Woody Species Population Structure and Regeneration Status in Hereje Natural Forest, Southwest Ethiopia

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Abstract

Finding potential management interventions to lessen the negative effects of deforestation and forest degradation requires understanding the population structure and regeneration status of woody species in Ethiopia's Hereje Natural Forest. The local population relies on the forest for ecosystem services, which in turn, alters the plant diversity and age structure of the forest and the regeneration status for future generations is uncertain. Hence, this study was conducted with the objective of determining the Woody Species population structure and regeneration status of woody species in Hereje Natural Forest in Southwest Ethiopia Three parallel transect lines (every 100 m) were established along altitudinal gradients, and 45 plots of 20 m x 20 m were used to collect vegetation data. Living woody species were counted and measured using diameter at breast height (DBH) measurements for DBH>2.5cm in each plot. Each main plot had five 2mx2m (4m^2) subplots, one in the center and four at the corners. The regeneration status of each subplot was assessed by the species of woody plants present (seedlings, saplings, and mature trees/shrubs).On the studied plots, a total of 44 plant species were identified and classified into 28 families and 41 genera. The most relatively dominant species in the Hereje forest were *Syzygium guineense* (24.47%), *Ficus sur* (20%), *Combretum molle (*18.58%), *Croton macrostachyus* (18.11%), and *Terminalia schimperiana* (9.29%). According to the results, the density of tree species in the forest decreases as DBH classes increase. The predominance of small DBH classes is a result of excessive cutting for certain size classes by the local community, indicating extensive changes in the woody plant diversity and age structure. Overall, the forest's regeneration status was fair. Urgent interventions and enforced regulations are required to halt the major cause of forest deterioration, namely human-induced activities such as cattle grazing, illegal timber harvesting, and firewood collection. For long-term forest stability and biodiversity conservation, additional in-depth ecological studies are recommended regarding potential management interventions, monitoring protocols, and other ecological factors that contribute to the sustainable use of the forest and its products.

1. Introduction

Ethiopia is renowned for its wide range of vegetation types, from alpine to desert ecosystems due to the influence of physiographic, altitudinal, climatic, and edaphic factors on the landscape. Ethiopia's flora consists of approximately 6,027 vascular plant species, of which 10% are endemic taxa, and provides numerous economic, sociocultural, and environmental benefits [1, 2]. According to various literary sources, Ethiopia's forest cover once covered 40% of the nation, but that proportion has since fallen to less than 15.7%[3]. Ethiopia's forest cover is 17,07 million hectares [4], and these natural forest remnants are in the southwest and southeast of the country [3]. The country's population is growing rapidly (90 million) [5], and the alarming rate of population growth is causing high deforestation and forest degradation, which are critical environmental issues [6]. Managing and restoring Ethiopia's forests is a national priority due to the numerous obstacles and many challenges involved.

The greatest threats to the conservation of Ethiopia's natural resources are the intensive use of forest lands for agriculture, infrastructure expansion, mining, urban expansion, logging, overgrazing, uncontrolled fires, demand for fuel wood and construction materials, and human settlements[7,8]. In addition to human activities, environmental factors such as altitude, climate (precipitation and temperature), soil type, and the interaction of these factors can influence the distribution and patterning of forest vegetation [9]. Reduction in forest cover has numerous repercussions, including soil erosion, diminished watershed protection with the possibility of flooding, and loss of biological diversity [10].According to [6], forest degradation and deforestation lead to the instability of the ecosystem and a decrease in the availability of diverse forest products and services.

Knowledge of the woody plant species population structure and their natural regeneration status analysis of a specific area has long been considered a prerequisite for forest conservation efforts[11].Assessing the population structure and natural regeneration status of woody plant species in each forest resource has downstream benefits for identifying essential elements of protecting threatened species, plant diversity, monitoring the status of the forest and economic species, and contributing to the conservation and maintenance of biodiversity[11,12].

The future composition of forests is contingent on the long-term regeneration status (potential reproduction and recruitment) of tree species [13, 14]. The population structure of a forest stand is one of the most crucial determinants of which tree species are dominant and how the stand develops. Good regeneration indicates a species' environmental adaptability, such as acclimation to climatic influences and biotic interferences [15]. The evaluations of seedling and sapling density values are metric indicators of the species' regenerative capacity [16]. Successful regeneration for woody tree species is largely dependent on three key factors:(i) initiation of new seedlings, (ii) establishment of seedlings and saplings, and (iii) the growth potential and longevity of seedlings and saplings [17].

Therefore, research into the population structure, regeneration status, and canopy tree density of major tree species is important for comprehending the forest's management history and ecology [18].Producing accurate information about a region's forest resources is a prerequisite for sustainable forest management and planning [19].The management of forest regeneration is essential for sustainable forest practice because it safeguards carbon stock and monitors forest health indicators in a region [20, 21].

This study aims to investigate the population structure and regeneration potentials of various natural forest tree species of Hereje natural forest to predict future vegetation trends. Even though Hereje forest provides essential ecological services and socioeconomic value to the local community, there is insufficient knowledge about sustainable use and management of the forest and how human pressure will affect forest structure, succession, and land cover change over the long term. This is the first study on Hereje National Forest’s woody species vegetation structure and regeneration status.

2. Materials and Methods

2.1. Description of the study area

Hereje Forest is in Boloso Bombe district of the Wolaita zone within the Southern Nation Nationality and People Region(SNNPR) ($37^{0}33'0''$–$37^{0}36'0''$E, $7^{0}4'30''$–$7^{0}7'30''$N) , Ethiopia (Fig: 1). It is approximately 398 km away from Addis Ababa, at an elevation of 1,542 to 2,375 m above sea level[22].The region is separated into three agro climatic zones: *Dega* (Highland), covers25%, *Woinadega* (Midland) covers45%, and *Kola* (Lowland) covers 30%.

The study area receives an average of 1427 millimeters of precipitation annually, with the primary rainy season occurring from July to September. The annual average temperature is 21.2^{o}C (min 13.6^{o}c max28.8^{o}c) [23]. The study area is predominated by Vertisol (51.73 %) and Nitisol (48.27%). The local economy is primarily dependent on subsistence agriculture [22].

2.2. Data collection

2.2.1. Reconnaissance Survey

Researchers conducted a forest-wide reconnaissance survey, between February 1-20, 2019, to learn more about the study area and find suitable locations for representative sampling plots.

2.2.2. Sampling design

To collect the woody species vegetation data on population structure and regeneration, systematic sampling design, with random starting points, was applied following [24] and [25]. The woody species or tree species data was collected from March to May of 2019, from a total of 45 plots established. The sampling locations were distributed along three parallel transect lines spaced 100m apart. Along each transect, sample plots of 20m×20m (400m^2) were placed at a distance of 100m apart to measure and record the DBH. To collect seedling and sampling data, five 2m2m (4m^2) subplots were established, one at each corner and one in the center of the main plot.

The tree density, height, and DBH were measured, recorded, and used to characterize vegetative structure. All trees and shrubs with a height >2m and a DBH >2.5cm were measured. The diameter measurements were taken at a height of approximately 1.3 meters above the ground using a measuring tape and later converted in to DBH as indicated in equation 3. The regeneration status of the forest was determined by counting the number of seedlings, saplings, and mature trees and shrubs in the forest.

2.3. Data Analysis

2.3.1. Plant Population Structural Data Analysis

The tree density, frequency, dominance, DBH, basal area (BA), and Important Value Index (IVI) were analyzed in accordance with sing [26]. The relative density, relative frequency, dominance, important value index (IVI), and basal area were calculated [25] formula to determine the forest's vegetation structure and dominant plant species.

1. $\text{Density} = \text{Count of individuals of species} \frac{A}{\text{sampled area}}$

2. $\text{Relative density(RD)} = (\text{No of individuals of species A/total number of individuals in the area}) \times 100$

3. Diameter at Breast Height (DBH) $= C/\pi$ Where, C-circumference, $\pi = 3.14$

4. Basal area of a tree (BA) = $d2/4$, where d= diameter at breastheight (DBH) $\pi = 3.14$

5. Dominance= Basal area or total cover of species A/ sampled area.

6. Relative dominance= (dominance of species A / total dominance of all species) × 100.

7. Relative frequency= (freq value for species A/total of all frequency values for all species) ×100.

8. Important Value Index (IVI) = Relative density + Relative frequency + Relative dominance.

2.3.2 Regeneration Data Analysis

The regeneration status of the Hereje forest was determined by calculating the present-absence data ratios from the total species among seedlings, saplings, and matured trees. It is necessary to compare the number of seedlings to saplings and saplings to mature trees to determine the state of forest regeneration for a particular species [7, 15, 27-29] .Several category were used to categorize the forest's regeneration status.

1. “New, “species has no mature stage, only sapling and/or seedling stages.
2. “None,” species absent in the seedling and sapling stages, but appear mature;
3. “Good” regeneration, seedling > sapling > mature tree;
4. “Fair” regeneration, seedling > sapling < mature tree;
5. “Poor” regeneration, species endures during the sapling stage but not during the seedling stage. (regardless of whether saplings are less than, more than, or equal to mature)

Population structure is defined as the numerical distribution of individuals of differing size or age groups within a given species population at a given moment [30].For this study, plants with heights were classified as seedlings (<1 m), saplings (<1-3 m), and mature trees/ shrubs (>3m), respectively. In this study, all individuals of species encountered in the plots were grouped into five arbitrary diameter classes.1 = 2.50-5.20cm, 2 = (5.21-7.5cm), 3 = (7.5-10cm), 4 = (10.1-20cm), 5 = (>20.1cm), and accompanying histograms were developed.

3. Results

3.1. Vegetation structure Analysis

3.1.1. Density and Diameter at Breast Height (DBH)

A total of 1179 individuals (736.9 stem/ha) were counted with the DBH > 2.5cm within sampled plots. The density of wood species is comparable to that of [31], who conducted a study in the nearby district's Wotagisho forest. For the DBH class, the highest density (212.5stem/ha) of woody plant species was noted in smaller size classes (2.5-5.2cm), and the lowest density (91.3/ha) of woody species was observed in larger size classes, with DBH class greater than 20cm (Table 1). In general, the density investigation showed the dominance of small-sized trees and shrubs in the forest. These results might further suggest that the nearby community selectively exploited large-sized species for different purposes. The distribution of DBH class sizes generally takes the form of an irregular inverted J-shape. Similar results were reported by [32, 33]

Table 1
DBH class and the density of woody species in the Hereje forest

Class	Diameter range in (DBH)cm	Density/ha	The no of individuals 900 m²	Percentage
1	2.5-5.2cm	212.5	340	28.84
2	5.21–7.5.cm	185.6	297	25.19
3	7.51-10cm	145.6	233	19.76
4	10-20cm	101.9	163	13.83
5	> 20.1cm	91.3	146	12.38

3.1.2. Basal Area and Importance Value (IVI) of woody Species

Based on DBH data, the total basal area of all tree species distributions in the Hereje forest was calculated and found to be 41.9 m2/ha(Table 2). This basal area value is greater than from virgin tropical forests in Africa is 23– 37 m2 /ha [34]. Based on the basal area calculation, the largest amount of Hereje forest was contributed by *Syzygium guineense* (9.92%), *Ficus sur* (8.11%), *Combretum molle* (7.54%), *Croton macrostachyus* (7.35%), *Millettia ferruginea* (6.34%) (Table 2)and these five species basal area covers 39.26 of the study area. Thus, species with the largest contribution to Basal area can be considered the most important species in forest.

Table 2
Basal area and percentage of five dominant tree species in Hereje Forest

S.N	Name of the species	Basal area (m^2/ha)	Percentage (%)
1	*Combretum molle*	3.16	7.54
2	*Millettia ferruguinea*	2.66	6.34
3	*Croton macrostachyus*	3.08	7.35
4	*Ficus sur*	3.4	8.11
5	*Syzygium guineense*	4.16	9.92
	Total	16.46	39.28

[35], asserts that basal area measurements, rather than stem counts, are a better indicator of a forest's various tree species' relative importance. The basal area of the Hereje forest was found to be greater than that of several other regional forests, including, Amoro Forest [36], the Central plateau of Shewa Menegesha and Chilimo forest ([35], GuraLop ho[37], Adelle [38]and Angada [39] whereas, several other forests have higher than that of Hereje forest (Table 3).

Table 3
Basal area of some of the selected forests in Ethiopia

Forest	BA m^2/ha	Authors
Amoro Forest	18.5	[36]
Asabot	22.45	[39]
Adelle	26	[38]
GuraLopho	29.63	[37]
Central plateau of Shewa Chilimo	36.1	[35]
Central plateau of Shewa Menegesha	36.5	[35]
Hereje	41.9	present study
Denkoro	45	[32]
Wotagisho forest (an adjacent forest)	45.14	[31]
Komto	50.72	[40]
Alata-Bolale	53.3	[41]
Kenech	56.8	[42]
Jibat	60.9	[43]
Chato	65.8	[44]
YemrehaneKirstos	72	[45]
KaftaSheraro National ark	79.3	[46]
Angada	79.8	[47]
Berbere	87.49	[48]
MennaAngetu	94	[49]
Central plateau of Shewa Wof-washa	101.8	[35]
Belete	103.5	[28]
KimpheLafa	114.4	[50]
Dodola	129	[51]

3.1.3. Important Value Index (IVI)

Three factors were used to calculate the importance value index (IVI): relative frequency, relative density, and relative dominance [24].The IVI is ecologically essential and a key structural parameter in vegetation studies, as it is the most realistic aspect of vegetation study used to compare the ecological significance of species [34].

Species with the maximum IVI value are dominant among specified vegetation [52]. The dominant and ecologically most important species may also be the most successful at regenerating. This could be because they are resistant to pathogens are attractive to pollinators, attract animals that spread seeds, or prefer browsing animals (which is the least preferred [53].

The highest IVI value was contributed by the species *Calpurnia aurea, Syzygium guineense, Maytenus gracilipes, Rytigynia neglecta, Ziziphus mauritiana*, and *Vernonia myriantha*(Table 4 and appendix 1).Such species are the principal dominant and ecologically the most important in the Hereje forest compared with other woody species. These species have higher relative density, frequency, and dominance. They are the most successful species in regeneration because they are often pathogen-resistant, least preferred by overgrazing and browsing animals have high seed dispersal within the existing environmental conditions, and are well-adapted to high-pressure disturbances.

Table 4

The five highest and the three least IVI value of woody plant species in theHereje forest.

Scientific Name	RD	RF	RD	IVI
Calpurnia aurea	3.28	3.96	5.94	13.18
Syzygiumguineense	3.03	3.96	5.48	12.47
Maytenusgracilipes	3.09	3.64	5.47	12.2
Rytigynaneglecta	2.89	3.96	5.23	12.08
Ziziphus mauritiana	2.86	3.8	5.17	11.83
Ficus vasta	0.17	0.31	0.31	0.79
Lippiaadoensis	0.08	0.62	0.12	0.82
Eucalyptus camaldulensis	0.1	0.62	0.15	0.87
RD = relative density, RF = relative frequency, RD = relative dominance; IVI = important value index				

From this study, the majority of woody plant species received a lower IVI value. Consequently, management and conservation efforts may prioritize these species threatened with local extinction. *Ficus vasta, Lippia adoensis, Eucalyptus camaldulensis, Juniperus procera, Dodonaea angustifolia, Gravillea robusta, Podocarpus falcatus*, *Solanum incanum*, were among the least common species in the area (appendix 1).

*Calpurnia aurea, Syzygium guineense, Maytenus gracilipes, Rytigynia neglecta and Ziziphusmauritiana*are the five dominant and ecologically important species in the Hereje natural forest because they have the highest IVI values respectively, whereas*Eucalyptus camaldulensis, Lippia* *adoensis, Ficus vasta* are with least IVI in the forest. The individual IVI values of these species should determine the priority for their conservation. i.e. the highest priority for the conservation of species with the lowest IVI value, and the lowest priority for the species with the highest IVI value.

3.1.4. Dominant plant species

The most notable species among the 44 total woody plant species in Hereje Forest were *Syzygiumguineense* (24.47%),*Ficus sur* (20%),*Combretum molle* (18.58%), *Croton macrostachyus* (18.11%)and *Terminalia schimperiana* (9.29%)(Table 5).The least dominant species were*Juniperus procera* (2.18%), *Ficus vasta* (1.88%), *Teclea nobilis* (0.08%)and *Flacourtia indica* (0.02%).

Table 5
The most dominant and least dominant plant species in Hereje forest

Plant species	Total basal area	Dominance	Relative dominance	Percentage
Syzygium guineense	4.16	3.51	5.48	24.47
Ficus sur	3.4	0.48	0.75	20
Combretum molle	3.16	2.15	3.56	18.58
Croton macrostachyus	3.08	2.13	3.33	18.11
Millettiaferruguinea	2.66	2.24	3.5	15.65
Terminalia schimperiana	1.58	2.28	3.56	9.29
Podocarpus falcatus	0.98	0.22	0.34	5.76
Olea europaea ssp.	0.48	1.53	2.39	2.82
Grevillea robusta	0.4	0.17	0.26	2.35
Garcinia buchananii	0.38	0.28	0.44	2.23
Juniperus procera	0.36	0.13	0.2	2.18
Ficus vasta	0.32	0.2	0.31	1.88
Eucalyptus camaldulensis	0.26	0.1	0.5	1.53
Brucea antidysenterica	0.22	2.71	4.23	1.29
Teclea nobilis	0.014	0.86	1.34	0.08
Maesa lanceolata	0.012	2.02	3.19	0.07
Flacourtia indica	0.004	0.42	0.66	0.02
Total	21.47m^2/ha	19.23	34.04	100%

3.2. Frequency

Frequency is the number of plots in the study area where a particular species was found. Homogeneity and heterogeneity of given vegetation are indicated by its frequency, where an abundance of species in a higher frequency class and a lack of species in a lower frequency class both reveal a similar species composition. In contrast, the presence of a large number of species in the lower frequency classes and a small number of species in the higher frequency classes indicates greater heterogeneity [34].

The trees and shrubs were classified into three frequency woody species classes based on their frequency values in the study site (Table 6).The two most frequently occurring species were *Syzygium guineense* (51.11%) followed by *Maytenus gracilipes* (46.66%).The species with a minor occurrence include *Lippia adoensis, Eucalyptus camaldulensis*, and *Juniperus procera.* A relatively large number of species were found in lower-frequency classes, while a low number were found in high-frequency classes. These findings showed the existence of a relatively high degree of floristic heterogeneity in the forest

Table 6
Frequency class in Hereje forest

Frequency class	**1**	**2**	**3**
Range	0.04–0.20	0.21–0.36	0.37–0.51
No of species	16	15	13

3.3. Height Class of Tree Species

The trees in the study area were divided into three height classes: the first class (early stage), such as seedlings, saplings, and small-sized trees, the second class (middle-stage), and third class (old stage). The percentage of trees decreases with the increase in height class i.e. the highest percentage of trees were found in the first class, and the least percentage of trees was found in the third class. There are fewer individuals with an increase in height, which is a pattern that represents good reproduction status and regeneration potential. The maximum height percentage was found in the first class (66%), in the second height class (30%), and in the third height class (4%) (Table 7).

The declining proportion from the first to the third class indicated that aged trees were enormously consumed for different activities by the surrounding community. The general design of the height class distribution of Hereje forest characteristically has reversed J- shaped pattern common in natural forests.

Table 7
Number of tree individual species in height classes

Class	**Height range (m)**	**No of individuals**	**Percentage**
I	< 3	1965	43.58%
II	3.1-5	1332	29.54%
III	> 5	1212	26.88%

3.4. Vertical Stratification of the Tree Species in Hereje Forest

The vertical stratification of the trees in the study area was examined using the IUFRO classification scheme [34]. According to this scheme, trees with a height above 2/3m top height represent the upper story (4% of our sample), a tree with a height between 1/3 and 2/3m represents the middle story (35% of our sample), and a tree with height < 1/3m lower story (61%) (Fig. 2).As the vertical stratification increased from the lower to the upper story, the percentage of individual species decreased. Nearly all species' density was found in the lower and middle story, with only a few individual species in the upper story.

The key species found in the forest's middle and the upper layers are *Ficus vasta, Fcus sur, Syzygium guineense, Eucalyptus camaldulensis*, and *Terminalia schimperiana.*The lower story was fundamentally dominated by shrubs and small trees such asn*Flacouria indica, Pterolobium stellatum, Carissa edulis, Calpurnia aurea*, and other species.

3.2. Regeneration Status of Woody Plant Species

The regeneration status of any given forest can be analyzed from its composition and density of seedlings, saplings, and trees/shrubs. *Maytenus gracilipes* is one of the species with the highest number of seedlings in the Hereje forest (appendix 2). The dominance of small-sized individual species in the forest indicated the quality of rate of regeneration. The demographics of the seedlings and saplings in our research were found to be higher than those of matured individual species, indicating that reasonable regeneration is taking place (Fig. 3). This study is in accordance with prior research on forest growth [42].

The expected cause for insufficient seedlings and saplings in some of the species of in the study forest might be overgrazing, browsing, seed predation, less disease resistance, moisture and warmth stress, light limitation, lack of confined place for recruitment, fewer seed spreading mechanisms, in addition to the cascading effects of pressure from human originations. This asymmetry in vegetation age structure indicates that prioritizing better management and conservation measures on the site is necessary, and previous research has posited a similar rationale for management interventions [53]

The main regenerated woody plant species in the area were *Maytenus gracilipes, Syzygium guineese*, and *Calpurnia aurea.* On the other hand, some of the least regenerated species were *Ocimum gratissum, Schrebera alata* whereas, *Flacourtia indica. Ficus sur, Ficus vasta*, and *Garcinia buchananii* comparatively have no recruitment potential.

The natural regeneration of forests are import for the preservation of genetic resources, its development and ecosystem services enrichement.This is supported by the international conventions for biodiversity conservation and climate change mitigation and national policies state of many countriess. In this study the regeneration of the forest in this study area is good.

4. Conclusions

There was a variability of population dynamics and age structure in the Hejere forest, likely primarily due to human pressure that has significantly impaired the regeneration of the mature forest. We used DBH classes, height ranges, and vertical stratification of vegetation distribution to demonstrate which species are regenerating, and the vulnerability of individual species in the forest by size classes. The maximum percentage of individual woody plant species was found in the lower frequency classes demonstrating floristic heterogeneity in the forest. However, these results also indicate the predominance of small-sized individuals found in the lower class than higher classes are likely due to excessive cutting for selected size classes, and exploitation for different purposes by the surrounding community.

Three layers of tree/shrub canopies (lower, middle, and upper) were identified from the vertical stratification of the forest. As was observed from the importance value index *Syzygium guineense, Combretum molle, Croton macrostachyus*, and *Terminalia schimperiana* were the dominant tree species.

Good regeneration potential was observed in the study site indicating the density of seedlings and saplings was greater than that of matured individual species and is mainly influenced by human activities practiced there. Generally, the forest showed scattered occurrence in few species, with irregular and periodic recruitment, where the common seedlings and saplings developed into large-size classes of vegetation. Although, various economically and ecologically important species showed abnormal recruitment patterns with poor reproduction. Recognizing such serious facts requires sustainable management, conservation, and utilization of forest resources and prioritization of restoration initiatives to reestablish plant populations.

Based on the current findings, the forest is largely depleted with possible causes originating from human disturbances such as charcoaling, agricultural expansion, commercial logging, firewood collection, grazing, etc. These impacts severely influence species diversity, population structure, and regeneration status. Thus, this study suggests the need for an urgent intervention to stop disturbances in the forest, mainly human-induced actions such as cattle grazing, illegal timber harvest, and fuelwood collection, which are significant sources of forest deterioration.

The present study focused on woody species population structure and regeneration status, therefore, additional studies on floristic composition, plant community types, environmental parameters, soil composition, seed bank, and non-woody vegetation of the forest is recommended.

Declarations

Consent for publication: not applicable

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Figures

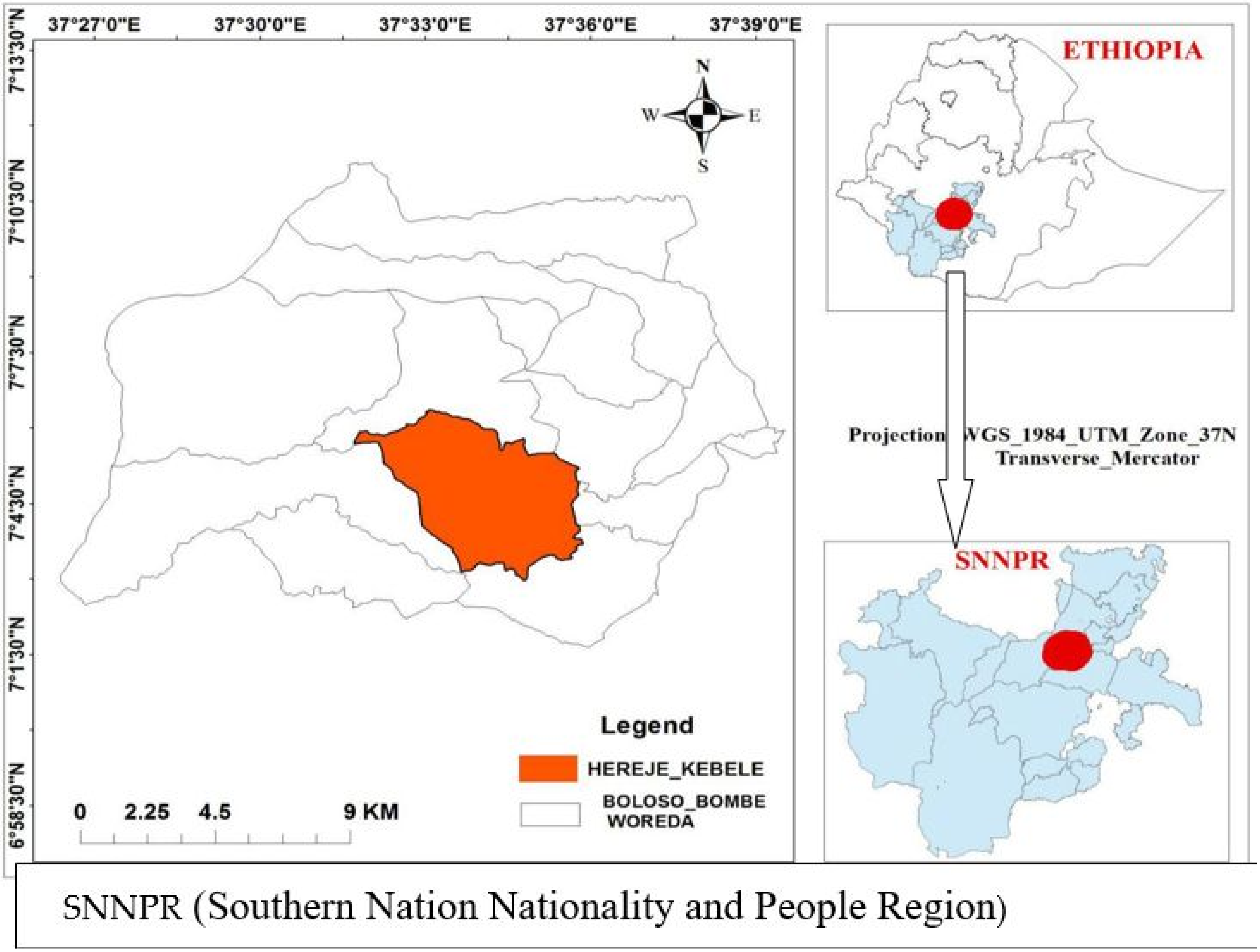

Figure 1

Map of the study area Hereje kebele where Hereje forest.

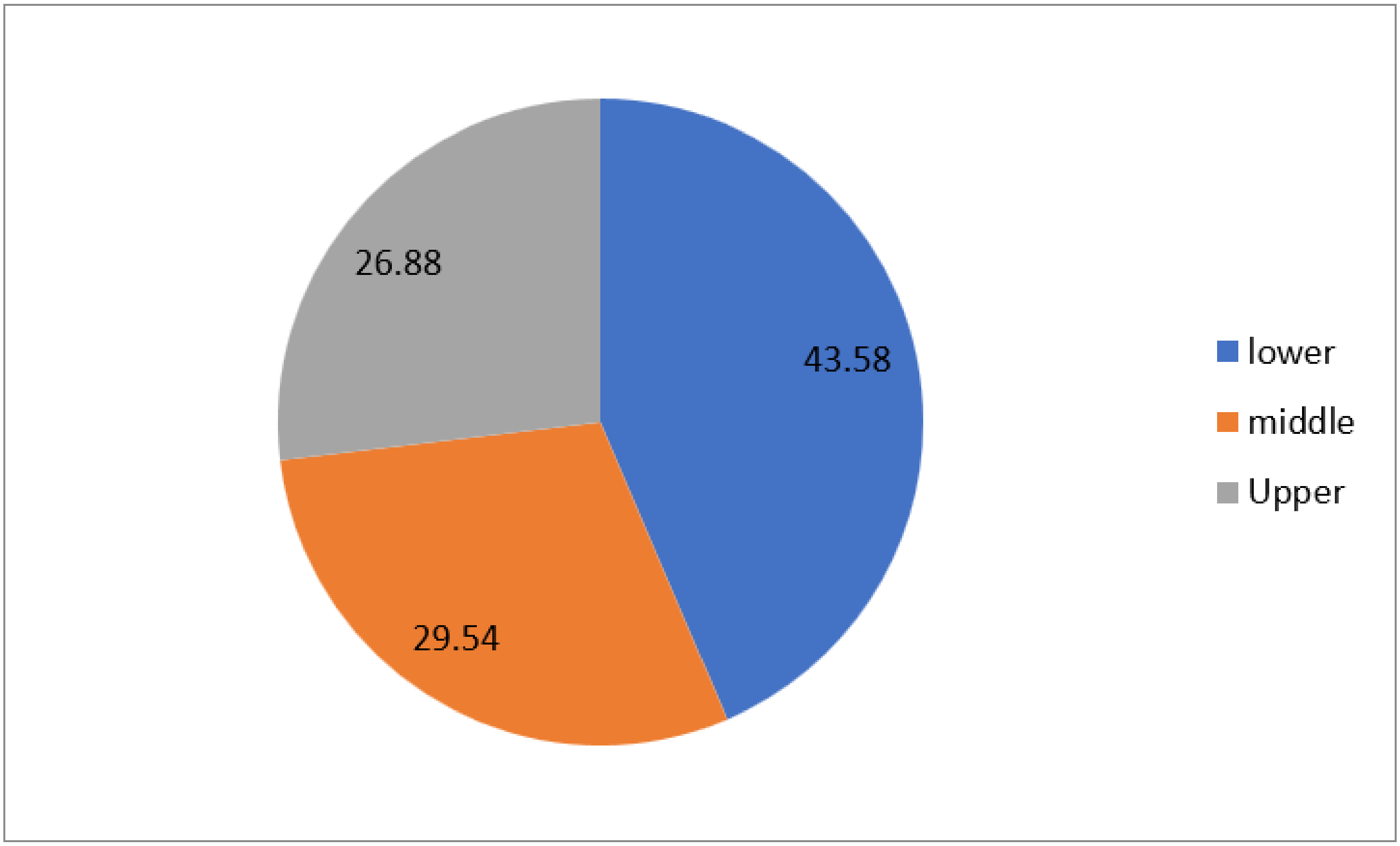

Figure 2

Vertical stratification of the tree species in lower, middle, and upper story

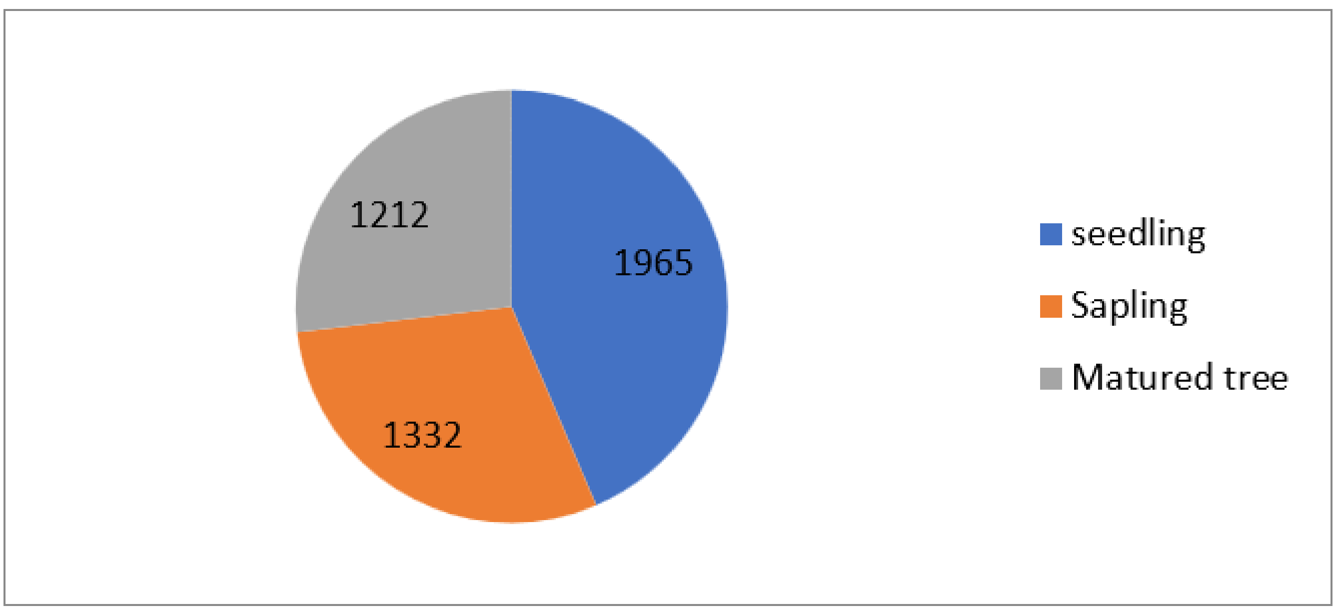

Figure 3

Hereje forest density distribution proportion of seedling, sapling, and mature woody plant species

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