EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 72 (2026): 37 - 45
Journal homepage: https://eqa.unibo.it/

published by

Woody species diversity, structure and regeneration status of Omo National Park, Southern Ethiopia

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Article info
Received 30/7/2025; received in revised form 27/11/2025; accepted 10/1/2026
DOI: 10.60923/issn.2281-4485/22570

Abstract
Ethiopia's rich ecological landscapes, including its protected areas, are increasingly threatened by deforestation, agricultural encroachment, overgrazing, and climate variability. This study assessed the woody species composition, structure, and regeneration status of Omo National Park, located in southwestern Ethiopia. A total of 97 main plots (20 m × 20 m) for mature trees, 97 subplots (5 m × 5 m) for saplings, and 388 microplots (1 m × 1 m) for seedlings were systematically established. Woody species with a diameter at breast height (DBH) ≥ 2.5 cm and height ≥ 2.5 m were measured. In total, 72 woody species belonging to 51 families and 28 genera were recorded, comprising 39.5% trees, 57.9% shrubs, 1.6% tree/shrub forms, and 0.21% climbers from 950 individual plants. Fabaceae (10 spp.) and Combretaceae (7 spp.) were the most species-rich families. The park exhibited a high Shannon diversity index (3.34) and evenness (0.74), with a mature woody plant density of 244.8 individuals ha^{-1} and a total basal area of 17.76 m^2 ha^{-1}. Species frequency declined with increasing DBH and height classes. Seedling and sapling densities were 450 and 411.6 individuals ha^{-1}, respectively, indicating good overall regeneration status. The study highlights the need for targeted monitoring and management of dominant and potentially invasive species to ensure the park's ecological sustainability.

Keywords: *Woody species diversity, regeneration status, basal area, DBH, Omo National Park*

Introduction

Ethiopia is widely recognized as one of Africa's biodiversity hotspots, encompassing a broad range of ecosystems from humid montane rainforests to arid desert landscapes (Kelbessa et al., 2014; Siraj et al., 2016; Asefa et al., 2020). This ecological richness is attributed to the country's complex topography, diverse climatic conditions, and unique evolutionary history (Sintayehu, 2018). As part of the Horn of Africa biodiversity hotspot, Ethiopia is home to a high diversity of woody flora and endemic species (Zhou et al., 2021). Despite this, the country's forest cover has declined significantly due to anthropogenic pressures such as agricultural expansion, overgrazing, and unsustainable resource use (Mesfin et al., 2020). Nevertheless, forests continue to be reservoirs of woody species richness, particularly in protected areas, which play a vital role in conserving terrestrial biodiversity (FAO and UNEP, 2020). Ethiopia's vegetation types are highly influenced by the East African Rift Valley system and altitudinal variations, ranging from Afroalpine zones to dry lowland ecosystems (Asefa et al., 2020). According to Friis et al. (2010), Ethiopian vegetation can be classified into 12 types, including Acacia-Commiphora woodlands, moist and dry Afromontane forests, Combretum-Terminalia woodlands, and Afroalpine belts. The structure and composition of these ecosystems are shaped by factors such as altitude, soil, climate, and human interference (IPCC, 2015). However, deforestation and forest degradation have severely impacted Ethiopia's native and endemic plant species (Asefa et al., 2020). In response, Ethiopia has implemented various land rehabilitation initiatives over the past three decades. These include Sustainable Land Management (SLM)

DOI: 10.60923/issn.2281-4485/22570

practices, expansion of protected areas, and large-scale afforestation and reforestation programs (Young, 2011; Minnick et al., 2014; FAO and UNEP, 2020). Notably, the Green Legacy Initiative launched in 2019 aimed to plant 20 billion trees to combat land degradation and enhance ecosystem resilience (Getahun, 2020; Assefa et al., 2022). African forest ecosystems not only support endemic plant species (Linder and Verboom, 2015; Proches and Ramdhani, 2023) but also play critical roles in food security, traditional medicine, and cultural practices (Kokwaro, 2009; Bitariho et al., 2023). In Ethiopia, iconic native species such as *Podocarpus falcatus*, *Croton macrostachyus*, and *Olea europaea* are declining due to deforestation, with adverse ecological and socio-economic impacts (Atsbha and Wayu, 2020; Kewessa et al., 2022). Despite this, forests remain central to the country's rural economy by supplying energy, food, and supporting livelihoods (Cherinet and Lemi, 2023). To ensure sustainability, monitoring and evidence-based forest management are essential for conserving native plant diversity, enhancing car-bon sequestration, and maintaining ecosystem services (Newton et al., 2021; Alem et al., 2022). Given these challenges and opportunities, this study seeks to assess the com-position, structure, and regeneration status of woody species in Omo National Park, one of Ethiopia's largest and ecologically significant protected areas (Fig.1). Specifically, the research addresses the following questions: (1) What is the diversity of woody species in Omo National Park?; (2) How are the park's forests structured in terms of species density, basal area, and diameter class distribution?; and (3) What is the regeneration status of woody vegetation in the park, particularly regarding seedling and sapling abundance?

Materials and Methods

Description of the study area

This study was conducted in Omo National Park (ONP), one of Ethiopia's largest and most ecologically significant protected areas. The park is located in the southwestern part of the country, straddling several administrative districts: Salamago and Surma Woredas in South Omo Zone, and Maji and Menti Woredas in Bench Maji Zone of the Southern Nations, Natio-nalities, and Peoples' Region (Fig. 1). Geographically, ONP lies within the lower Omo River Valley, between 35°24'–36°05' E longitude and 05°24'–06°15' N lati-tude, approximately 870 km southwest of Addis Ababa (EWCA, 2013). The park spans an area of approximately 3,438 km² and is situated at altitudes ranging from 450 to 1,541 meters above sea level, encompassing diverse ecological zones. It primarily falls within the *upper and lower kola* agro-climatic zones, characterized by a semi-arid to sub-humid climate with an annual rainfall ranging from 500 to 1,000 mm (Feleha, 2018). The dominant vegetation type is a mosaic of open grassy plains interspersed with patches of woodland and bushland. Prominent woody plant

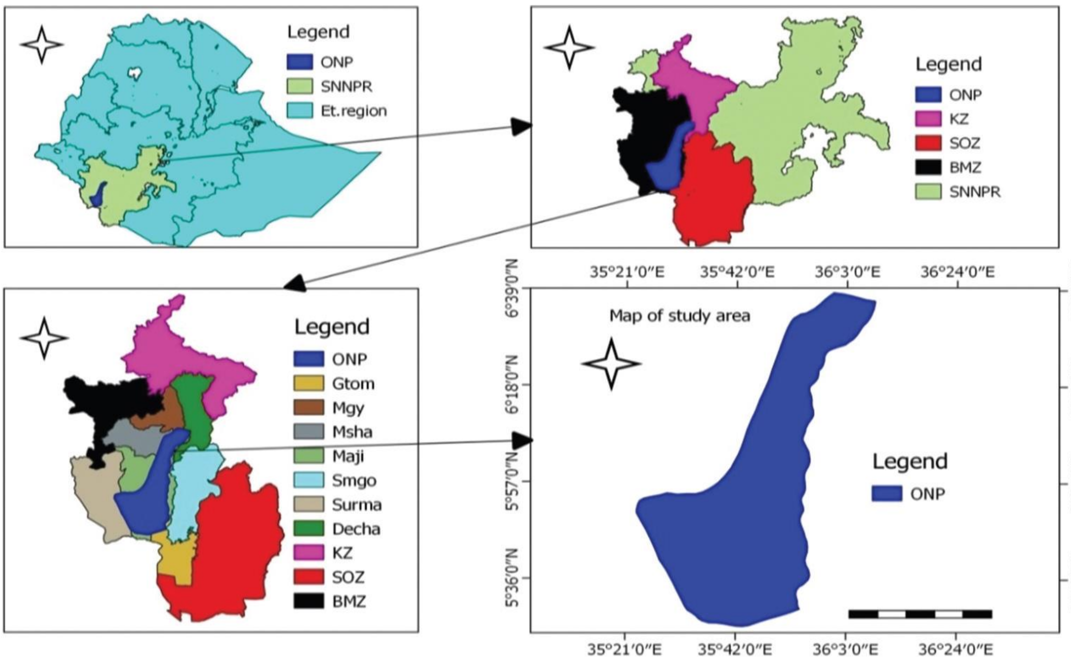

Figure 1
Location map of the study area (source: Armaw & Molla, 2022).

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Species include *Acacia seyal*,*Terminalia brownii*, *Omocarpum trichocarpum*, *Commiphora africana*, and *Lannea schweinfurthii* (Feleha, 2018. Omo National Park is also known for its rich faunal diversity. It harbors 75 species of mammals, including large herbivores and carnivores; 325 species of birds, making it an important bird area; 13 species of fish; and 11 species of amphibians, underscoring its ecological im-portance and conservation value (Feleha, 2018; Armaw and Molla, 2022).

Sampling design

Sampling plots were systematically established along fifteen parallel transect lines used to survey the diversity and structure of the woody plant species. Parallel line transects were laid at an interval of 1000 m while plots were spaced on each transect line at an interval of 500 m. To avoid edge effect, the first and the last sampling plot on each transect were laid 50 m inwards from the edge of the forest randomly (Girma and Maryo, 2018). The sampling plot was framed within an outer 400 m² (20 m × 20 m) plot (Dibaba et al., 2014) and within the main plot, one sub-plot of 25 m² (5 m × 5 m) was established at the center (Ellenberg and Mueller-Dombois, 1974).

Data collection and identification

The woody species data were collected from the main plot of 20 m × 20 m (400 m²) for tree species, while the sub-plot of 25 m² (5 m × 5 m) located at the center of the outer plot was used for shrubs. Trees and shrubs were measured following Mueller-Dombois and Ellenberg (1974). Accordingly, trees and shrubs taller than 2 m and with a DBH of > 2.5 cm were measured, with trees defined as single-stemmed and shrubs as multi-stemmed woody species. The seedling and sapling data was collected from the four corners of the main plot (Fig. 2). Diameter at Breast Height of individual trees and shrubs at 1.3 m was measured using a meter tape and calliper, and height was measured using a Suunto Clinometer (William et al., 2009). For trees branched below breast height, the diameter was measured separately for the branches and was averaged (Assefa et al., 2014; Dibaba et al., 2014). The coordinates and altitude of the sampled plots were determined using a Garmin GPS and Suunto clinometer, respectively. Herbarium specimens were collected with flowers and fruits to simplify identification, labeled, coded, and pressed using newspaper, blotters, and a wood frame. Finally, they were dried for proper identification at the Addis Ababa National Herbarium.

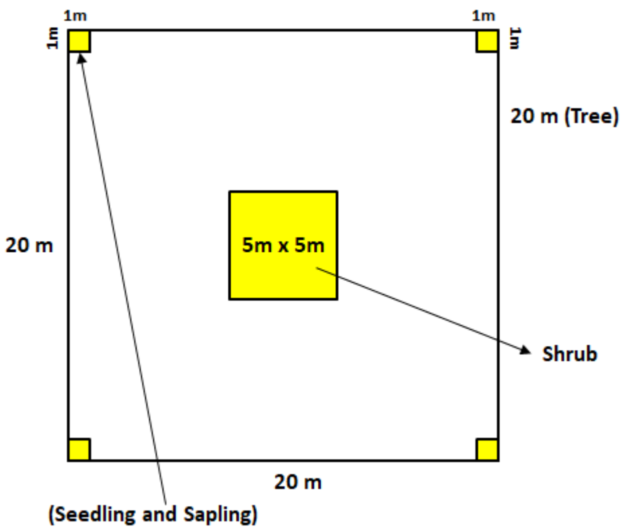

Figure 2. *Quadrant Layout design used for field vegetation data collection*

Data analysis

A) Floristic diversity. Species diversity was calculated using the Shannon-Wiener Diversity Index (H') and Simpson's Diversity Index (1-D). Species evenness (J) was also determined. The Shannon-Wiener Index was calculated as:

$$H' = - \Sigma(p_i * \ln p_i) \quad [1]$$

where H' is the Shannon-Wiener Diversity Index, p_i is the proportion of individuals belonging to the i-th species, and ln is the natural logarithm. Simpson's Diversity Index was calculated as:

$$1\text{-}D = 1 - \Sigma(p_i)^2 \quad [2]$$

where D is the Simpson's Dominance Index and p_i is the proportion of individuals of the i-th species. Evenness was calculated as:

$$E = (H' / H'_{max}) \quad [3]$$

where E is Evenness, H' is the Shannon-Wiener diversity index, and $H'_{max} = \ln(S)$ is the natural logarithm of the total number of species (S) in the community.

B) Floristic structure. The quantitative structure data analysis was made using density, frequency, diameter at breast height (DBH), dominance, importance value index (IVI) and basal area.

C) Density. Density is defined as the number of plants of a certain species per unit area.

$$D = (\text{Number of individuals of a species}) / (\text{Sampled area in hectares}) \quad [4]$$

The relative density of the species was calculated by

DOI: 10.60923/issn.2281-4485/22570

using the following formula:

RD = (Number of individuals of a species / Total number of individuals) × 100 [5]

D) Frequency. Frequency is the chance of finding a species in a particular sample and was calculated as:

Frequency = (Number of plots in which a species occurs / Total number of plots) × 100 [6]

Relative frequency was calculated as:

Relative Frequency = (Frequency of species A / Total frequency of all species) × 100 [7]

E) Dominance and relative dominance. Dominance was measured in terms of basal area. The basal area (BA) for an individual tree was calculated as: $BA = \pi(DBH/2)^2$, where DBH is in meters. The total basal area per hectare for a species was then calculated by summing the basal areas of all individuals of that species and scaling it to a per-hectare basis. Dominance (DO) for a species was calculated as the total basal area per hectare for that species. Relative dominance (RDO) was calculated as:

RDO = (Dominance of a species / Total dominance of all species) × 100 [8]

F) Importance value index. The Importance Value Index (IVI) was used to determine the ecological significance of each woody species. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance was summed up together and this value is designated as the Importance Value Index or IVI of the species (Kent and Coker, 1992). IVI = Relative density + Relative frequency + Relative dominance.

Analysis of the regeneration status of woody plants species

In each of the 1 m × 1 m microplots, the numbers of all seedlings that are less than 1 m in height were recorded. Individuals attaining > 1 m but less than 3 m in height with DBH less than 2.5 cm were considered as saplings and then counted. The regeneration status of the forest was analyzed by comparing saplings and seedlings with the mature trees. According to Singh et al. (2016), the regeneration status is good, if seedlings > saplings > adults; Fair regeneration, if seedlings > or ≤ saplings ≤ adults; the status is poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); and if a species is present only in an adult form it is considered as not regenerating.

Results and Discussion

Woody species composition and diversity

A total of 72 woody species belonging to 28 genera and 51 families were identified from 97 plots in the study area. Of the 950 individual plants recorded, 39.5% (375) were trees, 57.9% (550) were shrubs, 1.6% (15) were tree/shrub forms, and 0.21% (2) were climbers. In the study sites, the major dominant woody plant families in the National park were Fabaceae with 10 species (13.69%), followed by Combretaceae with 7 species (9.58%), Rhamnaceae with 6 species (8.23%), and Anacardiaceae with 5 species (6.85%) (Table 1).

Table 1. *Top six families of woody species in Omo National Park*

Family	Number of species	Percent (%)
Fabaceae	10	13.69
Combretaceae	7	9.58
Rhamnaceae	6	8.23
Anacardiaceae	5	6.85
Celastraceae	4	5.47
Tiliaceae	3	4.11
Other	37	52.07
Total	72	100

The variation in species richness and distribution was reflected by the Shannon diversity index (H'), which ranged from 2.05 to 3.33 across different altitudinal gradients. The evenness (J) varied from 0.58 to 0.90, and Simpson's diversity index (1-D) ranged from 0.08 to 0.46 (Table 2).

Table 2. *Species Richness, Diversity and Evenness of the woody plants along an altitudinal gradient.*

No	Altitudinal variation (m a.s.l.)	Richness	H'	Evenness (J)	Simpson (1-D)
1	458-590	21	2.25	0.74	0.28
2	461-856	40	3.33	0.90	0.46
3	490-621	35	2.68	0.76	0.16
4	454-668	34	2.05	0.58	0.08
5	518-847	18	2.18	0.76	0.36

Structure of vegetation

Density of woody species. The total density of mature trees and shrubs was 244.85 individuals ha^{-1}. *Acacia senegal (L.) Wild.* had the highest density of 51.54 individuals ha^{-1} (21%), followed by *Acacia tortilis*

DOI: 10.60923/issn.2281-4485/22570

(Frossk.) Hayne (31.44 individuals ha⁻¹, 12.8%) and ad *Acacia seyal Del.* (14.69 individuals ha⁻¹, 5.9%) (Table 3). A total of 1597 saplings and 1746 seedlings were recorded across all plots, corresponding to densities of 411.6 and 450 individuals ha⁻¹, respectively, for the 72 representative woody plant species.

Botanical Name	Total Individuals	Frequency (%)	Density (individuals ha⁻¹)	Density (%)
Acacia senegal	200	14.7	51.54	21.0
Acacia tortilis	122	11.0	31.44	12.8
Acacia seyal	57	3.68	14.69	5.9
Balanites aegyptiaca	50	2.76	12.88	5.26
Combretum adenogonium	49	3.98	12.63	5.16
Ficus sur	48	4.90	12.37	5.05
Terminalia spinosa	30	3.68	7.73	3.15
Other	394	55.3	101.57	41.68
Total	950	100	244.85	100

Table 3
Frequency and density of dominant woody species in Omo National Park.

Diameter at Breast Height (DBH) and height class distribution. The distribution of all woody species individuals across DBH size classes showed a reverse J-shaped pattern. The majority of individuals (320) were in the lowest DBH class (2.5–6 cm), with numbers decreasing pro- gressively in higher classes (186 in 6–12 cm; 116 in 13–18 cm; and only 8 in the >46 cm class) (Figure 3). Species like *Acacia senegal* and *Combretum adenogo-nium* were common in the lower classes, while *Ziziphus mucronata* and *Tamarindus indica* were found in the highest class. The height class distribution also showed a higher number of individuals in the middle and lower classes. The third height class (9.01–12 m) contained the most individuals (202), followed by the first class (2.5–6 m) with 181 individuals, and the second class (6.01–9 m) with 144 individuals (Figure 4). Only 62 individuals were recorded in the tallest height class (>24.01 m), including species like *Acacia tortilis* and *Ficus sur.*

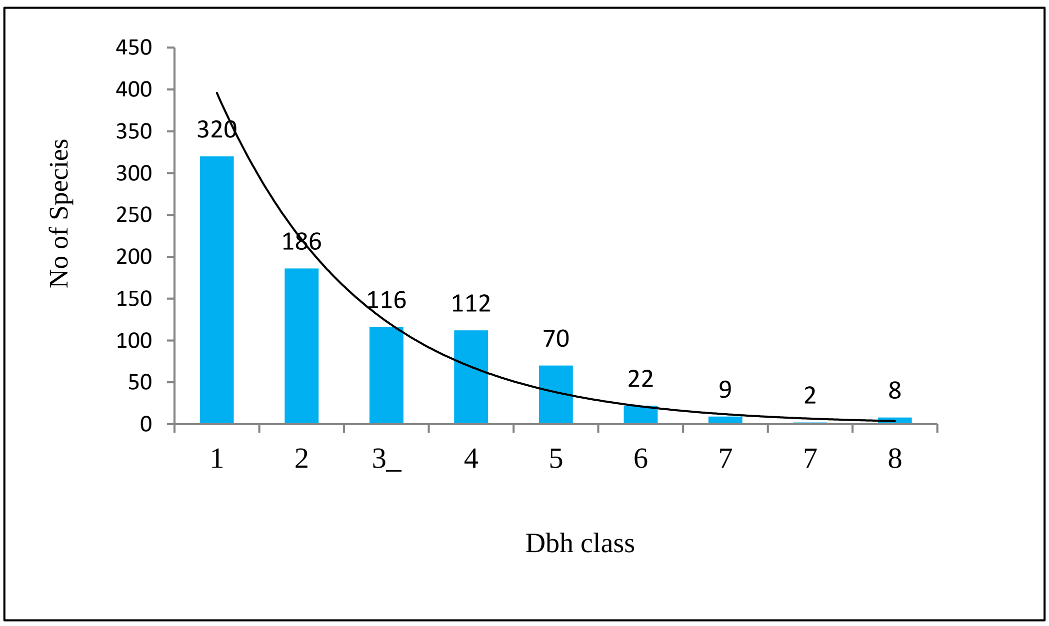

Figure 3
DBH class distribution of woody species in Omo National Park.

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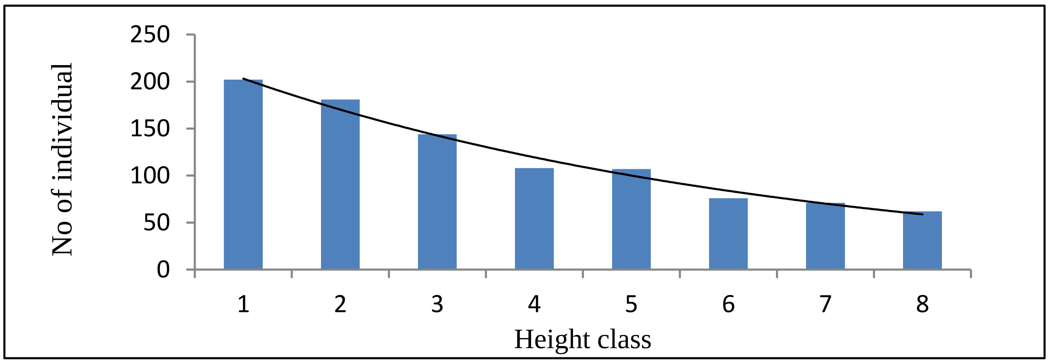

Figure 4
Height class distribution of woody species in Omo National Park.

Basal Area and dominance. The total basal area of woody plants in Omo National Park was 17.76 m² ha⁻¹. *Acacia tortilis* contributed the most to the basal area (4.13 m² ha⁻¹, 23.29%), followed by *Balanites aegyptiaca* (2.08 m² ha⁻¹, 11.73%) and *Ficus sur* (1.73 m² ha⁻¹, 9.74%) (Table 4).

Important Value Index (IVI). The top ten woody species with the highest Importance Value Index (IVI) were led by *Acacia tortilis* (IVI=47.16, 15.72%), *Acacia senegal* (IVI=38.31, 12.77%), and *Balanites aegyptiaca* (IVI=19.74, 6.58%) (Table 5). Rare species, based on low IVI values, included *Lannea schweinfurthii* and *Combretum aculeatum*.

Table 4
Basal Area (BA) and Dominance of dominant Woody Plant Species in Omo National Park.

Botanical name	BA (m²/ha)	BA (%)	Dominance	Dominance (%)
Acacia tortilis	4.13	23.29	1.066	23.38
Balanites aegyptiaca	2.08	11.73	0.54	11.84
Ficus sur	1.73	9.74	0.44	9.65
Bersama abyssinica	1.03	5.79	0.265	5.80
Terminalia spinosa	1.006	5.66	0.26	5.70
Acacia seyal	0.89	5.01	0.23	5.00
Other	6.89	38.78	1.75	38.63
Total	17.76	100	4.56	100

Table 5
Top ten woody species of Omo National Park by Importance Value Index (IVI).

Botanical Name	RF	RD	RDO	IVI	IVI %
Acacia tortilis	11.0	12.84	23.28	47.16	15.72
Acacia senegal	14.7	21.05	2.53	38.31	12.77
Balanites aegyptiaca	2.76	5.26	11.72	19.74	6.58
Ficus sur	4.90	5.05	9.73	19.69	6.56
Acacia seyal	3.68	6.00	5.00	14.68	4.89
Terminalia spinosa	3.68	3.15	5.66	12.49	4.17
Acacia abyssinica	3.37	2.94	5.00	11.33	3.77
Combretum adenogonium	3.98	5.15	0.35	9.50	3.17
Bersama abyssinica	0.92	1.15	5.79	7.87	2.62
Tamarindus indica	2.76	1.57	2.10	6.44	2.15
Other	47.8	35.84	28.84	112.79	37.60
Total	100	100	100	300	100

RF= Relative Frequency, RD= Relative Density, RDO= Relative Dominance

DOI: 10.60923/issn.2281-4485/22570

Regeneration status

The regeneration status was determined by comparing densities across life stages. The study found a total of 1597 saplings per hectare, representing 72 woody species in 28 genera and 51 families, and 1746 seedlings per hectare for 65 woody species. There were 950 mature individuals ha^{-1} (Fig 4).

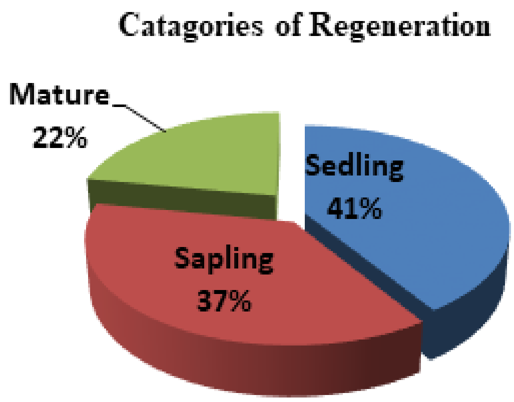

Figure 5. *Density of seedlings, saplings, and mature trees per hectare in Omo National Park.*

The ratios were as follows: The ratio of seedlings to mature trees and shrubs was 1.8. The saplings to mature trees and shrubs ratio was 1.7. Similarly, the seedling to sapling ratio was 1, indicating larger seedling, saplings than mature trees and shrubs. The density of seedlings (1746 individuals ha^{-1}) was higher than that of saplings (1597 individuals ha^{-1}), which in turn was higher than that of mature trees (950 individuals ha^{-1}) (Figure 5). This pattern (seedlings > saplings > mature trees) indicates a "good" regeneration status according to Singh et al. (2016). Similarly, Balwant et al. (2014) categorization, seedlings (1746) > saplings (1597) > matured trees and shrubs (950), resulting in a good regeneration status.

Species accumulation curve

The species accumulation curve for woody species in Omo National Park is shown in Figure 6. The steep initial slope indicates high species richness, while the curve beginning to plateau suggests that the sampling effort was sufficient to capture the majority of species present in the study area.

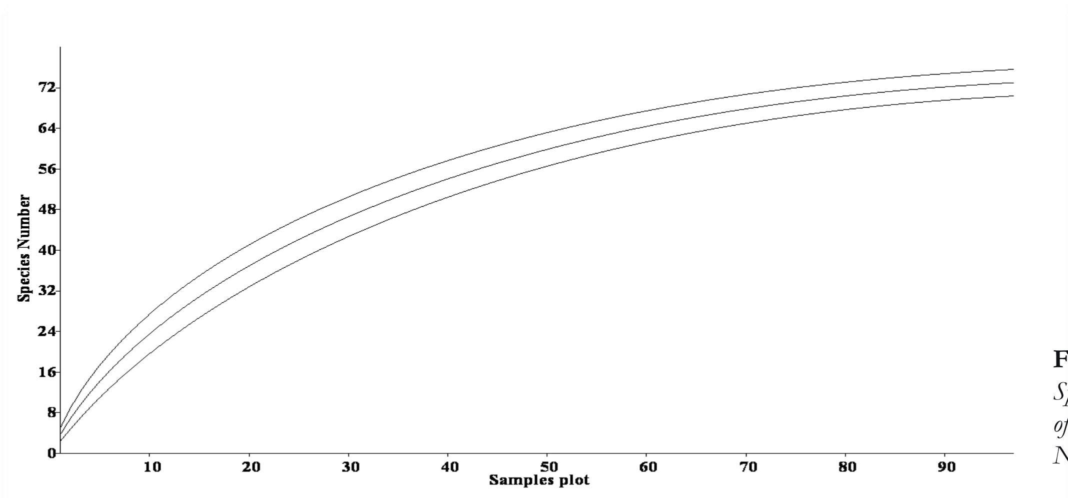

Figure 6
Species accumulation curve of woody species in Omo National Park (ONP).

Discussion

The findings of this study reveal that Omo National Park supports a diverse and structurally complex woody plant community, which is undergoing active regeneration. The high species diversity (H'=3.34) and the reverse J-shaped DBH distribution are indicative of a healthy and dynamic ecosystem. The dominance of families like Fabaceae and Combretaceae is consistent with other studies in Ethiopian dry forests and savannas (Mekonnen et al., 2022; Sewagegn et al., 2022). The good regeneration status, evidenced by the high density of seedlings and saplings, is a positive indicator for the long-term sustainability of the park's forest resources. However, the ecological dominance of a few *Acacia* species suggests that continuous monitoring is essential to manage potential imbalances and to conserve the numerous rare species with low IVI values. The results underscore the critical conservation value of Omo National Park as a refuge for biodiversity in southwestern Ethiopia.

Conclusion and Recommendations

This study establishes a crucial baseline on the woody vegetation of Omo National Park, revealing a ecosystem of significant conservation value. The findings indicate that the park supports considerable woo-

DOI: 10.60923/issn.2281-4485/22570

dy species diversity, characterized by a healthy population structure and promising regeneration potential. The reverse J-shaped DBH distribution and the high density of seedlings relative to saplings and mature trees are particularly encouraging, suggesting active recruitment and a self-sustaining forest dynamics. The current ecological structure is defined by the dominance of key species such as *Acacia tortilis* and *Acacia senegal*, which play a foundational role in the woodland ecosystem. To ensure the long-term preservation and sustainable management of this vital natural heritage, a proactive and integrated approach is recommended. First, the implementation of a long-term monitoring program is essential to systematically track changes in species composition, population structure, and regeneration status, with particular attention paid to both dominant and rare species. Second, vigilant management is required to monitor and control the presence and potential spread of exotic species, such as *Prosopis juliflora*, to prevent future ecological disruption. Furthermore, the success of these conservation efforts hinges on the active engagement of local communities; this can be achieved through participatory forest management initiatives and awareness programs designed to reduce anthropogenic pressures and foster a shared sense of stewardship. Finally, to inform a more holistic management strategy, further research should be conducted on the impacts of climate change, local soil-plant relationships, and the ethnobotanical uses of the park's flora. By implementing these measures, the ecological integrity and rich biodiversity of Omo National Park can be effectively safeguarded for future generations, ensuring it continues to fulfill its critical role as a cornerstone of Ethiopia's protected area network.

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