Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Floristic Composition, Population Structure and Biomass Carbon of Combretum-Terminalia Woodlands in Northwestern Ethiopia

Dejene Reda
Ethiopian Biodiversity Institute, Assosa Center
Shiferaw Abebe
shiferaw.abebe@bdu.edu.et

Bahir Dar University
Getaneh Gebeyehu
Injibara University

Research Article

Keywords: Combretum-Terminalia woodland, species diversity, carbon stock, population structure, regeneration dynamics

Posted Date: November 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11568814/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Floristic Composition, Population Structure and Biomass Carbon of *Combretum-Terminalia* Woodlands in Northwestern Ethiopia

Dejene Reda [1], Shiferaw Abebe [2*] and Getaneh Gebeyehu [3]

1. Ethiopian Biodiversity Institute, Assosa Center, Assosa, Ethiopia.
2. Department of Disaster Risk Management and Sustainable Development, Institute of Disaster Risk Management and Food Security Studies, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia.
3. Department of Biology, Injibara University, P.O. Box 40, Injibara, Ethiopia.

Correspondence: shiferaw.abebe@bdu.edu.et

Abstract

The *Combretum-Terminalia* woodlands of northwestern Ethiopia are ecologically significant dryland ecosystems providing biodiversity and carbon sequestration services but face increasing anthropogenic pressures. This study systematically assessed woody species composition, population structure, regeneration status, and biomass carbon stocks in the Sherkole Woodland Reserve (SWR) using 23 sampling plots across altitudinal gradients. All woody individuals with a diameter at breast height (DBH) ≥ 2.5 cm were inventoried, and their DBH and total height were measured. A total of 41 woody species were identified, dominated by *Fabaceae* and *Combretaceae* families, with high floristic diversity (H'= 3.12). Several key species, including *Boswellia papyrifera* and *Adansonia digitata*, exhibited severe recruitment failures, indicating demographic instability. Mean total biomass was 221.74 ± 34.40 Mg ha^{-1}, corresponding to 104.22 ± 16.17 Mg C ha^{-1} carbon stock, underscoring the woodland's role as a substantial carbon sink. These findings highlight the need for targeted in situ protection and enrichment planting to maintain biodiversity and sustain carbon storage functions amid ongoing environmental threats.

Key word: *Combretum-Terminalia* woodland; species diversity; carbon stock; population structure; regeneration dynamics

Introduction

Dry forests and woodlands cover approximately 54% of the African land area (FAO 2019) and function as vital socio-ecological buffering systems. They support rural livelihoods by supplying fuelwood, timber, non-timber forest products (NTFPs), and livestock fodder (Teketay et al. 2010; Lemenih and Kassa 2011), while simultaneously mitigating soil erosion and regulating regional hydrological regimes and carbon cycles (Chidumayo and Gumbo 2010; Lemenih and Kassa 2011). Despite their critical ecological and socio-economic importance, these dryland ecosystems are increasingly threatened by climate change, recurrent drought, agricultural land conversion, overgrazing, and unsustainable harvesting practices, driving widespread vegetation degradation and attendant biodiversity loss (Alem et al. 2022; Assefa et al. 2022; Chepkoech et al. 2024).

In Ethiopia, *Combretum–Terminalia* woodlands constitute a dominant dryland vegetation, distributed across the western and northwestern lowlands (Awas and Nordal 2007; Friis et al. 2010, 2022). Floristically, these ecosystems are characterized by dominant tree species belonging to the families *Combretaceae* (e.g., *Combretum* spp., *Terminalia* spp., *Anogeissus leiocarpa*) and *Fabaceae* (e.g., *Lonchocarpus laxiflorus*, *Pterocarpus lucens*, *Dalbergia melanoxylon*, *Piliostigma thonningii*) (Friis et al. 2010, 2022). Adapted to harsh environmental gradients, seasonal unimodal rainfall, and periodic fire regimes (Masresha et al. 2024; Yasin et al. 2026), these woodlands function as a critical ecological buffer against desertification along the Sudano-Sahelian fringe. Beyond their structural role, the *Combretum–Terminalia* woodlands serve as vital habitats and genetic reservoirs for high-value hardwoods, medicinal plants, crop wild relatives, and threatened resin-producing species such as *Boswellia papyrifera* (Lemenih and Kassa 2011; Eshete et al. 2012; Lemenih et al. 2014). Furthermore, they contribute substantially to climate change mitigation by storing terrestrial carbon in aboveground wood biomass, root systems, and dryland soils (Tesfaye and Negash 2018; Manaye et al. 2019; Abich et al. 2021, 2022).

Despite their socio-ecological importance, *Combretum–Terminalia* woodlands in northwestern Ethiopia are rapidly degrading due to a combination of human-driven pressures, such as population growth, resettlement, expansion of commercial and shifting agriculture, artisanal mining, uncontrolled seasonal fires, and unsustainable fuelwood extraction. These factors accelerate habitat fragmentation and genetic erosion (Lemenih et al. 2014; Abebe et al. 2021; Abere et al. 2022, 2023; Zewdie et al. 2023; Masresha et al. 2024). The degradation is especially severe in key ecological corridors like the Sherkole District, where unregulated artisanal mining and slash-and-burn agriculture have destabilized woodland ecosystems (Abebe and Reda 2026). If this trend continues, it will not only reduce native biodiversity and genetic resources but also transform resilient dryland woodlands into degraded scrublands, leading to persistent land degradation and increased risk of desertification.

Reversing this trajectory of woodland degradation requires actionable conservation frameworks grounded in empirical ecological data. Specifically, designing effective management interventions depends on quantifying floristic composition, population diameter distributions, and recruitment bottlenecks. While regional vegetation assessments provide coarse-scale overviews, localized empirical studies integrating biomass carbon accounting with fine-scale demographic health metrics across threatened dryland management units remain

limited. To address this critical knowledge gap, this study evaluated the structural dynamics, species composition, and carbon sequestration capacity of the *Combretum–Terminalia* woodland ecosystem in the Sherkole Woodland Reserve (SWR), northwestern Ethiopia. Specifically, the study aimed to: (1) inventory woody species richness, floristic diversity, and community composition across the woodland landscape; (2) analyze population diameter distributions and regeneration dynamics for identifying threatened taxa requiring urgent conservation; and (3) quantify stand-level biomass carbon stocks to assess the ecosystem's climate change mitigation potential.

Reversing the ongoing degradation of these woodlands requires conservation strategies that are informed by robust ecological data. Effective management interventions depend on detailed assessments of species composition, population structure (including the distribution of tree sizes), and regeneration challenges (Gebeyehu et al. 2019). Although regional vegetation surveys offer broad overviews, there is a lack of localized studies that combine biomass carbon measurements with detailed demographic analyses in threatened dryland areas. To fill this knowledge gap, the present study investigated the structural dynamics, species composition, and carbon sequestration potential of the *Combretum–Terminalia* woodland ecosystem in the SWR, northwestern Ethiopia. The specific objectives were to: (1) document woody species richness, diversity, and community composition; (2) analyze population structure and regeneration patterns to identify species at risk; and (3) quantify biomass carbon stocks to evaluate the ecosystem's potential for climate change mitigation.

Methods and materials

Description of the study area

The study was conducted in the Sherkole Woodland Reserve (SWR), an area encompassing approximately 520 ha of natural woodland in the Sherkole District, northwestern Ethiopia. Bounded by latitudes 10°36'35.95" N to 10°36'55.26" N and longitudes 34°45'31.20" E to 34°46'10.78" E, the reserve is administratively situated within Sherkole District, roughly 96 km northeast of the regional capital, Assosa, and 670 km west of Addis Ababa. The landscape is defined by rolling terrain with an average elevation of approximately 800 m above sea level (Fig. 1).

The study area experiences a unimodal precipitation regime characteristic of the lowland Sudano-Sahelian belt, defined by a distinct rainy season extending from May to October,

followed by a protracted hot, dry period from November to April. Mean annual precipitation is approximately 858.6 mm, with mean monthly minimum and maximum temperatures of 13.9 °C and 29.8 °C, respectively, placing the reserve within the dry *kolla* (semi-arid lowland) agro-ecological zone. Edaphically, the landscape is dominated by Nitisols and Acrisols, which are generally well-drained but susceptible to nutrient leaching following canopy clearance (Awlachew and Aster 2009).

Vegetation across the reserve consists of classic *Combretum–Terminalia* broad-leaved deciduous woodland. The canopy is dominated by small- to medium-sized trees with broad, deciduous leaves, with the primary floristic matrix comprising key woody families including *Combretaceae* (e.g., *Combretum* spp., *Terminalia* spp.), *Fabaceae*, and *Burseraceae* (e.g., *Boswellia papyrifera*) (Awas and Nordal 2007). The district covers an estimated area of 1,978.59 km² with a population of approximately 35,542 inhabitants (18,616 females), where 94% of the population residing in rural areas, local livelihoods rely heavily on traditional agro-pastoralism, swidden agriculture, artisanal gold mining, and the extraction of timber and non-timber forest products (NTFPs) (Central Statistical Agency 2026).

Sampling and data collection methods

A preliminary reconnaissance survey was conducted in October 2025 in collaboration with local community representatives, agricultural development agents, and local administrative officers to assess baseline site conditions and delineate the boundaries of the SWR. Based on this survey, homogeneous woodland stands were identified, and boundary turning points were recorded using a handheld Global Positioning System (GPS) receiver. To capture environmental and elevational variability, a systematic transect sampling design was established along the prevailing slope gradient (Kent, 2011). Two parallel transects were laid out across the altitudinal range of the woodland reserve.

A total of 23 main sample plots ($10\ \text{m} \times 50\ \text{m}$; $500\ \text{m}^2$ each), covering a cumulative sampling area of 1.15 ha, were systematically distributed along the transects at regular intervals of 100 m (Asmamaw et al. 2025). Within each main plot, all woody species were identified by their local and scientific names using the published volumes of the Flora of Ethiopia as well as Flora of Ethiopia and Eritrea (Friis et al. 2010, 2022) and their abundance and percentage visual canopy cover were estimated.

For all living woody individuals with a diameter at breast height $(\text{DBH}) \geq 2.5\ \text{cm}$, was measured using a tree calliper and diameter tape (Gebeyehu et al. 2019). Total tree height was

measured using a clinometer. For stems exhibiting burls, deformities, or stem swellings at breast height, measurements were taken immediately above the point of irregularity. For individuals branching below or at breast height, each stem was measured separately and recorded. For shrub species, diameter was measured at stump height (DSH, ≈ 30 cm above ground) (Yeshitila et al. 2023). The frequency, species identity, and diameter of dead tree stumps were also recorded to assess historical harvesting intensity (Gebeyehu et al. 2019).

To evaluate regeneration dynamics, five nested sub-plots ($2\text{ m} \times 4\text{ m}$; 8 m^2 each) were established within each 500 m^2 main plot, four at the corners and one at the plot center yielding a total of 115 sub-plots (with total area of 0.09 ha). The long axes of the sub-plots were oriented parallel to the main plot boundaries. Seedlings and saplings were defined as woody individuals with DBH < 2.5 cm or total height < 1.5 m, and their total counts per species were recorded within each sub-plot (Masresha et al. 2024).

2.3. Data Analysis

2.3.1. Species Diversity and Composition and Structure

To evaluate the floristic structure and ecological dominance of the woodland community, structural parameters were calculated for each woody species across the sample plots as follows:

I). Density (D**) and Relative density (**RD**):**

$$\text{D} = \frac{\sum N_i}{A} \quad \left(\text{stems ha}^{-1}\right)$$

$$\text{RD} = \left(\frac{n_i}{N}\right) \times 100 \quad (\%)$$

where n_i is the total number of individuals of species i, N is the total number of individuals of all species across all plots, and A is the total sampled area in hectares.

II). Frequency (F**) and Relative frequency (**RF**):**

$$\text{F} = \left(\frac{Q_i}{Q_t}\right) \times 100 \quad (\%)$$

$$\text{RF} = \left(\frac{F_i}{\sum F}\right) \times 100 \quad (\%)$$

where Q_i is the number of sample plots in which species i occurred, Q_t is the total number of sample plots ($Q_t = 23$), and $\sum F$ is the sum of frequency values for all recorded species.

III). Basal Area (m^2) for each tree/shrub stem was calculated from DBH or DSH (cm) (Wiegand 1971):

$$\mathrm{BA} = \frac{\pi \times d^2}{40{,}000} \approx 0.00007854 \times d^2$$

Stand basal area ($m^2\ ha^{-1}$) per species was calculated by summing individual basal areas per hectare.

IV) Relative dominance (RDo) was computed as (Maguran 2004):

$$\mathrm{RDo} = \left(\frac{\mathrm{BA_i}}{\mathrm{BA_t}}\right) \times 100 \quad (\%)$$

where $\mathrm{BA_i}$ is the total basal area of species i, and $\mathrm{BA_t}$ is the total basal area of all species in the sampled area.

V). **Important value index (IVI)**: The ecological importance of each species within the woodland community was determined by summing its relative structural metrics (Magurran 2021):

$$\mathrm{IVI} = \mathrm{RD} + \mathrm{RF} + \mathrm{RDo}$$

VI). **Species diversity and evenness:** were quantified using the Shannon–Wiener diversity index (H′) (Shannon 1948) and Pielou's evenness index (J′) (Simpson 1949):

$$\mathrm{H}' = -\sum_{i=1}^{S}(p_i \times \ln(p_i))$$

$$\mathrm{J}' = \frac{\mathrm{H}'}{\mathrm{H}'_{\max}} = \frac{\mathrm{H}'}{\ln(S)}$$

where $p_i = \frac{n_i}{N}$ is the proportion of individuals belonging to species i, ln is the natural logarithm, and S is the total species richness (total number of identified species).

The regeneration status of each woody species was evaluated based on the relative population densities of seedlings, saplings, and mature adult trees, and classified into five distinct categories (Chauhan et al. 2008; Gebeyehu et al. 2019): good regeneration (seedling density > sapling density > adult density), fair regeneration (seedling density > sapling density ≤ adult density, or seedling density ≤ sapling density ≤ adult density), poor regeneration (species present solely in the sapling stage with complete absence of seedlings, regardless of adult tree density), no regeneration (species represented exclusively by mature adult trees, with complete absence of both seedlings and saplings), and new regeneration (species represented solely by seedling and/or sapling stages, with no mature adult individuals present in the sampled canopy).

3.2.2. Biomass and Carbon Accounting

Aboveground biomass (AGB) was estimated using the pantropical allometric equation (Chave et al. 2014):

$$\mathrm{AGB} = 0.0673 \text{ x } (\rho \text{ x } \mathrm{DBH}^2 \text{x } \mathrm{H})^{0.976}$$

Where: AGB = above ground biomass (Mg), ρ = wood density (g/cm^3), DBH = diameter at breast height (cm) and H = height of a tree (m). In accordance with national carbon accounting baselines established by the Ethiopian Ministry of Environment, Forest and Climate Change (MEFCC 2017), a regional basic wood density value of $\rho = 0.590$ g cm^3 was applied.

Belowground biomass (BGB) was estimated using a biome-specific root-to-shoot ratio of 0.25, established for tropical dry woodlands and savannas (Mokany et al. 2006):

$$\mathrm{BGB} = \mathrm{AGB} \times 0.25$$

The application of root-to-shoot ratio across mature tree size classes is justified under IPCC (IPCC 2006) Tier-2 guidelines for dryland pachycaul savannas, where structural root allocation scales linearly with massive trunk biomass to maintain structural stability against seasonal drought stress (source).

The total biomass (TB) was computed from sum of AGB and BGB: $\mathrm{TB} = \mathrm{AGB} + \mathrm{BGB}$. Finally, total biomass (TB) was converted to elemental carbon (C) stock and carbon dioxide equivalents (CO_2e) using standard conversions (IPCC 2006): $\mathrm{Carbon\,(C)} = \mathrm{C\ fraction}\ (0.47) \times \mathrm{TB}$; and $\mathrm{CO_2e} = \mathrm{C} \times 3.67$. To scale individual tree biomass estimates (kg tree^{-1}) to area-density values (Mg ha^{-1}), tree biomass values within each 500 m^2 plot (0.05 ha) were summed and expanded to per-hectare equivalents using a fixed plot expansion factor ($\mathrm{EF} = 20$). Plot-level biomass density ($\mathrm{TB_{plot}}$, Mg ha^{-1}) was calculated as:

$$\mathrm{TB_{plot}} = \left(\sum_{j=1}^{m} \mathrm{TB_{tree},}_{j} \right) \times \frac{20}{1{,}000}$$

Where m represents the total number of inventoried stems in the plot. Matrix-level biomass carbon stocks (Mg C ha^{-1}) were subsequently derived by scaling average individual tree biomass by the mean stand density (D, stems ha^{-1}) empirical to each land-use type and multiplying by the IPCC (IPCC 2006) default carbon fraction ($\mathrm{CF} = 0.47$).

2.4. Statistical Analysis

Data organization and preliminary tabular management were executed using Microsoft Excel. All phytosociological parameters, including stem density (D), relative density (RD), frequency, relative frequency (RF), basal area, relative dominance (RDo), and the Importance Value Index

(IVI) alongside alpha diversity metrics (species richness S, Shannon–Wiener diversity index H', and Pielou's evenness index, J) were calculated by importing the species abundance matrix into R software (version 4.5.1) using the vegan package (Oksanen et al., 2022).

Continuous biophysical variables (stem density, basal area, biomass, and carbon stocks) were evaluated for distributional properties. Normality was assessed using the Shapiro-Wilk test, and homoscedasticity was verified using Levene's test at a significance threshold of $\alpha = 0.05$. Parametric variables conforming to normality assumptions ($p > 0.05$) are reported as means $\pm$ standard error (SE). Skewed continuous metrics exhibiting high spatial dispersion were analyzed using descriptive dispersion statistics to reflect spatial aggregation and canopy heterogeneity across the woodland reserve.

3. Results

3.1. Woody Species Composition

A total of 41 woody plant species were recorded in the SWR (Table 1). Out of these, 40 were identified to species level, while one remained unidentified and was recorded locally by its Berta name as "Shibiq," representing a shrub/tree growth habit. The identified species belong to 31 genera and 21 families. The most species-rich family was *Fabaceae* (represented by 13 species, accounting for 31.7% of the total), followed by *Moraceae* (5 species) and *Combretaceae* (4 species).

Growth habit categorization revealed that the majority of woody taxa are trees (85.4%), followed by shrubs (9.8%), climbers (2.4%, *Saba comorensis*), and bamboos/grasses (2.4%, *Oxytenanthera abyssinica*) (Table 1). The upper canopy is dominated by prominent species including *Adansonia digitata*, *Sterculia africana*, *Breonadia salicina*, *Pterocarpus lucens*, *Vitex doniana*, *Tamarindus indica*, *Albizia malacophylla*, *Dalbergia melanoxylon*, and *Balanites aegyptiaca*. The middle canopy comprises *Acacia hecatophylla*, *Acacia seyal*, *Anogeissus leiocarpa*, *Combretum collinum*, *Combretum molle*, *Entada africana*, *Grewia mollis*, *Terminalia laxiflora*, and *Stereospermum kunthianum*. The Shannon–Wiener diversity index (H') was 3.123, reflecting both high species richness and an equitable distribution of individuals across taxa.

3.2. Frequency distribution and Floristic heterogeneity

The majority of woody species were concentrated in the lower frequency classes (Table 2). Approximately 50% of the recorded species occurred in frequency class D (21–40%), and 30% occurred in frequency class E (0–20%). Conversely, only about 5% of species fell into class B

(61–80%), and none occupied the highest frequency class A (81–100%). The most frequent woody species encountered were *Dichrostachys cinerea* (69.56%), *Lannea fruticosa* (65.20%), *Maytenus senegalensis* (52.17%), *Combretum collinum* (47.80%), and *Acacia seyal* (43.50%). In contrast, the least frequent species included *Boswellia papyrifera*, *Albizia malacophylla*, *Ficus* spp., and *Entada africana*.

3.3. Density, Basal area, and Dominance

The total stem density for woody individuals with DBH/DSH $\geq$ 2.5 cm was 594 stems ha^{-1}. The density-class distribution result showed that no species fell into Class A (>100 stems ha^{-1}), only 7.3% were 50.1 – 100 stems ha^{-1} (Class B), 31.7% of were 10.1-50 stems ha^{-1} (Class C), 46.3% of the species were represented in density Class D (1.1-10) and 14.6% of stems ha^{-1} were represented in density class E (< 1) (Table2). Thus, approximately 60.9% of the recorded woody species had densities of less than 10 stems ha^{-1}. Species with sparse densities included *Acacia seyal*, *Ficus* spp., *Ficus sycomorus*, *Ficus thonningii*, *Sterculia africana*, and *Ximenia americana*.

The total BA for all woody species with DBH/DSH $\geq$ 2.5 cm was 46 m^2 ha^{-1}. Basal area dominance was heavily concentrated among large individuals ($DBH > 42.6$ cm). *Vitex doniana* accounted for the highest mean basal area proportion, followed by *Ficus thonningii*, *Adansonia digitata*, *Breonadia salicina*, and *Ficus* spp., with mean basal area values of 1.00, 0.57, 0.49, 0.48, and 0.34 m^2, respectively. Conversely, species such as *Oxytenanthera abyssinica*, *Saba comorensis*, and *Dalbergia boehmii* exhibited minimal basal area contributions (0.0007 m^2 to 0.003 m^2).

3.4. Importance Value Index (IVI)

The IVI highlighted dominant structural components across the reserve (Table 3). The species exhibiting the highest ecological importance ($IVI > 10$) were *Vitex doniana*, *Ficus thonningii*, *Breonadia salicina*, and *Adansonia digitata*. *Vitex doniana* recorded the highest IVI primarily due to its exceptional relative dominance. Mid-tier species with IVI values exceeding 5, included *Balanites aegyptiaca*, *Lannea fruticosa*, and *Pterocarpus lucens*. Conversely, species exhibiting the lowest IVI values such as *Syzygium* spp., *Saba comorensis*, *Strychnos innocua*, *Ficus* spp., and *Stereospermum kunthianum* point toward heightened vulnerability and conservation priority.

3.5. Population structure and regeneration status

Analysis of diameter size classes revealed three distinct structural groups among the woody populations (Table 4, Fig. 3):

Group 1 (Poor/absent recruitment): Species showing inverted or abnormal distributions characterized by a lack of representation across smaller DBH classes and over-representation of large trees. This group includes *Adansonia digitata*, *Albizia malacophylla*, *Boswellia papyrifera*, *Breonadia salicina*, *Dalbergia melanoxylon*, *Dalbergia boehmii*, *Pterocarpus lucens*, *Sterculia africana*, *Stereospermum kunthianum*, *Ficus* spp., *Ficus sycomorus*, and *Ficus thonningii*.

Group 2 (Reproduction present, deficient recruitment): Species with active juvenile presence but limited progression into intermediate size classes, including *Balanites aegyptiaca*, *Combretum collinum*, *Combretum molle*, *Grewia mollis*, *Vitex doniana*, *Terminalia laxiflora*, *Syzygium* spp., and *Tamarindus indica*.

- **Group 3 (Stable/good recruitment):** Species with robust representation across lower and upper diameter classes, including *Acacia hecatophylla*, *Acacia seyal*, *Gardenia ternifolia*, *Ziziphus mauritiana*, "Shibiq", and *Strychnos innocua*.

Regeneration assessments based on seedling and sapling densities identified 30 woody species (comprising 14 genera and 15 families) actively represented in the understory. These were categorized into three conservation priority tiers based on regeneration density (Table 5):

- **Priority (Absent regeneration):** Species with zero seedling/sapling density, including *Adansonia digitata*, *Albizia malacophylla*, *Boswellia papyrifera*, *Dalbergia melanoxylon*, *Dalbergia boehmii*, *Ficus* spp., *Ficus sycomorus*, *Ficus thonningii*, *Saba comorensis*, and *Sterculia africana*.
- **Second priority (Low regeneration, density < 50):** Species such as *Diospyros mespiliformis*, *Combretum molle*, *Entada africana*, *Gardenia ternifolia*, *Grewia mollis*, *Lannea welwitschii*, *Lonchocarpus laxiflorus*, *Pterocarpus lucens*, *Stereospermum kunthianum*, *Strychnos innocua*, *Syzygium* spp., *Tamarindus indica*, *Terminalia laxiflora*, *Vitex doniana*, and *Ximenia americana*.
- **Third priority (Adequate regeneration, density ≥ 50):** Species demonstrating robust understory establishment, including *Dichrostachys cinerea*, *Anogeissus leiocarpa*, *Lannea fruticosa*, *Maytenus senegalensis*, *Oxytenanthera abyssinica*, *Piliostigma thonningii*, *Tamarix nilotica*, *Ziziphus mauritiana*, and "Shibiq".

3.6. Biomass and Carbon Stock Potential

The mean total biomass across the assessed woody stems was 221.74 ± 34.40 Mg ha^{-1}, consisting of 177.39 ± 27.52 Mg ha^{-1} of AGB and 44.35 ± 6.88 Mg ha^{-1} of biomass BGB (Table 6). This biomass potential yielded a mean carbon stock of 104.22 ± 16.17 Mg C ha^{-1}, translating to mean carbon dioxide equivalent (CO_2e) storage capacity of 382.48 ± 59.33 Mg CO_2e ha^{-1}. Biomass distribution displayed marked positive skewness and high dispersion; individual AGB values ranged widely from a minimum of 8.87 Mg ha^{-1} to a maximum of 1,411.83 Mg ha^{-1}, driven by a dense matrix of small trees interspersed with occasional large-diameter canopy specimens.

The mean total biomass across the assessed woody stems was 221.74 ± 34.40 Mg ha^{-1}, comprising 177.39 ± 27.52 Mg ha^{-1} of AGB and 44.35 ± 6.88 Mg ha^{-1} of BGB (Table 6). This biomass corresponds to a mean carbon stock of 104.22 ± 16.17Mg C ha^{-1}, equivalent to 382.48 ± 59.33 Mg CO_2 e ha^{-1}. The distribution of biomass was highly uneven, with most trees being small but a few large-diameter canopy specimens contributing disproportionately to the total biomass, as indicated by the wide range of individual AGB values (8.87 – 1,411.83 Mg ha^{-1}).

4. Discussion

4.1. Woody Species Composition and Diversity

The identification of 41 woody plant species across 31 genera and 21 families demonstrates that the SWR supports a diverse assemblage typical of dry deciduous woodlands. Although broader regional surveys in Benishangul-Gumuz report over 1,100 vascular plant species from 117 families (Awas and Nordal 2007; Friis et al. 2010, 2022), the lower species count in this study reflects its focus on woody species within the specific and small boundaries of the woodland reserve. In comparison to other localized studies in western and northwestern Ethiopian lowlands (Yeshitila et al. 2024; Masresha et al. 2024; Yasin et al. 2026), the species richness observed here is consistent with plot-level variations influenced by local habitat conditions and human disturbances.

Notwithstanding these differences in scale and taxonomic scope, the structural dominance of the families *Fabaceae* and *Combretaceae* aligns closely with the general floristic characteristics of the *Combretum–Terminalia* woodland vegetation type described across Ethiopia (Temesgen and Warkineh 2020; Friis et al. 2022; Yeshitila et al. 2024; Masresha et al. 2024). This dominance highlights the ecological resilience and adaptability of *Fabaceae*

and *Combretaceae* species under moisture stress and frequent environmental or anthropogenic pressures.

Furthermore, the growth habit analysis dominated by trees (85.4%) alongside subordinate shrubs, climbers (e.g., *Saba comorensis*), and lowland bamboo (*Oxytenanthera abyssinica*) highlights a distinct multilayered canopy structure typical of dry deciduous formations. The upper canopy is characterized by large-statured tree species such as *Adansonia digitata*, *Sterculia africana*, and *Vitex doniana*, indicating that the woodland retains important structural attributes and mature niches despite local anthropogenic pressures. This multilayered configuration and functional habit distribution closely mirror structural descriptions of *Combretum-Terminalia* woodlands across western and northwestern Ethiopia, where woody perennials dominate the vertical strata.

Moreover, the Shannon–Wiener diversity index (H'=3.123) falls within the upper range documented for dry deciduous formations in western Ethiopia, such as the Dabena woodland (Yeshitila et al. 2023) and Metema woodland (H' = 3.67) (Wale et al. 2012). A notable floristic feature of the SWR is that 80% of the inventoried woody species were confined to lower frequency classes (D and E). In dryland vegetation ecology, such a high proportion of infrequent taxa signifies high floristic heterogeneity, microclimatic niche partitioning, and irregular spatial dispersion across the landscape (Gillison 2013; Assefa et al. 2022).

4.2. Frequency distribution and Floristic diversity

The frequency classes analysis results revealed a pronounced distribution pattern wherein approximately 80% of all recorded woody species fell into the lower frequency classes (D and E), with a distinct absence of representation in higher abundance classes. In vegetation ecology, a high proportion of species confined to lower frequency classes serves as a direct indicator of high floristic heterogeneity and irregular, patchy spatial dispersion across the landscape (Maguran 2004; Gillison 2013). Species such as *Dichrostachys cinerea*, *Lannea fruticosa*, and *Combretum collinum* exhibited high ecological constancy, confirming that the site provides an optimal natural habitat for drought-tolerant, resilient deciduous scrub and tree taxa typical of degraded or secondary dry woodlands (Assefa et al. 2022). Conversely, restricted and economically valuable species like *Boswellia papyrifera* and *Albizia malacophylla* displayed low spatial frequency and sparse distribution. This high patchiness and limited localized occurrence underscore their acute vulnerability to anthropogenic disturbances, selective tapping or clearing, and habitat fragmentation, a trend widely documented across dry deciduous

ecosystems in northern and northwestern Ethiopia (Lemenih and Kassa 2011; Eshete et al. 2012; Alem et al. 2022). Consequently, these findings highlight the need for conservation attention to protect vulnerable species from localized extirpation.

4.3. Density, Basal Area, and Dominance

The total stem density of 594 ha^{-1} observed in the Sherkole Woodland Reserve compares favourably with similar protected or semi-enclosed dryland reserves across northwestern Ethiopia and neighbouring regions (Eshete et al. 2012; Assefa et al. 2022; Yeshitila et al. 2023, 2024; Masresha et al. 2024). This considerable stem density indicates that the reserve maintains substantial woody stocking, buffered by localized protection and lower historical extraction rates relative to heavily settled adjacent tracts. However, density-class analysis exposed an underlying structural skew: over 60% of species occurred at densities below 10 stems ha^{-1}, demonstrating that overall numerical density is driven by a handful of prolific, highly resilient taxa rather than uniform stocking across all recorded species. The taxa occurring at sparse densities (< 1 stem ha^{-1}) include *Acacia seyal* Del., *Ficus sycomorus* L., *Ficus thonningii* Blume, *Sterculia africana* (Lour.) Fiori, and *Ximenia americana* L., highlighting species that are particularly vulnerable to localized disturbance.

The total basal area (46 m^2 ha^{-1} for stems DBH/DSH > 2.5 cm) confirms a high structural contribution from large-diameter canopy trees (DBH > 42.6 cm) (Balderas Torres & Lovett, 2013). Stand basal area was dominated by *Vitex doniana* Sweet (1.00 m^2 ha^{-1}), followed by *Ficus thonningii* Blume (0.57 m^2 ha^{-1}), *Adansonia digitata* L. (0.49 m^2 ha^{-1}), *Breonadia salicina* (Vahl) Hepper & Wood (0.48 m^2 ha^{-1}), and *Anogeissus leiocarpa* (A.DC.) Guill. & Perr. Conversely, minimal contributions were recorded for *Oxytenanthera abyssinica* (A.Rich.) Munro (0.0007 m^2 ha^{-1}), *Saba comorensis* (Boj.) Pichon (0.0010 m^2 ha^{-1}), and *Dalbergia boehmii* Taub. (0.0030 m^2 ha^{-1}), alongside negligible inputs from *Strychnos innocua* Del., *Tamarix nilotica* (Ehrenb.) Bunge, and *Ximenia americana* L. These patterns confirm that a few large-statured species drive vertical stratification, microclimatic regulation, and stand volume, whereas minor basal area contributors exert negligible influence on total woody biomass despite their numerical presence (Balderas Torres and Lovett 2013; Ali et al. 2019).

4.4. Importance Value Index (IVI) and Species Conservation Prioritization

In the SWR, the distribution of species IVI scores reveals strong structural dominance concentrated within a few canopy taxa alongside high ecological vulnerability among minor

components. Species exhibiting the highest ecological importance (IVI > 10.0) were *Vitex doniana* Sweet, *Ficus thonningii* Blume, *Breonadia salicina* (Vahl) Hepper & Wood, and *Adansonia digitata* L. (Table 3, Fig. 3). *Vitex doniana* attained the highest overall IVI value primarily because of its substantial relative basal area dominance, despite displaying an irregular (non-normal) diameter size-class distribution. Secondary ecological contributors (IVI > 5.0) included *Balanites aegyptiaca* (L.) Delile, *Lannea fruticosa* (Hochst.) Engl., and *Pterocarpus lucens* Guill. & Perr., which collectively drive upper-canopy complexity and microclimatic regulation across the *Combretum–Terminalia* woodland matrix (Wale et al., 2012).

From a genetic resource management perspective, species exhibiting high IVI values require lower immediate species-specific recovery intervention, as their high structural representation buffers them against rapid localized extirpation (Eshete et al. 2012). Conversely, species recording exceptionally low IVI scores such as *Stereospermum kunthianum* Cham., *Strychnos innocua* Delile, *Saba comorensis* (Bojer) Pichon, *Ficus* spp., and *Syzygium* spp. (Fig 5) occupy minimal structural and spatial footprints within the reserve. The low ecological constancy and sparse population density of these low-IVI taxa signify ecological vulnerability and highlight the need for conservation attention and inclusion in local in situ conservation and community-managed enrichment planting schemes (Wale et al. 2012; Kifle et al. 2022; Anamo et al. 2023).

The Importance Value Index integrates density, frequency, and dominance to identify ecologically influential taxa. In SWR, high IVI scores achieved by *Vitex doniana*, *Ficus thonningii*, *Breonadia salicina*, and *Adansonia digitata* reflect their heavy basal area contributions and structural prominence. Conversely, taxa recording low IVI values alongside poor regeneration such as *Syzygium* spp., *Saba comorensis*, *Strychnos innocua*, and *Stereospermum kunthianum* represent rare or suppressed elements requiring immediate protective intervention. Relying solely on IVI can be misleading if high index values mask underlying demographic bottlenecks; therefore, integrating IVI rankings with population structure and regeneration inventories provides a robust foundation for multi-criteria conservation prioritization.

4.5. Population Structure and Regeneration Dynamics

In the SWR, while continuous inverse-J size distributions in pioneer taxa like *Combretum collinum* reflect self-replacing demographic stability, the severe recruitment failure documented among key economic and ecological species, including *Boswellia papyrifera*,

Dalbergia melanoxylon, *Albizia malacophylla*, *Breonadia salicina*, and *Adansonia digitata* signals acute structural degeneration. The complete absence or truncation of seedling and sapling stages in these priority species reveals an aging canopy failing to replace itself. This demographic disruption aligns with patterns observed across northwestern Ethiopia, where *Boswellia papyrifera* consistently exhibits bell-shaped diameter distributions indicative of long-term recruitment arrest (Eshete et al. 2012; Wale et al. 2012; Yosef et al. 2019). The ecological drivers underpinning this recruitment collapse are multi-faceted: intensive livestock overgrazing destroys palatable juvenile shoots, recurrent unmanaged late dry-season fires destroy soil seed banks, and continuous resin tapping severely weakens reproductive vitality and seed germinability in *Boswellia* stands (Lemenih and Kassa 2011; Eshete et al. 2012; Wale et al. 2012; Kassahun et al. 2024).

4.6. Species Prioritization for Conservation and Management Implications

Developing effective *in situ* and *ex situ* conservation strategies for dryland woodland ecosystems requires an integrated diagnostic approach that moves beyond single-variable assessments (Kent 2012; Magurran 2021). Relying solely on the Importance Value Index (IVI) can be misleading; while low IVI values highlight taxa with low numerical density, frequency, and basal area footprint, even species exhibiting high IVI values may suffer from underlying demographic collapse if mature cohorts are not backed by active regeneration (Eshete et al. 2012). Therefore, to establish robust conservation priorities across the Sherkole Woodland Reserve, species were evaluated at the intersection of three ecological indicators: (1) low ecological dominance ($IVI < 1.0$), (2) discontinuous or abnormal size-class diameter distributions, and (3) complete failure or absence of natural regeneration (seedlings and saplings) (Table 4, Table 5).

Applying this multi-criteria evaluation framework identifies several ecologically and socio-economically vital woody species facing acute localized vulnerability (Figure 5b). Taxa such as *Boswellia papyrifera* (Delile) Hochst., *Breonadia salicina* (Vahl) Hepper & Wood, *Adansonia digitata* L., *Balanites aegyptiaca* (L.) Delile, *Dalbergia melanoxylon* Guill. & Perr., *Sterculia africana* (Lour.) Fiori, and *Ficus* species exhibit severe demographic impairment. These species are characterized by an over-representation of aging, large-diameter individuals alongside a complete absence or severe truncation of seedling and sapling cohorts (Group I / Priority I). In northwestern Ethiopia, such regeneration failures in multi-purpose dryland species are exacerbated by synergistic anthropogenic pressures, including unregulated

livestock overgrazing, frequent dry-season wildfires, unmanaged timber and fuelwood harvesting, and unsustainable oleo-gum resin extraction (Eshete et al. 2012; Wale et al. 2012; Yeshitila et al. 2024).

Furthermore, species combining restricted spatial distributions with exceptionally low IVI scores, including *Syzygium* spp., *Saba comorensis* (Bojer) Pichon, *Strychnos innocua* Delile, and *Stereospermum kunthianum* Cham., occupy precarious ecological niches within the woodland matrix. Without targeted conservation interventions, these vulnerable populations may be at risk of localized decline as mature individuals senesce. Consequently, species assigned to Priority I demand urgent management interventions, including the establishment of community-managed enclosures to eliminate grazing interference, controlled fire management, *in situ* gene pool protection, and active enrichment planting using local seed sources within participatory forest governance frameworks.

4.7. Biomass and Carbon Storage Potential of *Combretum-Terminalia* woody Species

The present study found that SWR stored a mean total biomass carbon of 104.22 ± 16.17 Mg C ha^{-1} and mitigation potential of 382.48 ± 59.33 Mg CO_2e ha^{-1}. This carbon density exceeds values reported for drier or heavily exploited *Boswellia* woodlands in Kafta-Humera (16.71–19.29 Mg C ha^{-1} AGC) and Lemlem Terara (27.91 Mg C ha^{-1} AGC) (Yosef et al. 2019), as well as residential green spaces in southern Ethiopia (64.35 Mg C ha^{-1}) (Asfaw and Zergaw 2022). Furthermore, aboveground carbon (83.37 Mg C ha^{-1}) recorded in the SWR exceeds that of private residential green infrastructure and agroforestry systems in southern Ethiopia (64.35 Mg C ha^{-1}) (Asfaw and Zergaw 2022), while surpassing heavily degraded dry Afromontane reserves such as the Desa'a forest in northern Ethiopia (10.22 Mg C ha^{-1} AGC) by more than eightfold (Tetemke et al. 2021). However, it remains lower than moist-buffered transitions like Godebe National Park (201.24 Mg C ha^{-1} living carbon) but substantially higher than drier *Acacia* woodland strata (71.10 Mg C ha^{-1}**)** within the same landscape (Taju and Marelign 2022). These spatial variations in carbon stocks across dryland ecosystems are driven by differences in protection status that mitigate anthropogenic degradation, a pronounced 'big-tree' mass effect concentrating biomass in large canopy dominants and localized edaphic-moisture gradients (Slik et al. 2013; Chave et al. 2014; Yosef et al. 2019).

Generally, these findings confirm that *Combretum–Terminalia* woodlands reserve function as critical carbon sinks and offer major opportunities for nature-based climate solutions, national

REDD+ initiatives, and community-based forest conservation frameworks. Nevertheless, because standing carbon is heavily concentrated in over-mature canopy trees that currently suffer from severe seedling and sapling recruitment bottlenecks, the long-term permanence of this carbon reservoir may be at risk unless proactive in situ protection and regeneration management are instituted.

5. Conclusion

This study highlighted that the *Combretum–Terminalia* woodland ecosystem of the SWR maintains critical ecological values, as an important regional carbon sink and a vital reservoir of dryland biodiversity. However, these positive structural indicators mask underlying demographic vulnerabilities. The coexistence of high standing biomass with severe recruitment bottlenecks evidenced by irregular size-class distributions, low frequency scores, and complete regeneration failures among economically and ecologically vital taxa (e.g., *Boswellia papyrifera*, *Adansonia digitata*, and *Breonadia salicina*) indicates that the present woodland composition lacks long-term demographic stability (sustainability). Without targeted interventions, senescing canopy dominants will not be replaced by younger cohorts, threatening future ecosystem integrity and carbon sequestration capacity.

To safeguard the floristic diversity, structural resilience, and carbon storage functions of the SWR, the following recommendations are forwarded:

- **Targeted conservation prioritization:** Implement strict *in situ* protection such as temporary grazing exclosures around remnant populations of high-priority species (e.g., *Boswellia papyrifera*, *Adansonia digitata*, *Albizia malacophylla*, and *Breonadia salicina*).), complemented by targeted *ex situ* propagation.
- **Community-based (participatory) forest management (PFM):** Empower local communities through collaborative governance structures to regulate extractive pressures, manage livestock grazing, and mitigate dry-season wildfires.
- **Active ecological restoration:** Establish community nurseries utilizing native seed sources and undertake enrichment planting for keystone species where natural regeneration is suppressed.
- **Targeted silvicultural research:** Prioritize empirical investigations into soil seed bank dynamics, seedling establishment constraints, and the physiological responses of dryland taxa to changing climatic regimes.

Declarations

Author contributions statement

D.R was involved in the conceptualization, investigation, data collection, data curation, and validation and writing of the draft. S.A was involved in the conceptualization, investigation, methodology, data analysis, and writing of the manuscript. G.G was involved in the investigation, methodology, data analysis, and writing of the manuscript.

Ethical approval: The study protocol and vegetation inventory procedures were reviewed and approved by the Institutional Review Board (IRB, No. 21) of Bahir Dar University. The research was carried out in accordance with the Declaration of Helsinki and relevant institutional guidelines. Field research permits were granted by local administrative offices across the study site.

Consent to participate: Informed consent was obtained from all individual participants included in the study prior to data collection.

Consent to publish: Informed consent for the publication of socio-economic survey findings, associated data, and any identifiable individual images or photographs was obtained from all participants.

Competing interests: The authors declare no conflict of interests.

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Funding: The study received no financial support from any organization.

References

Abebe S, Minale AS, Teketay D (2021) Socio-economic importance of the bamboo resources in the Lower Beles River Basin, north-western Ethiopia. Environ Dev Sustain. https://doi.org/10.1007/s10668-021-01938-4

Abebe, S., Reda, D (2026) Socio-economic importance and biomass carbon stocks of African baobab (*Adansonia digitata* L.) in Northwestern Ethiopia. *Discov Sustain*. https://doi.org/10.1007/s43621-026-05040-5

Abere M, Eshete A, Alemu A (2022) Traditional uses and local management practices of Adansonia digitata L. in different ethnic groups of Quara wereda, North West low land of Ethiopia. Trees, For People 7:100188. https://doi.org/10.1016/j.tfp.2021.100188

Abere M, Yilma Z, Tsegie T, et al (2023) Population structure and phenological attributes of Adansonia digitata L. (baobab) in Northwestern lowland area of Ethiopia. Heliyon 9:e22571. https://doi.org/10.1016/j.heliyon.2023.e22571

Abich A, Alemu A, Gebremariam Y, et al (2021) Allometric models for predicting aboveground biomass of Combretum-Terminalia woodlands in Amhara, Northwest Ethiopia. Trees, For People 5:100122. https://doi.org/10.1016/j.tfp.2021.100122

Abich A, Negash M, Alemu A, Gashaw T (2022) Aboveground Biomass Models in the Combretum-Terminalia Woodlands of Ethiopia: Testing Species and Site Variation Effects. Land 11:811. https://doi.org/10.3390/land11060811

Alem S, Hassen N, Teshome M, et al (2022) Floristic Composition, Diversity, Population Structure and Regeneration Status of Woody Species in Four Church Forests in Ethiopia. In: Kindu, M., Wassie, A., Teketay, D., Schneider, T., Lemenih, M., Konke T (ed) State of the Art in Ethiopian Church Forests and Restoration Options. Springer International Publishing, Cham, pp 127–149

Ali A, Lin S, He J, et al (2019) Big-sized trees overrule remaining trees' attributes and species richness as determinants of aboveground biomass in tropical forests. Glob Chang Biol 25:2810–2824. https://doi.org/10.1111/gcb.14707

Anamo A, Mammo S, Temesgen M (2023) Floristic composition and community analysis of woody species in Hereje Natural Forest, southwest Ethiopia. SN Appl Sci 5:48. https://doi.org/10.1007/s42452-022-05265-9

Asfaw Z, Zergaw Y (2022) Woody Species Diversity and Biomass Carbon Sequestration in Private Residential Green Infrastructure of Dilla Town, Southern Ethiopia. Int J For Res 2022:. https://doi.org/10.1155/2022/4017094

Asmamaw M, Fisaha G, Wassie KB (2025) Woody plants composition, structure and regeneration status of Muger Zala natural forest, Central Ethiopia. Sci Rep 16:3556. https://doi.org/10.1038/s41598-025-33509-2

Assefa A, Bekele T, Demissew S, Abebe T (2022) Investigation of Woody Species Structure and Regeneration Status in the Central Rift Valley, Sidama Regional State, Ethiopia. Int J For Res 2022:1–15. https://doi.org/10.1155/2022/7021477

Awas T, Nordal I (2007) Benishangul Gumuz Region in Ethiopia: A centre of endemism for Chlorophytum - With a description of C. pseudocaule sp. nov. (Anthericaceae). Kew Bull 62:129–132

Balderas Torres A, Lovett JC (2013) Using basal area to estimate aboveground carbon stocks in forests: La Primavera Biosphere's Reserve, Mexico. Forestry 86:267–281. https://doi.org/10.1093/forestry/cps084

Central Statistical Agency. Population size by sex, region, zone and wereda, Ethiopia. Ethiop. Stat. Serv. Addis Ababa, Ethiopia. 2023. Accessed on August 12, 2026, via:

https://ess.gov.et/wp-content/uploads/2023/09/Population-of-Zones-a nd-Weredas-Projected-as-of-July-2023.pdf

Chauhan P, Negi V, Singh L, Manhas R (2008) Regeneration Status of Sal Forests of Doon Valley. Ann For 16:178–182

Chave J, Réjou-Méchain M, Búrquez A, et al (2014) Improved allometric models to estimate the aboveground biomass of tropical trees. Glob Chang Biol 20:3177–3190. https://doi.org/10.1111/gcb.12629

Chepkoech EK, Agevi H, Lung'ayia H, Tsingalia HM (2024) Woody Species Composition, Stand Structure and Regeneration Status of Londiani Forest in Kenya. Forests 15:653. https://doi.org/10.3390/f15040653

Chidumayo EN, Gumbo DJ (eds) (2010) The Dry Forests and Woodlands of Africa: Managing for Products and Services. Earth Scan, Washington DC

Eshete A, Teketay D, Lemenih M, Bongers F (2012) Forest Ecology and Management Effects of resin tapping and tree size on the purity , germination and storage behavior of Boswellia papyrifera (Del .) Hochst . seeds from Metema District , northwestern Ethiopia. For Ecol Manage 269:31–36. https://doi.org/10.1016/j.foreco.2011.12.049

Friis I, Demissew S, Breugel P van (2010) Atlas of the potential vegetation of Ethiopia. The Royal Danish Academy of Sciences and Letter, Copenhagen, Denmark

Friis I, Paulo van B, Odile W, Demissew S (2022) WESTERN WOODLANDS OF ETHIOPIA: A study of the woody vegetation and flora between the Ethiopian Highlands and the lowlands of the Nile Valley in the Sudan and South Sudan, Series B,. Det Kongelige Danske Videnskabernes Selskab, Copenhagen, Denmark

Gebeyehu G, Soromessa T, Bekele T, Teketay D (2019) Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, northwestern Ethiopia. Ecosyst Heal Sustain 5:199–215. https://doi.org/10.1080/20964129.2019.1664938

Gillison AN (2013) Community , Ecosystem and World Level. In: Maarel EE Van Der, Franklin J (eds) Vegetation Ecology, Second. Wiley-Blackwell (John Wiley & Sons, Ltd.), Chichester, United Kingdom.

IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories. In: Eggelston, S., Buendia, L., Miwa, K., Ngara, T. and Tanabe K (ed) Forest Land: Agriculture, Forest and Other land uses. Japan, pp 1–83

Kassahun AA, Abate DF, Belete DA (2024) The effects of disturbance on woody species composition, structure and regeneration status in the ura natural forest, Guangua district,

Awi Zone, Ethiopia. Heliyon 10:e38155. https://doi.org/10.1016/j.heliyon.2024.e38155

Kent, M (2011). Vegetation Description and Data Analysis: A Practical Approach. UK: John Wiley & Sons.

Kifle ET, Khamzina A, Son Y, et al (2022) Woody Species Composition, Diversity, Structure and Uses of Selected Church Forests in Central Ethiopia. In: Kindu, M., Wassie, A., Teketay, D., Schneider, T., Lemenih, M., Konke T (ed) State of the Art in Ethiopian Church Forests and Restoration Options. Springer International Publishing, Cham, pp 205–223

Lemenih M, Kassa H (2011) Opportunities and challenges for sustainable production and marketing of gums and resins in Ethiopia. Center for International Forestry Research (CIFOR), Bogor Barat 16115, Indonesia

Lemenih M, Kassa H, Kassie GT, et al (2014) Resettlement and Woodland Management Problems and Options : A Case Study from North-western Ethiopia. L Degrad Dev 25:305–318. https://doi.org/https://doi.org/10.1002/ldr.2136

Maguran AE (2004) Measuring Biological Diversity - Chapter 4. Blacl well Science Ltd., Malden, USA

Magurran AE (2021) Measuring biological diversity. Curr Biol 31:R1174–R1177. https://doi.org/10.1016/j.cub.2021.07.049

Manaye A, Tesfamariam B, Tesfaye M, Werku A (2019) Contribution of dry forests and forest products for climate change adaptation in Tigray Region. In: Bouwer R, Zablone Owiti (eds) AFRICAN CLIMATE RISKS CONFERENCE 2019: dismantling barriers to urgent climatae adaptation action. Addis Ababa, Ethiopia

Masresha G, Melkamu Y, Mulu G (2024) Woody Species Composition, Structure, and Status of Regeneration in Pugnido Forest, Gambella Region, Western Ethiopia. Scientifica (Cairo) 2024:1–15. https://doi.org/10.1155/2024/3961434

Ministry of Environment Forest, Environment and Climate Change (MFECC) (2017) Ethiopia's Forest Reference Level Submission to the UNFCCC. Addis Ababa, Ethiopia

Mokany K, Raison RJ, Prokushkin AS (2006) Critical analysis of root: Shoot ratios in terrestrial biomes. Glob Chang Biol 12:84–96. https://doi.org/10.1111/j.1365-2486.2005.001043.x

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., ... & Wagner, H. (2022). *vegan: Community Ecology Package*. R package version 2.6-4. https://CRAN.R-project.org/package=vegan

Shannon CE (1948) A Mathematical Theory of Communication. Bell Syst Tech J 27:379–

423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Simpson EH (1949) Measurement of Diversity. Nature 163:688–688. https://doi.org/10.1038/163688a0

Slik JWF, Paoli G, McGuire K, et al (2013) Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. Glob Ecol Biogeogr 22:1261–1271. https://doi.org/10.1111/geb.12092

Taju M, Marelign A (2022) Carbon stock and climate change mitigation potential of Godebe National Park, North West Ethiopia. Proc Int Acad Ecol Environ Sci 12:17–30

Temesgen F, Warkineh B (2020) Woody Species Structure and Regeneration Status in Kafta Sheraro National Park Dry Forest, Tigray Region, Ethiopia. Int J For Res 2020:. https://doi.org/10.1155/2020/4597456

Tesfaye M, Negash M (2018) Combretum-Terminalia vegetation accumulates more carbon stocks in the soil than the biomass along the elevation ranges of dryland ecosystem in Southern Ethiopia. J Arid Environ 155:59–64. https://doi.org/10.1016/j.jaridenv.2018.02.004

Tetemke BA, Birhane E, Rannestad MM, Eid T (2021) Species diversity and stand structural diversity of woody plants predominantly determine aboveground carbon stock of a dry Afromontane forest in Northern Ethiopia. For Ecol Manage 500:119634. https://doi.org/10.1016/j.foreco.2021.119634

Wale HA, Bekele T, Dalle G (2012) Floristic diversity, regeneration status, and vegetation structure of woodlands in Metema Area, Amhara National Regional State, Northwestern Ethiopia. J For Res 23:391–398. https://doi.org/10.1007/s11676-012-0275-z

Wiegand H (1971) Pielou, E. C. An introduction to mathematical ecology. Biom Z 13:219–220. https://doi.org/10.1002/bimj.19710130308

Yasin EHE, Gibreel HH, Siddig AAH, et al (2026) Spatiotemporal changes in woody species composition, diversity, and regeneration reveal rapid degradation of a savanna woodland in Blue Nile state, Sudan. Front For Glob Chang 9:. https://doi.org/10.3389/ffgc.2026.1835477

Yeshitila K, Bekele T, Wondimu T, Demissew S (2023) Vegetation composition and structure of Dabena woodland in western Ethiopia. Rend Lincei 34:953–965. https://doi.org/10.1007/s12210-023-01181-1

Yeshitila K, Demissew S, Wondimu T, Bekele T (2024) Plant Diversity and Relationship between Plant Communities and Environmental Variables in *Combretum-Terminalia* Woodland, Western Ethiopia. Int J Ecol 2024:. https://doi.org/10.1155/2024/9991266

Yosef BA, Eshetu Z, Garedew E, Kassa H (2019) Carbon stock potentials of woodlands in north western lowlands of Ethiopia. J Sustain For 38:629–650. https://doi.org/10.1080/10549811.2019.1598874

Zewdie S, Sahle K, Kassa H, et al (2023) Towards an integrated national fire management system in Ethiopia: a review of experiences, gaps, patterns and MODIS data. Addis Ababa, Ethiopia

Table 1. Woody species composition and taxonomic overview of SWR

SN	Scientific name	Local name (Berta)	Family	Growth habit
1	*Acacia hecatophylla* Steud. ex A.Rich.	Qudu	Fabaceae	Tree
2	*Acacia seyal* Del.	Qashi Fudi	Fabaceae	Tree
3	*Acacia* spp.	Atsemendu	Fabaceae	Tree
4	*Adansonia digitata* L.	Agungulees	Bombacaceae	Tree
5	*Albizia malacophylla* (A.Rich.) Walp.	Gendher	Fabaceae	Tree
6	*Anogeissus leiocarpa* (A.DC.) Guill. & Perr.	Qey	Combretaceae	Tree
7	*Balanites aegyptiaca* (L.) Del.	Qeha	Balanitaceae	Tree
8	*Boswellia papyrifera* (Del.) Hochst.	Agolgolo	Burseraceae	Tree
9	*Breonadia salicina* (Vahl) Hepper & Wood	Digle	Rubiaceae	Tree
10	*Combretum collinum* Fresen.	Gushel	Combretaceae	Tree
11	*Combretum molle* R.Br. ex G.Don	Ageraa	Combretaceae	Tree
12	*Dalbergia melanoxylon* Guill. & Perr.	Shangur	Fabaceae	Tree
13	*Dalbergia boehmii* Taub.	Tsaba	Fabaceae	Tree
14	*Dichrostachys cinerea* (L.) Wight & Arn.	Tari	Fabaceae	Tree
15	*Diospyros mespiliformis* A.DC.	Murqe	Ebenaceae	Tree
16	*Entada africana* Guill. & Perr.	Dirtsegn	Fabaceae	Tree
17	*Ficus* spp.	Ensha	Moraceae	Tree
18	*Ficus sycomorus* L.	Neyisha	Moraceae	Tree
19	*Ficus thonningii* Blume	Tseera	Moraceae	Tree
20	*Gardenia ternifolia* Schumach. & Thonn.	Aqenda	Rubiaceae	Tree
21	*Grewia mollis* A.Juss.	Hornotse	Tiliaceae	Tree
22	*Lannea fruticosa* (Hochst. ex A.Rich.) Engl.	Quwa	Anacardiaceae	Tree
23	*Lannea welwitschii* (Hiern) Engl.	Quwa hurhondu	Anacardiaceae	Tree
24	*Lonchocarpus laxiflorus* Guill. & Perr.	Afud	Fabaceae	Tree
25	*Maytenus senegalensis* (Lam.) Exell	Agero	Celastraceae	Tree
26	*Oxytenanthera abyssinica* (A.Rich.) Munro	Gagu	Poaceae	Grass / Bamboo
27	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Megel	Fabaceae	Tree
28	*Pterocarpus lucens* Guill. & Perr.	Amroro	Fabaceae	Tree

29	*Saba comorensis* (Boj.) Pichon	Bishqor	Apocynaceae	Climber
30	*Sterculia africana* (Lour.) Fiori	Qombo	Sterculiaceae	Tree
31	*Stereospermum kunthianum* Cham.	Ahor qororo	Bignoniaceae	Tree
32	*Strychnos innocua* Del.	Abomboqo	Loganiaceae	Tree
33	*Syzygium* spp.	Lidi	Myrtaceae	Tree
34	*Tamarindus indica* L.	Mela	Fabaceae	Tree
35	*Tamarix nilotica* (Ehrenb.) Bunge	Atsenda	Tamaricaceae	Shrub
36	*Terminalia laxiflora* Engl. & Diels	Ashihur	Combretaceae	Tree
37	*Vitex doniana* Sweet	Atsoda	Verbenaceae	Tree
38	*Ximenia americana* L.	Bibi	Olacaceae	Shrub
39	*Ziziphus mauritiana* Lam.	Amhorson	Rhamnaceae	Tree
40	*Ziziphus mauritiana Lam.*	Amhorson	Rhamnacae	Tree
41	-	Shibiq		Shrub

Table 2: Woody species density (stems ha^{-1}) distribution across in SWR

SN	Species name	Density (stems ha^{-1})	Density class
1	*Acacia hecatophylla*	11.30	C
2	*Acacia seyal*	0.87	E
3	*Acacia* spp.	2.61	D
4	*Adansonia digitata*	6.09	D
5	*Albizia malacophylla*	2.61	D
6	*Anogeissus leiocarpa*	33.04	C
7	*Balanites aegyptiaca*	19.13	C
8	*Boswellia papyrifera*	5.22	D
9	*Breonadia salicina*	3.48	D
10	*Combretum collinum*	49.57	C
11	*Combretum molle*	31.30	C
12	*Dalbergia melanoxylon*	18.26	C
13	*Dalbergia boehmii*	1.15	D
14	*Dichrostachys cinerea*	36.52	C

15	*Diospyros mespiliformis*	5.22	D
16	*Entada africana*	5.22	D
17	*Ficus* spp.	0.87	E
18	*Ficus sycomorus*	0.87	E
19	*Ficus thonningii*	0.87	E
20	*Gardenia ternifolia*	14.78	C
21	*Grewia mollis*	9.57	D
22	*Lannea fruticosa*	40.87	C
23	*Lannea welwitschii*	7.83	D
24	*Lonchocarpus laxiflorus*	86.09	B
25	*Maytenus senegalensis*	11.30	C
26	*Oxytenanthera abyssinica*	50.43	B
27	*Piliostigma thonningii*	53.04	B
28	*Pterocarpus lucens*	5.22	D
29	*Saba comorensis*	6.09	D
30	*Sterculia africana*	0.87	E
31	*Stereospermum kunthianum*	9.57	D
32	*Strychnos innocua*	2.61	D
33	*Syzygium* spp.	2.61	D
34	*Tamarindus indica*	5.22	D
35	*Tamarix nilotica*	2.61	D
36	*Terminalia laxiflora*	14.78	C
37	*Vitex doniana*	15.65	C
38	*Ximenia americana*	0.87	E
39	*Ziziphus mauritiana*	3.48	C
40	*Ziziphus mauritiana Lam.*	3.48	D
41	*Shibiq(Berta)*	10.43	C

Note: Density classes are based on stems ha^{-1} *where; A = >100, B = 50.1–100, C = 10.1–50, D = 1.1–10, E = <1.*

Table 3. Importance value of woody species (in descending order) in SWR

SN	Species name / Local name	RD	RDo	RF	IVI
1	*Syzygium* spp.	0.00	0.77	0.80	1.58
2	*Saba comorensis* (Boj.) Pichon	0.00	0.06	1.61	1.67
3	*Strychnos innocua* Del.	0.00	0.46	1.21	1.67
4	*Ficus* Spp.	0.00	0.54	1.21	1.75
5	*Stereospermum kunthianum* Cham.	0.00	0.35	1.61	1.96
6	*Delbergia boehmii* Taub.	0.06	0.01	2.01	2.08
7	*Albizia malacophylla* (A.Rich.)	0.00	0.39	2.01	2.40
8	*Dalbergia melanoxylon* Guill.	0.00	0.39	2.01	2.40
9	*Entada africana* Guill. & Perr.	0.01	0.26	2.41	2.68
10	*Dichrostachys cinerea*	0.06	0.31	2.41	2.78
11	*Ximenia americana* L.	0.01	0.45	2.33	2.79
12	*Combretum collinum* Fresen.	0.08	0.72	2.01	2.81
13	*Lonchocarpus laxiflorus* Guil.	0.01	0.80	2.01	2.82
14	*Oxytenanthera abyssinica* (A.Rich.)	0.09	0.02	2.81	2.92
15	*Acacia hecatophylla* Steud. ex	0.01	0.62	2.81	3.46
16	*Terminalia laxiflora* Engl. & D.	0.01	1.48	2.01	3.49
17	*Anogeissus leiocarpa* (A.DC.) G.	0.06	2.31	1.21	3.57
18	*Gardenia ternifolia* Schum. & T.	0.07	0.29	3.21	3.58
19	*Shibiq* (Berta local name)	0.01	0.33	3.33	3.67
20	*Grewia mollis* A.Juss.	0.01	0.43	3.62	4.06
21	*Lannea welwitschii* (Hiern) Eng.	0.00	2.44	1.61	4.06
22	*Boswellia papyrifera* (Del.) H.	0.01	1.26	2.81	4.08
23	*Tamarindous indica* L.	0.02	2.55	1.61	4.18
24	*Piliostigma thunningii* (Schum.)	0.01	0.37	4.02	4.39
25	*Ficus sycomorus* L.	0.02	3.19	1.21	4.41
26	*Acacia seyal* Del.	0.00	1.02	3.62	4.64
27	*Ziziphus mauritiana* Lam.	0.02	1.09	3.55	4.66
28	*Combretum molle* R.Br. ex G.Do.	0.05	0.88	4.42	5.35

29	*Acacia* Spp.	0.00	1.46	4.02	5.48
30	*Maytenus senegalensis* (Lam.) E.	0.08	0.93	4.82	5.84
31	*Ptercarppus lucens* Guill. & Pe.	0.01	3.96	2.41	6.38
32	*Diospyros mespiliformis* A.DC.	0.01	4.83	1.61	6.45
33	*Lannea fruticosa* (Hochst. ex A.	0.14	0.41	6.03	6.58
34	*Dichrostachys cinerea* (L.) Wig.	0.01	0.46	6.43	6.90
35	*Sterculia africana* (Lour.) Fi.	0.02	4.23	3.21	7.46
36	*Balanites aegyptiaca* (L.) Del.	0.03	3.77	4.02	7.82
37	*Adanosonia digitata* L.	0.01	9.79	1.61	11.41
38	*Breonadia salicina* (Vahl) He.	0.01	9.66	2.50	12.16
39	*Ficus thonningii* Blume	0.02	11.43	3.21	14.66
40	*Vitex doniana* Sweet.	0.00	20.20	3.21	23.41

Table 4. List of species recorded to population structure grouping

Group 1	**Group 2**	**Group 3**
Adanosonia digitata L.	*Balanites aegyptiaca* (L.) Del.	*Acacia hecatophylla* Steud.ex
Albizia malacophylla (A.Rich.) Walp.	*Combretum collinum* Fresen.	*Acacia seyal* Del.
Boswellia papyrifera (Del.) Hochst.	*Combretum molle* R.Br.ex G.Do	*Gardenia ternifolia* Schum.&T
Breonadia salicina (Vahl) Heppehr &Wood	*Grewia mollis* A.Juss.	*Ziziphus mauritiana* Lam.
Dalbergia melanoxylon Guill.	*Vitex doniana* Sweet.	Shibiq (Berta)
Delbergia boehmii Taub.	*Terminalia laxiflora* Engl.&D	*Strychnos innocua* Del.
Ptercarppus lucens Guill.&Pe	*Syzygium* spp.	
Sterculia Africana (Lour.) Fi	*Tamarindous indica* L.	
Stereospermum kunthianum Cha		
Ficus Spp.		
Ficus sycomorus L.		
Ficus thonningii Blume		

Table 5. List of species under regeneration status

SN	Scientific/ Local name	Density
Group 1		
1	*Adanosonia digitata* L.	-
2	*Albizia malacophylla* (A.Rich) Walp.	-
3	*Boswellia papyrifera* (Del.) H	-
4	*Breonadia salicina* (Vahl) He	-
5	*Dalbergia melanoxylon* Guill.	-
6	*Delbergia boehmii* Taub.	-
7	*Ficus* Spp.	-
8	*Ficus sycomorus* L.	-
9	*Ficus thonningii* Blume	-
10	*Saba comorensis (Boj.) Pichon*	-
11	*Sterculia Africana (Lour.) Fi*	-
Group 2		
1	*Diospyros mespiliformis A.DC.*	9.57
2	Ashensheqe	40.87
3	*Combretum molle R.Br.ex G.Don*	20
4	*Entada africana Guill.&Perr.*	9.57
5	*Gardenia ternifolia Schum.&Thonn*	40.87
6	*Grewia mollis A.Juss.*	37.39
7	*Lannea welwitschii(Hiern)Engl.*	40.87
8	*Lonchocarpus laxiflorus Guill.&Perr*	12.17
9	Metselo	13.04
10	*Ptercarppus lucens Guill.&Perr*	13.91
11	*Qori*	14.78
12	Silfudy	25.22
13	*Stereospermum kunthianum Cham.*	26.09
14	*Strychnos innocua Del.*	34.78
15	*Syzygium spp.*	20

16	*Tamarindous indica L.*	39.13
17	*Terminalia laxiflora Engl.&Diels*	49.57
18	*Vitex doniana Sweet.*	20.87
19	*Ximenia americana L.*	37.39
Group 3		
1	*Dichrostachys cinerea*	86.96
2	*Anogeissus leiocarpa(A.DC.) Guill.&Perr.*	74.78
3	*Gardenia ternifolia Schum.&Thonn*	74.78
4	*Lannea fruticose (Hochst.ex A. Rich.) Engl.*	74.78
5	Hishu (Berta)	74.78
6	*Maytenus senegalensis (Lam.) Excll*	63.48
7	*Oxytenanthera abyssinica (A.Rich.)* Munro	347.82
8	*Piliostigma thunningii (Schum.)* Milne-Redh	72.17
9	*Tamarix nilotica (Ehrenb.) Bunge*	260.87
10	*Ziziphus mauritiana Lam.*	104.35
11	Shibiq (Berta)	226.1

Table 6. Carbon stocks and CO_2equivalent potential of woody species in SWR

AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})	CS (Mg C ha^{-1})	CO_2 e (Mg CO_2 e ha^{-1})
177.39 ± 27.52	44.35 ± 6.88	221.74 ± 34.40	104.22 ± 16.17	382.48 ± 59.33

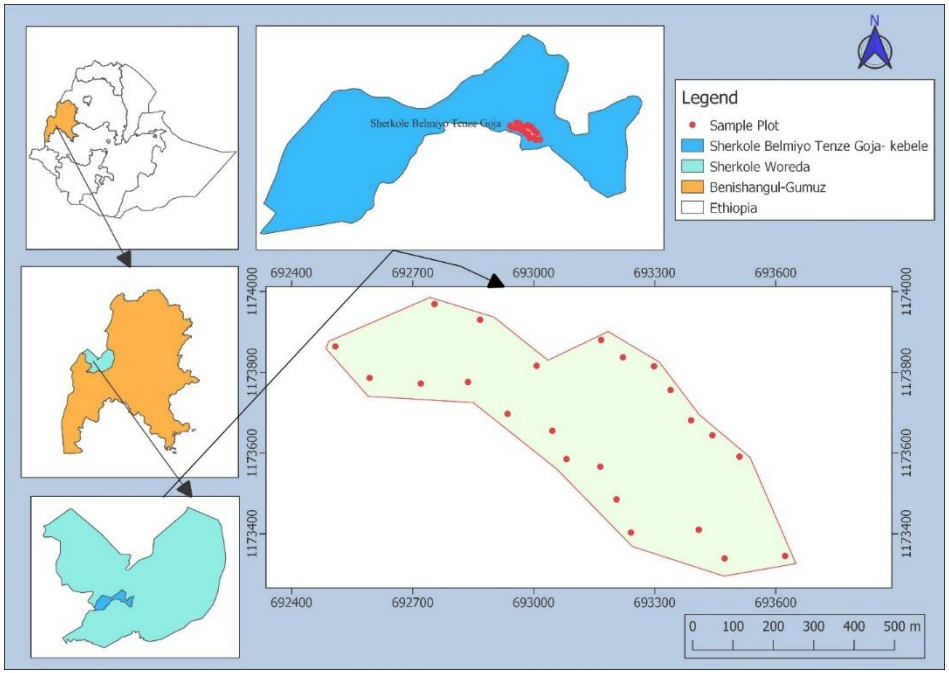

Fig 1. Map of the study area

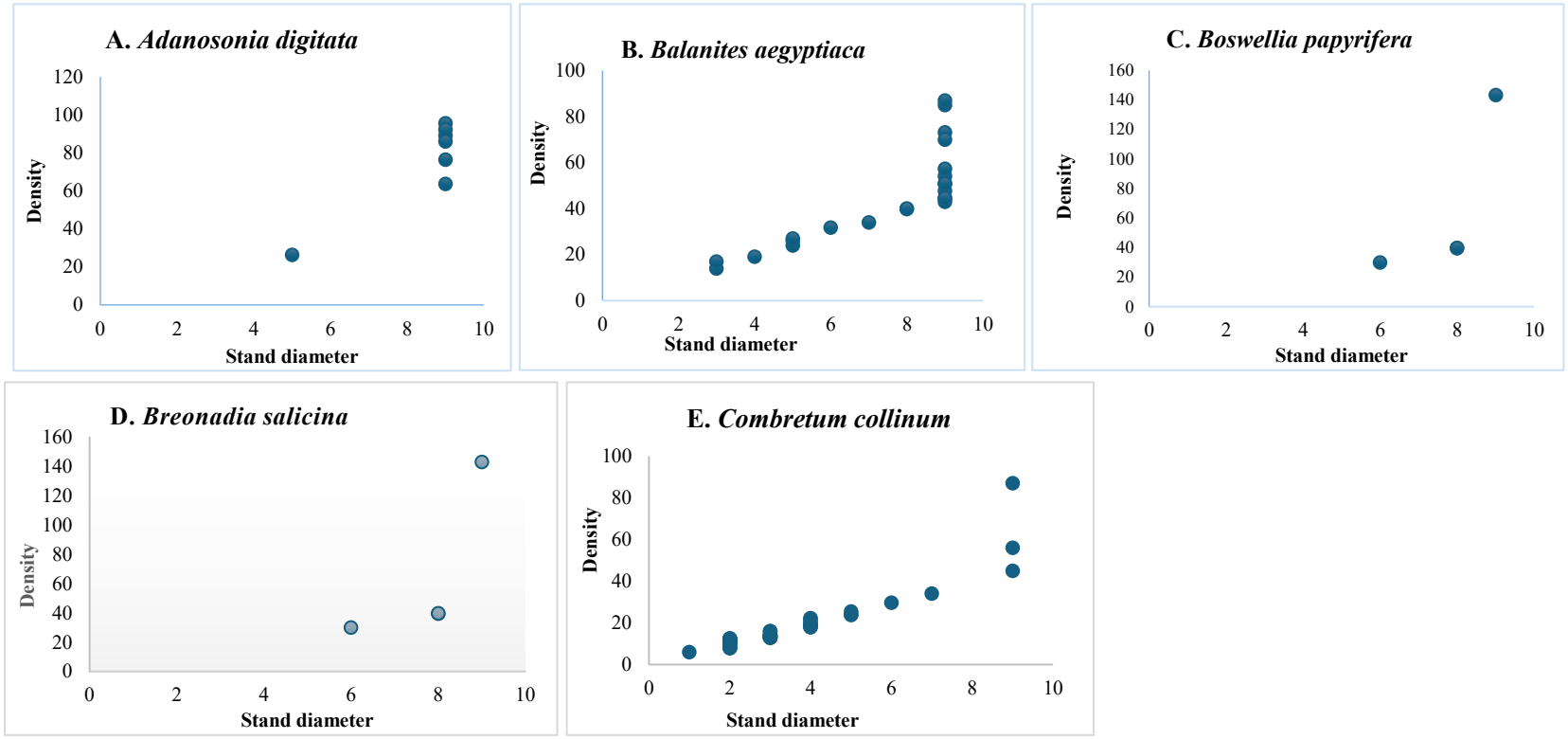

Fig 2. Population structure of dominant species of SWR; where, 1=2.6-7.5, 2=7.6-12.5, 3=12.6-17.5, 4=17.6-22.5, 5=22.6-27.5, 6=27.6-32-5, 7=32.6-37.5, 8=37.5-42.5, 9 ≥ 42.6 m.

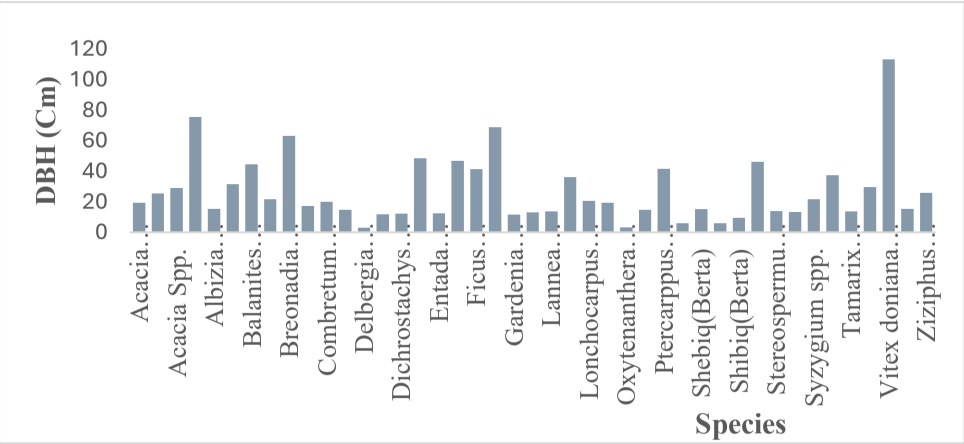

Fig 3. Population structure (DBH) of woody species


(a)
(b)

Fig 4. Field photographs showing sample woody plant species which need urgent conservation: (a) *Boswellia papyrifera*, (b) *Saba comorensis, and* (c) *Adanosonia digitata*. Photo credit: Dejene Reda