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Research article

Woody species composition, structure, and diversity of homegarden agroforestry systems in southern Tigray, Northern Ethiopia

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ABSTRACT

Nowadays, the conservation of biodiversity is a major environmental challenge globally. Homegarden agroforestry systems (HGAFs) have a large potential for biodiversity conservation. However, little attention has been given to the relative importance of HGAFs in terms of biodiversity conservation. The present study, therefore, aimed to estimate and compare the woody species diversity and structure of HGAFs and adjacent natural forest (NF) in Northern Ethiopia. Three sites were purposively selected based on the presence of HGAFs and NF adjacent to each other. A stratified sampling system was used to select representative homegardens from different wealth categories. In NF, a systematic transect sampling technique was employed. A total of 90 sample plots (10 m × 20 m) were used to collect vegetation data. A total of 32 species representing 26 genera and 20 families were identified from the studied HGAFs and NF. Thirty woody species belonging to 24 genera and 20 families were recorded in the HGAFs whereas, 11 species, belonging to 9 genera and 8 families were recorded in the NF. Native woody species accounted for 66% of all woody species recorded in both HGAFs and NF. Stem density, richness, and diversities of woody species were significantly higher in HGAFs than in NF ($p \leq 0.05$). Trees and shrubs in the HGAFs had significantly lower stem diameters, height, and basal area than the adjacent NF ($p \leq 0.05$). The results show that HGAFs complements the NF for biodiversity conservation and supports in counteracting the loss of woody species from the natural ecosystem. Hence, promoting HGAFs habitats in human-dominated landscapes should be part of the biodiversity conservation strategy.

1. Introduction

Homegarden agroforestry systems (HGAFs) is defined as land-use practices involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial crops and invariably, livestock, within the compounds of individual houses, the whole crop-tree-animal unit being managed by the family labor (Fernandes and Nair, 1986). The system has the potential to increase biodiversity in the agricultural landscape while reducing habitat loss and fragmentation (Bardhan et al., 2012). Recently, agroforestry systems have attracted attention from both industrialized and developing countries for providing ecosystem services such as biodiversity conservation, carbon sequestration, soil quality, and preserving air and water quality (Albrech and Kandji, 2003). It is the most widespread old-age practice in developing countries. Approximately 1.2 billion people depend directly on a variety of agroforestry products and services (Mendelsohn, 2001).

The diversity of plant species is the basis of terrestrial ecosystems (Senthilkumar et al., 2009). It is vital for human well-being and provides natural habitats for plants and animals (Muthukuda, 2009; Beaumont et al., 2011). Tropical forests are the main terrestrial ecosystems with the greatest diversity of species, and the majority of the 34 global biodiversity hotspots identified worldwide occur within tropical forests (Mittermeier et al., 1999). Particularly, more than 90% of biodiversity resources are found in human-dominated landscapes in the tropics (Garrity, 2004). However, as a result of anthropogenic activities, tropical forests are faced with deforestation and forest degradation which resulted in the ultimate loss of biodiversity (Talbot, 2010).

Deforestation and its associated impact on biodiversity in the tropics in general and northern Ethiopia, in particular, are mainly associated with human pressure. Some of the drivers of deforestation and associated biodiversity loss include agricultural expansion, charcoal making, fuelwood collection, illegal logging, fire and the need for construction of wood (Esser et al., 2002; Badege, 2003; Nyssen et al., 2009; Temesgen et al., 2014). The influence on biodiversity is revealed as shifts in phenology, interactions, species distributions, morphology, and net primary productivity (Beaumont et al., 2011). The impact has been severe

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particularly in the natural forests of Tigray, Northern Ethiopia (Esser et al., 2002). Studies show that human-dominated landscapes such as HGAFs play an important role in biodiversity conservation while sustaining livelihood (Pamela and John, 2003; Eskil et al., 2011; Endale et al., 2016; Gachuiri et al., 2017).

HGAFs contribute to biodiversity conservation by providing supplementary habitat for species tolerating a certain level of disturbance (Jose, 2009), and conserve remnant native species and their gene pools (Das and Das, 2005; Harvey and Villalobos, 2007). In certain cases, erosion control and water recharge roles of HGAFs prevent the degradation and loss of surrounding habitat. And also, buffering the pressure on deforestation of the surrounding natural habitat. Furthermore, it creates a 'matrix of connectivity' between natural and/or modified forest remnants (Nyhus and Tilson, 2004; Bhagwat et al., 2008). Tropical homegardens contain a high diversity of trees, shrubs, vegetables and crop species, and animals (Tesfaye, 2005). Because of their species richness through the domesticated and wild plant and animal species, homegardens are regarded as an ideal production system for *in-situ* and *circa situm* conservation of a wide range of plant genetic resources (Masum et al., 2008).

With the fact that woody species are disappearing at an alarming rate and thus, the role of HGAFs as a conservation tool needs to be further explored. The studies undertaken in HGAFs in Ethiopia focused on system design, soil fertility management, and system interactions and less emphasis has been placed on its role in biodiversity conservation (Asfaw and Agren, 2007; Teklay et al., 2007; Negash et al., 2012). Therefore, this study aims to assess the contribution of HGAFs in relation to the adjacent natural forest in conserving woody species composition, diversity, and structure in southern Tigray, northern Ethiopia.

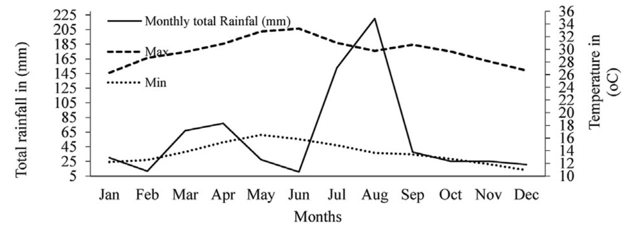

Figure 2. Climate diagram of Raya Alamata, southern Tigray, Northern Ethiopia. The monthly average for the years 1997–2017 was obtained from the Ethiopian metrological agency.

2. Materials and methods

2.1. Description of the study site

The study sites are situated at Raya Alamata, southern Tigray, Northern Ethiopia. It is located 600 km north of Addis Ababa and about 180 km south of the Tigray Regional capital, Mekelle (Figure 1).

The annual mean rainfall ranges from 299 to 1067 mm, with a mean monthly maximum and minimum temperatures of 26.97 °C and 14.8 °C, respectively (Figure 2).

Topography features of the study area range from 1450 to 1750 m.a.s.l. Farmers deliberately plant and retain native trees and shrubs in their agricultural landscapes for various purposes such as food, fiber, and energy. The natural forest is managed using local bylaws and serves as a source of fodder and sociocultural services to the surrounding community. The homegardens are dominated by *Ziziphus spina-christi, Eucalyptus camaldulensis,* and *Balanites aegyptiaca* while in natural forests *Acacia*

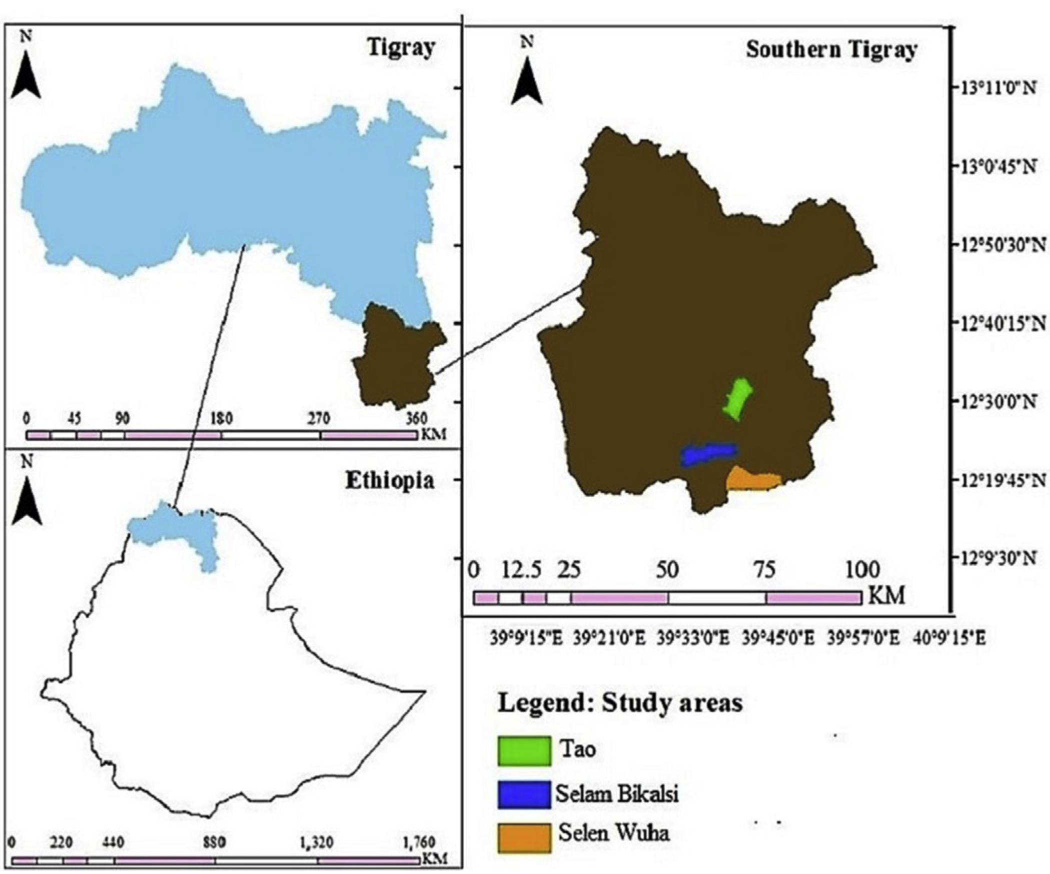

Figure 1. Map of the study area.

tortilis, Acacia seyal, and *Balanites aegyptiaca* are the most dominants species (Eyasu and Tassew, 2019).

2.2. Site selection and layout

Three specific sites having similar biophysical condiction were purposefully selected based on the existence of HGAFs, and adjacent natural forest (NF). This was to avoid differences in species composition that may be created due to differences in altitude.

In homegardens, wealth categorizations of individual households (HHs) were made to accommodate the influence of the wealth status on woody species diversity. Proportionally 45 sample plots (18 from the poor, 15 medium, and 12 rich wealth status) were randomly selected. The criteria for differentiating HHs into different wealth categories were set by key informants.

In NF, a systematic transect sampling technique was used. In each of the sites, five parallel line transects were laid along the slope. Transect lines laid on the forest floor were used to make the sample plots distributed uniformly throughout the forest stand. The distance between transect lines was 450 m and 200 m between sample plots laid down along the transect. GPS waypoints were used to allow transects to be parallel with one another. Similar to homegarden, 45 sample plots were systematically assigned along the transect lines of NF to data collection.

2.3. Data collection

To assess woody species diversity and dominance of HGAFs in relation to NF, biometric parameters such as diameter at breast height (DBH) and height were measured on all the trees within each plot. Inventory of woody species in both land-uses was taken from sample plot size 10 m × 20 m. Tree/shrub in the study area was defined as woody plants with DBH ≥2.5 cm and height ≥1.5m. Specifically, trees were defined as a woody perennial plant with a single main stem or in case of coppice several stems and has a more or less definite crown. While shrubs were woody perennial plants, often without a definite crown, several stems growing from the same root.

The saplings and seedlings were counted within 4 m^2 (2 m × 2 m) sub-plots in the main plot, from the corners, and in the middle (Linger, 2014; Mekonnen et al., 2014). For identification of species in the field, vernacular names using key informants and literature were used (Woldemichael et al., 2010). The scientific nomenclature was carried out following Bekele-tesemma et al. (2007) and Ermias (2011).

Measurement of tree/shrub diversity was based on an inventory of all woody species above 20 cm height in the sample plot (Negash, 2013). Species richness (S), Shannon-Weiner diversity index (H), equitability/evenness (J) and species dominance using Simpson dominance index (Cd) (Krebs, 1985; Magurran, 1988) were estimated following formula:

Species richness (S) was calculated by

$$S = \sum ni \quad \text{Eq. (1)}$$

where ni is the number of species in a community.

$$H' = -\sum_{i=1}^{s} \text{Pi}\ \ln(\text{Pi}) \quad \text{Eq. (2)}$$

Where: H' = Shannon diversity indices; Pi = proportion of individuals found in the i^{th} species.

$$\text{Equitability (evenness)} J = \frac{H'}{H' max} = \frac{-\sum_{i=1}^{s} \text{Piln}\, pi}{\ln s} \quad \text{Eq. (3)}$$

Where S = the number of species; H' = , Shannon diversity indices and Pi = proportion of individuals found in the i^{th} species.

$$D = 1 - \sum_{i=1}^{S} pi^2 \quad \text{Eq. (4)}$$

Where D = Simpson's index of species diversity; S = number of species; Pi = proportion of total sample belonging to the ith species.

The Sørensen coefficient of similarity (Ss) (Kent and Coker, 1992) was used to calculate the species similarities of HGAFs and adjacent NF. Sørensen coefficient of similarity (Ss) was defined by;

$$S_s = \frac{2a}{(2a+b+c\ \ )} \quad \text{Eq. (5)}$$

Where, Ss = Sørensen similarity coefficient; a = number of species common to both samples; b = number of species in HGAFs; c = number of species in NF.

The importance value index (IVI) for each woody species in the two land-uses were calculated as follows:

$$\text{Important Value index (IVI)} = \text{Relative dominance} + \text{Relative density} + \text{Relative frequency} \quad \text{Eq. (6)}$$

Stand characteristics such as stem density, basal area, mean diameter, diameter class distribution and height class distributions were computed for each plot and averaged per stand unit for all tree/shrubs individuals with a DBH ≥2.5 cm and a height of ≥1.5 cm. In case trees/shrubs forking around/just below 1.5 m were measured at breast height and the overall DBH of the forks determined as the square root of the sum of squares of individual stems (Snowdon et al., 2002). The woody species were clustered into thirteen diameter classes of 5 cm interval: Class 1 = [<7.5], Class 2 = [7.50–12.49], Class 3 = [12.50–17.49], Class 4 = [17.50–22.49], Class 5 = [22.50–27.49], Class 6 = [27.50–32.49], Class 7 = [32.50–37.49], Class 8 = [37.50–42.49], Class 9 = [42.50–47.49], Class 10 = [47.50–52.49], Class 11 = [52.50–57.49], Class 12 = [57.50–62.49], Class 13 = DBH ≥62.50 cm and into eleven height classes at 3.5 m intervals: Class 1 = [1.5–5], Class 2 = [5.00–8.49], Class 3 = [8.50–11.99], Class 4 = [12.00–15.49], Class 5 = [15.50–18.99], Class 6 = [19.00–22.49], Class 7 = height [22.50–25.99], Class 8 = height [26.00–29.49], Class 9 = height [29.50–32.99], Class 10 = height [33–36.49], Class 11 = height [36.50–39.99].

The regeneration status of the entire community of the woody species was analyzed by the ratios of seedling to sapling to mature individuals.

2.4. Statistical analysis

The normal distribution of the data set was tested using the Shapiro-Wilk test and it was considered significant at $p \geq 0.05$. F test and Leven's test was used to calculate the homogeneity of variance of the data. In cases where data were not normally distributed, the data were transformed into log values. Whereas the data that were not normally distributed even after transformation and hence, the Kruskal-Wallis test was used for all comparisons because this test is usually little affected by heterogeneous data (Baltosser and Zar, 1996). The HGAFs and adjacent NF were the independent variables while the vegetation data were considered dependent variables. The difference between means was estimated by using a t-test (Kruskal--Wallis in cases of non-normality) at $p \leq 0.05$. The statistical analysis was done by using the R software program (version 3.3.4.) (R core team 2018).

3. Results

3.1. Woody species composition

A total of 32 woody species representing 26 genera and 20 families were identified in the study area (Table 1). Of these 30 species, 24 genera, and 20 families were encountered in HGAFs whereas 11 species, belonging to 9 genera and 8 families were recorded in the adjacent NF.

Table 1. Woody species frequency, relative abundance, life-forms, nature of the establishment, and uses of trees and shrubs in HGAFs and adjacent NF of Raya Alamata, southern Tigray, Ethiopia (n = 45 for HGAFs and n = 45 for NF).

S/N	Woody species	Local name	Family	Life form	Plot (%)	RA (%)	Plot (%)	RA (%)	W/P	I/E	Uses
					HGAFs	HGAFs	NF	NF			
1	*Acacia seyal* Del.	Wancho	Fabaceae	T	94.44	7.68	100.00	25.77	W	I	1,7,9,12,13,14,16,18
2	*Acacia tortilis* (Forssk.) Hayne	Karwora	Fabaceae	T	66.67	2.83	100.00	19.09	W	I	1,7,9,13,14,16,18
3	*Azadirachta indica* A. Juss.	Nim	Meliaceae	T	27.78	1.09			p	E	1,7,9,12,13,16,17,18,19
4	*Balanites aegyptiaca* (L.) Del.	Bedano	Balanitaceae	T	88.89	13.84	100.00	20.43	w	I	7,8,9,10,12,13,16
5	*Capparis tomentosa* Lam.	Harengama	Capparidaceae	S/C	38.89	1.38	73.33	3.74	w	I	9,11,12
6	*Carissa edulis* (Forssk.) Vahl	Agam	Apocynaceae	S	27.78	1.01	33.33	1.47	w	I	8,9,11,12,17
7	*Catha edulis* (Vahl) Forssk. Ex Endl.	Chat	Celastraceae	S	16.67	1.81			p	I	9,12,15
8	*Citrus aurantifolia* (Christm.) Swingle	Lomin	Rutaceae	S	77.78	2.10			p	E	8,12
9	*Citrus medica* L.	Tirungo	Rutaceae	S	27.78	0.51			p	E	8,12
10	*Citrus reticulate* B.	Menderin	Rutaceae	S	11.11	0.22			p	E	8
11	*Citrus sinensis* (L.) Osb.	Aranshi	Rutaceae	S	33.33	1.88			p	E	8
12	*Coffea arabica* L.	Buna	Rubiaceae	S	55.56	4.93			p	I	4,6
13	*Cordia africana* Lam.	Wanza	Boraginaceae	T	50.00	5.14			w	I	1,7,8,9,12,13,16,17,18
14	*Croton macrostachyus* Del.	Mekanisa	Euphorbiaceae	T	5.56	0.22	13.33	1.20	w	I	1,7,9,10,12,16,18
15	*Dichrostachys cinerea* (L.) Wight & Arn.	Harshmarsha	Fabaceae	T/S	0.00	0.00	6.67	0.13	w	I	1,7,9,10,11,12,14,16,18
16	*Dodonaoea angustifolia* L.f.	Tahses	Sapindaceae	S	5.56	0.14			w	I	5,7,10
17	*Ehretia cymosa* Thonn.	Ulaga	Boraginaceae	T/S	38.89	2.25			w	I	1,7,9,10,12,16
18	*Eucalyptus camaldulensis* Dehnh.	Keyh Bahrzaf	Myrtaceae	T	83.33	19.28			p	E	1,9,16,17
19	*Faidherbia albida* (Delile) A.Chev.	Garbe	Fabaceae	T	16.67	0.22	20.00	0.67	W	I	1,7,9,13,14,18
20	*Ficus sycomorus* L.	Oda	Moraceae	T	5.56	0.14			w	I	2,8,9,12,13,14,17,18
21	*Grevillea robusta* R. Br.	*Grevillea*	Proteaceae	T	5.56	0.07			p	E	2,8,9,12,13,14,17,18
22	*Grewia ferruginea* Hochst.exA.Rich.	Meleglaga	Tiliaceae	S	11.11	0.14	6.67	0.13	w	I	7,8,9,10,16
23	*Luceana leucocerphala* Lam.	Lucinia	Fabaceae	T/S	38.89	1.88			p	E	1,7
24	*Mangifera indica* L.	Mango	Anacardiaceae	T	50.00	5.07			p	E	1,7,8,9,13,17,18
25	*Moringa stenopetala* (Bak. f.) Cuf.	Shiferaw	*Moringaceae*	T	16.67	1.52			p	I	1,7,8,11,12,13,18
26	*Olea europaea subspcuspidate* (Wall. ex DC.) Cifferri	Awlie	Oleaceae	T	38.89	2.75			w	I	1,9,12,16
27	*Pavetta oliveriana* Hiern	Shimeja	Rubiaceae	S			46.67	20.43	w	I	8,9,10
28	*Persea americana* Mill.	Avocado	Lauraceae	T	27.78	0.58			p	E	8,13
29	*Psidium guajava* L.	Zeytun	Myrtaceae	T	55.56	2.61			p	E	8,9,10
30	*Rhamnus prinoides* L'Herit.	Gesho	Rhamnaceae	S	27.78	1.38			p	I	9,12
31	*Ziziphus mucronata* Willd.	Kunkura-hado	Rhamnaceae	T/S	11.11	0.43	73.33	6.94	w	I	8,9,10,11,12,13,
32	*Ziziphus spina-christi* (L.) Desf.	Kunkura	Rhamnaceae	T/S	100.00	16.88			w	I	7,8,9,10,11,13,16

Where, **Local names**: Tigrigna name; **Land-uses**: HGAFs-Homegarden agroforestry system and NF-Natural forest; **RA**- Relative abundance; **LF**- Life form: T -Tree, S-Shrub; T/S- Tree or shrub; S/C- Shrub or Climber **Establishment methods**: W-Wild, P- planted; **State of the species**; I-indigenous, E-exotic species; Uses source from Bekele-tesemma, (2007); Bekele-Tesemma et al. (1993) 1: bee forage, 2:beehives construction, 3:beehives hanging, 4: cash, 5:farm tools, 6:flavouring drink, 7:fodder, 8:fruit/food, 9:Fuelwood, 10:household's utensils, 11:live fences, 12: medicine, 13:Shade, 14:Soil fertility, 15:stimulus, 16:Timber/poles, 17:Ornamental, 18:Soil conservation, 19:Insecticide.

Among the woody species, trees constituted 47% (15 species), shrubs 34% (11 species) and tree/shrubs 16% (5 species), and shrub/climber (one) 3% of species measured.

Indigenous tree and shrub species accounted for 66% (21 out of 32 species, 1020 individuals, n = 90) of woody species recorded, and the remainder were non-native (420 individuals, n = 90). The highest number of woody indigenous species was recorded in NF (100%, 11 of 11 species), and HGAFs (66%, 21 of 30).

3.2. Woody species diversity

The diversity indices showed high values in the HGAFs compared to adjacent NF. Shannon and Simpson's indices were estimated to 2.71 and 0.90 respectively for HGAFs, while the values for NF were 1.76 and 0.81, respectively.

Analysis of variance showed that there were strongly significant differences ($p < 0.001$) between HGAFs and adjacent NF in terms of the mean value sample plots (10 m × 20 m) of richness, abundance, and

Table 2. Mean (±SD) richness, abundance, woody species diversity index of Shannon, Simpson and Shannon Evenness of homegardens (HGAFs) and adjacent native forests (NF) in Raya Alamata, southern Ethiopia.

Land-uses	n	Richness	Abundance	Shannon diversity (H′)	Simpson's diversity (D)	Evenness (H'/H_{max})
HGAFs	45	6 (±2.60)[b]	25 (±11.43)[b]	1.31 (±0.46)[b]	0.64 (±0.17)[b]	0.79 (±0.16)
NF	45	3 (±1.35)[a]	17 (±10.30)[a]	0.79 (±0.36)[a]	0.46 (±0.19)[a]	0.76 (±0.18)
P value		<0.001	<0.001	<0.001	<0.001	0.41

The different letters indicate significant differences between the two land-uses at $p < 0.05$.

diversity indices of woody species (Table 2). However, no significant difference ($p > 0.05$) was observed for Equitability (evenness) of woody species between the two land-use systems. This indicates that the distribution of woody species in the two land-uses was almost similar.

Sørensen's similarity of woody species showed in HGAFs and the adjacent NF is 38% and this indicates a higher dissimilarity of woody species between the two land-uses.

3.3. Stand characteristics

The stand characteristics were significantly different ($p < 0.05$) between HGAFs and adjacent NF in terms of diameter, height, basal area, and tree density (Table 3).

3.4. DBH and height distribution

Community structure was constructed based on the densities of DBH and height classes of woody species in both HGAFs and NF (Figure 3 and Figure 4). The results show that the number of individuals decreases as the DBH and height of the individual increases.

3.5. Regeneration status

The total seedlings, saplings, and mature individuals of all woody species were 2711, 2211, and 1063 in HGAFs while in NF 1989, 1200 and 707 ha^{-1} were recorded. The ratio of seedling and sapling individuals to mature individuals in HGAFs and NF was 2.6: 2 and 2.8: 1.7 respectively. The three highest numbers of saplings and seedlings in HGAFs were *Z. spina-christi*, *B. aegyptiaca,* and *A. seyal* respectively while in NF *P. oliveriana*, *B. aegyptiaca* and *A. seya* were the top three respectively.

3.6. Importance value index (IVI)

The IVI showed that *Z. spina-christi* (60%), *E. camaldulensis* (56%) and *B. aegyptiaca* (50%) were the top three important species in HGAFs (Table 4).

While in a natural forest, the most important three woody species were *A. tortilis* (119%), *A. seyal* (78%) and *B. aegyptiaca* (71%) respectively (Table 5). These were also recorded as abundant, frequent, and dominant species in NF.

4. Discussion

4.1. Woody species composition

The high number of woody species in HGAFs over NF was associated with farmers' exotic tree planting and retention of indigenous trees in the homegarden. This may show agroforestry could serve as a complementary habitat for harboring the native woody species and hence, helps to conserve and counteract the loss of the species from a natural forest. Other studies conducted in different parts of Ethiopia also reported similar results of a higher number of woody species in HGAFs than adjacent NF, for example, Tolera et al. (2008) in Arsi Negele south-central highlands of Ethiopia; Guyassa and Raj (2013) in Abreha –we-Atsebeha watershed, Tigray region, Ethiopia; Tefera et al. (2014) in Debark District, Northern Ethiopia. On the other hand, the result contradicts the findings of Yakob et al. (2014) in Gimbo woreda, southwest Ethiopia.

In both HGAFs and adjacent NF, Fabaceae contributed the greatest number of species, which were represented by four species. In HGAFs, the Fabaceae and Rutaceae had 4 species each, Rhamnaceae 3, Boraginaceae and Myrtaceae had 2 species each, and ranked first, second, and third respectively. The Anacardiaceae, Apocynaceae, Balanitaceae, Capparidaceae, Celastraceae, Euphorbiaceae, Lauraceae, Meliaceae, Moraceae, Moringaceae, Oleaceae, Proteaceae, Rubiaceae, Sapindaceae, and Tiliaceae had only one species. A similar report by Agize et al. (2013) and Talemos et al. (2013) indicated that they use more of Fabaceae in Southern Ethiopia. The results on the woody species composition of homegardens indicated that the present study area was floristically richness and harbored woody species from diverse genera and families. This fits well with the notion that homegardens are valuable sources of agrobiodiversity mostly in woody species (Habtamu and Zemede, 2011). Whereas in adjacent NF, Fabaceae had 4 and Apocynaceae, Balanitaceae, Capparidaceae, Euphorbiaceae, Rhamnaceae, Rubiaceae, and Tiliaceae represented by only one species each.

Variations were also observed in terms of the relative frequency of indigenous trees in plots (Table 1). *Z. spina-christi* (100%), *A. seyal* (94%), *B. aegyptiaca* (89%), and *A. tortilis* (67%) were the four most frequently found indigenous tree species in HGAFs (n = 45). *Z. spina-christi*, an indigenous species grows up to 16 m tall, giving the HGAFs in the study sites a forest-like appearance. The species is highly preferred by farmers in the study sites for food (fruit), firewood, charcoal, timber, furniture, utensils, fodder (fruit, leaves), shade, live fence, and fencing material (dry branches), owing to its relatively light crown and small leaves.

A. seyal is a native species that was retained on HGAFs for its firewood, charcoal, poles, medicine, fodder (leaves), bee forage, shade, and nitrogen fixation purpose. *B. aegyptiaca* is also a native plant, used for food (fruit), medicine, firewood, charcoal, timber (furniture), fodder (leaves, young shoots, fruit), and shade. While in adjacent NF, *A. seyal* (100%), *A. tortilis* (100%), *B. aegyptiaca* (100%), and *Z. spina-christi* (73%) were the four most frequently found indigenous tree species (n = 45). Woody species identified in the HGAFs and adjacent NF were used for various functional and ecological purposes (Table 1).

4.2. Woody species diversity

The diversity indices demonstrated high value in the HGAFs compared to adjacent NF. This is likely attributed to the planting of exotic tree species and maintenance of the indigenous ones, and their occurrences evenly in HGAFs over adjacent NF. While the low Shannon diversity index in NF shows that only a few woody species were dominant in the land-use, where a value of 2 is regarded as a threshold for medium diversity (Barbour et al., 1999). The reason is owing to the larger dominance of *A. seyal, B. aegyptiaca* and *P. oliveriana,* which accumulated 66% of the woody species abundance in the adjacent NF. It can be inferred that agroforestry helps to conserve woody species diversity through increasing habitat for forest-dependent native species (Mcneely and Schroth, 2006). The result is similar to the study on homegardens of Abreha-we-Atsebeha watershed, Tigray region, Ethiopia (Guyassa and Raj, 2013). The Shannon index found in homegardens of this study was

Table 3. Stand characteristics (Mean ± SD) of HGAFs and adjacent NF in Raya Alamata, southern Tigray, Ethiopia.

Land-uses	n	DBH (cm)	Height (m)	BA (m^2ha^{-1})	Tree density (stems ha^{-1})
HGAFs	45	12.93 (±5.59)^a	8.38 (±3.43)^a	16.32 (±10.67)^a	1063 (±457.66)^b
NF	45	22.33 (±8.86)^b	10.13 (±2.96)^b	20.55 (±10.47)^b	707 (±433.62)^a
p- value		<0.001	0.005	0.03	<0.001

Different letters in the column indicate significant differences between land-uses at $p < 0.05$.

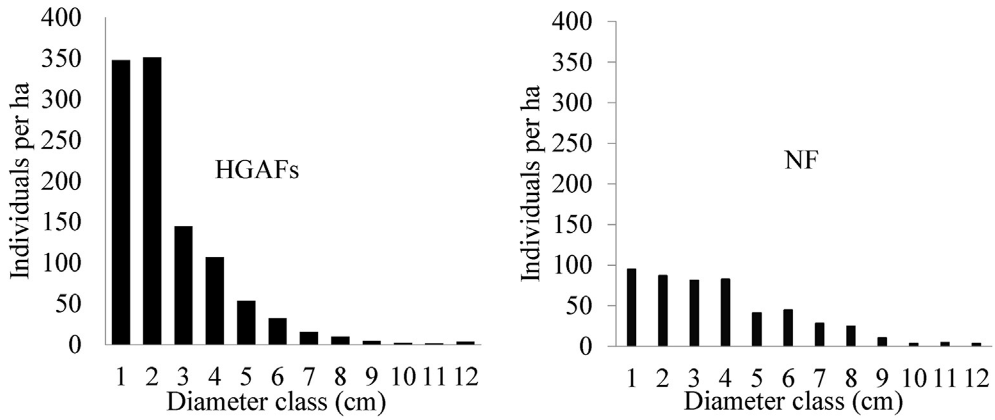

Figure 3. Diameter class (cm) distribution of woody species per hectare encountered in the HGAFs and adjacent NF: 1 = [<7.5], Class 2 = [7.50–12.49], Class 3 = [12.50–17.49], Class 4 = [17.50–22.49], Class 5 = [22.50–27.49], Class 6 = [27.50–32.49], Class 7 = [32.50–37.49], Class 8 = [37.50–42.49], Class 9 = [42.50–47.49], Class 10 = [47.50–52.49], Class 11 = [52.50–57.49], Class 12 = [57.50–62.49], Class 13 = DBH ≥62.50 cm.

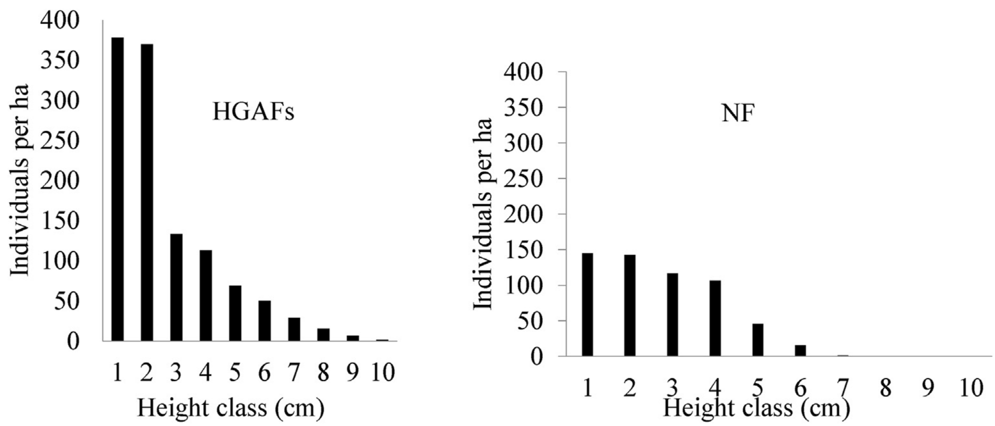

Figure 4. Height class (cm) distribution of woody species per hectare encountered in the HGAFs and adjacent NF: Class 1 = [<5], Class 2 = [5.00–8.49], Class 3 = [8.50–11.99], Class 4 = [12.00–15.49], Class 5 = [15.50–18.99], Class 6 = [19.00–22.49], Class 7 = height [22.50–25.99], Class 8 = height [26.00–29.49], Class 9 = height [29.50–32.99], Class 10 = height [33–36.49], Class 11 = height [36.50–39.99].

lower than those studies elsewhere in Ethiopia (H' = 3.016–3.28) (Mekonnen et al., 2014). However, it was relatively higher than what was found in homegardens of Sidama, southern Ethiopia (H' = 1.21 to 1.5) (Tesfaye, 2005) and in the central highland of Ethiopia (H' = 1.98) (Tolera et al., 2008). The variation may be attributed to differences in farmers' management intensity, and on environmental conditions. Farmers' shade management intensity includes species selection, setting spacing, pollarding, lopping, and thinning. Shannon evenness found in this study showed the higher homogeneity of woody species among farms of the HGAFs compared to adjacent NF.

Nine of the eleven wood species recorded from the NF were also recorded in the HGAFs in the study area. Woody species retained in homegardens are remnants of the NF which once had covered the area. However, Sørensen's result indicates a higher dissimilarity of woody species between the two land-uses. This is due to farmers introduce exotic trees for various purposes and hence, retaining indigenous woody species available in a NF of the study area. These include *C. africana*, *D. angustifolia*, *E.cymosa*, *F. sycomorus*, *O. europaea*, *R. prinoides,* and *Z. mucronata*.

4.3. Stand characteristics and regeneration status

At the stand level, trees and shrubs had the smallest stem diameters, height and basal area in HGAFs in relation to adjacent NF. The lower woody species structure in the HGAFs may due to dense spacing, short rotation of harvest, and pollarding practices. However, the stem density of woody species in HGAFs amounted to 1063 stems ha^{-1} and in NF 707 stems ha^{-1}. The HGAFs tree density of the study area was within the range of what was reported in the agroforestry system in southern Ethiopia (86–1082 trees ha^{-1}) (Tesfaye, 2005).

The diameter distribution shows that 82% in HGAFs and 58% in adjacent NF are below 19 cm DBH. Similarly, 70% and 57% of the height distribution were <8.5m in HGAFs and adjacent NF respectively. The result also confirms that the number of individuals decreases as the DBH and height class of the individual increase. This result is similar to the findings of other studies that compared HGAFs in relation to adjacent NF (Gebrehiwot and Hundera, 2014). The overall stand characteristics of HGAFs and adjacent NF can help understand the status of regeneration. DBH and height class distribution of all individuals in different size classes shows an inverted J shape distribution (Figure 3 and Figure 4), implying that the majority of the species had the highest number of individuals at relatively low DBH and height classes with a gradual decrease towards high DBH and height classes. This indicates a healthier recruitment process and the population dynamics of the woody species under the study area (Tesfaye et al., 2002).

The overall regeneration status of both land-uses showed the presence of the highest seedlings, followed by saplings and mature individuals, implying that most of the woody species in the study land-uses have

Table 4. Woody species Relative Density (RD %), Relative Frequency (RF %), Relative Dominance (RDo%) and Importance Value Index (IVI) in HGAFs land use.

S/N	Local Name	Scientific Name	RD (%)	RF (%)	RD0 (%)	IVI (%)
1	Kunkura	*Ziziphus spina-christi* (L.) Desf.	23.44	14.81	22.19	60.44
2	Keyh Bahrzaf	*Eucalyptus camaldulensis* Dehnh.	26.76	9.63	19.44	55.83
3	Bedano	*Balanites aegyptiaca* (L.) Del.	19.34	11.88	18.79	50.01
4	Wancho	*Acacia seyal* Del.	10.66	9.63	5.45	25.75
5	Wanza	*Cordia africana* Lam.	7.14	4.81	9.27	21.23
6	Karwora	*Acacia tortilis* (Forssk.) Hayne	3.92	6.67	9.17	19.76
7	Mango	*Mangifera indica* L.	7.04	2.96	2.93	12.94
8	Buna	*Coffea arabica* L.	6.84	4.07	0.4	11.32
9	Awlie	*Olea europaea subspcuspidate* (Wall. ex DC.) Cifferri	3.82	3.7	2.44	9.96
10	Lomin	*Citrus aurantifolia* (Christm.) Swingle	2.92	5.56	0.02	8.49
11	Zeytun	*Psidium guajava* L.	3.62	3.33	1.09	8.04
12	Ulaga	*Ehretia cymosa* Thonn.	3.12	2.96	1.76	7.84
13	Nim	*Azadirachta indica* A. Juss.	1.51	1.85	2.11	5.47
14	Aranshi	*Citrus sinensis* (L.) Osb.	2.62	2.22	0.15	4.99
15	Lucinia	*Luceana leucocerphala* Lam.	2.62	1.85	0.26	4.73
16	Shiferaw	*moringa stenopetala* L.	2.11	1.11	0.63	3.86
17	Chat	*Catha edulis* (Vahl) Forssk. Ex Endl.	2.52	1.11	0.2	3.83
18	Avocado	*Persea americana* Mill.	0.8	2.22	0.24	3.27
19	Tirungo	*Citrus medica* L.	0.7	2.22	0.25	3.18
20	Gesho	*Rhamnus prinoides* L'Herit.	1.91	1.11	0.1	3.12
21	Mekanisa	*Croton macrostachyus* Del.	0.3	0.37	2.14	2.81
22	Harengama	*Capparis tomentosa* Lam.	1.91	0.74	0.1	2.75
23	Agam	*Carissa edulis* (Forssk.) Vahl	1.41	1.11	0.03	2.55
24	Garbe	*Faidherbia albida* (Delile) A.Chev.	0.3	0.74	1.39	2.44
25	Kunkura-hado	*Ziziphus mucronata* Willd.	0.6	0.74	0.26	1.6
26	Menderin	*Citrus reticulate* B.	0.3	0.74	0.3	1.34
27	Meleglaga	*Grewia ferruginea* Hochst.exA.Rich.	0.2	0.74	0.05	1
28	*Grevillea*	*Grevillea robusta* R. Br.	0.1	0.37	0.18	0.65
29	Oda	*Ficus sycomorus* L.	0.2	0.37	0.07	0.64
30	Tahses	*Dodonaoea angustifolia* L.f.	0.2	0.37	0.03	0.6

Table 5. Woody species Relative Density (RD%), Relative Frequency (RF%), Relative Dominance (RDo%) and Importance Value Index (IVI) in NF land use.

S/N	Local Name	Scientific Name	RD (%)	RF (%)	RD0 (%)	IVI (%)
1	Karwora	*Acacia tortilis* (Forssk.) Hayne	31	26.2	61.3	119
2	Wancho	*Acacia seyal* Del.	41.9	17.5	18.4	77.8
3	Bedano	*Balanites aegyptiaca* (L.) Del.	33.2	22.2	15.3	70.8
4	Kunkura	*Ziziphus spina-christi* (L.) Desf.	11.3	11.9	3.26	26.5
5	Harengama	*Capparis tomentosa* Lam.	6.07	9.52	0.08	15.7
6	Shimeja	*Pavetta oliveriana* Hiern	1	6.35	0.5	7.85
7	Garbe	*Faidherbia albida* (Delile) A.Chev.	1.08	3.17	1.58	5.84
8	Agam	*Carissa edulis* (Forssk.) Vahl	2.39	2.38	0.05	4.82
9	Mekanisa	*Croton macrostachyus* Del.	1.95	0.5	1	3.45
10	Harshmarsha	*Dichrostachys cinerea* (L.) Wight & Arn.	0	0.79	0.01	0.8
11	Meleglaga	*Grewia ferruginea* Hochst.exA.Rich.	0.22	0.31	0.12	0.65

worthy potential to sustain the population (Melese and Ayele, 2017; Mewded et al., 2019; Myo et al., 2016). The highest number of saplings and seedlings in HGAFs were *Z. spina-christi, B. aegyptiaca, A. seyal* and *A. tortilis* while in adjacent NF were *P. oliveriana, B. aegyptiaca, A. seyal,* and *Z. spina-christi* respectively. This confirms that these woody species have a higher preference in the HGAFs and seedling survival rates than adjacent NF in the study area. Besides, these species are more viable and less affected by disturbance factors. However, *C. africana, C. macrostachyus, D. cinerea, F. albida, F. sycomorus, O. europaea and Z. mucronata* in HGAFs and *G. ferruginea, F.albida, D. cinerea, C. macrostachyus* in NF were the woody species with no sapling and seedling. Species with the absence of seedlings and saplings are under threat of local extinction (Gurmessa et al., 2012). Thus, management and conservation priority should be given to species with no or few seedlings and saplings.

4.4. Importance value index (IVI)

Woody species with a highly important value index (IVI) is considered more important than those with low IVI. This is likely due to their wider economic role (Talemos and Sebsebe, 2014) and the ecological requirement of the life strategy of the species (Neelo et al., 2015). IVI is also an important parameter that reveals the prioritizing of species for conservation (Berhanu et al., 2016; Tadele et al., 2013; Zegeye et al., 2006). Species with high IVI value need low priority for conservation effort whereas those with low IVI value need high conservation effort. Therefore, the indigenous woody species in HGAFs such as *O. europaea*, *C. macrostachyus*, *A. albida*, *Z. mucronata*, *G. ferruginea*, *F. sycomorus,* and *D. angustifolia* had low IVI (<10%) values and hence, need conservation priority.

5. Conclusion

The study showed that HGAFs maintained higher in species richness, stem density, and diversity of woody species than adjacent NF, even several decades after deforestation. HGAFs is also important for preserving the most economical and ecological value trees such as *C. africana, D. angustifoliaL, E. cymosa, F. sycomorus, O. europaea, R. prinoides* and *Z. spina-christi,* which are not nowadays available in adjacent NF of the study area. Thus homegardens, where the farmers have a strong incentive to keep valuable tree species, will act as essential land-uses for the conservation of many species due to active management by the farmers, but species with a low value for the farmers are likely to extinct.

Thus, our study concluded that HGAFs of the study area, which supports local livelihoods and provides food, is essential for the conservation of biodiversity which complements the NF, and helps to counteract the loss of woody species from the NF. So, establishing and promoting HGAFs habitats in human-dominated landscapes should be part of the biodiversity conservation strategy.

Declarations

Author contribution statement

Gebru Eyasu: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Motuma Tolera, Mesele Negash: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data included in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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