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Contrasting Species Diversity and Values in Home Gardens and Traditional Parkland Agroforestry Systems in Ethiopian Sub-Humid Lowlands

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Received: 5 February 2019; Accepted: 11 March 2019; Published: 15 March 2019

Abstract: Understanding the complex diversity of species and their potential uses in traditional agroforestry systems is crucial for enhancing the productivity of tropical systems and ensuring the sustainability of the natural resource base. The aim of this study is the evaluation of the role of home gardens and parklands, which are prominent tropical agroforestry systems, in the conservation and management of biodiversity. Our study quantified and compared the diversity of woody and herbaceous perennial species and their uses in traditional home gardens and parkland agroforestry systems under a sub-humid climate in western Ethiopia. A sociological survey of 130 household respondents revealed 14 different uses of the species, mostly for shade, fuelwood, food, and as traditional medicine. Vegetation inventory showed that the Fisher's α diversity index and species richness were significantly higher in home gardens (Fisher's α = 5.28 $\pm$ 0.35) than in parklands (Fisher's α = 1.62 $\pm$ 0.18). Both systems were significantly different in species composition (Sørenson's similarity coefficient = 35%). The differences occurred primarily because of the high intensity of management and the cultivation of exotic tree species in the home gardens, whereas parklands harbored mostly native flora owing to the deliberate retention and assisted regeneration by farmers. In home gardens, *Mangifera indica* L. was the most important woody species, followed by *Cordia africana* Lam. and *Coffea arabica* L. On the other hand, *Syzygium guineense* Wall. was the most important species in parklands, followed by *C. africana* and *M. indica*. The species diversity of agroforestry practices must be further augmented with both indigenous and useful, non-invasive exotic woody and herbaceous species, particularly in parklands that showed lower than expected species diversity compared to home-gardens.

Keywords: herbaceous perennial species; household respondents; questionnaire survey; species richness; woody species

1. Introduction

Tropical forests are vital hosts of global biodiversity as they support approximately two-thirds of all known species and contain 65% of the world's endangered species [1]. The removal or destruction of forest cover resulted in significant losses of tropical and global biodiversity, owing to the destruction of forest-based habitats and species [2]. Tree cover continuously decreased in the tropics for the past 17 years [3]. Deforestation is primarily a concern for developing countries in the tropics [4,5], where significant agricultural demand for land is often coupled with a lack of economic incentives for forest conservation [6]. For example, in Ethiopia, the rapid expansion of agricultural land and the degradation of forests are associated with rapid human population growth (2.5% per year), with the population largely depending on extensive agriculture. Ethiopian animal husbandry, in particular, is characterized by the largest number of livestock in Africa, and increasingly claims land and forest resources [7]. The reduction in forest cover and loss of biodiversity, particularly through deforestation, could activate abrupt, irreversible, and harmful changes, including regional climate change, degradation of rainforests to savannas, emergence of new pathogens [1], extinction of native flora and fauna species, and the displacement of indigenous people [8,9].

Agroforestry practices might be able to reconcile the needs for food production and biodiversity conservation via the integration of trees, shrubs, crops, or animals in the same system [10,11] by the provision of habitats for edge species [12], conservation of remnant native species and their gene pools [11,13], provision of corridors and stepping stones for persistence and movement of flora and fauna species by linking fragmented habitats [10,12], erosion control and water recharge, and buffering the logging pressure on the surrounding natural forest. Generally, from the viewpoint of recurrent food shortages, projected climate change, and increasing prices of fossil fuels, agroforestry is attracting increasing interest from the research and development communities as a cost-effective way to enhance food security, while simultaneously contributing to climate change adaptation and mitigation [14]. In Ethiopia, agroforestry was credited as a sustainable farming practice that uses and conserves biodiversity and limits agricultural expansion into natural forests [15]. However, this circa situm (farm-based) conservation of biodiversity was only recently advocated by the Convention on Biological Diversity [10,16,17].

The tropical agroforestry systems including those in Ethiopia are indicative of the complex, multi-layer structure of the natural forest with a rich plant diversity [18] and are shaped by deliberate planting or retention, and assisted regeneration of useful woody species [18,19]. These traditional agroforestry systems represent a valuable source of genetic resources, in addition to the natural and planted forests [20]. Among the tropical agroforestry systems, home gardens in particular exhibit high species diversity and structural complexity [21–23], and are recognized as being essential for the conservation and sustainable management of tropical forest landscapes [24,25]. Parklands are another prominent type of tropical agroforestry, covering relatively large areas of scattered trees and shrubs on cultivated or recently fallowed cropping fields. These many indigenous species of trees are deliberately preserved, and their regeneration is assisted in the agricultural environment because of their specific use [26].

Some characteristic examples of this practice in Ethiopia include *Cordia africana* Lam. intercropping with maize, and *Faidherbia albida*-based agroforestry [26]. The parkland agroforestry systems have significant socio-economic and environmental values [27]. For instance, N_2-fixing woody species in parklands improve soil fertility, enhance crop productivity, and increase soil moisture to facilitate microbial activity such as that of arbuscular mycorrhiza [28]. Home gardens and parklands can also serve as sinks of atmospheric CO_2 [28,29]. Direct benefits from agroforestry systems are in the form of food, medicine, cooking oil, firewood, shelter, tools, and forage [30,31] for domestic use and income generation [32]. The generally rich diversity in structure and composition of tropical agroforestry systems is, however, influenced by climate, elevation, soil moisture, and nutrient availability [33], and farm characteristics such as farm size, cropping pattern, and management [18,34]. Home gardens are reported as having more species than parklands or other agroforestry systems; however, different farming practices influence the potential of agroforestry to accommodate woody plant diversity and uses [35]. Moreover, evidence exists [32,33,36] that the high demand for arable land and unsustainable cropping practices induced degradation of the soil and tree components of agroforestry parklands, particularly in the semi-arid areas of Africa. This increasing anthropogenic pressure requires evaluation of the current status of agroforestry systems and development of adaptive measures such as the domestication of soil-improving tree species [37].

Study of the biological structure of agroforestry systems as indicated by the number and abundance of species provides insights into the relative importance of different plant species, and helps identify important elements of plant diversity, such as threatened and economically important species, to increase their abundance and productivity [38,39] Biodiversity measures (i.e., species diversity and species richness) are widely used as indicators of ecosystem health and human influence on ecological systems [38,40], and are factored in the monitoring of the status of agroforests and in successful conservation management [41–48]. However, vegetation inventories that document biodiversity status are often precluded in tropical developing countries where resources are lacking for extensive field surveys [40].

One of the common approaches for documenting the importance of agroforestry practices for rural livelihoods in developing countries is via study of the indigenous or local knowledge [49]. The current research challenge is to develop user-inspired and user-oriented management approaches [50,51] such as community-based natural resource management, transition management, sustainability, and sustainability education [50]. Acknowledging that success in development is more likely when local knowledge is considered [49,52], there is a need to document the importance of indigenous knowledge for sustainable development of agroforestry [53].

By integrating both local knowledge and ecological assessment, the present study aimed to evaluate the role of home gardens and parklands, the two most prominent tropical agroforestry systems, in the conservation and management of native vegetation in Ethiopia, which covers several agro-climatic zones and is an important spot of tropical biodiversity, yet experiences serious deforestation and land degradation problems. The specific objectives included (i) determining and comparing floristic composition in the agroforestry systems and their diversity and species richness via a field survey in western Ethiopia, and (ii) evaluating the uses, values, and management of woody and herbaceous species by the local population. We hypothesized that home gardens would have higher diversity and, thus, play a greater role in biodiversity conservation than parklands due to the higher intensity of management and use values of home-garden plant species compared to parkland plant species.

2. Materials and Methods

2.1. The Study Area

The present study was carried out in six villages of the Assosa district in western Ethiopia (Figure 1). The area is known for its widespread home-garden and parkland agroforestry practices and rich indigenous knowledge on traditional plant uses [54]. Assosa is one of 21 districts in the Benishangul Gumuz National Regional State of western Ethiopia. The history of Assosa district is marked by significant human settlement authorized by the ex-government of Ethiopia during the major droughts in the 1970s.

The district covers an area of 1991.41 km^2 [54] and is characterized by an elevational range of 1300 to 1470 m above sea level (a.s.l.) and a sub-humid climate with mean minimum and maximum temperatures of 14.4 and 28.5 °C, respectively [55]. The Assosa study area has a mono-modal rainfall pattern from the end of April through October [54]. The average annual rainfall is approximately 1291.2 mm [55].

The dominant soil types are dystric nitisols and orthic acrisols [54,56] with well-drained, reddish-brown clay loam acidic soils [55]. According to Reference [55], the soils in the study area are characterized by very low organic carbon and nitrogen contents, indicative of a low fertility status. The low nutrient status of the soils is constrained by the limited use of both organic and inorganic fertilizers and the loss of nutrients mainly through leaching [55].

Subsistence agriculture is the major economic activity, engaging approximately 80% of the population [55,56]. Major agricultural crops include millet, sorghum, maize, sesame, cotton, soy bean, coffee, and mango. These are produced by rain-fed and, to some extent, irrigated agriculture.

Recurrent crop failures are reported, caused by erratic rainfall in the area, which negatively affect food security [56].

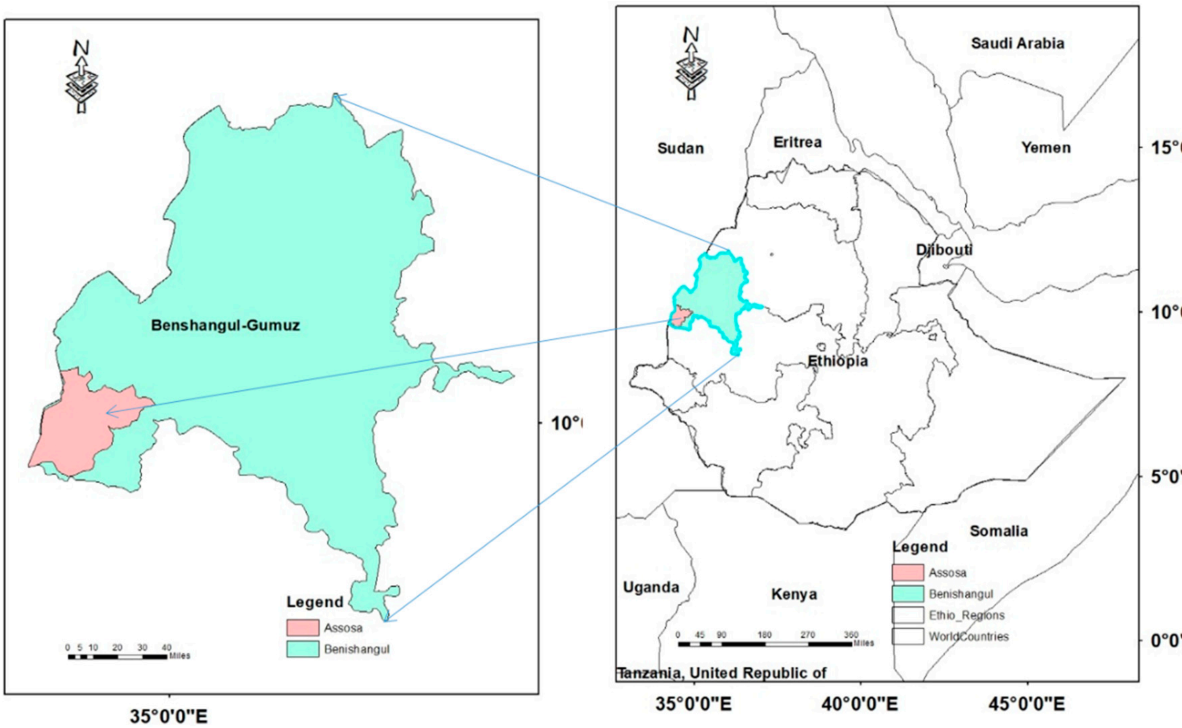

Figure 1. Location of Assosa district in western Ethiopia.

2.2. Household Survey

Based on the presence of agroforestry practices, six out of 74 villages were purposefully selected in the Assosa district. The villages were located between 6 and 21 km away from the Assosa central town. A list of all residents in each village in the Assosa district was collected from the records of the village administration (*kebele*) and development agents. Household respondents (HHs) were chosen using a stratified random sampling approach by adapting the wealth ranking technique of Reference [57], which categorizes farmers in three wealth categories, i.e., poor, moderately endowed, and rich. For each category, a simple random sampling (draw method) was employed to select 8% of the HHs in each village, giving a total of 130 HHs. Of these, 26% were poor, 38% were moderately endowed, and 36% were rich. The HHs were categorized into the three wealth categories by the key informants (KIs), who were farmers and had lived in Assosa for at least 35 years. The KIs were knowledgeable about local situations such as environmental and livelihood changes and local resource management. The information concerning indigenous knowledge on tree species and their uses, tree management practices, and associated constraints was gathered via questionnaire-based interviews with the HHs from 1 February to 15 March 2012.

Each HH had 1-9 family members aged 20-87 years (Table 1). The HHs were engaged in agricultural practices on private, small-land holdings. The 38 female HH heads were widowed or divorced women, relying either on hired labor or who engaged their young children in after-school work on their farmlands. The average land area owned by a farmer was 1.2 ± 0.1 ha and the proportion of land area allocated to parklands (43%) was greater than that allocated to home gardens (15%) (Table 2).

Table 1. Socio-economic characteristics of the 130 household heads interviewed in Assosa district, western Ethiopia.

Socio-Economic Characteristics		Number (%) of Respondents
Sex	Male	92 (70.8)
	Female	38 (29.2)
Age	20–35	17 (13.1)
	36–50	81 (62.3)
	51–65	28 (21.5)
	65–87	4 (3.1)
Literacy status	Literate	76 (58.5)
	Illiterate	54 (41.5)
Marital status	Married	92 (70.8)
	Not married	3 (2.3)
	Widowed	27 (20.7)
	Divorced	8 (6.2)
Wealth category	Poor	34 (26.2)
	Moderately endowed	49 (37.7)
	Rich	47 (36.1)
Family size	1–3 people	29 (22.3)
	4–7 people	85 (65.4)
	8–10 people	16 (12.3)

Table 2. Share of total land area allocated to home gardens, parklands and other land uses per farmer in Assosa district, western Ethiopia.

Village	Average Total Land Area per Farmer (ha)	Percentage of Land Allocated to Home Gardens (%)	Percentage of Land Allocated to Parklands (%)	Percentage of Land Allocated to Other Land Uses (%)
Amba8	0.6 ± 0.04	14	37	49
Megele37	0.9 ± 0.09	18	45	37
Megele39	0.9 ± 0.09	17	50	33
Amba7	0.8 ± 0.03	11	43	46
Nebarkomshga	3.7 ± 0.42	21	51	28
Amba13	1.0 ± 0.03	15	36	49
Total average	1.2 ± 0.09	15	43	42

Note: Other land uses include miscellaneous lands owned by household respondents (HHs) allocated to pasture, cropland with no trees, and shrubs. The sample size was 130 households.

2.3. Vegetation Survey

To obtain an inventory of the woody and herbaceous perennial species, 54 HHs (and, thus, 54 home-garden plots and 54 parkland plots) were selected out of the 130 surveyed HHs, i.e., three HHs from each wealth category, totaling nine HHs per village (six villages in total) and a pair (i.e., managed by the same HH) of home gardens and parklands per HH. We ensured that both land-use types were managed by the same HH to control for variations in management practices within HHs. Moreover, given that the study was carried out in a relatively small area where the site conditions (i.e., climate, topography, altitude) remain relatively homogenous, as described in Section 2.1, we assumed that variations in site conditions have less influence on the vegetation composition compared to differences in land management practices.

The study of the composition of woody and herbaceous species was done in the home gardens and parklands of the selected HHs. In the parklands, 50 m $\times$ 50 m quadrants were established as sampling plots because the minimum size of a farmland owned by a local farmer was 2500 m^2 (based on KI interviews cross-checked with personal observations). In contrast, the sampling in home gardens was performed using 30 m × 30 m quadrants defined by the KIs as the minimum size (~1000 m^2) of a home garden per farmer in the area [35].

Local names of plant species in each sampling plot were identified with the help of members of the local communities participating in the survey. Consequently, the plant species nomenclature was defined following References [58,59]. The species that could not be identified in the field were sampled (mainly for foliage), pressed flat to dry, and transported for identification to the Herbarium Laboratory of Addis Ababa University, Ethiopia.

The total number of woody and herbaceous perennial plants in the sampling quadrants was counted and recorded to determine the relative abundance of each species. The stem diameter at breast height (dbh) of all woody and herbaceous perennial (*Musa × paradisiaca* L., *Oxytenanthera abyssinica* (A. Rich.) Munro, and *Carica papaya* L.) plants with dbh ≥ 5 cm was measured in each sampling plot. When branching occurred below 1.3 m of the plant height, the dbh of all branches was measured and the average value was calculated. The dbh value was also used to calculate the basal area of plants with dbh ≥ 5 cm as follows:

$$BA = \frac{\pi(dbh)^2}{4}, \quad (1)$$

where BA is the basal area (cm^2).

Species dominance was calculated as the ratio of the total BA of the plants of each species to the total sampled area. The relative abundance (ra), relative dominance (rd), and relative frequency (rf) were calculated as follows:

$$\text{ra} = \frac{\text{Number of individuals of species}}{\text{Total number of individuals}} \times 100\%, \quad (2)$$

$$\text{rd} = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}} \times 100\%, \quad (3)$$

$$\text{rf} = \frac{\text{Frequency of species 1}}{\text{Total frequency of all species}} \times 100\%. \quad (4)$$

Therefore, the importance value index (IVI) indicating the importance of each species in the system was calculated as follows:

$$\text{IVI} = \text{ra} + \text{rd} + \text{rf}. \quad (5)$$

2.4. Species Diversity and Richness

To characterize the species diversity and richness in the studied agroforestry systems, we used Fisher's α index and the species–area relationship (SAR). These indicators were chosen because they are less sensitive to sample size. Fisher's α index is a parametric diversity index, which assumes that species abundance follows a logarithmic distribution [60]. It is a scale-independent indicator of diversity and was computed as follows:

$$S = a * \ln\left(1 + \frac{n}{a}\right), \quad (6)$$

where S is the number of taxa, n is the number of individuals, and α is Fisher's α.

The species–area relationship (SAR) is concerned with the number of species in areas of different size, irrespective of the identity of species within the areas [61]. The power function (Equation (7)) is the most commonly used model to describe the form of the species–area curve [62,63].

$$S' = S_0 A^z, \quad (7)$$

where S' is the number of species, A is the area, S_0 is the number of species in a unit area (A = 1), and z is a model parameter ($0 < z < 1$).

Furthermore, the Sørensen similarity coefficient was chosen to compare the similarity in the species composition of home gardens and parklands because it gives more weight to the species that are common in the samples rather than to those that only occur in either sample [64]. The Sørensen similarity index (*Ss*) was calculated as follows:

$$Ss = \left(\frac{2a}{2a + b + c}\right) \times 100, \quad (8)$$

where a is the number of species common to both samples, b is the number of species in sample 1, and c is the number of species in sample 2.

2.5. Statistical Analysis

Fisher's α index was compared among the six villages and between the two agroforestry practices. The data distribution could not be normalized by transformations. Therefore, the non-parametric Kruskal–Wallis test was used to check the significance of the differences. The species–area curves were plotted for each land-use type separately, and the SARs were fitted with the power function (Equation (7)). The analyses were performed using Microsoft Excel 2010, SPSS software (v. 24) and R version 3.4.3 [65].

3. Results and Discussion

3.1. Floristic Composition of Home Gardens and Parklands

During the HH survey, four agroforestry practices were identified. The dominant practices were home gardens and parklands, and the less common practices were alley cropping and on-farm boundary planting. The home-garden agroforestry was practiced by all HHs (n = 130) and the parklands by only 30 HHs (23% of the total sampled HHs). Alley cropping and on-farm boundary planting were practiced by 10% and 7% of HHs, respectively. All practices were previously reported as representative, particularly in southern Ethiopia [66], as well as in many other tropical regions [19]. In particular, home gardens were stated as being the most common among the smallholder agroforestry practices in the Ethiopian highlands, hosting higher woody species diversity than the nearby natural woodlands or forest lands [54,67].

The Assosa vegetation survey identified 57 woody and herbaceous perennial species (the latter being *C. papaya*, *M.* × *paradisiaca*, and *O. abyssinica*), with 56 of the species present in home gardens and 22 in parklands. The identified species belonged to 27 plant families. The most dominant family Fabaceae was represented by 11 woody species (19.3% of the total number of species recorded) and was followed by families Euphorbiaceae, Rutaceae, and Myrtaceae, represented by 4–6 species and constituting 10.5%, 8.8%, and 7%, respectively (Table 3).

Overall, 35 species were only found in home gardens but not in parkland agroforestry systems of the sampled HHs. One tree species, *Allophylus abyssinicus* (Hochst.) was found only in the parklands. A total of 21 species occurred in both agroforestry systems (Table A3, Appendix A). Overall, species composition significantly differed between the systems as judged by the relatively low Sørensen similarity coefficient (35%). Most of the woody species retained by farmers in parklands and home gardens were remnants of the natural vegetation, which covered the area before the settlements appeared in the 1970s and the Ethiopian natural disaster (famine) times. Afterward, planting of both native and exotic species occurred, mostly in home gardens and in some parklands. Planted timber tree species included *Albezia gummifera* (J.F. Gmel.) C.A. Sm., *Melia azedarach* L., *Cordia africana* Lam., *Grevillea robusta* A. Cunn. ex R.Br., and *Eucalyptus camaldulensis* Dehnh. For fruit trees, *Citrus aurantifolia* (Christm.) Swingle, *Citrus sinensis* (L.), and *Mangifera indica* L. were identified. Several species such as *Catha edulis* (Vahl) Endl., *Rhamnus prinoides* L'Hér., *Coffea arabica* L., and *O. abyssinica* were planted as perennial cash crops. These findings (Tables A1 and A2, Appendix A) corroborate with previous studies in the upper Blue Nile Basin and western Ethiopia, which reported the common presence of tree species *Croton macrostachys* Hochst. ex Delile, *Acacia abyssinica* Benth, and *C. africana* Lam. managed by farmers on their agricultural lands [26].

Table 3. Woody and herbaceous perennial species and corresponding families identified in home gardens and parkland agroforestry systems in Assosa district, western Ethiopia.

No.	Family	Number of Species	Percentage	Number of Individuals
1	Fabaceae	11	19.3	113
2	Euphorbiaceae	6	10.5	72
3	Rutaceae	5	8.8	90
4	Myrtaceae	4	7.0	236
5	Bignoniaceae	3	5.3	33
6	Anacardiaceae	2	3.5	240
7	Celastraceae	2	3.5	163
8	Sapindaceae	2	3.5	5
9	Moraceae	2	3.5	23
10	Proteaceae	2	3.5	19
11	Combretaceae	2	3.5	54
12	Acanthaceae	1	1.8	55
13	Annonaceae	1	1.8	1
14	Boraginaceae	1	1.8	172
15	Burseraceae	1	1.8	1
16	Caricaceae	1	1.8	38
17	Casuarinaceae	1	1.8	14
18	Cupressaceae	1	1.8	3
19	Lauraceae	1	1.8	8
20	Meliaceae	1	1.8	31
21	Musaceae	1	1.8	107
22	Poaceae	1	1.8	170
23	Rhamnaceae	1	1.8	131
24	Rosaceae	1	1.8	2
25	Rubiaceae	1	1.8	188
26	Sterculiaceae	1	1.8	13
27	Tiliaceae	1	1.8	1
	Total	57	100	

Based on the IVI ranking, *M. indica* was the most important woody species in home gardens, followed by *C. africana* and *C. arabica* (Tables 4 and A1, Appendix A), whereas, in parkland agroforestry systems, *Syzygium guineense* (Willd.) DC., *M. indica*, *C. africana*, *Terminalia brownii* Fresen., and *O. abyssinica* were the top five most important species (Tables 5 and A2, Appendix A).

Table 4. Importance value index (IVI) ranking of the top 10 woody and herbaceous perennial species in home gardens of Assosa district, western Ethiopia.

Name of the Species	IVI
Mangifera indica	65
Cordia africana	30
Coffea arabica	21
Catha edulis	16
Eucalyptus camaldulensis	15
Oxytenanthera abyssinica	14
Musa x paradisiacal	12
Rhamnus prinoides	12
Syzygium guineense	10
Citrus sinensis	10

Table 5. Importance value index (IVI) ranking of the top 10 woody and herbaceous perennial species in parkland agroforestry systems of Assosa district, western Ethiopia.

Name of the Species	IVI
Syzygium guineense	112
Cordia africana	45
Mangifera indica	29
Terminalia brownii	24
Ficus sur	14
Oxytenanthera abyssinica	13
Calpurnia aurea	8
Dombeya torrida	7
Musa x paradisiacal	5
Eucalyptus camaldulensis	4

3.2. Species Richness and Diversity in Home Gardens and Parklands

A high species diversity is often associated with important ecological services such as nutrient cycling, soil and water conservation, and resilience under anthropogenic pressure [10,12]. In this study, 56 and 22 species were counted in home gardens and parklands, respectively. The SARs predicted that 33 species·ha^{-1} and 4 species·ha^{-1} would be recorded for home gardens and parklands, respectively (Figure 2), suggesting that home gardens are likely to be richer in species compared to parklands. Our findings are reminiscent of the findings by Reference [35], who showed that home-garden agroforestry systems in the sub-humid eco-climatic zone of Ethiopia host higher woody species richness (64 species) than the nearby natural woodlands (32 species) and forest lands (31 species). The accumulation of a greater number of species in home gardens compared to parklands observed in the present study may be attributed to the planting preference of exotic species in home gardens (25 exotic vs. 31 indigenous species) than in parklands (eight exotic vs. 14 indigenous species) (Tables A1 and A2, AAppendix A). The introduced exotic species included perennial cash crops (e.g., *C. edulis*), fruit trees (e.g., *M. indica*), and those used as live fences and windbreaks (e.g., *Jatropha curcas* L.) in home gardens [54]. Although some of the exotic species have the potential to be invasive (e.g., *M. azedarach*, *G. robusta*; Tables A1 and A2, Appendix A), none of them were reported as invasive species in the study area by the HHs.

Comparison of species richness observed in tropical agroforestry globally is complicated by the difference in altitude, amount of rainfall, type of soil, and other factors such as differences in social, environmental, and economic conditions that influence species distribution and provenances [19,54]. For example, relatively low tree species richness (27) was recorded in home gardens of Kandy, Sri Lanka [68]. In Tanzania, East Africa [69,70], both studies counted 53 home-garden tree species and, thus, a higher richness comparable with results from our study (56). Reference [71] encountered 60 tree species in Mexican home gardens and even higher richness was reported from India, where Reference [21] observed 87 home-garden tree species in Assam and 71 tree species in Kerala state. The largest number, 179 woody species in home gardens, was reported from west Java, Indonesia [31].

Higher species richness in parklands than that observed in Assosa (22 species) was reported elsewhere in Ethiopia and in sub-Saharan Africa. For instance, Reference [33] recorded 48 and 41 woody species during fallow periods and crop cultivation, respectively, in parklands of Burkina Faso, West Africa. A study in south central Ethiopia [35] identified 32 woody species in parklands (during the cultivation phase). The lower species richness in Assosa parklands (22 species or an average of 4 species·ha^{-1}) might be associated with the history of human settlement in the 1970s, which increased the demand for agricultural land and wood.

Fisher's α diversity index was significantly higher for home gardens than for parklands in the study area (Table 6). There was no significant difference in Fisher's α index among the villages within each agroforestry system (Table 6). The higher species diversity in home gardens may be attributed to better and intensive management by family labor, in particular women and children [72]. According to the HHs, various silvicultural practices are applied to manage and maintain the plant species for different purposes in the agroforestry systems (Tables 7 and A5, Appendix A). These include manure (e.g., cow dung) application, watering, pruning, trimming, and fumigation-based control of pest and diseases (Tables 7 and A5, Appendix A). Although similar management practices are applied for both parklands and home gardens, the latter is continuously and more intensively managed by family labor (Table 7). The contribution of family labor as an important human capital for the management of home gardens based on the indigenous knowledge, skills, and abilities of the farming community was reported by Reference [73].

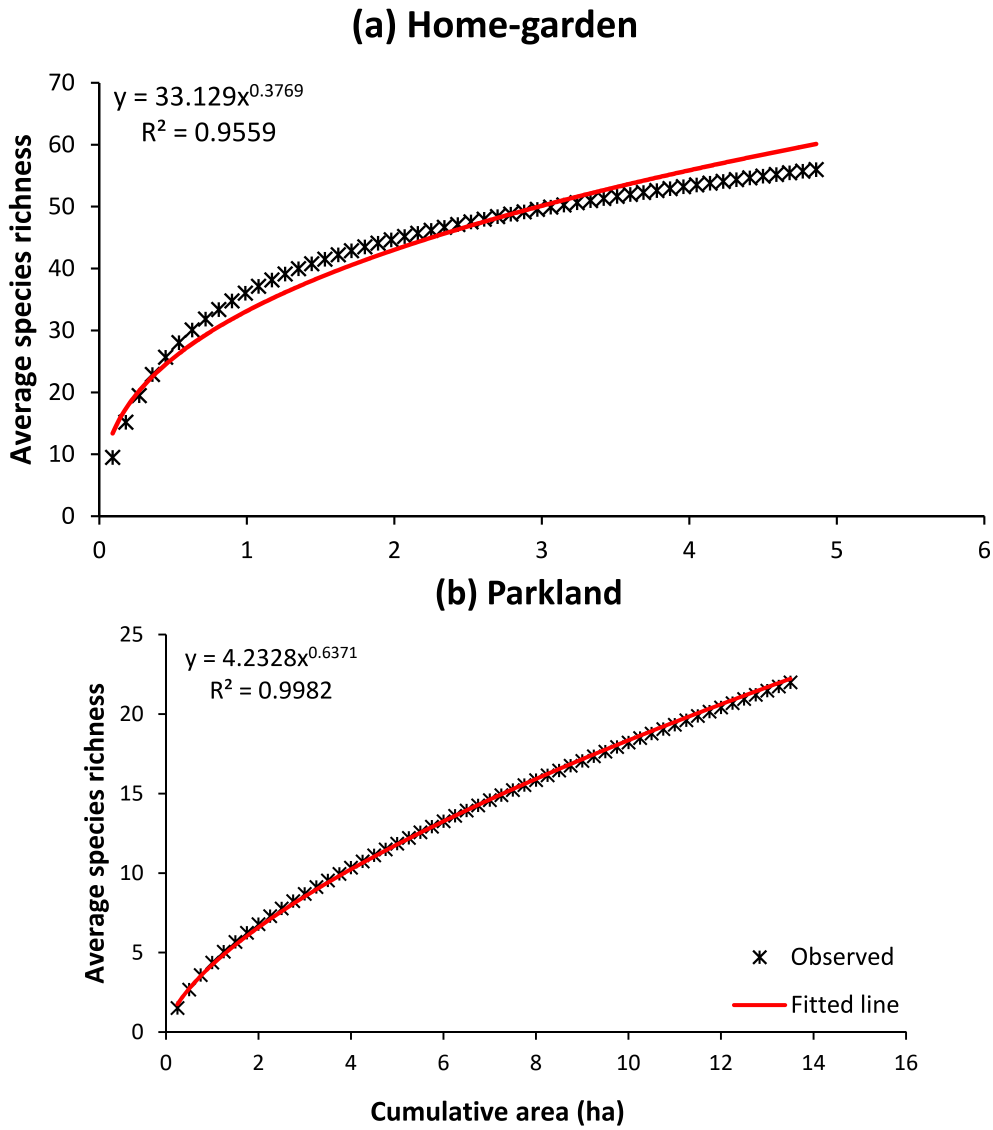

Figure 2. Species–area curves for (**a**) home gardens and (**b**) parkland agroforestry systems in Assosa district, western Ethiopia.

Additionally, the higher diversity of home gardens is an indication of secure property rights as testified by the HHs. The farmers unanimously mentioned that they felt more secure about planting commercially important exotic plants in their home gardens, for which they have full ownership rights, than in parklands. Similarly, the importance of secure land tenure for tree planting and biodiversity conservation was reported in several studies [35,74,75]. Altogether, intensive management, access to family labor, and secure property rights led to higher diversity in home gardens than in parklands in the Assosa district.

Table 6. Comparison of Fisher's α diversity index between home gardens and parkland agroforestry systems in Assosa district, western Ethiopia. Values are means ± standard errors.

Villages	Agroforestry Practice	Fisher's α
Amba8	Home gardens	$5.91^{a} \pm 0.70$
	Parklands	$1.55^{b} \pm 0.41$
Megele37	Home gardens	$4.31^{a} \pm 0.36$
	Parklands	$1.90^{b} \pm 0.57$
Megele39	Home gardens	$4.36^{a} \pm 0.57$
	Parklands	$0.87^{b} \pm 0.17$
Amba7	Home gardens	$5.63^{a} \pm 1.17$
	Parklands	$1.99^{b} \pm 0.33$
Nebarkomshga	Home gardens	$6.62^{a} \pm 1.13$
	Parklands	$2.18^{b} \pm 0.63$
Amba13	Home gardens	$4.86^{a} \pm 0.79$
	Parklands	$1.24^{b} \pm 0.25$
All villages	Home gardens	$5.28^{a} \pm 0.35$
	Parklands	$1.62^{b} \pm 0.18$

Note: For each village and for all villages, the mean values with the same superscripts are not significantly different at the $p < 0.05$ significance level.

Table 7. Home-garden and parkland agroforestry management practices as reported by HHs in Assosa district, western Ethiopia.

Management Practices	Home Garden	Parkland
Manure (cow dung) application	++	+
Irrigation	++	−
Soil management activities (harrowing/hoeing/ploughing)	++	+
Tending activities (e.g., trimming, pollarding, pruning, lopping, and coppicing)	++	+
Traditional pest and disease control (fumigation)	++	+
Plant species regeneration activities (seeding planting, assisted natural regeneration)	++	+

Note: (+) and (−) indicate whether the management is applied in the agroforestry systems or not, respectively; (++) indicates a higher intensity of management for a given practice. Further details on the management practices are provided in Table A5 (Appendix A).

3.3. Uses of Agroforestry Species

The woody and herbaceous perennial species in home gardens and parkland agroforestry systems in Assosa were stated by the HHs as sources of primarily food, fiber, fodder, timber, fuelwood, medicine, and other products of commercial value such as fruit from *M. indica* and foliage-derived stimulant from *C. edulis* (Figure 3; Table A4, Appendix A). All agroforestry species were credited with an improved microclimate due to the provision of shade. Next in importance, judged by the number of species named, was the provision of fuelwood (e.g., *E. camaldulensis* and *O. abyssinica*), food (e.g., *M. indica* and *M. × paradisiaca*), and traditional medicine (e.g., *C. macrostachyus* and *Justicia schimperiana* (Hochst. ex Nees) T. Anderson) (Table A4, Appendix A). Most significantly, the farmers harvested edible fruits of *M. indica*, *C. cinencis*, and *S. guineense* for domestic consumption and for sale, and the stems of *C. africana*, *A. gummifera*, and *Ficus sur* Forssk for timber (Figure 3). The respondents also mentioned soil fertility maintenance and a range of services associated with live fences, such as protection against soil erosion, microclimate amelioration, and recreational value in addition to the main purpose of border demarcation. Some uses were highly specific, such as the use of foliar juice from *M. azedarach* trees as an insect pest repellant to protect corn seedlings, exemplifying the variety of local knowledge [54,76].

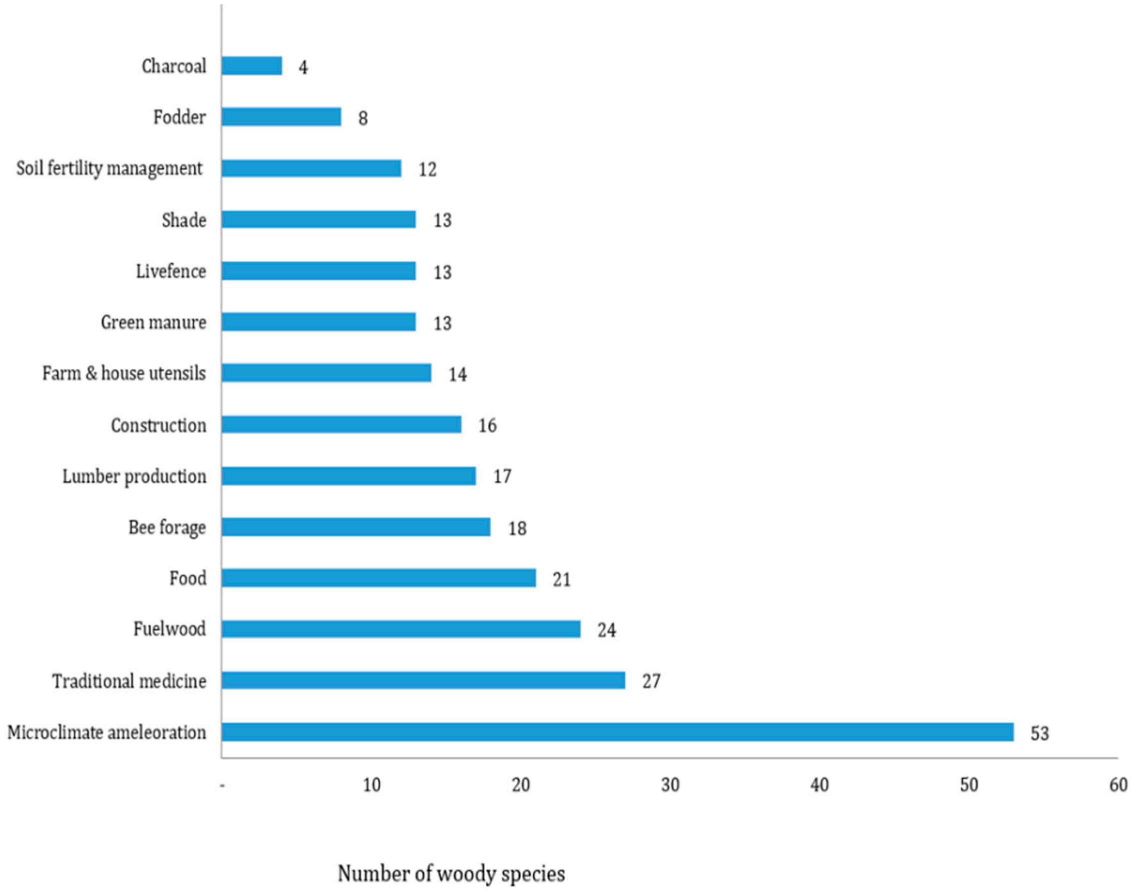

Figure 3. Local uses and values of woody and herbaceous perennial species in home gardens and parkland agroforestry systems in Assosa district, western Ethiopia.

These agroforestry benefits were reported as advantageous for enhancing ecological sustainability and improving the income and livelihood of rural people [19,77]. Thus, both indigenous and exotic tree and shrub species appeared important for farmers in Assosa district. Farmers ranked the indigenous *C. africana* and the exotic fruit species *M. indica* as being most important due to their relative productivity and profitability (Figure 3). However, the respondents stated that they faced insufficient yields from agroforestry species (from both home gardens and parklands), which might be due to the prevalence of management problems such as water shortages [54], as mentioned by the HHs.

The multipurpose use of woody plants is commonly reported in tropical agroforestry systems (e.g., Reference [78]). Similarly, HHs in western Ethiopia mentioned that most of the woody and herbaceous perennial species were used for more than one purpose. For instance, the wild fruit tree *S. guineense* is used for both charcoal making and as a food source, whereas almost all the species in the study area were mentioned to contribute to the improvement of the local microclimate (Figure 3; Table A4, Appendix A). Reference [79] showed that, out of the 2374 plant species identified as being important for smallholders in three tropical regions (Africa, South America, and Southeast Asia), 732, 639, 582, and 421 species were used for fuelwood, human food, animal fodder, and soil improvement, respectively. In Africa alone, 357 tree species were used for fuelwood, 295 for fodder, 295 for food, and 194 species for soil improvement [79]. The relative importance of tree uses is largely consistent with our results, showing the largest number of species being used for fuelwood and food, and a significant number credited with soil fertility management (Figure 3).

As mentioned by the HHs, the benefits of the agroforestry woody and herbaceous perennial species in the amelioration of the local microclimate are multifold, as the plants provide shade for people, grazing animals, and accompanying crops (Table A4, Appendix A). According to Reference [80], shading by tree canopies reduces evaporation from the soil surface and lowers air temperature. Specifically, Reference [81] recorded a 5 °C reduction in ambient temperature in the shaded versus open area during midday in a savanna ecosystem of Senegal.

The study by Reference [79] in tropical agroforestry systems emphasized in situ germplasm conservation of native plant species [82]. The effectiveness of the conservation of native flora is apparent in our study, as suggested by the larger share of indigenous versus exotic species, particularly in the parklands. Results by Reference [79] showed that smallholders are able to use a wide range of both indigenous and exotic trees. Similarly, the HHs in Assosa mentioned various uses of plants both from exotic and indigenous species, emphasizing the economic advantages of the former and traditional uses (such as for medicine) of the latter.

4. Conclusions

This case study in sub-humid western Ethiopia showed that prevailing agroforestry systems of home gardens and parklands that contain nearly 60 woody and herbaceous perennial species supply more than 14 different goods and services to local farmers. These agroforestry practices are, therefore, crucial in conserving the biodiversity on farms.

In spite of the larger area sampled for parklands, the home gardens showed higher species richness and diversity than did parklands owing to better management and protection by family labor, secure land tenure, and also because of the cultivation of exotic species. In contrast, parklands mostly harbored native flora via assisted natural regeneration, but were characterized by lower than expected species richness owing to the agricultural use of land.

The importance of the tree species judged by their useful values as perceived by the HH respondents was in agreement with the overall importance of these species as revealed in the vegetation survey. Therefore, boosting the low diversity of parklands and sustainable management of home gardens is crucial for the conservation of native vegetation and diversification of agroforestry land use. The management of agroforestry species using the local indigenous knowledge of farmers and further augmenting with both indigenous and useful, non-invasive exotic woody and herbaceous species is an important step toward agroforestry development in the study area.

Author Contributions: E.T., conceptualization, data collection, analysis, and writing of the draft manuscript; A.K., commenting, writing, reviewing, and editing; A.A., commenting; Y.S., guidance, commenting, and editing; F.N., commenting and data analysis.

Funding: This study was carried out with the support of 'R & D Program for Forest Science Technology (Project No. 2018110A00-1920-BB01)' provided by Korea Forest Service (Korea Promotion Institute).

Acknowledgments: We acknowledge "Agricultural Technical Vocational Education and Training College" of Assosa, Ethiopia and "World Vission Ethiopia" Assosa-Homosha district office, for allotting transportation for the research work. Korea University, Department of Environmental Science and Ecological Engineering also facilitated the preparation and publication of the manuscript. We are also grateful to the reviewers for their insightful and constructive comments.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Home-garden woody and herbaceous perennial species ordered according to their frequency of occurrence in Assosa district, western Ethiopia.

No.	Species Name	Origin	Potential of Invasiveness *	Basal Area (m^2)	Relative Dominance (%)	Relative Frequency (%)	Relative Abundance (%)	Importance Value Index
1	*Mangifera indica*	E	Yes	18.25	42.39	10.1	12.57	65.06
2	*Cordia africana*	I	No	5.5	12.78	9.49	7.97	30.24
3	*Coffea arabica*	I	No	1.06	2.46	7.27	11.08	20.81
4	*Catha edulis*	I	No	0.68	1.58	4.85	9.33	15.76
5	*Citrus sinensis*	E	No	0.28	0.65	4.85	3.05	8.55
6	*Oxytenanthera abyssinica*	I	No	0.51	1.18	4.85	8.4	14.43
7	*Rhamnus prinoides*	I	No		0	4.24	8.15	12.39
8	*Eucalyptus camaldulensis*	E	Yes	3.23	7.5	4.04	3.05	14.59
9	*Carica papaya*	E	No	0.99	2.3	3.23	2.36	7.9
10	*Musa × paradisiaca*	E	No	1.4	3.25	3.23	5.97	12.46
11	*Stereospermum kunthianum*	I	No	0.28	0.65	2.63	0.93	4.21
12	*Syzygium guineense*	I	No	2.39	5.55	2.63	1.68	9.86
13	*Citrus aurantifolia*	E	Yes	0.15	0.35	2.42	1.12	3.89
14	*Melia azedarach*	E	Yes	1.21	2.81	2.42	1.68	6.92
15	*Leucaena leucocephala*	E	Yes	0.09	0.21	2.22	1.8	4.24
16	*Psidium gujava*	E	No	0.11	0.26	2.02	1.18	3.46
17	*Grevillea robusta*	E	Yes	0.16	0.37	1.82	1.06	3.25
18	*Ricinus communis*	I	No	0.1	0.23	1.82	1.24	3.3
19	*Terminalia brownii*	I	No	0.98	2.28	1.82	1.06	5.15
20	*Croton macrostachyus*	I	No	0.44	1.02	1.62	0.75	3.38
21	*Entada abyssinica*	I	No	0.39	0.91	1.41	2.3	4.62
22	*Justicia schimperiana*	I	No	0.08	0.19	1.41	3.42	5.02
23	*Manihote sculenta*	E	No	0.03	0.07	1.41	0.44	1.92
24	*Persea americana*	E	No	0.17	0.39	1.41	0.5	2.31
25	*Spatodea campanulata*	E	No	0.49	1.14	1.41	0.62	3.17
26	*Albizia gummifera*	I	No	0.51	1.18	1.21	0.5	2.89
27	*Casimiroa edulis*	E	No	0.25	0.58	1.21	0.5	2.29
28	*Ficus sur*	I	No	1.14	2.65	1.21	0.56	4.42
29	*Jatropha curcas*	E	Yes	0.17	0.39	1.21	1.93	3.54
30	*Citrus aurantium*	E	No	0.07	0.16	1.01	0.44	1.61
31	*Jacaranda mimosifolia*	E	Yes	0.14	0.33	1.01	0.5	1.83
32	*Casuarina canninghamiana*	E	No	0.34	0.79	0.81	0.56	2.16
33	*Morus alba*	E	Yes	0.1	0.23	0.81	0.5	1.54

Table A1. *Cont.*

No.	Species Name	Origin	Potential of Invasiveness *	Basal Area (m^2)	Relative Dominance (%)	Relative Frequency (%)	Relative Abundance (%)	Importance Value Index
34	*Calpurnia aurea*	E	No	0.01	0.02	0.61	0.19	0.82
35	*Cupresus lusitanica*	E	No	0.1	0.23	0.61	0.19	1.03
36	*Sesbania sesban*	I	No	0.06	0.14	0.61	0.31	1.06
37	*Acacia abyssinica*	I	No	0.44	1.02	0.4	0.25	1.68
38	*Combretum aculeatum*	I	No	0.11	0.26	0.4	0.12	0.78
39	*Maytenus senegalensis*	I	No	0.01	0.02	0.4	0.12	0.55
40	*Prunus persica*	E	No	0.02	0.05	0.4	0.12	0.57
41	*Tamarindus indica*	I	No	0.03	0.07	0.4	0.12	0.6
42	*Annona senegalensis*	I	No	0.01	0.02	0.2	0.06	0.29
43	*Boswellia papyrifera*	I	No	0.02	0.05	0.2	0.06	0.31
44	*Cajanus cajan*	E	No	0	0	0.2	0.06	0.26
45	*Citrus medica*	E	No	0.01	0.02	0.2	0.06	0.29
46	*Dodonaea angustifolia*	I	No	0	0	0.2	0.06	0.26
47	*Dombeya torrida*	I	No	0.03	0.07	0.2	0.06	0.33
48	*Erythrina abyssinica*	I	No	0.14	0.33	0.2	0.12	0.65
49	*Euphorbia abyssinica*	I	No	0.01	0.02	0.2	0.06	0.29
50	*Euphorbia trucalii*	I	No	0	0	0.2	0.06	0.26
51	*Faurea speciose*	E	No	0.15	0.35	0.2	0.06	0.61
52	*Grewia mollis*	I	No	0.02	0.05	0.2	0.06	0.31
53	*Lannea fruticose*	I	No	0.14	0.33	0.2	0.06	0.59
54	*Millettia ferruginea*	I	No	0.01	0.02	0.2	0.12	0.35
55	*Myrtus communis*	I	No	0.01	0.02	0.2	0.37	0.6
56	*Pilostigma thonningii*	I	No	0.03	0.07	0.2	0.06	0.33
					100	100	100	

Note: I = indigenous, E = exotic. * The potential of invasiveness of exotic species was derived from References [83,84].

Table A2. Parkland woody and herbaceous perennial species ordered according to the frequency of occurrence in Assosa district, western Ethiopia.

No.	Species Name	Origin	Potential of Invasiveness *	Basal Area (m^2)	Relative Dominance (%)	Relative Frequency (%)	Relative Abundance (%)	Importance Value Index
1	*Syzygium guineense*	I	No	6.89	45	32.5	34.04	111.55
2	*Cordia africana*	I	No	2.04	13.32	20	11.7	45.03
3	*Mangifera indica*	E	Yes	1.35	8.82	11.25	8.51	28.58
4	*Terminalia brownii*	I	No	1.29	8.43	7.5	7.98	23.9

Table A2. *Cont.*

No.	Species Name	Origin	Potential of Invasiveness *	Basal Area (m^2)	Relative Dominance (%)	Relative Frequency (%)	Relative Abundance (%)	Importance Value Index
5	*Ficus sur*	I	No	1.32	8.62	3.75	1.6	13.97
7	*Calpurnia aurea*	I	No	0.18	1.18	3.75	3.46	8.38
6	*Oxytenanther abyssinica*	I	No	0.22	1.44	2.5	9.31	13.25
8	*Dombeya torrida*	I	No	0.41	2.68	1.25	3.19	7.12
9	*Musa × paradisiaca*	E	No	0.2	1.31	1.25	2.93	5.48
10	*Catha edulis*	I	No	0.01	0.07	1.25	2.93	4.24
11	*Combretum aculeatum*	I	No	0.24	1.57	1.25	1.33	4.15
12	*Coffea arabica*	I	No	0.01	0.07	1.25	2.66	3.97
13	*Allophylus abyssinicus*	I	No	0.2	1.31	1.25	1.06	3.62
14	*Eucalyptus camaldulensis*	E	Yes	0.07	0.46	1.25	1.86	3.57
15	*Lannea fruticose*	I	No	0.15	0.98	1.25	1.33	3.56
16	*Casuarina canninghamiana*	E	No	0.14	0.91	1.25	1.33	3.49
17	*Acacia abyssinica*	I	No	0.2	1.31	1.25	0.8	3.35
18	*Melia azedarach*	E	Yes	0.15	0.98	1.25	1.06	3.29
19	*Albezia gumifera*	I	No	0.13	0.85	1.25	0.8	2.9
20	*Citrus sinensis*	E	No	0.02	0.13	1.25	1.06	2.44
21	*Citrus aurantifolia*	E	Yes	0.02	0.13	1.25	0.8	2.18
22	*Grevillea robusta*	E	Yes	0.07	0.46	1.25	0.27	1.97
	Sum				100	100	100	

Note: I = indigenous, E = exotic. * The potential of invasiveness of exotic species was derived from References [83,84].

Table A3. The importance value index (IVI) of woody and herbaceous perennial species common to parklands and home gardens of Assosa district, western Ethiopia.

No.	Species and the Respective Family Name	Importance Value Index	
		Home Garden	Parkland
1	*Mangifera indica* (Anacardiaceae)	65.06	28.58
2	*Cordia africana* (Boraginaceae)	30.24	45.03
3	*Coffea arabica* (Rubiaceae)	20.81	3.97
4	*Catha edulis* (Celasteraceae)	15.76	4.24
5	*Eucalyptus camaldulensis* (Myrtaceae)	14.59	3.57
6	*Oxytenanther abyssinica* (Poaceae)	14.43	13.25
7	*Musa × paradisiaca* (Musaceae)	12.46	5.48

Table A3. *Cont.*

No.	Species and the Respective Family Name	Importance Value Index	
		Home Garden	Parkland
8	*Syzygium guineense* (Myrtaceae)	9.86	111.55
9	*Citrus sinensis* (Rutaceae)	8.55	2.44
10	*Melia azedarach* (Meliaceae)	6.92	3.29
11	*Terminalia brownii* (Combretaceae)	5.15	23.9
12	*Ficus sur* (Moraceae)	4.42	13.97
13	*Citrus aurantifolia* (Rutaceae)	3.89	2.18
14	*Grevillea robusta* (Proteaceae)	3.25	1.97
15	*Albezia gumifera* (Fabaceae)	2.89	2.9
16	*Casuarina canninghamiana* (Casuarinaceae)	2.16	3.49
17	*Acacia abyssinica* (Fabaceae)	1.68	3.35
18	*Calpurnia aurea* (Fabaceae)	0.82	8.38
19	*Combretum aculeatum* (Combretaceae)	0.78	4.15
20	*Lannea fruticose* (Anacardiaceae)	0.59	3.56
21	*Dombeya torrida* (Sterculiaceae)	0.33	7.12

Table A4. Major woody and herbaceous perennial species and their uses in Assosa district, western Ethiopia as stated by the households. "?" stands for other purposes not mentioned by the HHs.

Species and the Respective Family Name	Proposed Uses			
Catha edulis (Celastraceae)	Stimulant	Microclimate amelioration	?	?
Coffea arabica (Rubiaceae)	Stimulant	Microclimate amelioration	?	?
Terminalia brownii (Combretaceae)	Fumigation	Microclimate amelioration	?	?
Faurea speciose (Proteaceae)	Fumigation	Microclimate amelioration	?	?
Acacia abyssinca (Fabaceae)	Charcoal making	Microclimate amelioration	?	?
Combretum aculeatum (Combretaceae)	Charcoal making	Microclimate amelioration	?	?
Eucalyptus camaldulensis (Myrtaceae)	Construction	Fuelwood	Microclimate amelioration	?
Syzygium guineense (Myrtaceae)	Construction	Food	Charcoal making	Microclimate amelioration
Sesbania sesban (Fabaceae)	Soil fertility enhancement	Fodder	Microclimate amelioration	?
Albezia gumifera (Fabaceae)	Soil fertility enhancement	Shade	Microclimate amelioration	?
Piliostigma thonningii (Fabaceae)	Fodder	Bee forage	Traditional medicine	Microclimate amelioration
Cordia africana (Boraginaceae)	Fodder	Food	Shade & Microclimate amelioration	House utensils
Leucaena leucocephala (Fabaceae)	Fodder		Microclimate amelioration	?
Morus alba (Moraceae)	Fodder	Live fence	Microclimate amelioration	?
Jatropha curcas (Euphorbiaceae)	Live fence	Fuelwood	Microclimate amelioration	?

Table A4. *Cont.*

Species and the Respective Family Name	Proposed Uses			
Entada abyssinica (Fabaceae)	Live fence	Fuelwood	Microclimate amelioration	?
Grewia mollis (Tiliaceae)	Farm implements	House utensils	Microclimate amelioration	?
Ficus sur (Moraceae)	Farm implements	House utensils	Food	Microclimate amelioration
Justicia schimperiana (Acanthaceae)	Bee forage	Traditional medicine	Live fence	Microclimate amelioration
Millettia ferruginea (Fabaceae)	Shade	Soil fertility enhancement	Microclimate amelioration	?
Mangifera indica (Anacardiaceae)	Food	Shade	Microclimate amelioration	?
Croton macrostachyus (Euphorbiaceae)	Traditional medicine	Shade	Microclimate amelioration	?
Psdium gujava (Myrtaceae)	Traditional medicine	Microclimate amelioration	?	?
Manihot esculenta (Euphorbiaceae)	Food	?	?	?
Musa × paradisiaca (Musaceae)	Food	?	?	?
Melia azedarach (Meliaceae)	Traditional medicine	Fuelwood	Microclimate amelioration	?

Table A5. Management practices in home gardens and parkland agroforestry systems, as stated by the HHs in Assosa district, western Ethiopia.

Woody Species Regeneration Methods		Management of Woody Species				Agroforestry Management Problems		Impacts of Pests and Diseases on Important Agroforestry Woody Species		
Sources of Seedlings	**Number of HHs**	**Management Activities**	**Species Mostly Receiving the Management**	**Purpose of Management**	**Number of HHs**	**Management Problem**	**Number of HHs**	**Species Mostly Affected**	**Causative Agents**	**Number of HHs**
Government nurseries	99	Pollarding	*Cordia africana* Lam.	To reduce shade effects on crops	120	Land tenure	116	*Mangifera indica* L.	Aphids and ants	23
Private and communal nurseries	27	Coppicing	*C. africana*	To obtain planting material	120	Termite attack	93	*C. africana*	Wood borers	20
Neighboring village nurseries	22	Pollarding	*Eucalyptus camaldulensis* Dehnh.	To obtain construction wood	85	Low survival of seedlings	41	*Coffea arabica* L.	Insects	22
Naturally regenerating seedlings	10	Coppicing	*E. camaldulensis*	To obtain planting material	85	Scarcity of water	35	*Citrus sinensis* (L.) Osbeck, *C. aurantium* L., *C. medica* L.	Black spots on fruits and leaves	23
-	-	Pollarding	*Jatropha curcas* L.	To optimize the height of live fences and to harvest fuelwood	25	Disease and pest attacks (other than termite attack)	23	*Catha edulis* (Vahl) Forssk. ex Endl.	Black spots on stems and leaves	15
-	-	-	-	-	-	Decline of soil fertility	22	-	-	-
-	-	-	-	-		Scarcity of seedlings	20	-	-	-

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