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

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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 the world. A stratified sampling system was used to select representative homegardens from different wealth strata (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 < 0.05). Trees and shrubs in the HGAFs had significantly lower stem diameters, height, and basal area than the adjacent NF (p < 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.
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 ex situ 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.

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 26.9°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.

Figure 2. Climate diagram of Raya Alamata, southern Tigray, Northern Ethiopia. The monthly average for the years 1997–2017 was obtained from the Ethiopian meteorological agency.
tortils, 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 condition 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 a 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 m² (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 (Gd) (Krebs, 1985; Magurran, 1988) were estimated following formula:

Species richness (S) was calculated by

\[
S = \sum_{i=1}^{n} n_i \quad \text{Eq. (1)}
\]

where \( n_i \) is the number of species in a community.

\[
H' = -\sum_{i=1}^{n} P_i \ln(P_i) \quad \text{Eq. (2)}
\]

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

Equitability (evenness)\( J = \frac{H'}{H_{\text{max}}} = \frac{-\sum_{i=1}^{n} P_i \ln P_i}{\ln s} \quad \text{Eq. (3)}\)

Where \( S \) = the number of species; \( H_{\text{max}} \) = Shannon diversity indices and \( P_i \) = proportion of individuals found in the \( i^{th} \) species.

\[
D = 1 - \sum_{i=1}^{s} P_i^2 \quad \text{Eq. (4)}
\]

Where \( D \) = Simpson's index of species diversity; \( S \) = number of species; \( P_i \) = proportion of total sample belonging to the \( i^{th} \) 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:

\[
S_s = \frac{a + b - c}{a + b} \quad \text{Eq. (5)}
\]

Where, \( S_s \) = 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:

Important Value index (IVI) = Relative dominance + Relative density + Relative frequency

\[
\text{Eq. (6)}
\]

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 = [0–7.5], 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 (Baltassar 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.
Among the woody species, trees constituted 47% (15 species), shrubs 34% (11 species) and tree/shrubs 16% (5 species), and shrub/climber (one) 3% species of measured species.

Indigenous tree and shrub species accounted for 66% (21 out of 32 species), 90) of woody species recorded, and the

| S/N | Woody species | Local name | Family | Life form | Plot (%) HGAFs | RA (%) HGAFs | Plot (%) NF | RA (%) NF | W/P | I/E | Uses |
|-----|---------------|------------|--------|-----------|----------------|--------------|--------------|-----------|-----|-----|------|
| 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 (Forsk.) Hayne | Karwora | Fabaceae | T         | 66.67          | 2.83          | 100.00       | 19.09     | W   | I   | 1,7,9,13,14,16,18 |
| 3   | Asidracantha 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. | Harenegama | Capparidaceae | S/C       | 38.89          | 1.38          | 73.33        | 3.74      | W   | I   | 9,11,12 |
| 6   | Carissa edulis (Forsk.) -Vahl | Agam     | Apocynaceae | S         | 27.78          | 1.01          | 33.33        | 1.47      | w   | I   | 8,9,11,12,17 |
| 7   | Catha edulis (Vahl) Forsk. Ex Engl. | Chat     | Celastraceae | S         | 16.67          | 1.81          |             |           | p   | I   | 9,12,15 |
| 8   | Citrus aurantiifolia (Christm.) Swing. | Lomin    | Rutaceae | T         | 77.78          | 2.10          |             |           | p   | E   | 8,12 |
| 9   | Citrus medica | Tirungo   | Rutaceae | T         | 27.78          | 0.51          |             |           | p   | E   | 8,12 |
| 10  | Citrus reticulata B. | Menderin  | Rutaceae | T         | 11.11          | 0.22          |             |           | E   |     | 8   |
| 11  | Citrus sinensis (L.) Osb. | Aranshi   | Rutaceae | T         | 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   | 1,7,9,12,13,16,17,18 |
| 14  | Crotone macrostachus Del. | Mekusina  | Euphorbiaceae | T         | 5.56           | 0.22          | 13.33        | 1.20      | w   | I   | 1,7,9,10,12,16,18 |
| 15  | Dichrostachys cineras (L.) Wight & Ars. | Harshmasha | Fabaceae | T/S       | 0.00           | 0.00          | 6.67         | 0.13      | w   | I   | 1,7,9,10,11,12,14,16,18 |
| 16  | Dodonaea anguinefolia L. | Tahbes   | Sapindaceae | S         | 5.56           | 0.14          |             |           | p   | E   | 5,10 |
| 17  | Ehretia cymosa | Ulaga    | Apocynaceae | T/S       | 38.89          | 2.25          |             |           | w   | I   | 1,7,9,10,12,16 |
| 18  | Eucalyptus camaldulensis Dehn. | Krey Bahrza | Myrtaceae | T         | 83.33          | 19.28         |             |           | p   | E   | 1,7,9,17,16 |
| 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 sycomor L. | Oda       | Moraceae | T         | 5.56           | 0.14          |             |           | w   | I   | 2,8,9,12,13,14,17,18 |
| 21  | Grevillea robusta R. Br. | Grevilles | Proteaceae | T         | 5.56           | 0.07          |             |           | p   | E   | 2,8,9,12,13,14,17,18 |
| 22  | Grewia ferruginea Hochst.ex.A.Rich. | Meleglaga | Tiliaceae | S         | 11.11          | 0.14          | 6.67         | 0.13      | w   | I   | 7,8,9,10,16 |
| 23  | Lucuma incamophila Lam. | Lucinia   | Fabaceae | T/S       | 28.89          | 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 stenoptala (Bak. f.) Cuf. | Shiferaw | Moringaceae | T         | 16.67          | 1.52          |             |           | p   | I   | 1,7,8,11,12,13,18 |
| 26  | Olea europea subsp cupidata (Wall. ex DC.) Cifferri | Awilie   | Oleaceae | T         | 38.89          | 2.75          |             |           | w   | I   | 1,9,12,16 |
| 27  | Panneta 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.

**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 diversity indices.
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 HGFs 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 HGFs 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 HGFs 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 HGFs while in NF 1989, 1200 and 707 ha−1 were recorded. The ratio of seedling and sapling individuals to mature individuals in HGFs and NF was 2.6: 2 and 2.8: 1.7 respectively. The three highest numbers of saplings and seedlings in HGFs 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 HGFs (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 HGFs 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 HGFs than adjacent NF, for example, Tolera et al. (2008) in Arsi Negele south-central highlands of Ethiopia; Guyassa and Raj (2013) in Abreha–we-Atsbeha 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 HGFs and adjacent NF, Fabaceae contributed the greatest number of species, which were represented by four species. In HGFs, 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 Azgize 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 rich 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 Zemedu, 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 HGFs (n = 45). Z. spina-christi, an indigenous species grows up to 16 m tall, giving the HGFs 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 HGFs 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 HGFs 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 HGFs 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 HGFs 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
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 $< 8.5$ m 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
worthy potential to sustain the population (Melese and Ayele, 2017; Mewedel 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, P. 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. angustifolia*, *E. cymosa*, *F. sycomorus*, *O. europaea*, *R. prisoiodes* 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 is 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

Gebre 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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