Environment and Ecology 42 (4A) : 1783—1789, October—December 2024
Article DOI: https://doi.org/10.60151/envec/DNQO1015
ISSN 0970-0420

Assessing Woody Species Diversity in Dembecha District, Northwestern Ethiopia: Agroecological and Landholding Perspectives

Belayneh Kelemu, Beyene Belay, Bilisuma Hailu, Fekadu Debebe

Received 11 March 2024, Accepted 20 October 2024, Published on 29 November 2024

ABSTRACT

The cultivation of perennial woody species in Ethiopia's agricultural landscape is recognized for its contributions to biodiversity conservation and soil fertility. This research aimed to assess the diversity of woody species in the agricultural landscape of Dembecha district, located in northwestern Ethiopia. Three kebeles, representing distinct agroecologies (highland, midland, and lowland), were selected for the study. A total of 30 households, with 10 randomly chosen from each agroecology, participated in the inventory of woody species. The height of the woody species was gauged using a clinometer, and the diameter at breast height (DBH) of species with a diameter exceeding 5cm was measured using a diameter tape. Statistical Package for Social Science (SPSS) version 21 was employed to compare means across the study kebeles and different landholding sizes. The inventory results revealed the presence of 45 woody species in the study area, with 25 species recorded in both the highland and midland areas, and 18 in the lowland areas. The assessment of species diversity, using the Shannon diversity index, showed significant variation across agroecologies, ranging from 1.1 in the lowland to 2.00 in the midland ($p<0.05$). Similarly, species diversity varied significantly among different landholding sizes, particularly between small landholding size (0.5-1.5ha) and medium (1.51-2.5ha) and large landholding size (>2.51ha) ($p<0.05$). The Shannon diversity index ranged from 1.2 for small landholding size to 1.72 for large landholding size. Notably, *Eucalyptus camaldulensis* and *Croton macrostachyus* emerged as the most abundant species recorded in the study.

Keywords Agroecology, Richness, Household, Landholding Size.

INTRODUCTION

Agriculture serves as the backbone of Ethiopia's economy and is a primary occupation for the Ethiopian population (Yigezu 2021, NBE 2018). The combination of rapid population growth and a longstanding history of sedentary agriculture has

Belayneh Kelemu[1], Beyene Belay[2], Bilisuma Hailu[3], Fekadu Debebe[4]*

[1]Lecturer
Department of Natural Resources Management, College of Agriculture and Natural Resource, Jinka University, Jinka, Ethiopia

[2]PhD Scholar, [3]Lecturer
Department of Natural Resource Management, College of Agriculture and Environmental Science, Bahir Dar University, Bahir Dar, Ethiopia

[4]Lecturer
Department of Natural Resource Management, College of Agriculture, Food and Climate Science, Injibara University, Injibara, Ethiopia

Email: fekadudebebe21@gmail.com
*Corresponding author

resulted in shifts in land use and cover, contributing to environmental degradation in numerous developing countries, Ethiopia included (Leach and Mearns 2013). The expanding population and consequent environmental impacts on forest ecosystems have led to the depletion of forest areas, habitat fragmentation, soil degradation, and biodiversity losses (Olagunju 2015). Factors such as population growth, the quest for arable land, demand for construction materials, and the expansion of commercial farms have been identified as drivers of deforestation in Ethiopia (Hassen 2013). Deforestation is particularly pronounced in mountainous regions of sub-Saharan Africa, especially the Ethiopian highlands (Deribew and Dalacho 2019).

In the early 20th century, Ethiopia's land was covered by trees to the extent of 35%, but recent reports indicate a significant reduction, with only 11% of the total land area (12.296 million ha) now covered by forests (FAO 2010). The estimated deforestation rate is alarming, with an annual loss of 1,410 km^2, equivalent to a deforestation rate of 1.1% (FAO 2015). The economic repercussions of genetic resource loss due to deforestation in Ethiopia are estimated to range between 0.4 and 1.5 billion USD per year (Srinivasan 2014).

Ethiopia's diverse topography, coupled with population growth and agricultural expansion, introduces altitude as a significant factor influencing tree diversity across different regions of the country. Studies reveal a decline in tree species richness with increasing altitude, emphasizing the role of environmental factors in shaping biodiversity (Mewded *et al.* 2020, Toru *et al.* 2023). Additionally, landholding size emerges as a crucial factor influencing woody species diversity in Ethiopia. Larger landholdings are associated with higher woody species richness, diverse composition, and distinct population structures compared to smaller landholdings (Haile *et al*. 2017, Melese *et al.* 2017, Lemage and Legesse 2018, Mehari *et al.* 2019).

In the Amhara region of northern Ethiopia, the average size of landholdings for farming families has dwindled to less than 1 hectare per family. This trend has led to the rapid conversion of forests, woodlands, and shrub lands into crop fields and treeless rangelands (Mengistu and Hager 2010). Deforestation rates in Ethiopia are challenging to measure accurately (Duriaux-Chavarria *et al.* 2021), and recent satellite imagery analyses reveal highly variable changes in forest cover between landscapes (Hishe *et al*. 2021). Despite these challenges, the loss of woody plant diversity poses a significant threat to the well-being of subsistence farming communities (Wassie 2020).

To address land degradation, smallholder farmers worldwide intentionally incorporate trees and shrubs into their croplands and grazing areas. Researchers have highlighted the multifaceted roles of woody plants in traditional farming systems (Lovell *et al.* 2018). The intentional planting of trees and woody plants on farmland depends on local farmers' knowledge regarding tree use and management, the economic values of species, land size, tenure systems, and sociocultural factors (Joa *et al.* 2018). Many local communities are renewing efforts to retain and plant useful trees and shrubs within croplands and grazing areas, aiming to increase food, health, and energy resource availability to farming families.

These practices diversify income generation opportunities and optimize the productivity, stability, and resilience of farming systems (Gidey *et al.* 2019). Moreover, planting and protecting trees and shrubs can contribute to reversing deforestation, offsetting socio-economic impacts related to land scarcity, as farming families can derive multiple products from their relatively small landholdings. This study aims to assess the diversity of woody species in the agricultural landscape.

MATERIALS AND METHODS

Study area

The research was carried out in the Dembecha district, situated in the West Gojjam Zone of the Amhara National Regional State in Ethiopia. Geographically, it is positioned between 37°11′ 00″-37°38′ 51″ E longitude and 10°19′ 62″-10°19′ 21″ N latitude. The elevation of Dembecha woreda ranges from 967 to 2600 m.a.s.l. According to traditional Ethiopian agro-ecological classification, the majority of Dembecha woreda falls

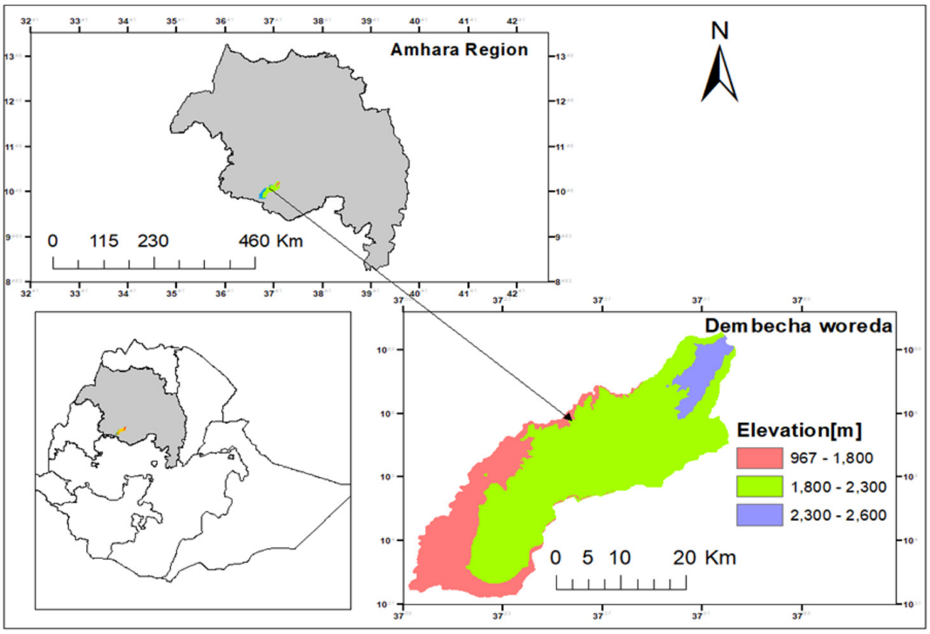

Fig. 1. Map of study area.

under the middle altitude category known as "Woina Dega," (1,800 – 2,300 m.a.s.l) followed by lowland or "Kolla," (967 – 1,800 m.a.s.l) and highland or "Dega" (2,300 – 2,600 m.a.s.l) (Fig. 1).

The land use distribution is dominated by cultivated land, which covers an area of 76,440 hectares and accounts for 78.05% of the total land area. Natural forest land occupies 4,202 hectares, representing 4.3% of the land. Plantation forests cover 5,838 hectares, making up 6% of the total land area. Grazing land covers 11,446 hectares, comprising 11.6% of the land use (Table 1) (DWADO 2023).

Study area selection

Stratified random sampling design was used to select study kebeles (the lowest administration in Ethiopia). First the district was divided into different agroecology and three kebeles were selected randomly, Anjenie from highland (2,500 – 2,800 m.a.s.l), Wad from midland (1,500 – 2,000 m.a.s.l) and Enewend from lowland (less than1500 m.a.s.l).

Table 1. Major land use type in the study area.

Major land use type	Area in hectare	Proportion (%)
Cultivated land	76440	78.05
Natural forest land	4202	4.3
Plantation forest	5838	6
Grazing land	11446	11.6

Household survey

All the 203 HHs were interviewed with regarding to source of trees species, benefits of trees species and their management of tree species on their agricultural landscape mainly key informant, developmental agent and community facilitator (Table 2). Sample households (HHs) were selected based on the formula given below so as to minimize the bias for socio-economic data (Kothari 2004).

$n=z^2PQN/E^2(N-1)+Z^2PQ$----------------------------equation (1)

Table 2. The number of selected households in the study kebeles.

Name of agroecology	Household size	Household sample size	Household size selected for diversity assessment
Highland (Dega)	753	66	10
Midland (Woina Dega)	1332	69	10
Low land (Kolla)	989	68	10
Total	4160	203	30

Where n=Sample size
N=number of house hold
P=Level of precision ………………… 5%=0.05
E=Allowed error which is 5%=0.05
Q=1-P=1-0.05=0.95
Z= Confident interval 95%, 1.96 from Z – table

Methods of data collection

All the woody species in each household's farmland (10 HHs from highland, 10 HHs from midland and 10 HHs from lowland kebeles) were assessed. Wood species with DBH (1.30m above the ground) ≥ 5 cm were measured following (Zebene 2016, Gidey *et al.* 2019). In addition, to determine the abundance (number of individuals), all saplings (woody species DBH < 5 cm and seedlings with height greater than 1.5 m) and seedlings (woody species with height less than 1.5 m) were counted (Senbeta *et al.* 2002, Gidey *et al.* 2019). The height and DBH were measured by clinometer and diameter tape respectively. The farm land size of each farmer was taken from land ownership map given farmers from the government administrative.

Vegetation data analysis

Diversity measures such as Shannon diversity index, species richness and evenness were evaluated. The indices were selected based on their frequent occurrence in plant diversity assessment studies and ease of applicability. The formula for computing diversity indices were indicated below:

Shannon-Wiener Diversity Index (H'): Shannon-Wiener diversity Index is measured through a combination of species richness (the number of species per sample) and species evenness (the relative abundance of each species) (Begon *et al.* 2006).

The Shannon-Wiener diversity index was calculated as:

$$H' = -\sum_{i=1}^{s} \text{pilnpi} \quad \text{....equation (2)}$$

Where; H' = Shannon diversity index, Pi is proportion of individuals found in the i^{th} species, S is the number of species, i = 1, 2, 3…..s

Species Richness (S): Species richness is the biological appropriate measurement of alpha (α) diversity and the total number of species in an ecological community relative to the total number of all individuals in that community and can be calculated by using Margalef's index of richness (Dmg) (Magurran 1988).

$$D_{mg} = \frac{S-1}{\text{In } N} \quad \text{.....equation (3)}$$

Where; S is total number of species, N is total number of individuals in the sample, ln is natural logarithm

Species Evenness (Equitability Index): Evenness refers to the variability in the relative abundance of species. The evenness index describes the equality of species abundance in the community (Begon *et al.* 2006). Evenness (J) was calculated as:

$$J = -\sum_{i=1}^{S} \frac{\text{pilnpi}}{\text{In } S} = \frac{Hi}{\text{In } S} \quad \text{equation (4)}$$

Where; H' is the Shannon diversity index, S is the number of species in a particular altitudinal gradient and Pi = is the proportion of total individuals in the i^{th} species.

Values of the index (H') usually lie between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5 (Kent and Coker 1992).

Statistical analysis

The data which were collected from field inventory was organized and recorded in Microsoft excel 2013 datasheet. The altitudinal gradient and landholding size were considered as independent variables while species diversity, species evenness and species richness were considered as dependent variable. Vegetation data were analyzed univariate analysis. Variables were compared using one way analysis of variance (ANOVA) with the help of Statistical Package for the Social Sciences (SPSS) version 21 with statistical difference were observed ($p \leq 0.05$), Tukey's HSD test were used to separate the means.

RESULTS AND DISCUSSION

Woody species abundance, richness and diversity

The site documented a total of 45 woody species from

Table 3. The overall diversity index of woody species at three kebeles in the entire households.

Study area	Shannon diversity	Species evenness	Species abundance	Species richness
Highland	0.37	0.11	3353	25
Midland	2.51	0.78	424	25
Lowland	1.32	0.46	593	18

31 families. Among the 4370 individuals recorded, 593, 424, and 3353 were observed in lowland, midland, and highland kebeles, respectively (Table 3). In the lowland kebele, *Eucalyptus camaldulensis* dominated with 398 individuals (64.1%), followed by *Croton macrostachyus, Vernonia amygdalina,* and *Nuxia congesta* (Table 3). Similarly, the midland kebele exhibited *Eucalyptus camaldulensis* as the most abundant species, followed by *Croton macrostachyus, Cordia africana,* and *Vernonia amygdalina* (Table 3). In the highland kebele, *Eucalyptus camaldulensis* was predominant, followed by *Cupressus lusitanica, Albizia gummifera,* and *Acacia pilispina* (Table 3). The Shannon diversity index for this site was notably low at 0.37 compared to midland (2.51) and lowland (1.32) sites, attributed to the dominance of *Eucalyptus* species (Table 3).

In both studied kebeles, *Eucalyptus camaldulensis* and *Croton macrostachyus* emerged as the most abundant species, preferred by farmers. Conversely, in the highland, *Eucalyptus camaldulensis* and *Cupressus lusitanica* were prevalent, with their abundance attributed to the steep slope, marginality, and lower fertility of agricultural lands, making them more suitable for plantation than crop production (Tesfaw *et al.* 2023). The high abundance of *Eucalyptus* species in the area is also driven by market demands and economic incentives, sometimes resulting in the conversion of arable farmlands (Tesfaw *et al.* 2023, Abiyu and Raja 2015).

Following *Eucalyptus camaldulensis, Croton macrostachyus* emerged as the second most abundant species in the two kebeles due to its importance for soil fertility, aligning with previous studies (Gidey *et al*. 2019. Melaku *et al.* 2022). Notably, midland kebele exhibited the highest species diversity, likely due to favorable climatic conditions supporting the growth of a diverse range of tree and shrub species. Additionally, the Shannon diversity index tends to increase with higher species richness, as noted by (Abebe *et al*. 2010).

Woody species diversity, richness and abundance along agroecology

Variations in the diversity of woody species among households in different agroecological categories were found to be significant in the midland kebele (Table 4). Woody species diversity in the midland agroecology significantly differed from both lowland and highland kebeles whereas no significant difference was observed between highland and lowland kebeles (Table 4). The highest woody species richness in the midland kebele is attributed to well-organized irrigation practices and the agroecological suitability of the area. Additionally, midland regions often feature a combination of ecological characteristics from both lowland and highland areas, creating a distinctive and diverse habitat. This encompasses a blend of temperature, precipitation, and soil attributes conducive to supporting a wide array of plant species. Moreover, midland areas typically fall within an altitudinal range that offers favorable conditions for various species, leading to a greater overlap of species from lowland and highland regions and subsequently resulting in increased species richness.

The result is agreed with the previous work in northwestern Ethiopia (Gidey *et al.* 2019). In contrast, research in northeastern Ethiopia indicated a reduction in the number of taxa, stem density, richness, and diversity with increasing elevation, particularly from homestead to boundary and on-farm plantation

Table 4. Mean (± standard deviation) diversity and evenness indices of woody species among three agroeclogy categories of the study kebeles.

Agroecology	Diversity	Evenness
Highland	1.46 ± 0.55^{a}	0.62 ± 0.28^{a}
Midland	2.00 ± 0.32^{b}	0.92 ± 0.06^{a}
Lowland	1.10 ± 0.44^{a}	0.71 ± 0.24^{a}
Over all mean	1.52 ± 0.57	0.75 ± 0.24

Note: Different letter (s) ordered vertically on mean values show a significant difference at $p < 0.05$ among the three agroecologies.

Table 5. Mean (± standard deviation) diversity and evenness indices of woody species among three land holding size categories of study kebeles.

Land holding size (ha)	Diversity	Evenness
Small (0.5-1.5)	1.20 ± 0.67[a]	0.74 ± 0.24[a]
Medium (1.51-2.5)	153 ± 0.65[bc]	0.72 ± 0.31[a]
Large (>2.51)	1.72 ± 0.38[c]	0.83 ± 0.14[a]
Overall	1.51 ± 0.58	0.74 ± 0.24

Single different letters on mean values of richness and abundance in column indicates that significant difference at ($p < 0.05$) whereas similar letters indicates that non-significant at ($p > 0.05$).

niches (Meseret *et al.* 2022). Another study reported a consistent decrease in species diversity and richness with increasing altitude (Shimono *et al.* 2010, Mewded *et al.* 2020, Toru *et al*. 2023).

Effect of land holding size in tree diversity and abundance in agricultural landscape

As indicated in Table 5, there was a significant difference in woody species diversity based on landholding size categories: Small (0.5-1.51 ha), medium (1.5-2.5 ha), and large (>2.51 ha) in the studied kebeles. The study revealed a mean difference between medium and large landholding sizes, but statistically, there was no significant difference (Table 5). Farmers with larger land holdings demonstrated the capacity to plant a greater number of trees on their farmlands, whereas those with smaller holdings focused on a limited selection of trees that provided direct benefits due to land scarcity for food crop production. Similar results obtained in southern and central Ethiopia (Getahun *et al*. 2017, Deneke and Mesele 2023). Other studies also showed that larger landholding size can support greater woody species diversity and richness (Haile *et al.* 2017, Lemage and Legesse 2018, Melese *et al*. 2017). Conversely, species evenness did not exhibit a statistically significant difference among landholding sizes in the studied kebeles (Table 5). This lack of significance can be attributed to the dominance of a few species in the area, notably *Eucalyptus camaldulensis* being the most abundant.

CONCLUSION

The overall diversity of woody species within the examined agroecologies exhibited variations. The midland agroecology stood out with the highest woody species diversity, particularly in the midland kebele where well-organized irrigation practices and agroecological suitability contributed to this richness. Midland areas, characterized by a blend of ecological features from both lowland and highland regions, created a diverse habitat. Furthermore, the diversity of woody species demonstrated a significant difference concerning landholding size. Larger land holdings displayed greater diversity in woody plants compared to smaller ones. This is primarily due to the expansive nature of larger lands, providing more ecological niches and habitat diversity conducive to a broader spectrum of woody plant species. Larger areas also experience less human disturbance, facilitating natural processes like succession and colonization, resulting in a more diverse woody plant community. Conversely, smaller land holdings may face constraints in space and resources, leading to a reduced diversity of woody plants. However, it's crucial to recognize that the correlation between landholding size and woody plant diversity is not absolute, with potential exceptions influenced by factors such as location, climate, and management practices.

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