tree	4	39	16	187
Diospyros abyssinica	Ebenaceae	Lookkoo gurraacha	Tree	10	29	2	11
Dovyalis abyssinica	Flacourtiaceae	Koshomii	Shrub	36	141	10	31
Dovyalis verrucosa	Flacourtiaceae	Liqimee	Shrub	51	518	17	136
Dracaena afromontana	Dracaenaceae	Cacaa	Shrub	2	25	–	–
Ekebergia capensis	Meliaceae	Somboo	Tree	6	6	1	2
Erica arborea	Ericaceae	Saatoo	Shrub	15	125	–	–
Eucalyptus camaldulensis	Myrtaceae	Baargamo dimaa	Tree	–	–	2	19
Eucalyptus citriodora	Myrtaceae	Baargamo	Tree	–	–	1	18
Eucalyptus globulus	Myrtaceae	Baargamo adii	Tree	2	16	5	71
Eucalyptus saligna	Myrtaceae	–	Tree	1	1	1	28
Ficus sur	Moraceae	Harbu	Tree	1	5	–	–
Galiniera saxifraga	Rubiaceae	Buniitii	Shrub	3	8	–	–
Grevillea robusta	Proteaceae	Giraavilliyaa	Tree	–	–	5	67
Hagenia abyssinica	Rosaceae	Heexoo	Tree	2	3	–	–
Hypericum quartinianum	Hypericaceae	Hindhee	Shrub	2	8	–	–
Juniperus procera	Cupressaceae	Hindheessa/Gatira	Tree	64	761	26	152
Justicia schimperiana	Acanthaceae	Dhummugaa	Shrub	1	12	5	40
Landolphia buchananii	Apocynaceae	Hiddaa Geeboo	Climber	5	14	3	7
Maesa lanceolata	Primulaceae	Abbayyii	Tree	1	2	1	1
Maytenus arbutifolia	Celastraceae	Axaaxii	Shrub/tree	3	16	–	–
Maytenus gracilipes	Celastraceae	Qarxammee	Shrub	1	1	–	–
Maytenus senegalensis	Celastraceae	Kombolcha	Tree	61	437	23	289
Maytenus undata	Celastraceae	Kolaatii	Shrub	–	–	–	–
Myrica salicifolia	Myricaceae	Barooddo	Shrub	6	9	–	–
Myrsine africana	Myrsinaceae	Qachama	Shrub	43	714	12	79
Myrsine melanophloeos	Primulaceae	Algee	Tree	4	28	–	–
Nuxia congesta	Loganiaceae	Bixxaannaa	Tree	4	6	–	–
Olea europea	Oleaceae	Ejersa	Tree	64	647	26	165
Olinia rochetiana	Penaeaceae	Daalachoo	Tree	54	325	7	41
Osyris quadripartita	Santalaceae	Waatoo	Shrub	17	44	4	13
Periploca linearifolia	Apocynaceae	Hiddaa annannoo	Climber	2	32	–	–
Pinus radiata	Pinaceae	–	Tree	1	1	7	105

Scientific name	Family	Afan Oromo	Habit	Abundance and occurrence of species by forest type			
				natural forest		mixed plantation forest	
				occurrence	abundance	occurrence	abundance
Pittosporum viridiflorum	Pittosporaceae	Soolee	Tree	13	38	–	6
Podocarpus falcatus	Podocarpaceae	Birbirsa	Tree	36	225	13	52
Polyscias fulva	Araliaceae	Tulaa	Shrub	1	16	2	2
Prunus africana	Rosaceae	Hoomii	Tree	12	29	2	2
Psychotria orophila	Rubiaceae	–	Shrub	3	6	–	
Pterolobium stellatum	Fabaceae	Hidda gurrisa	Climber	1	1	1	2
Rhamnus staddo	Rhamnaceae	Qadiidaa	Shrub	3	5	1	1
Rosa abyssinica	Rosaceae	Goraa	Shrub	12	27	3	7
Rubus apetalus	Rosaceae	Haltufa	Shrub	1	3	2	3
Salix mucronata	Salicaceae	Alaltu	Shrub	1	1	–	–
Scolopia theifolia	Salicaceae	Kolfaa	Tree	45	603	14	111
Searsia glutinosa	Anacardiaceae	Xaaxessaa	Shrub	18	37	4	8
Searsia pyroides	Anacardiaceae	Laboobesa	Tree	3	6	–	–
Smilax aspera	Smilacaceae	Harangamaa gurracha	Climber	7	10	1	3
Solanecio gigas	Asteraceae	Bosoqqa	Shrub	20	56	10	19
Spathodea campanulata	Bignoniaceae	Hoolotoo	Tree	–	–	3	17
Spiniluma oxyacantha	Sapotaceae	Biitee	Shrub	51	279	20	143
Stephanotis schimperi	Apocynaceae	Hidda gorrisa	Climber	–	–	3	6
Tacazzea conferta	Apocynaceae	Hidda aaannoo	Climber	14	34	4	11
Teclea nobilis	Rutaceae	Hadhessaa	Shrub/tree	18	53	12	84
Vernonia amygdalina	Asteraceae	Ebicha	Shrub	3	5	1	1
Vernonia auriculifera	Asteraceae	Reejii	Shrub	2	2	2	2

Of the 71 woody species recorded, 31 species (43.7%) are trees, 26 species (36.6%) are shrubs, 4 species (5.6%) are categorized as both shrubs/trees and 10 species (14.1%) are woody climbers (Table 1). The higher number of tree species suggests their dominance in the forest structure, while the significant presence of shrubs highlights their adaptability to withstand various environmental and anthropogenic factors that challenge woody species in the Menagesha Suba Forest. The family Fabaceae was the most dominant, represented by 7 species (9.9%), followed by Apocynaceae (7.0%), Asteraceae, Celastraceae, Myrtaceae, and Rosaceae, each contributing 4 species (5.6%). Additionally, six families were represented by 2 species (2.8%) each, and 31 families were represented by only 1 species each. Overall, 12 families, comprising species groups of 7, 1, 4, and 2, collectively accounted for 56.3% of the total woody species, while the 31 single-species families made up the remaining 43.7% (Table 2).

Diversity of woody species. The diversity indices calculated for woody species in Menagesha Suba Forest indicate a relatively high level of species diversity and ecological balance. The Shannon Diversity Index (H') was 3.06, reflecting substantial species richness within the forest. The maximum possible diversity (H_{max}) was 4.23, suggesting that the forest has not yet achieved its full potential for species diversity. The species evenness value of 0.72 indicates a moderately uniform distribution of individuals among species, showing that certain species are more dominant than others. Additionally, the Simpson's Diversity Index (D) was 0.93, underscoring the low probability of randomly encountering the same species twice, further confirming the forest's high biodiversity. Interestingly, the high Shannon-Wiener diversity and evenness values highlight the ecological importance of Menagesha Suba Forest as a vital refugium for woody species diversity and a key area for biodiversity conservation in Ethiopia under unprecedented anthropogenic pressures and climate change threats.

The density of woody species in Menagesha Suba Forest. In this study, a total of 8,070 individuals (3,211 mature trees, 2,507 saplings, and 2,352 seedlings) of woody species were recorded across 94 plots in Menagesha Suba Forest. The total density of woody species was 2,146.28 individuals per hectare, with the 10 most dominant species contributing 1,609.84 individuals per hectare. *Juniperus procera* was the most abundant species, with a density of 241.49 individuals per hectare, followed by *Olea europea*, *Myrsine africana*, and *Scolopia theifolia* (Table 3). This higher density in Menagesha Suba Forest highlights its ecological richness and significant role in supporting high levels of woody vegetation. It further emphasizes the importance of the Menagesha Suba Forest for biodiversity conservation in Ethiopia.

Frequency of woody species in Menagesha Suba forest. The analysis of the frequency of woody species in Menagesha Suba Forest provides critical insights into species distribution and adaptability within the montane forest ecosystem. The total frequency recorded across all species was 1209.6%, highlighting the widespread occurrence and ecological significance of multiple species throughout the forest. Notably, *Olea europaea*, *Juniperus procera*, and *Maytenus senegalensis* emerged as the most frequently occurring species, with frequencies of 95.7%, 94.7%, and 89.4%, respectively.

Table 2
List of woody plant families with their number of genera and species in Menagesha Suba Forest, Central Highlands of Ethiopia

Family	Genera	No. of species	Percent
Fabaceae	4	7	9.86
Apocynaceae	4	5	7.04
Asteraceae	1	4	5.63
Celastraceae	1	4	5.63
Myrtaceae	1	4	5.63
Rosaceae	2	4	5.63
Anacardiaceae	1	2	2.82
Cupressaceae	1	2	2.82
Flacourtiaceae	1	2	2.82
Primulaceae	2	2	2.82
Rubiaceae	1	2	2.82
Salicaceae	1	2	2.82
Acanthaceae	1	1	1.41
Araliaceae	1	1	1.41
Asparagaceae	4	1	1.41
Bignoniaceae	1	1	1.41
Dracaenaceae	1	1	1.41
Ebenaceae	1	1	1.41
Ericaceae	1	1	1.41
Euphorbiaceae	1	1	1.41
Hypericaceae	1	1	1.41
Icacinaceae	1	1	1.41
Loganiaceae	1	1	1.41
Meliaceae	1	1	1.41
Melianthaceae	1	1	1.41
Moraceae	1	1	1.41
Myricaceae	1	1	1.41
Myrsinaceae	1	1	1.41
Oleaceae	1	1	1.41
Penaeaceae	1	1	1.41
Pinaceae	2	1	1.41
Pittosporaceae	1	1	1.41
Podocarpaceae	1	1	1.41
Proteaceae	2	1	1.41
Ranunculaceae	1	1	1.41
Ranunculaceae	1	1	1.41
Rhamnaceae	1	1	1.41
Rutaceae	1	1	1.41
Santalaceae	1	1	1.41
Sapotaceae	1	1	1.41
Scrophulariaceae	1	1	1.41
Simaroubaceae	1	1	1.41
Smilacaceae	1	1	1.41

Table 3
Density of the 10 most dominant woody species in Menagesha Suba Forest (this table highlights the contribution of the most abundant species to the overall woody species density in the study area, with *Juniperus procera* being the most dominant species)

Species	Density	Relative dominance
Juniperus procera	241.49	11.53
Olea europea	215.96	10.31
Myrsine africana	210.90	10.07
Scolopia theifolia	200.80	9.59
Maytenus senegalensis	193.09	9.22
Dovyalis vericosa	174.20	8.32
Spiniluma oxyacantha	110.37	5.27
Olinia rochetiana	96.54	4.61
Carissa spinarum	93.35	4.46
Afrocarpus falcatus	73.14	3.49

These species exhibited relative frequencies of 7.9%, 7.8%, and 7.4%, collectively representing 23.1% of the forest's overall frequency. Their dominance underscores their high adaptability to the high-altitude and montane conditions characteristic of the Menagesha Suba forest. Other species also contributed substantially to the frequency distribution, including *Spiniluma oxyacantha* (74.5%), *Dovyalis vericosa* (72.3%), and *Scolopia theifolia* (69.2%), which collectively accounted for 17.9% of the relative frequency (Table 7). Similarly, species such as *Olinia rochetiana* (64.9%), *Myrsine africana* (58.5%), *Carissa spinarum* (57.5%), and *Afrocarpus falcatus* (51.1%) reflected significant adaptability and ecological roles within the forest.

The higher frequency values of the dominant species indicate their widespread presence across the sampled plots and their importance in shaping the forest's ecological composition. These species, particularly *Olea europaea* and *Juniperus procera*, are known for their resilience to environmental stressors, such as variations in temperature, water availability, and human-induced pressures, making them keystone species in the forest. Conversely, the relatively lower frequency of some species, like *Acacia saligna* and *Salix mucronata*, may suggest niche specialization or less competitive adaptability compared to the dominant species.

Importance value index (IVI) of woody species. The results of the IVI of woody species in the Menagesha Suba Forest revealed that the most dominant and ecologically important woody species, were *Juniperus procera*, *Olea europaea*, *Maytenus senegalensis*, *Scolopia theifolia*, *Dovyalis vericosa*, *Myrsine africana*, *Spiniluma oxyacantha*, *Olinia rochetiana*, *Carissa spinarum*, and *Afrocarpus falcatus* (Table 4). These species had higher IVI values compared to others in the forest, indicating their greater ecological roles. Among these, *Juniperus procera* had the highest IVI (86.49%), making it the most ecologically significant species, followed by *Olea europaea* (28.2%) (Table 4 and 7). The species with the greatest IVI values are recognized as the leading dominants in the forest ecosystem while species with lower IVI values were less dominant and contributed less to the forest structure and composition. The dominance of these species underscores their adaptability and pivotal role in maintaining the ecological balance of the Menagesha Suba Forest.

Table 4
Selected 10 most ecologically significant woody species in Menagesha Suba Forest (this table summarizes the relative density (RD), relative frequency (RF), relative dominance (RDO), and importance value index (IVI) of key woody species)

Scientific name	RD	RF	RDO	IVI
Juniperus procera	11.53	7.83	67.14	86.49
Olea europea	10.31	7.92	9.98	28.20
Maytenus senegalensis	9.22	7.39	1.07	17.68
Scolopia theifolia	9.59	5.72	1.02	16.32
Dovyalis vericosa	8.32	5.98	0.66	14.96
Myrsine africana	10.07	4.84	0.01	14.91
Spiniluma oxyacantha	5.27	6.16	2.00	13.43
Olinia rochetiana	4.61	5.37	2.22	12.20
Carissa spinarum	4.46	4.75	0.11	9.31
Afrocarpus falcatus	3.49	4.22	1.55	9.26

Diameter class distribution. The diameter class distribution of woody species in Menagesha Suba Forest was analyzed by categorizing trees into 12 DBH (diameter at breast height) classes. The highest number of woody species was observed in the second DBH class, followed by the first and third classes, whereas the lowest number of species occurred in the eighth and ninth classes. This pattern reflects the population dynamics and recruitment processes of the forest species. The irregular distribution observed suggests selective cutting of individual species for various purposes, disrupting the natural structure. However, the high number of woody species in the lower DBH classes indicates a strong reproduction and recruitment potential for the forest's woody species, which is vital for its regeneration. These findings highlight the need for conservation measures to ensure the persistence of larger diameter classes and overall forest structure in the studied forest.

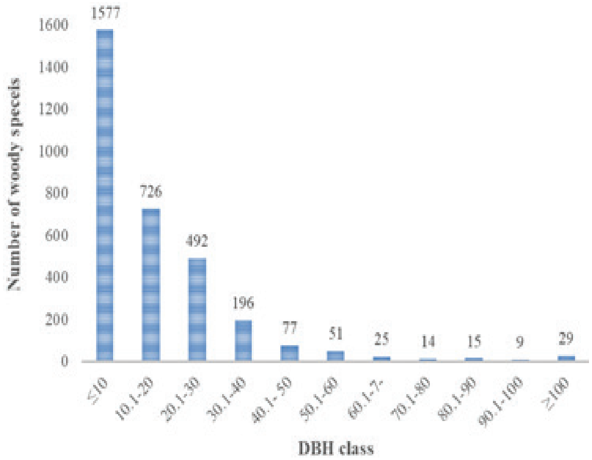

Fig. 3. The DBH class distributions of all woody plant species in Menagesha Suba Forest

Height class distribution. The highest number of individuals was recorded in the first height class, followed by the second and third classes (Fig. 4). This distribution pattern indicates a dominance of smaller-sized woody species in the forest. As the height classes increased, the number of individuals decreased, which is a typical characteristic of a well-established forest structure, where larger trees become less abundant compared to younger or smaller individuals. This pattern is indicative of the forest's potential to contribute to biodiversity conservation, as smaller individuals represent the regeneration phase, critical for the future stability and ecological resilience of the forest.

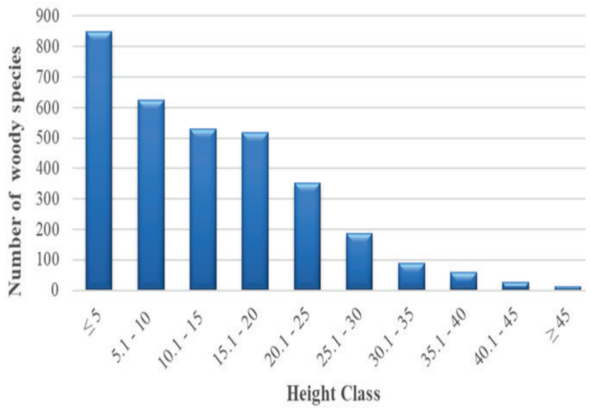

Fig. 4. Distribution of woody plant species across different height classes in Menagesha Suba Forest, Central Ethiopia: the figure illustrates a dominance of smaller-sized individuals in the forest, with a decreasing number of individuals in higher height classes, reflecting a typical forest structure and indicating the forest's potential for biodiversity conservation and future ecological resilience

Basal area of woody species. In this study, the total basal area was recorded at 152.2 m². Among the species contributing to this total, *Juniperus procera* had the highest basal area, contributing 97.5 m² (64.1%), followed by *Olea europaea* with a basal area of 14.5 m² (9.5%, Table 5). The lowest basal areas were contributed by *Buddleia polystachya* and *Solanecio gigas*, with recorded values of 0.0003 and 0.0007 m², respectively (Table 7). These findings suggest that the Menagesha Suba Forest has relatively better growth potential and the capacity to retain higher biomass, highlighting its significant contribution to biodiversity conservation and forest provisioning ecosystem services.

Table 5
Top 10 selected woody species with higher basal area (m²) in Menagesha Suba Forest, Central Ethiopia

Scientific name	Basa area, m^2	Percentage, %
Juniperus procera	97.53	64.08
Olea europea	14.49	9.52
Eucalyptus globulus	10.13	6.66
Cupressus lusitanica	8.09	5.32
Olinia rochetiana	3.23	2.12
Spiniluma oxyacantha	2.91	1.91
Afrocarpus falcatus	2.25	1.48
Grevillea robusta	2.10	1.38
Eucalyptus saligna	1.74	1.14
Maytenus senegalensis	1.56	1.04

Regeneration status of Menagesha Suba forest. The regeneration status of Menagesha Suba Forest was assessed by examining the density and number of seedlings, saplings, and mature woody plant species (Fig. 5). Our results revealed that a total of 2352 individual seedlings (29.1% ind./ha), 2507 saplings (31.1% ind./ha), and 3211 mature individuals (39.8% ind./ha), were recorded. This distribution indicates that the forest is currently experiencing a fair level of regeneration, with a balance between young and mature individuals. The presence of a significant number of seedlings and saplings suggests a sustainable future for the forest's biodiversity, reinforcing its role in biodiversity conservation and its potential to continue providing essential ecosystem services in the future. These findings underline, with caution, the importance of remnant forests like Menagesha Suba Forest in maintaining ecological resilience and prioritizing future forest conservation efforts.

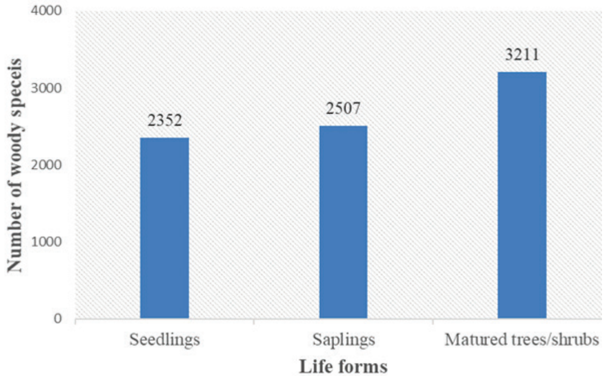

Fig. 5. Regeneration status of Menagesha Suba Forest, showing the density of seedlings (29.1% ind./ha), saplings (31.1% ind./ha), and mature woody plant species (39.8% ind./ha), indicating a fair regeneration capacity and highlighting the forest's role in biodiversity conservation and future ecosystem service provision

The regeneration status of woody species in the Menagesha Suba Forest reveals that the majority of the species exhibit fair regeneration (43 species, 60.6%). Only a small proportion of species show good regeneration (3 species, 4.2%) or are represented by new individuals (3 species, 4.2%). However, a concerning proportion of species exhibit poor regeneration (15 species, 21.1%) or show no regeneration at all (7 species, 9.9%). This highlights the need for focused management interventions to improve the regeneration capacity of species with poor or no regeneration. The regeneration status of woody species has significant implications for the sustainability of forest ecosystem provisioning services. The dominance of species with fair regeneration (43 species, 60.6%) suggests that the forest is moderately capable of maintaining its species composition and ecosystem functions. However, the low proportion of species with good regeneration (4.2%) and new individuals (4.2%) raises concerns about the forest's ability to replenish its biodiversity and sustain long-term productivity.

The presence of species with poor regeneration (21.1%) and no regeneration (9.9%) is particularly alarming, as it indicates potential gaps in the recruitment of key species that provide essential ecosystem services such as timber, fuelwood, non-timber products, carbon sequestration, and soil stabilization. Without intervention, this could compromise the forest's ability to support local livelihoods and ecological stability over time. To ensure the sustainability of ecosystem provisioning services, conservation efforts must focus on enhancing regeneration processes. This could involve reducing anthropogenic pressures, such as overharvesting and grazing, and implementing active restoration measures like enrichment planting and protection of seed sources. Supporting species with poor or no regeneration is critical to maintaining forest resilience and ensuring that ecosystem services continue to benefit both local communities and the broader environment.

Preference for woody plants and their ecosystem services. Of the total 71 woody species recorded, local people reported using 43 species for various purposes. Exotic species such as *Eucalyptus globulus*, *Cupressus lusitanica*, and *Grevillea robusta* were among those commonly utilized. The uses of these species are summarized in Table 5. Only woody species recorded during the vegetation survey were assessed for their uses, excluding additional woody species not occurring in the study plots. Regarding the purposes of use, the most common use category was fuelwood, with 26 species (60.5%) being utilized for this purpose. Other prominent use categories included house construction (17 species, 39.6%), household utilities (16 species, 37.2%), farming tools (21 species, 48.8%), and fences (22 species, 51.2%). Additionally, 15 species (34.8%) were used for honey production, eight species (18.6%) for animal fodder, and 12 species (27.9%) for soil fertility improvement. Some other species were identified as important for medicinal purposes, with 13 species (30.2%) being reported, and nine species (20.9%) were noted for other uses.

The most versatile species, i.e., those with the highest number of uses, included *Juniperus procera*, *Croton macrostachyus*, *Eucalyptus* spp., *Cupressus lusitanica*, *Nuxia congesta*, and *Olea europea*, each with six or more distinct uses. These species were used for multiple purposes, including fuelwood, house construction, and honey production. Of the recorded species, 15 species were identified as the most widely utilized, with each being mentioned by more than 40 respondents. These species included *Juniperus procera*, *Croton macrostachyus*, *Cupressus lusitanica*, and *Eucalyptus* spp. Among exotic species, *Pinus* spp. and *Grevillea robusta* were reported for their utility in house construction and poles.

Discussion

Woody species composition of Menagesha Suba Forest. The composition of 71 woody species belonging to 43 families in Menagesha Suba Forest unveils its unique biodiversity and ecological significance as a remnant dry Afromontane forest. Similar studies in Ethiopian highlands, such as in the Harenna Forest (Nigatu et al., 2017; Kewessa et al., 2019) have documented comparable species richness, confirming the importance of remnant forests in biodiversity hotspots. The dominance of the Fabaceae family in Menagesha Suba Forest is consistent with studies in other Ethiopian forests (Masresha et al., 2015; Dibaba et al., 2022), where the family is often noted for its ecological versatility and nitrogen-fixing abilities. These characteristics enhance soil fertility, promote forest resilience, and support diverse ecological functions. However, the uneven distribution of families, with 31 families represented by a single species, signals a vulnerability to environmental and anthropogenic pressures, as reported by (Berhanu et al., 2022) in Sheka Forest. Such imbalances highlight the need for conservation strategies targeting underrepresented families to safeguard the forest's compositional diversity.

Table 6
List of woody plant species benefiting local people; number of purposes that a species serves; list of uses of species

Species	No. of uses of species	Ecosystem services									
		1	2	3	4	5	6	7	8	9	10
Acacia abyssinica	5	+	+	–	–	–	+	+	+	–	–
Acacia decurrens	4	+	–	+	–	+	–	–	+	–	–
Acacia saligna	5	+	+	+	+	+	–	–	–	–	–
Albizia gummifera	6	+	+	+	–	–	–	+	+	–	+
Apodytes dimidiata	4	–	–	+	+	–	–	–	+	–	–
Asparagus africanus	5	+	–	–	–	+	–	+	+	+	–
Bersama abyssinia	3	+	–	–	–	–	–	–	–	+	–
Buddleja polystachya	3	+	–	–	–	–	–	–	+	–	–
Calpurnia aurea	6	–	–	+	+	+	–	–	–	+	+
Carissa edulis	2	–	–	–	+	–	–	–	–	–	–
Croton macrostachyus	8	+	+	+	+	+	–	+	+	+	–
Cupressus lusitanica	6	+	+	+	+	+	–	–	–	–	+
Diospyros abyssinica	2	–	–	–	+	–	–	–	–	–	–
Dovyalis verrucosa	5	–	–	–	+	+	–	–	–	+	+
Dracaena afromontana	1	–	–	–	–	–	+	–	–	–	–
Ekebergia capensis	6	+	+	+	+	–	–	–	+	–	–
Erica arborea	4	+	–	+	–	–	–	+	–	–	+
Eucalyptus globulus	6	+	+	+	+	+	–	–	–	–	–
Ficus sur	5	+	–	+	–	–	+	+	+	–	–
Grevillea robusta	4	+	+	+	–	+	–	–	–	–	–
Juniperus procera	7	+	+	+	+	+	–	+	–	–	–
Maesa lanceolata	5	+	–	–	–	+	+	+	–	+	–
Maytenus senegalensis	6	+	–	–	–	+	+	+	–	+	–
Myrsine africana	4	+	–	–	–	+	–	–	–	–	–
Myrsine melanophloeos	2	+	–	–	–	–	–	–	–	+	–
Nuxia congesta	6	+	–	+	+	–	–	+	+	–	–
Olea europea	6	+	+	–	+	+	–	–	–	–	+
Olinia rochetiana	3	–	–	–	+	+	–	–	–	–	–
Pinus radiata	6	+	+	+	+	–	–	+	–	–	–
Pittosporum viridiflorum	2	–	–	–	–	–	–	–	–	–	+
Podocarpus falcatus	5	+	+	+	–	–	–	–	–	+	+
Polyscias fulva	3	–	–	–	+	–	–	–	–	–	–
Rhamnus staddo	2	–	–	–	–	+	–	–	–	–	–
Rosa abyssinica	5	–	+	–	+	+	–	–	+	–	+
Scolopia theifolia	4	+	+	–	+	+	–	–	–	–	–
Searsia pyroides	3	–	+	–	–	–	–	–	+	+	–
Solanecio gigas	3	+	–	–	–	–	+	–	–	–	–
Spathodea campanulata	4	–	–	–	+	–	–	+	+	–	–
Spiniluma oxyacantha	2	–	–	–	+	+	–	–	–	–	–
Stephanotis schimperi	4	+	+	–	+	–	–	–	–	+	–
Teclea nobilis	4	–	+	+	–	+	–	–	+	–	–
Vernonia amygdalina	2	–	–	–	–	+	+	–	+	+	–
Vernonia auriculifera	2	–	–	–	–	+	+	–	–	–	–

Notes: 1 – fuelwood, 2 – house construction, 3 – household utilities, 4 – farm tools, 5 – fences, 6 – animal fodder, 7 – soil fertility, 8 – honey production/beehives, 9 – medicine, 10 – other uses; "+" – denotes a benefit, "–" – a lack thereof.

Table 7
Selected woody species with their relative density, relative frequency, relative dominance, and importance value index of Menagesha Suba Forest, Central Ethiopia

Scientific name	D	RD	F	RF	DO	RDO	IVI
Acacia abyssinica	0.80	0.04	3.19	0.26	0.0266	0.0689	0.3708
Acacia decurrens	1.60	0.08	2.13	0.18	0.0000	0.0000	0.2521
Acacia saligna	0.53	0.03	1.06	0.09	0.0131	0.0338	0.1471
Afrocarpus falcatus	73.14	3.49	51.06	4.22	0.5994	1.5514	9.2644
Albizia coriaria	6.38	0.30	19.15	1.58	0.0982	0.2541	2.1420
Albizia gummifera	1.06	0.05	2.13	0.18	0.0035	0.0092	0.2358
Apobytes dimidiata	1.33	0.06	3.19	0.26	0.0174	0.0451	0.3724
Asparagus africanus	1.33	0.06	3.19	0.26	0.0000	0.0000	0.3273
Bersama abyssinica	62.23	2.97	50.00	4.13	0.0176	0.0456	7.1501
Brucea antidysenterica	3.72	0.18	6.38	0.53	0.0000	0.0000	0.7054
Buddleia polystachya	1.33	0.06	2.13	0.18	0.0272	0.0705	0.3099
Buddleia polystachya	1.33	0.06	3.19	0.26	0.0001	0.0002	0.3275
Calpurnia aurea	29.79	1.42	19.15	1.58	0.0060	0.0154	3.0205
Carissa spinarum	93.35	4.46	57.45	4.75	0.0416	0.1077	9.3133
Clematis simensis	9.84	0.47	17.02	1.41	0.0000	0.0000	1.8770
Croton macrostachyus	23.14	1.10	17.02	1.41	0.0596	0.1542	2.6659
Cupressus lusitanica	60.11	2.87	21.28	1.76	2.1500	5.3230	9.8750
Diospyros abyssinica	3.72	0.18	5.32	0.44	0.0033	0.0085	0.6260
Dovyalis abyssinica	45.74	2.18	48.94	4.05	0.0063	0.0164	6.2458
Dovyalis vericosa	174.20	8.32	72.34	5.98	0.2547	0.6592	14.9555
Dracaena afromontana	1.06	0.05	2.13	0.18	0.0020	0.0052	0.2319
Ekebergia capensis	1.86	0.09	7.45	0.62	0.1006	0.2605	0.9650
Erica arborea	33.24	1.59	15.96	1.32	0.0171	0.0443	2.9506
Eucalyptus camaldulensis	4.52	0.22	2.13	0.18	0.2421	0.6267	1.0184

Scientific name	D	RD	F	RF	DO	RDO	IVI
Eucalyptus citriodora	4.79	0.23	1.06	0.09	0.2693	0.6970	1.0135
Eucalyptus globulus	23.14	1.10	7.45	0.62	2.6954	6.9762	8.6964
Eucalyptus saligna	7.71	0.37	3.19	0.26	0.4615	1.1945	1.8265
Ficus sur	1.33	0.06	1.06	0.09	0.0262	0.0677	0.2192
Galiniera saxifraga	2.13	0.10	3.19	0.26	0.0550	0.1424	0.5078
Grevillea robusta	17.82	0.85	5.32	0.44	0.5572	1.4420	2.7324
Hagenia abyssinica	0.80	0.04	2.13	0.18	0.0173	0.0448	0.2588
Hypericum quartinianum	2.13	0.10	2.13	0.18	0.0000	0.0000	0.2775
Juniperus procera	241.49	11.53	94.68	7.83	25.9392	67.1365	86.4918
Justicia schimperiana	13.83	0.66	6.38	0.53	0.0000	0.0000	1.1879
Landolphia buchananii	7.45	0.36	3.19	0.26	0.0000	0.0000	0.6193
Maesa lanceolata	0.80	0.04	2.13	0.18	0.0019	0.0048	0.2188
Maytenus arbutifolia	1.60	0.08	3.19	0.26	0.0086	0.0222	0.3623
Maytenus gracilipes	1.33	0.06	3.19	0.26	0.0057	0.0149	0.3422
Maytenus senegalensis	193.09	9.22	89.36	7.39	0.4152	1.0746	17.6796
Myrica salicifolia	2.39	0.11	3.19	0.26	0.0541	0.1401	0.5182
Myrica salicifolia	1.33	0.06	3.19	0.26	0.0521	0.1349	0.4622
Myrsine africana	210.90	10.07	58.51	4.84	0.0038	0.0097	14.9147
Myrsine melanophloeos	7.45	0.36	4.26	0.35	0.0198	0.0511	0.7584
Myrsine sp.	1.33	0.06	2.13	0.18	0.0026	0.0068	0.2462
Nuxia congesta	1.60	0.08	3.19	0.26	0.0153	0.0397	0.3797
Olea europea	215.96	10.31	95.74	7.92	3.8548	9.9770	28.2015
Olinia rochetiana	96.54	4.61	64.89	5.37	0.8585	2.2220	12.1955
Osyris quadripartita	14.89	0.71	23.40	1.93	0.0048	0.0125	2.6584
Periploca linearifolia	8.51	0.41	2.13	0.18	0.0000	0.0000	0.5822
Pittosporum viridiflorum	4.26	0.20	5.32	0.44	0.0249	0.0644	0.7072
Pittosporum viridiflorum	2.13	0.10	8.51	0.70	0.0643	0.1664	0.9716
Prunus africana	7.45	0.36	12.77	1.06	0.0636	0.1646	1.5755
Psychotria orophila	1.60	0.08	3.19	0.26	0.0335	0.0867	0.4267
Pterolobium stellatum	18.35	0.88	3.19	0.26	0.0000	0.0000	1.1399
Rhamnus staddo	1.86	0.09	5.32	0.44	0.0057	0.0149	0.5435
Rosa abyssinica	9.04	0.43	15.96	1.32	0.0015	0.0038	1.7547
Rubus apetalus	1.60	0.08	3.19	0.26	0.0008	0.0021	0.3421
Salix mucronata	0.27	0.01	1.06	0.09	0.0000	0.0000	0.1006
Scepocarpus hypselodendron	1.86	0.09	3.19	0.26	0.0000	0.0000	0.3527
Scolopia theifolia	200.80	9.59	69.15	5.72	0.3925	1.0158	16.3179
Searsia glutinosa	12.23	0.58	24.47	2.02	0.0816	0.2113	2.8181
Searsia pyroides	1.60	0.08	3.19	0.26	0.0007	0.0019	0.3419
Smilax aspera	3.46	0.17	8.51	0.70	0.0006	0.0016	0.8702
Solanecio gigas	2.93	0.14	6.38	0.53	0.0002	0.0005	0.6678
Spathodea campanulata	4.52	0.22	3.19	0.26	0.0009	0.0022	0.4819
Spiniluma oxyacantha	110.37	5.27	74.47	6.16	0.7727	2.0000	13.4253
Tacazzea conferta	4.26	0.20	2.13	0.18	0.0000	0.0000	0.3790
Vepris nobilis	35.37	1.69	19.15	1.58	0.0222	0.0575	3.3292
Vernonia amygdalina	1.60	0.08	4.26	0.35	0.0024	0.0061	0.4341
Vernonia auriculifera	3.46	0.17	7.45	0.62	0.0026	0.0066	0.7873

Notes: D – density, RD – relative density, F – frequency, RF – relative frequency, DO – dominance, RDO – relative dominance, IVI – importance value index.

Diversity of woody species. The diversity indices calculated for woody species in Menagesha Suba Forest demonstrate a relatively high level of species diversity and ecological balance. The Shannon Diversity Index (H') of 3.06 reflects substantial species richness within the forest. In comparison, the maximum possible diversity (Hmax) of 4.23 suggests that the forest has not yet reached its full potential for species diversity. The species evenness value of 0.72 indicates a moderately uniform distribution of individuals among species, with certain species being more dominant than others. Additionally, the Simpson's Diversity Index (D) of 0.93 highlights a low probability of randomly encountering the same species twice, underscoring the forest's high biodiversity. These results align with findings from other dry Afromontane forests in Ethiopia, such as Wof-Washa, Boditi, and Bale Mountain forests, which also exhibit high species richness but are subject to significant anthropogenic pressures (Fisaha et al., 2013; Soromess & Kelbessa, 2014). However, the diversity in Menagesha Suba Forest is comparatively higher than in many fragmented landscapes, highlighting its ecological importance as a refugium for woody species diversity and a critical site for biodiversity conservation in the Central Highlands of Ethiopia. The results are consistent with global trends observed in other montane forests, such as the dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania (Mwakalukwa et al., 2023), where high species diversity and structural complexity contribute significantly to ecosystem resilience. Similar to these forests, Menagesha Suba Forest provides a critical habitat for a variety of species, even under increasing anthropogenic and climatic threats, making it a vital component of regional conservation efforts. Given its ecological significance, Menagesha Suba Forest plays an essential role in sustaining biodiversity, maintaining ecosystem services, and serving as a key conservation priority. These findings emphasize the need for integrative forest management approaches that balance biodiversity conservation with sustainable use, as highlighted in other studies of Ethiopian Afromontane ecosystems (Fisaha et al., 2013; Ayele et al., 2024).

Density of woody species. The density of 2,094 individuals per hectare recorded in Menagesha Suba forest exceeds densities reported in other Ethiopian Afromontane forests, such as Wof Washa Forest (Fisaha et al., 2013) and Jibat Forest (Muleta et al., 2021). This relatively high density underscores the forest's role as a biodiversity reservoir. The predominance of *Juniperus procera*, *Olea europea*, and *Calpurnia aurea* highlights the ecological importance of these species in maintaining forest structure, mirroring similar trends in the Ethiopian Highlands (Girma et al., 2012). However, the observed dominance by a few species warrants monitoring to prevent potential biodiversity imbalances.

Frequency of woody species. The high frequency of *Olea europaea* (95.7%) and *Juniperus procera* (94.7%) corroborates their adaptability and ecological importance in Ethiopian dry Afromontane forests. Similar studies in Ethiopia's Chilimo Forest (Siraj, 2019) have reported comparable dominance of these species, emphasizing their critical role in forest ecosystem functionality. Frequent occurrence also highlights their value as key providers of ecosystem services, such as soil stabilization, carbon sequestration, and local livelihoods.

Importance value index (IVI) of woody species. The high IVI values for *Juniperus procera*, *Olea europaea*, and *Maytenus senegalensis* show their ecological and economic importance, consistent with findings in the Jibat Forest (Muleta et al., 2021). These species are integral to forest stability and provide essential services, such as timber, fodder, and medicinal resources.

Diameter class distribution. The predominance of smaller diameter classes reflects the forest's strong natural regeneration potential, paralleling observations in similar ecosystems such as the Wof Washa forest (Fisaha et al., 2013). However, the irregular distribution in larger classes indicates anthropogenic pressures such as selective cutting, that disrupt forest structure and ecological integrity. Such disturbances were also reported in the Munessa-Shashemene Forest (Senbeta et al., 2002; Senbeta & Teketay, 2002) and highlight the urgency for implementing sustainable forest management practices to protect larger-diameter trees crucial for ecosystem stability and ecological processes, including habitat provision and carbon storage.

Height class distribution. The dominance of smaller height classes reflects strong regeneration potential but also signals potential disturbances limiting growth into higher classes. This pattern is consistent with findings in the Harenna Forest (Kuzmicheva et al., 2018; Kewessa et al., 2019), where smaller individuals dominated disturbed forest sites. Promoting natural and assisted regeneration could help address height-class imbalances and support the ecological succession necessary for long-term forest resilience.

Basal area of woody species. The total basal area of 152.2 m²/ha highlights the spatial dominance and biomass contribution of key species like *Juniperus procera*, which accounts for 64.1% of the total. Comparable findings in the forests of Chilimo and Munessa (Senbeta et al., 2002; Soromess & Kelbessa, 2014; Siraj, 2019) stated the ecological significance of such species in carbon sequestration and ecosystem service provisioning. Lower basal area values for species like *Buddleia polystachya* indicate the need for enrichment planting to enhance their ecological roles and representation in the forest.

Regeneration status of Menagesha Suba Forest. The balanced representation of seedlings (29.1%), saplings (31.1%), and mature individuals (39.8%) indicates a promising regeneration status for Menagesha Suba Forest. Similar trends in Wof Washa Forest (Fisaha et al., 2013) affirm the potential of remnant forests to sustain biodiversity through natural regeneration. However, anthropogenic pressures, such as grazing and illegal logging, could hinder regeneration, as noted in the Sheka Forest (Berhanu et al., 2022). Enhanced regeneration practices are essential for mitigating these threats and ensuring the forest's long-term sustainability (Lemenih & Teketay, 2005; Froumsia, 2012; Bilew et al., 2015).

Multifunctional forest ecosystem services. Woody species play a crucial role in supporting rural livelihoods and ecosystem functionality in Menagesha Suba Forest, a vital remnant of Ethiopia's dry Afromontane forests. Our study revealed a rich diversity of woody plants used by local communities for a wide range of purposes, demonstrating their significant contributions to household subsistence, local economies, and the broader ecological landscape. Local people utilize tree and shrub species for fuelwood, construction materials, poles, timber, fencing, animal fodder, medicinal purposes, honey production, soil fertility improvement, and household utilities. These findings align with previous studies (Shumi et al., 2019, 2021) that highlight the integral role of woody plants in rural livelihoods across sub-Saharan Africa. For instance, over 90% of rural households in sub-Saharan Africa rely on fuelwood as their primary energy source (Brouwer et al., 1997; Koffi et al., 2018), underscoring the importance of sustainable woody plant management. The ability of local people to recognize and utilize multiple ecosystem functions from provisioning services like fuelwood to regulating services like soil fertility improvement demonstrates their deep connection to the forest landscape and its resources (Brander et al., 2024). Our study highlights the importance of maintaining and enhancing the multifunctionality of landscapes to balance biodiversity conservation and local resource use. Conservation strategies should prioritize the protection of multipurpose native woody species through natural and assisted regeneration, and enhance practices like mixed-species plantations to enhance biodiversity spillover and as a buffer zone.

Conclusions

Menagesha Suba Forest, a vital remnant of Ethiopia's dry Afromontane forests, is an ecological and socioeconomic treasure due to its high woody species diversity, structural complexity, and natural regeneration potential. This study identified 71 woody species, with dominant species such as *Juniperus procera* and *Olea europaea*, while less-represented species like *Rumex nervosus* emphasize variability in species composition. High biodiversity indices (H' = 3.06; evenness = 0.72) affirms its status as a biodiversity hotspot, yet threats like selective logging, land-use changes, and grazing pressures jeopardize its ecological stability. The regeneration status analysis reveals that while the forest exhibits moderate regeneration potential, with 60.6% of species showing fair regeneration, the significant proportion of species with poor regeneration (21.1%) or no regeneration (9.9%) raises concerns about the sustainability of its provisioning ecosystem services. These services, which include timber, non-timber products, carbon sequestration, and ecotourism benefits, are critical for local communities and biodiversity conservation. The dominance of lower diameter classes indicates robust recruitment potential, but irregular diameter class distribution and evidence of selective cutting point to anthropogenic pressures, including agricultural expansion, open grazing, and the conversion of natural forests into monospecific plantations, threaten the forest's resilience.

To ensure the long-term sustainability of Menagesha Suba Forest, conservation priorities should focus on protecting underrepresented species, maintaining larger diameter classes, and fostering natural regeneration. Targeted reforestation and enrichment planting, along with the integration of mixed plantations as ecological corridors, could mitigate habitat fragmentation and promote biodiversity spillover. Community-based approaches to forest management, combined with sustainable forestry practices and participatory policy frameworks, are essential to balance conservation with ecosystem service provision. Further research into forest dynamics over time and space, and the regeneration ecology of key native species is critical for devising adaptive management strategies. By addressing both ecological and anthropogenic challenges, Menagesha Suba Forest can continue to serve as a resilient, biodiverse landscape that sustains ecological and socioeconomic functions for future generations.

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References

Ayele, A., Seid, A., Mekonnen, A. B., Wassie, W. A., Yemata, G., Yihune, E., Mekuriaw, A., & Shimeles, L. (2024). Woody species diversity, structure and regeneration status of the church forests in West Gojjam Zone, Northwestern Ethiopia. Trees, Forests and People, 16, 100570.

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J. S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters, 9(10), 1146–1156.

Bekele-Tesemma, A. (2007). Useful trees and shrubs for Ethiopia: Identification, propagation and management in 17 agro-ecological zones. In: Tengnas, B., Kelbessa, E., Demissew, S., & Maundu, P. (Eds.). RELMA in ICRAF Project. Nairobi.

Benti, D. B. (2011). Floristic composition, diversity and structure of woody plant species in Menagesha Suba State Forest, Central Ethiopia. Addis Ababa University, Addis Ababa.

Berhanu, Y., Dalle, G., Sintayehu, D. W., Kelboro, G., & Nigussie, A. (2022). Woody species dynamics in Sheka Forest Biosphere Reserve, Southwest Ethiopia. Forest Ecology and Management, 519, 120313.

Bhat, J. A., Kumar, M., Negi, A. K., Todaria, N. P., Malik, Z. A., Pala, N. A., Kumar, A., & Shukla, G. (2020). Species diversity of woody vegetation along altitudinal gradient of the Western Himalayas. Global Ecology and Conservation, 24, e01302.

Bilew, A., Kitessa, H., & Balcha, A. (2015). Floristic composition and structural analysis of Gelesha Forest, Gambella Regional State, Southwest Ethiopia. Journal of Ecology and The Natural Environment, 7(7), 218–227.

Brander, L. M., de Groot, R., Schägner, J. P., Guisado-Goñi, V., van't Hoff, V., Solomonides, S., McVittie, A., Eppink, F., Sposato, M., Do, L., Ghermandi, A., Sinclair, M., & Thomas, R. (2024). Economic values for ecosystem services: A global synthesis and way forward. Ecosystem Services, 66, 101606.

Brouwer, I. D., Hoorweg, J. C., & Van Liere, M. J. (1997). When households run out of fuel: Responses of rural households to decreasing fuelwood availability, Ntcheu District, Malawi. World Development, 25(2), 255–266.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global Environmental Change, 26(1), 152–158.

Deyessa, B. Z., & Emana, A. N. (2024). Impacts of the surrounding land use land cover changes on Suba Sabeta Forest, Ethiopia, and associated community perception. Sustainable Environment, 10(1), 2310878.

Dibaba, A., Soromessa, T., & Warkineh, B. (2022). Plant community analysis along environmental gradients in moist afromontane forest of Gerba Dima, South-Western Ethiopia. BMC Ecology and Evolution, 22(1), 12.

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., Hahn, N., Palminteri, S., Hedao, P., Noss, R., Hansen, M., Locke, H., Ellis, E. C., Jones, B., Barber, C. V., Hayes, R., Kormos, C., Martin, V., Crist, E., … Saleem, M. (2017). An ecoregion-based approach to protecting half the terrestrial realm. BioScience, 67(6), 534–545.

Duguma, D. W., Brueck, M., Shumi, G., Law, E., Benra, F., Schultner, J., Nemomissa, S., Abson, D. J., & Fischer, J. (2024). Future ecosystem service provision under land-use change scenarios in Southwestern Ethiopia. Ecosystems and People, 20(1), 2321613.

Duguma, D. W., Law, E., Shumi, G., Rodrigues, P., Senbeta, F., Schultner, J., Abson, D. J., & Fischer, J. (2023). Spatial predictions for the distribution of woody plant species under different land-use scenarios in Southwestern Ethiopia. Landscape Ecology, 38(5), 1249–1263.

Duguma, L. A., Hager, H., & Gruber, M. (2009). The community-state forest interaction in Menagesha Suba Area, Ethiopia: The challenges and possible solutions. Forests Trees and Livelihoods, 19(2), 111–128.

Fisaha, G., Hundera, K., & Dalle, G. (2013). Woody plants' diversity, structural analysis and regeneration status of Wof Washa natural forest, North-East Ethiopia. African Journal of Ecology, 51(4), 599–608.

Froumsia, M. (2012). Woody species composition, structure and diversity of vegetation of Kalfou Forest Reserve, Cameroon. Journal of Ecology and the Natural Environment, 4(13), 333–343.

Garbach, K., Milder, J. C., Montenegro, M., Karp, D. S., & DeClerck, F. A. J. (2014). Biodiversity and ecosystem services in agroecosystems. In: Van Alfen, N. K. (Ed.). Encyclopedia of agriculture and food systems. Academic Press. Vol. 2. Pp. 21–40.

Gebrehiwot, K., & Hundera, K. (2014). Species composition, plant community structure and natural regeneration status of belete moist evergreen montane forest, Oromia Regional State, Southwestern Ethiopia. Momona Ethiopian Journal of Science, 6(1), 97.

Gebreselassie, S., Kirui, O. K., & Mirzabaev, A. (2015). Economics of land degradation and improvement in Ethiopia. In: Nkonya, E., Mirzabaev, A., & von Braun, J. (Eds.). Economics of land degradation and improvement – a global assessment for sustainable development. Springer, Cham. Pp. 1–14.

Govaerts, R., Nic Lughadha, E., Black, N., Turner, R., & Paton, A. (2021). The world checklist of vascular plants, a continuously updated resource for exploring global plant diversity. Scientific Data, 8(1), 215.

Ishii, H. T., Tanabe, S. I., & Hiura, T. (2004). Exploring the relationships among canopy structure, stand productivity, and biodiversity of temperate forest ecosystems. Forest Science, 50(3), 342–355.

Jeldu, F. A., Tolera, M., & Woldeamanuel, T. (2023). Functional diversity along disturbance and environmental gradients in Ethiopian moist Afromontane forest. Biosystems Diversity, 31(4), 460–469.

Kewessa, G., Tiki, L., Nigatu, D., & Datiko, D. (2019). Effect of forest coffee management practices on woody species diversity and composition in Bale Eco-Region, Southeastern Ethiopia. Open Journal of Forestry, 9(4), 265–282.

Koffi, C. K., Gazull, L., & Gautier, D. (2018). Variability of household fuelwood consumption in a rural Sudano-Sahelian context in Burkina Faso. Energy for Sustainable Development, 47, 75–83.

Kuzmicheva, E. A., Khasanov, B. F., Krylovich, O. A., Debella, H. J., Worku, W. G., Yirga, S., & Savinetsky, A. B. (2018). Vegetation and climate history of the Harenna Forest (Bale Mountains, Ethiopia) in the Holocene. Biology Bulletin, 45(6), 537–548.

Lemenih, M., & Teketay, D. (2005). Effect of prior land use on the recolonization of native woody species under plantation forests in the highlands of Ethiopia. Forest Ecology and Management, 218(1–3), 60–73.

Lewis, S. L., Edwards, D. P., & Galbraith, D. (2015). Increasing human dominance of tropical forests. Science, 349(6250), 827–832.

Malik, A., Hussain, M. A., Iqbal, K., & Bhatt, A. B. (2014). Species richness and diversity along the disturbance gradient in Kedarnath wildlife sanctuary and its adjoining areas in Garhwal Himalaya, India. International Journal of Current Research, 6(12), 10918–10926.

Masresha, G., Soromessa, T., & Kelbessa, E. (2015). Status and species diversity of Alemsaga Forest, Northwestern Ethiopia. Advances in Life Science and Technology, 34, 87–99.

Muleta, T. T., Kidane, M., & Bezie, A. (2021). The effect of land use/land cover change on ecosystem services values of Jibat forest landscape, Ethiopia. GeoJournal, 86(5), 2209–2225.

Mwakalukwa, E. E., Mwakisu, A., & Maliondo, S. M. S. (2023). Woody species diversity, composition, structure and carbon storage of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania. International Journal of Tropical Drylands, 7(1), 26–36.

Nigatu, D., Tiki, L., Kewessa, G., & Datiko, D. (2017). Traditional coffee management practices and their effects on woody species structure and regeneration in Bale Eco-Region, Ethiopia. International Journal of Advanced Research, 5(6), 591–598.

Pillay, R., Venter, M., Aragon-Osejo, J., González-del-Pliego, P., Hansen, A. J., Watson, J. E. M., & Venter, O. (2022). Tropical forests are home to over half of the world's vertebrate species. Frontiers in Ecology and the Environment, 20(1), 10–15.

Senbeta, F., & Teketay, D. (2001). Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia. Tropical Ecology, 42(2), 175–185.

Senbeta, F., & Teketay, D. (2002). Soil seed banks in plantations and adjacent natural dry Afromontane forests of Central and Southern Ethiopia. Tropical Ecology, 43(2), 229–242.

Senbeta, F., Teketay, D., & Näslund, B. Å. (2002). Native woody species regeneration in exotic tree plantations at Munessa-Shashemene Forest, Southern Ethiopia. New Forests, 24(2), 131–145.

Shrestha, B. B., & Moe, S. R. (2015). Plant diversity and composition associated with Himalayan musk deer latrine sites. Zoology and Ecology, 25(4), 295–304.

Shumi, G., Dorresteijn, I., Schultner, J., Hylander, K., Senbeta, F., Hanspach, J., Ango, T. G., & Fischer, J. (2019). Woody plant use and management in relation to property rights: A social-ecological case study from Southwestern Ethiopia. Ecosystems and People, 15(1), 303–316.

Shumi, G., Rodrigues, P., Hanspach, J., Härdtle, W., Hylander, K., Senbeta, F., Fischer, J., & Schultner, J. (2021). Woody plant species diversity as a predictor of ecosystem services in a social-ecological system of Southwestern Ethiopia. Landscape Ecology, 36(2), 373–391.

Siraj, M. (2019). Forest carbon stocks in woody plants of Chilimo-Gaji Forest, Ethiopia: Implications of managing forests for climate change mitigation. South African Journal of Botany, 127, 213–219.

Solorio, F., Ramírez, L., Basu, S., Trenchard, L., Sarabia, L., Wright, J., Aguilar, C., Solorio, B., Ayala, A., & Ku, J. (2017). Native trees and shrubs for ecosystems services and the redesign of resilient livestock production systems in the Mexican neotropics. In: Ahuja, M. R., & Mohan Jain, S. (Eds.). Biodiversity and conservation of woody plants. Springer, Cham. Pp. 489–511.

Soromess, T., & Kelbessa, E. (2014). Interplay of regeneration, structure and uses of some woody species in Chilimo forest, Central Ethiopia. Science, Technology and Arts Research, 3(1), 90–100.

Tadesse, G., Zavaleta, E., Shennan, C., & Fitz Simmons, M. (2014). Prospects for forest-based ecosystem services in forest-coffee mosaics as forest loss continues in Southwestern Ethiopia. Applied Geography, 50, 144–151.

Tekalign, M., Van Meerbeek, K., Aerts, R., Norgrove, L., Poesen, J., Nyssen, J., & Muys, B. (2017). Effects of biodiversity loss and restoration scenarios on tree-related ecosystem services. International Journal of Biodiversity Science, Ecosystem Services and Management, 13(1), 434–443.

Tolessa, T., Senbeta, F., & Kidane, M. (2017). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosystem Services, 23, 47–54.

Workneh, Y., & Wasie, D. (2024). Effects of selective harvesting on diversity, structure, and regeneration of woody plants in mixed plantation of Menagesha Suba Forest, Central Ethiopia. International Journal of Forestry Research, 2024(1), 3355857.