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Agricultural Biodiversity and Ecosystem Services of Major Farming Systems: A Case Study in Yayo Coffee Forest Biosphere Reserve, Southwestern Ethiopia

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Abstract: Farming systems, with their concerns of biodiversity, ecosystem services, and productivity and production issues towards progress in human needs, wellbeing, and sustainable development, are challenging in most biosphere reserves. In this study, we assess the levels and trends of the agro-biodiversity and ecosystem services of different farming systems in the Yayo Biosphere Reserve in Ethiopia. Interviews with a total of 120 farmers, 16 key informants, and 12 focal group discussions (FDGs) were conducted, and species composition was assessed based on data collected on ten plots per major farming system. Result indicate that four farming systems, namely homegardens (HG), plantation coffee (PC), semi-forest coffee (SFC), and annual crop production (CP) systems, can be identified. Shannon and Evenness indices were highest in the HG system ($H' = 3.14$, $E = 0.8$), and lowest in the CP system ($H' = 0.71$, $E = 0.18$). Additionally, more diversified and relatively less cultivated farming systems provide more ecosystem services, and land users tend to practice less diversified farming systems in order to increase food supply at the expense of other ecosystem services. Therefore, this study recommends that diversified farming systems need to be considered to conserve or enhance specific ecosystem services in ways that reduce their negative tradeoffs.

Keywords: agro-biodiversity; biosphere reserve; ecosystem services; farming systems

1. Introduction

The agricultural practices of different farming systems, including their productivity and production, agro-biodiversity, environment, and related ecosystem services' issues towards the progress in human wellbeing and needs, and sustainable development, are challenging in biosphere reserves. Humans' wellbeing depends on ecosystems. "A farming system (FS) describes the structure and management of an agricultural production system dynamically arranged (designed) by the farmer and depending on his goals of production, priority of needs, and the regime of resources under specific natural, social and economic conditions" [1]. The global agricultural productivity (GAP) report in 2016 indicated that long-term global trends show a growing demand for food and agricultural products. At the same time, sustainable agriculture must not only satisfy human needs, but also conserve the natural resource base and sustain the economic viability of agriculture [2].

Many authors have argued that human wellbeing and progress towards sustainable development are vitally dependent upon improving the management of the Earth's ecosystems to ensure their conservation and sustainable use [3,4]. They also state that although demands for ecosystem services such as food, shelter, and clean water are growing, human actions are, at the same time, diminishing the capability of many ecosystems to meet these demands. In Ethiopian montane rainforests, economically valuable fountains of biodiversity are vanishing at accelerating rates due to diverging private and social net benefits from land conversion [5]. Land conversion is economically rational for farmers to convert forests into agricultural land and thereby improve their incomes. There are dynamic trends of ecosystem services and multiple agro-biodiversity practices throughout the various ecological zones and agricultural landscapes.

Ethiopia has four biosphere reserves and more than 80 forest priority areas [6], both characterized by a high level of interaction between humans and the environment. However, different farming systems can be found in both reserves, which are likely to differ regarding species composition, spatiotemporal structures of vegetation, biodiversity levels, and ecosystem functions and services [3,7,8]. In this study, we assessed farming trends, practices, and ecosystem services of different farming systems in the Yayo Biosphere Reserve, where especially coffee-based agricultural practices are common. The Yayo Coffee Forest Biosphere Reserve covers 167,021 ha, with the most important land cover types being forest, agricultural land, wetland, and grazing land. The whole landscape is part of the Eastern Afromontane Biodiversity Hotspot, which is one of the 34 globally important and yet threatened areas for biodiversity conservation [9]. The forest areas are further categorized into undisturbed natural forest, semi-forest coffee systems, managed for coffee production, and old secondary forests. These forests have local importance for coffee, spices, honey, and wood production. They also have regional and even international importance for the provision of ecosystem services through watershed protection (run-off control, water infiltration, soil retention) in the Nile Basin. The agricultural land consists of mainly smallholder farms with diverse crops and homegardens [9].

Yayo Biosphere Reserve is one of the habitats for diversity of *Coffea arabica* L., 1753 and, hence, is important for in situ conservation of the genetic diversity of the natural coffee. Coffee alone contributes around 70% of households' income in the area [10]. Data from 10 years ago indicated that over 150,000 people are living in the transition areas, deriving their livelihoods from semi-forest coffee production system in the buffer zone and different agricultural practices, including coffee plantation and home and forest gardens in the transition area [9].

Biosphere reserves attempt to reconcile environmental protection with sustainable development. However, according to Coetzer et al. [3], the reality of implementing dual 'conservation' and 'development' goals of the biosphere reserve model by UNESCO's Man and the Biosphere Programme (MAB), is challenging due to intensified and crop production-based agricultural activities of humans in the protected areas. Fragmentations of natural and cultural landscapes by anthropogenic actions in most tropical rain forests are likely to cause significant changes in agro-biodiversity and ecosystem functioning [11]. Yet, while we know that farming practices affect species numbers and compositions, our understanding of the specific impacts of these changes on the ecosystem functioning is very limited.

This study contributes to the understanding of different farming systems on the globally important ecosystems of Yayo forest and beyond. The results are relevant for the evidence-based implementation of sustainable and diversified farming practices in the Yayo Coffee Forest Biosphere Reserve and other protected areas.

2. Materials and Methods

2.1. Description of the Study Area

The research was conducted in four kebeles of the Yayo Coffee Forest Biosphere Reserve, namely Wabo and Bondawo Magala within the Yayo district and Wangegne and Gaba within the Hurumu district, situated in the Ilu Abba Bora Zone of the Oromia National Regional State, Southwestern Ethiopia (Figure 1). The Kebeles were selected based on their proximity to the biosphere reserve, which belongs to the center of origin of *Coffea arabica* [12]. Yayo BR is the largest and most important forest for the conservation of the wild populations in the world [9], and the area plays a key role in the conservation of the wild coffee populations and other species. It is located between latitude 8°

0′42′′ to 8°44′23′′ N and longitude 35°20′31′′ to 36°18′20′′ E [9]. The biosphere reserve includes Eastern Afromontane Biodiversity Hotspot and Important Bird Areas of international significance, and is also of high cultural and historical significance with many archaeological sites, ritual sites, caves, and waterfalls. The Yayo Coffee Forest Biosphere Reserve has three different management zones, namely core area, buffer zone, and transition area. The transition zone alone, where agricultural activity is dominant, occupies 70.5% of the total area of the biosphere reserve [9].

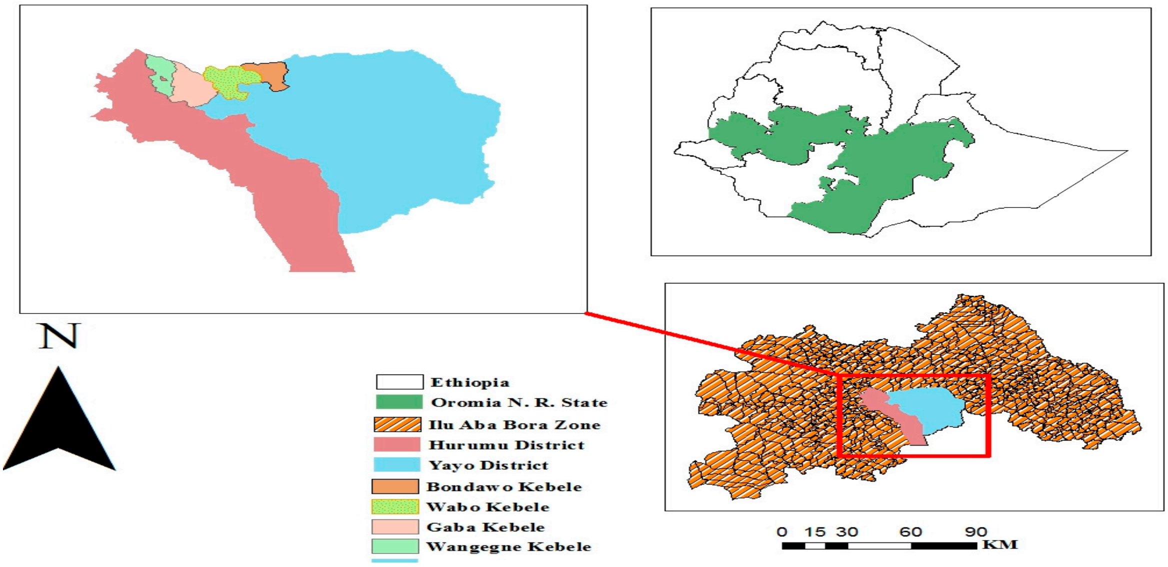

Figure 1. Map and location of study site, July 2017.

2.2. *Identification of Farming Systems*

There are many different farming systems being practiced within the Yayo Coffee Forest Biosphere Reserve. However, identifying the most practiced and major farming systems were important for the current study. Accordingly, major farming systems were identified based on interviews with representatives of government authorities in the study area and personal visits during narrative walks. 'Narrative walks', a qualitative method to collect grounded data according to Jerneck and Olsson [13], were used in this study to explore the social and natural dimensions of the complex and diverse natural, cultural, and agricultural landscapes of the subsistence agriculture in the area. Based on interviews with the government authorities in the area, such as the Agricultural Offices of Yayo and Hurumu districts, the Oroimia Forest and the Wild Life Enterprise of Ilu Aba Bora Branch, and the Environment and Coffee Forest Forum of Yayo area, we identified four major farming systems, namely homegardens (HG), plantation coffee (PC), semi-forest coffee (SFC), and annual crop production (CP) systems. Farmers were, for each field data collection activity, selected based on these interviews.

2.3. *Assessments of Species Diversity*

We assessed species diversity and the ecosystem service provisioning of different farming systems for the four identified farming systems. For this purpose, farmers were selected using stratified random sampling of farmers from four kebeles (villages), Bondawo Magala and Wabo kebeles of Yayo, and Gaba and Wangegne Kebeles of Hurumu districts. Following Chiarucci et al. [14], we assessed crop diversity on 10 plots with a size of 20 × 20 m plot (or 400 m^2 equivalent for linear areas). Ten plots were sampled for each farming system (Tables A1–A5).

Shannon diversity (H′) and evenness index (H′/LN(S)) were used to assess species diversity and their distribution in each major farming system. Species compositions (Species Richness_S) and their diversity index (Shannon_H′ and Evenness_H′/Ln(S)) were computed for the four major farming systems. This was based on 10 plots for each system to identify the linkage between agro-biodiversity and ecosystem services. The formula for this index is $S = -\sum (Pi \log (Pi))$ with $Pi = ni/N$, where N is the total number of individuals in a sample, ni are the individuals of species I, and A is the total number of species observed.

2.4. Assessment of Status and Trends of Ecosystem Service Provisioning

The contribution of each farming system to ecosystem service provisioning, as well as its trends, were assessed based on structured interviews with selected farmers from the four identified farming systems.

Interviews were conducted with 120 respondents from the households of 1815 in the 4 kebeles. The number of the respondents, n, was determined by the Kothari Formula (1) [15].

$$n = z^2 \times p \times q \times N/(e^2(N-1) + z^2 \times p \times q) \quad (1)$$

where N equals the size of the total population.

Assuming a standard variation of z = 1.96, a sample proportion p = 0.1, a probability for q = 0.9, and an acceptable error e = 0.05, a sample of 120 respondents were selected. Other criteria for the selection of respondents referred to their age (between 45 and 65 years), or if they were committee members of any local management unit, a model farmer a local elder, or an active farmer who had been practicing at least three of the four major farming systems. Using these criteria, we wanted to make sure that respondents were being selected that were experienced enough to recall their farming practices and their access to ecosystem services from the past 30 years.

The United Nations Millennium Ecosystem Assessment [16,17] provided the first consistent ecosystem services classification scheme, which served in this study as the basis for assessing the status of different ecosystems and their capacity to support human wellbeing. Based on structured interviews, trends of perceived ecosystem services from the major farming/cropping systems during the last 30 years in the selected villages/kebeles were collected. We focused our study on the period of 30 years to capture the trends of ecosystem service provisioning before and after the establishment of the biosphere reserve in 2009.

For the purpose of the interview, we defined and specified the four major ecosystem service categories (provisioning, regulatory, cultural, and supporting services) as particular services, such as for example, food, water, fuelwood, fodder, and genetic resource (Table A1). The respondents were asked based on Likert-scale questions to remember and describe the importance of the services they have received from the farming systems between 1987 and 2016 in 10-year intervals (1987–1996, 1997–2006, and 2007–2016) (Table A1). Additionally, they were asked for additional information about their own perception of the biosphere reserve.

2.5. Collection of Supporting and Checkup Information

In the four villages (Bondawo Magala, Wabo, Gaba, and Wangegne) 12 focus group discussions (FGDs) and a total of 16 key informant interviews were undertaken. The key informants included experts, model farmers, and members of the biosphere reserve management unit. Additionally, we conducted three FGDs with 6 to 8 randomly selected group members for each village. In total, 83 local community members participated in the group discussions (6 members in each of 5 FGD, 7 members in 3 of each FGD and 8 members in each of 4 FGDs).

For all structured interviews and species compositions data part, descriptive statistics of SPSS tool version 20 (IBM, New York, NY, USA), Past version 3 Øyvind Hammer, Oslo, Norway), and Microsoft Excel version 16 (MS, Redmond, WA, USA), were used as analyzing tools. Trends of ecosystem services (ES) were assumed from the frequencies of respondents on the relative importance.

3. Results and Discussion

3.1. Major Farming Systems

Key informant interviews indicated that the biosphere reserve is suitable for multiple farming systems and known for its high levels of agro-biodiversity. We found that four major farming systems are the most commonly practiced in the study area: homegarden agroforestry system (HG), plantation coffee system (PC), semi-forest coffee production system (SFC), and annual crop production system (CP).

3.1.1. Homegarden Agroforestry System

The homegarden system is the second most common farming system in the area. While most farmers are familiar with this system, the size and species compositions may vary from farmer to farmer (Figure 2). The crops of homegardens range from herbs, tubers, and roots, such as cabbage, anchote (*Coccinia abyssinica* (Lam.) Cogn.), godare (*Colocasia esculenta* (L.) Schott) to larger fruit and shade trees, like mango (*Mangifera indica* L.), avocado (*Persea Americana* Mill.), *Grevillea robusta* A.Cunn. ex R.Br., and *Cordia africana*. Additionally, most of the homegardens have dense stands of trees, including coffee, enset (*Ensete ventricosum* Lam.), and khat (*Catha edulis* (Vahl) Forssk. ex Endl.*)* (Table A2). In line with Muhamad et al. [18], we found that agroforestry plays an important role to conserve natural forests, thereby improving the livelihoods of local people and perceived as the source providing the most ecosystem services, followed by forest, and this finding indicated that agroforestry plays an important role as a compensating product of forest resources.

Figure 2. Homegardens (HG) and some compositions of them taken by the author, March 2017.

3.1.2. Plantation Coffee System (PC)

The plantation coffee system (PC) is a highly productive and intensively managed coffee farming system located in the buffer zone, transitional zone, and also in the homegardens of the area. Plantation coffee systems and semi-coffee forest production are very similar, but differ in terms of species composition and natural tree species components. While plantation coffee is a monoculture with lower levels of tree and shrub species diversity and well-structured stands, semi-coffee production systems tend to have a higher crop diversity with more complex stands. The result of key informant interviews has pointed out that some of the oldest plantation coffee stands were established during the so-called Derg regime (the Ethiopian political system and ruling party 1974–1991), when the Coordinating Committee of the Armed Forces, Police and Territorial Army ruled Ethiopia between 1974 and 1987. Between 1984 and 1986 (1976–1978 Ethiopian Calendar), the government pushed the local communities to settle in few areas, which also made them to expand coffee plantation into some marginal forest areas and agricultural fields near the natural forest.

Personal observations and focus group discussions indicate that the plantation size coffee system has been increasing, especially since 2009, as a consequence of the BR establishment (Figure 3). This result is also supported by the documentation of the nomination of Yayo Biosphere Reserve [9], which already anticipates the expansion of the biosphere buffer zone (doubling its size in the next decade), where plantation coffee systems managed by individual farmers are mostly located in the transition area. This trend has been supported by planting programs for coffee and indigenous shade trees, where these programs were implemented by governmental and some local and non-governmental organizations.

Figure 3. Photographs illustrating expanding trends of coffee plantation in the Yayo BR, photo taken by the author, March 2017.

3.1.3. Semi-Forest Coffee Production System (SFCS)

Semi-forest coffee production systems represent the oldest and most common farming system in the study area, known for their unique traditional coffee production practices. *Coffea arabica* is indigenous to the understory of the moist evergreen montane rainforest of Ethiopia [19,20]. Traditionally, coffee is produced by managing natural forests and coffee plants of wild origin in the SFC system. According to [20], this traditional method of coffee cultivation is a driver for preservation of indigenous forest cover, differing from other forms of agriculture and land use, which tend to reduce forest cover. This system has been distinguished from plantation coffee system by its dense tree and shrubs species compositions mixed with complex stands of coffee plants. We observed more indigenous tree diversity and denser understory components than in plantation coffee (Table A4). Semi-forest coffee is harvested from semi-wild plants in forest fragments, where farmers thin the upper canopy and annually slash the undergrowth. In traditional practice, farmers clear some shade trees and understory vegetation, which are competing with coffee, but maintain a combination of tree seedlings, shrubs, climbers, shade or multipurpose trees, and coffee plants (Figure 4). This result is supported by Gole et al. [9,19] which indicated that, in areas where the density of coffee plants is low, wild seedlings are picked from unmanaged forest and planted in gaps. Wild *Coffea arabica* shrubs are dominant in the system.

Figure 4. Pictures of semi-forest coffee production systems in the Yayo BR, photo taken by the author, April 2017.

3.1.4. Annual Crop Production Systems

In the transitional areas of the biosphere reserve, annual crop production (maize (*Zea mays* L.), sorghum (*Sorghum versicolor* Andersson), millet (*Eleusine indica* (L.) Gaertn.), teff (*Eragrostis tef* (Zucc.) Trotter), wheat (*Triticum aestivum* L., 1753), nug (*Guizotia abyssinica* (L.f.) Cass.), etc. (Table A5)) and perennial crops such as chat (*Catha edulis*) and coffee are common. We also observed woodlots, live fences, and boundary tree plantations, remnants of some indigenous tree and shrub species, and some forest patches in the system (Table A5). Furthermore, relative to the other farming systems in the area, the CP is intensively managed with some soil and water conservation activities being practiced in most fields (Figure 5). Annual crop production as key staple food for a majority of the human population [21] is of crucial importance for the food supply of the study area.

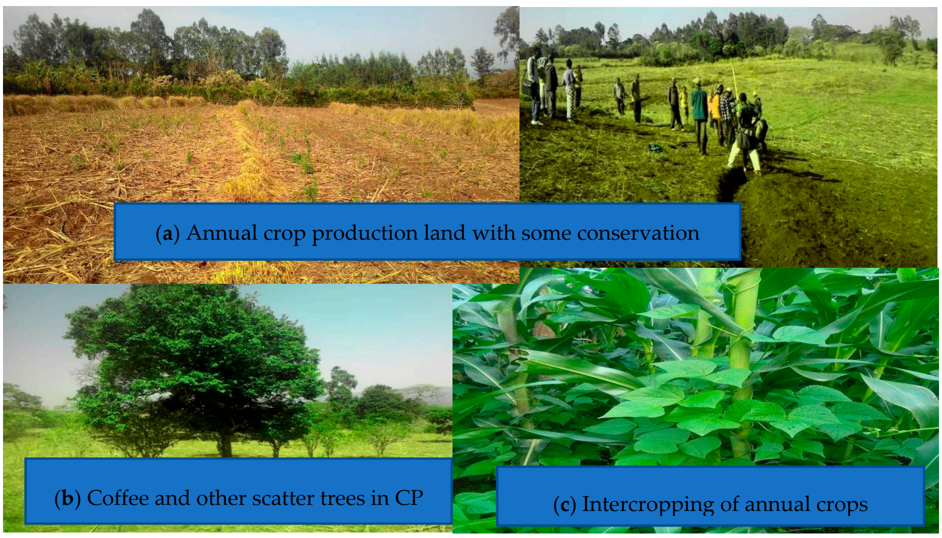

Figure 5. Annual crop production (CP) fields observed in Yayo BR photo taken by the author, April 2017.

3.2. Agro-Biodiversity within the Major Farming Systems

This study identified the links between agro-biodiversity and ecosystem goods and services, their overall benefits, and scenarios. In this study, agro-biodiversity refers to the variety and variability of flora that contribute to food and agriculture in the broadest sense, and the values associated with them. This is also reported by Jackson et al. [22], which stated that sometimes agro-biodiversity is considered to encompass a broader definition, to include the full diversity of all organisms living in agricultural landscapes, including biota for which function, in the human utilitarian point of view, is still unknown, where crops and livestock will be chosen by the farmer.

Species Compositions and Diversity Indices of the Farming Systems

The finding of this study revealed that the Shannon index (H′) and evenness are positively correlated, while species richness (S) was not. Shannon and evenness index were highest in the homegarden system (H′ = 3.14, Evenness = 0.8), and lowest in the annual crop production systems (H′ = 0.71, Evenness = 0.18) while the species richness (S) was highest for the semi-forest coffee system (S = 56) and lowest for the plantation coffee system (S = 28) (Table 1).

Table 1. Diversity indices of the major farming systems indicating species richness, Shannon diversity index and evenness of species within the systems, based on 10 plots of data for each.

Farming Systems	Diversity Indices		
	Species Richness (S)	Shannon (H′)	Evenness (H′/LN(S))
Homegarden System	50	3.14	0.80
Plantation Coffee System	28	1.21	0.36
Semi-Forest Coffee System	56	2.09	0.52
Annual Crop Production System	47	0.71	0.18

The farming systems identified in the study area have been managed for the production of food and income (compare also with [23]); agricultural landscapes can provide a wide range of goods and services to society. 'Ecosystem services' are those functions of ecosystems being provided by different agricultural activities which may directly or indirectly depend on the agro-biodiversity components. This study also identified that the agro-biodiversity within the annual crop production and plantation coffee systems in the study area is being lost, and observed, in some areas, at an accelerating rate. This result is in line with the finding reported by OECD (Organisation for Economic Co-operation and Development) [24], which discussed the fact that biodiversity is fundamental to sustaining life, supplying critical ecosystem services such as food provisioning, water purification, flood and drought control, nutrient cycling, and climate regulation, with less concern for agro-biodiversity.

Semi-forest coffee production systems tend to have the highest species richness followed by homegardens, annual crop, and plantation coffee systems, respectively. However, the Shannon and evenness diversity indices show that the diversity of homegarden systems are the highest, followed by semi-forest coffee, plantation coffee, and annual crop production systems, respectively (Table 1). The inconsistency of the different indices indicates that, in forested landscapes, direct and indirect aspects of agroforestry management might be more important than local forest cover for species distribution [25]. Habitat loss and forest fragmentation resulting from vegetation clearing for wild coffee production, however, has been a driver of global biodiversity loss [26].

3.3. Mapping of Ecosystem Services of the Major Farming Systems

We found that rural people were greatly aware of different ecosystem services they have been obtaining from the different farming systems (Table 2). Provisioning services were clearer and more readily comprehensible than other services, e.g., regulating services. In this study, we compare the use and trends of ecosystem service provisioning for the different farming systems based on four main categories: provisioning services, regulatory services, cultural services, and supporting services [16]. Understanding the tradeoffs among ecosystem services is critical to manage ecosystems for multiple goals [27].

Agricultural practices and socio-ecological benefits are strongly interrelated, which might also affect the ecosystem services of different farming systems (Table 2). Especially, land area used for agricultural production or for other purposes, such as nature conservation, presents a tradeoff to society in terms of ecosystem services provided. Agricultural lands provide food, feed, fiber and, increasingly, biofuels, while natural ecosystems provide other important ecosystem services (Table 3).

3.4. Ecosystem Services and Their Temporal Trends of the Major Farming Systems

For homegardens, the importance of food provisioning decreased considerably during the last 30 years. While 85.8% of all respondents referred to this ecosystem service for the time period between 1987 and 1996, only 55.8% mentioned it for the latest period of 2007–2016 (Table 3). Reasons for this decrease were, according to the focus group discussions, the expansion of family settlements, wild life damage, and shifts from food to cash crop and fruit tree production in homesteads. At the same time, respondents' percentage for description of food provisioning has been increased from 55% to 78.3% in plantation coffee system, and indicated almost the same through the study period in annual crop production system, which has been frequented between 98.3% to 100% (Table 3).

According to the percentage of respondents, there are significant tradeoffs among ecosystem services being provided by the farming systems. For instance, aesthetic value was described as very high (100%) in semi-forest coffee system and it was the least (only 2.5%) in annual crop production while food provision trend was opposite (100% for annual crop and only 70% for SFCS). Additionally, when the food provision of annual crop is being increased its soil formation value has been declined from 36.7 to 7.5%. There are also the same tradeoffs within all systems (Table 4).

Therefore, sustainable development options need to be considered to conserve or enhance specific ecosystem services in ways that reduce negative tradeoffs or that provide positive synergies with other ecosystem services through assimilations of agro-biodiversity, improving strategies in agricultural practices. Appropriate modifications in diversified agricultural practices and adoption of a more integrated approach to ecosystem and agro-biodiversity practices must be introduced to compensate the declining trends of the ecosystem services. On the other hand, favoring people living close to forests in farming systems strategies will promote prospective biodiversity conservation and help to maintain various ecosystem services as long as people's needs will be accommodated. Additionally, ecosystem services' valuation for the farming systems and organic coffee certification must be pushed forward, and schemes rewarding systems providing more services should be introduced.

In general, the relative importance of the temporal trends of ecosystem services being provided by the major farming systems has been seen as tradeoffs (Table 4). For instance, if we assume that the result of the first period (1987–1996) as a starting point and coded as a positive indicator, the spiritual service of all systems has been declining (+ − −) at both later periods (Table 4). On the other hand, climate regulation, soil formation, and habitat provisions of HG, PC and SFC systems have increased (+ + +), and genetic resource conservation, fuelwood, aesthetic, and educational values of SFCS, for instance, show a recovery trend (+ − +).

Table 2. Most important ecosystem services provided by the four major farming systems in the Yayo Biosphere Reserve.

	Major Farming Systems			
Types of Services	**Homegarden AF**	**Plantation Coffee**	**Semi-Forest Coffee**	**Crop Production**
Provisioning Services				
Food production	Fruits, tubers, vegetables, oils, pulses, and roots	Wild fruits	Wild fruits and some edible leaves of shrubs and climbers	Cereal, pulses, and horticultural crops are all the services
Biodiversity/genetic resources	Conservations of anchote (*Coccinia abyssinica)*, godare (*Colocasia esculenta*), and *Oromo dinich* (*Plectranthus edulis* (Vatke) Agnew) genetic resources	Protection of wild fruit trees and the five legally protected tree species	Protection of wild fruit shrubs, climbers, and the five legally protected tree species	Conservations of indigenous and legally protected tree species
Water (drinking, cooking, irrigation)			Source of pure streams, springs, and small rivers for humans and livestock	
Fuelwood and timber	Branches, stems, and leaves of fruit trees and others Crop residues	Dried coffee stems, shrubs, branches of shade trees for fuelwood, and shade trees such as *Cordia africana* for timber	The main source of fuelwood and timber production yet	Crop residues and branches of parkland trees and shrubs (*Cordia*, *Ficus*, *Croton*, etc.)
Fodder	Leaves and residues of fruit and border trees, live fences such as *Vernonia*	Leaves and fruits of shade trees, and weedy herbs in off-seasons	Leaves and fruits of shade trees, shrubs and weedy herbs in off-seasons	Crop residues, leaves, and fruits of parkland and shade trees
Medicinal values	Vegetables, tubers, roots, fruits, shrubs and herbs in the system, e.g. 'Qoricha bineensaa'—snake poison	*Croton, Vernonia*, *Olea*, *Premna*, Qomanyoo (*Brucea antidysenterica* J.F.Mill.*)*, 'Gizaawwaa', and others	*Maesa lanceolata*, *Croton*, 'Qomanyoo' (*Brucea antidysenterica)*, *Premna*, *Hagenia*, and other shrubs, trees and climbers	*Vernonia*, *Maesa lanceolata*, *Croton*, Qomanyoo *(Brucea antidysenterica*), *Premna*
Regulatory Services				
Climate regulation	Shade of fruit trees and others in the system	Coffee shades and shrubs used as soil moisture protection, shade provision for human and animals	Coffee shades and shrubs used as soil moisture protection, shade for lives	
Erosion protection	More density more protection, no tillage	Zero tillage, live fences, and leafy mulches of shade and other trees and shrubs	Uncultivable and protected to some extent	Vetivar grass strips and conservation structures

Table 2. *Cont.*

	Major Farming Systems			
Types of Services	**Homegarden AF**	**Plantation Coffee**	**Semi-Forest Coffee**	**Crop Production**
Water purification			Quality streams, and springs as a result of uncultivability	
Cultural Services				
Spiritual values	Big trees like *Ficus* species	Availability and multifunctionality of big and culturally respected trees	Availability and multifunctionality of big and culturally respected trees	
Aesthetic values	Landscape formation	Uniformity within each Under and lower storey species	Layers of different storey	
Educational values	Fruits, roots and tubers, and vegetables are becoming areas of research	Area of interest for international research on organic coffee production and multiplication systems	Area of interest for international research on organic coffee production and management systems	Research interest to enhance production and productivity
Recreation/ecotourism	Opportunities of evergreenness and attractiveness	Area of interest to maintain and enjoy cultural and natural landscapes	Area of interest to enjoy the biodiversity, cultural, and natural landscapes	
Supporting Services				
Soil formation	Litter falls, leguminous shrubs and crops, erosion control and livestock dung	Litter falls, erosion control of shade trees/shrubs	Litter falls, erosion control, and no tillage	Retention of crop residues through conservation agriculture
Habitat provision	Birds, insects, wild animals and others used the system, and the opportunity for corridors and nearby patches	Birds, insects, wild animals (climbers), and others used the system as home	Home for most types of living organisms, including big mammals, reptiles, etc.	Soil and water conservation structures for small animals and insects

From the above table, 15 actual and potential ecosystem services were mapped, and grouped into provision, supporting, regulating, and cultural ecosystem service categories. This has been done by focus group discussions and key informant interviews.

Table 3. Dynamics and temporal trends of ecosystem services of the major farming systems in the Yayo BR.

Ecosystem Services	Relative Importance of Ecosystem Services for Major Farming System in (%)											
	Homegarden AF System			Plantation Coffee System			Semi-Forest Coffee System			Annual Crop Land		
	1987–1996	1997–2006	2007–2016	1987–1996	1997–2006	2007–2016	1987–1996	1997–2006	2007–2016	1987–1996	1997–2006	2007–2016
Food Provision	85.8	70.9	55.8	55	76.6	78.3	96.6	78.3	70	98.3	100	100
BD/Genetic resources	76.6	55	27.5	78.3	70.9	42.5	97.5	87.5	99.1	29.2	15	6.7
Water Resource Provision	9.9	0	5.8	5.8	2.5	1.6	85.8	88.4	91.6	0	7.5	0
Fuelwood and Timber	56.6	76.6	85.8	92.5	100	100	100	100	96.6	67.5	98.4	98.4
Fodder Provision	37.5	67.4	87.5	95	97.5	91.7	100	100	91.7	52.5	63.3	64.2
Medicinal Value	79.1	93.3	100	99.2	100	100	100	100	92.4	73.4	87.5	84.2
Climate Regulation	93.4	100	100	95.9	100	100	100	100	100	32.5	43.3	24.2
Erosion Protection	97.1	100	99.1	95.8	100	97.5	100	100	100	48.3	36.7	38.3
Water Purification	0	4.2	7.5	6.7	0	0	60	58.4	39.2	5	0	0
Spiritual Services	59.1	33.4	30	33.4	8.3	4.2	83.4	79.1	68.4	10	3.3	3.3
Aesthetic Information	65.9	92.5	96.7	84.2	96.7	87.5	100	96.7	100	3.3	2.5	15
Educational Services	78.3	95	96.7	94.2	96.7	100	100	96.6	100	40	60	50.8
Recreation and Ecotourism	81.7	85.8	97.5	85.8	77.5	100	93.4	96.7	95.8	0	3.3	1.7
Soil Formation	95.1	100	100	94.2	94.2	100	100	100	100	36.7	14.1	7.5
Habitat Provision	91.6	100	100	99.2	100	100	98.3	100	100	31.7	56.7	52.5

The result illustrated the description results of ecosystem services being provided by the four major farming systems in the Yayo BR.

Table 4. Summary of trends and tradeoffs of ecosystem services in the major farming systems in the Yayo BR.

Major Farming Systems	Temporal Trends of Ecosystem Services within the Intervals of (1987–1996, 1997–2006 and 2007–2016)														
	Food Provision	**BD/Genetic resources**	**Water Resource Provision**	**Fuelwood and Timber**	**Fodder Provision**	**Medicinal value**	**Climate Regulation**	**Erosion Protection**	**Water Purification**	**Spiritual Services**	**Aesthetic Information**	**Educational Services**	**Recreation and Ecotourism**	**Soil Formation**	**Habitat Provision**
Homegarden	+ − −	+ − −	+ − +	+ + +	+++	+ + +	+ + +	+ + −	+ + +	+ − −	+ + +	+ + +	+ + +	+ + +	+ + +
Plantation Coffee	+ ++	+ − −	+ − −	+ + +	++ −	+ + +	+ + +	+ + −	+ − −	+ − −	+ + −	+ + +	+ − +	+ + +	+ + +
Semi-Forest Coffee	+ − −	+ − +	+ + +	+ − +	++ −	+ + −	+ + +	+ + +	+ − −	+ − −	+ − +	+ − +	+ + +	+ + +	+ + +
Annual Crop	+ + +	+ − −	+ + −	+ + +	++ +	+ + −	+ + −	+ − +	+ − −	+ − −	+ − +	+ + −	+ + −	+ − −	+ + −

Note: "+ + +" is to indicate that the services have been increasing since 1987; "+ − −" is to indicate that the services have been decreasing since 1987; "+ + −" is to indicate that the services increased from 1997 to 2006, and then decreasing from 2007 to 2016; "+ − +" is to indicate that the services decreased from 1997 to 2006, and then increased from 2007 to 2016.

3.5. Links of Agro-Biodiversity and Ecosystem Services in the Major Farming Systems

The result of this study revealed that the diversity of trees and shrubs in the major farming systems contributes to the provisioning of wood and non-wood products, and protects the environment, thereby enhancing ecosystem services of the systems (Table 2). The major farming systems, which were identified in the current study, have shown differences not only in the diversity, density, and composition of trees, but also in the ecosystem services they have been providing (Tables 3 and 4). In line with the findings of [28], the decrease in the diversity of trees and perennial components of the system, and its gradual replacement with new cash and annual food crops, could jeopardize the integrity and complexity of the system. This decreasing of diversity has been markedly modifying the functional properties of ecosystems [25], and the services they provide. Results of this study also showed that agro-biodiversity and ecosystem services being provided by those major farming systems are positively interrelated. On the other hand, most of the ecosystem services are derived mainly from annual crops systems, with the lowest species diversity and evenness, are declining rapidly. However, in the same system, this trend is reversed in some cases, like food, forage, and fuelwood provisions, where they have been increased in contrast to the diversity indices.

From the above table, we can estimate the relationships of diversity indices in each farming system and its different ecosystem services. The perception of the respondents for provision of the majority of ecosystem services was higher in areas of high taxon diversity, indicating both positive relationships and slight tradeoffs in maximizing single ecosystem services [29]. For example, SFC and HG systems, which have higher diversity indices, showed higher relative importance in pure water, fuelwood, timber, climate regulation, aesthetic, educational, recreational, soil formation, and habitat provisions.

Finally, the relationship between biodiversity and the rapidly expanding research and policy field of ecosystem services is confusing according to [30], globally in general, and in the Yayo Coffee Biosphere Reserve in particular. This statement underlines that the ecosystem science and human practices have not yet absorbed the lessons of this complex relationship, which suggests an urgent need to develop the interdisciplinary science of ecosystem management, bringing together ecologists, conservation biologists, resource economists, and others.

4. Conclusions and Recommendations

The major farming systems identified in this study, for the biodiversity comparison among them and ecosystem services (ES) assessment, are very common in the area, and they are of substantial social, economic, ecological, and environmental importance. The species compositions, management actions, and changes in the farming agro-ecosystems could affect the BR management towards sustainable development negatively and/or positively. Most of the temporal trends in the ES of the major farming systems have been increasing, especially in the more diversified systems, such as homegardens and semi-forest coffee systems. Regarding contemporary annual crop production system with lowest species diversity, most of them have shown declining trends. Food provisioning from annual crop farming system is highly significant, but many other ecosystem services, particularly those with regulatory, cultural, and supporting services, have been declined.

Ecosystems and the services they provide are critically important to our wellbeing and economic prosperity. This general truth underlines that people and their environment are inseparable. However, humans have been modifying the natural landscape and ecosystem functions to intensify certain provisioning services, such as food supply at the expense of others, for example, regulating services regardless of their sustainability. If local communities find themselves on the losing end of conservation measures, they will tend to overharvest the available resources to satisfy their basic needs.

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Appendix A Data Collection Formats/Sheets

Structured Questionnaires for Respondents

General information of the respondents

Field enumerator __________________ Date____________

Respondent's Name ____________________________ District _____________Name of the PA _____________ Gender: A. Female B. Male

GPS coordinates of residence (coordinates): North: _______________ East: ________________ Altitude (m.a.s.l.):_________________

Dynamics and temporal changes in ecosystem services major farming systems in the Biosphere Reserve

Table A1. Which of the following land-use/land-cover types do you practice or own and which are the associated benefits you utilized from each farming system type and each time period. Please indicate the importance through the numbers 1 = very important, 2 = important, 3 = medium, 4 = do not know, 0 = not important.

Year	Major Farming Systems	Types of Ecosystem Services														
		Provision Services						Regulation			Cultural				Supporting	
		1, Food production 2, Biodiversity/Genetic resources 3, Water (drinking, cooking, Irrigation) 4, Fuelwood and Timber 5, Fodder 6, Natural medicines						1, Climate regulation 2, Erosion protection 3, Water purification			1, Spiritual values 2, Aesthetic values 3, Educational values 4, Recreation and Ecotourism values				1, Soil formation 2, Habitat provision	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1987–1996 G.C	Homegarden AF															
	Plantation Coffee															
	Semi-Forest Coffee Systems (SFCS)															
	Annual Croplands															

Table A1. *Cont.*

Year	Major Farming Systems	Types of Ecosystem Services														
		Provision services						Regulation			Cultural				Supporting	
		1, Food production 2, Biodiversity/Genetic resources 3, Water (drinking, cooking, Irrigation) 4, Fuelwood and Timber 5, Fodder 6, Natural medicines						1, Climate regulation 2, Erosion protection 3, Water purification			1, Spiritual values 2, Aesthetic values 3, Educational values 4, Recreation and Ecotourism values				1, Soil formation 2, Habitat provision	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1997–2006 G.C	Homegarden AF															
	Plantation Coffee															
	Semi-Forest Coffee Systems (SFCS)															
	Annual Croplands															

Year	Major Farming Systems	Types of Ecosystem Services														
		Provision services						Regulation			Cultural				Supporting	
		1, Food production 2, Biodiversity/Genetic resources 3, Water (drinking, cooking, Irrigation) 4, Fuelwood and Timber 5, Fodder 6, Natural medicines						1, Climate regulation 2, Erosion protection 3, Water purification			1, Spiritual values 2, Aesthetic values 3, Educational values 4, Recreation and Ecotourism values				1, Soil formation 2, Habitat provision	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
2007 –2016 G.C	Homegarden AF															
	Plantation Coffee															
	Semi-Forest Coffee Systems (SFCS)															
	Annual Croplands															

If you do have any additional information and or remark it is free and open to add. Additional information that should be specified

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Table A2. Species Compositions of Homegarden System.

S. Number.	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others: 9. Shade	Abundance of the species in the system
1	Abiraangoo			6. Vegetables	1 and 2	13
2	Ancootee	*Coccinia abyssinica*	Cucurbitaceae	5. Root and tuber	1 and 7	49
3	Avokaadoo	*Persea americana*	Lauraceae	1. Fruit trees	1 and 7	22
4	Baargamoo	*Eucalyptus camaldulensis*	Myrtaceae	2. Timber trees	3 and 4	57
5	Baqarii/Kefii	*Salvia nilotica*	Lamiaceae	9. Spice	8. spice	12
6	Barbaree	*Capsicum annuum*	Solanaceae	9. Spice	1, 7, and 8	30
7	Bassoobilaa	*Ocimum americanum*	Lamiaceae	9. Spice	8. spice	11
8	Boqqolloo	*Zea mays*	Poaceae	8. Cereals	1. Food	221
9	Buna	*Coffea arabica*	Rubiaceae	9. Cash crop	1 and 7	219
10	Burtukaana	*Citrus sinensis*	Rutaceae	1. Fruit trees	1 and 7	7
11	Caatii	*Catha edulis*	Celastraceae	9. Cash crop	7. Income generation	218
12	Cadaa	*Euphorbia tirucalli*	Euphorbiaceae	9. Shrub	8. live fence	64
13	Dabaaqula/Buqqee	*Cucurbita pepo*	Cucurbitaceae	6. Vegetables	1. Food	16
14	Dafee/Boloqqee	*Phaseolus vulgaris*	Fabaceae	7. Pulse	1. Food	410
15	Dinnicha Oromoo	*Plectranthus edulis*	Lamiaceae	5. Root and tuber	1. Food	5
16	Eebicha	*Vernonia amygdalina/schimperi*	Asteraceae	3. Forage	2, 3, 5, and 6	45
17	Geeshoo	*Rhamnus prinoides*	Rhamnaceae	9. Shrub	1 and 7	6
18	Goodarree	*Colocasia esculenta*	Araceae	5. Root and tuber	1. Food	50
19	Giraaviiliyaa	*Grevillea robusta*	Proteaceae	2. Timber trees	3 and 4	24
20	Harangamaa	*Maerua aethiopica*	Capparidaceae	9. Climber	8. Live fence	16
21	Hundee diimaa	*Beta vulgaris*	Chenopodiaceae	5. Root and tuber	1 and 7	20
22	Indoodee	*Phytolacca dodecandra*	Phytolaccaceae	9. Climber	2 and 6	3
23	Irdii	*Curcuma domestica*	Zingiberaceae	9. Spice	8. Spice	20
24	Kaarotii	*Daucus carota*	Apiaceae	5. Root and tuber	1 and 7	8

Table A2. *Cont.*

S. Number.	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others: 9. Shade	Abundance of the species in the system
25	Kaashimiirii	*Conyza stricta*	Asteraceae	1. Fruit trees	1 and 7	9
26	Kookii	*Prunus persica*	Rosacaea	1. Fruit trees	1 and 7	10
27	Korchii	*Erythrina abyssinica*	Fabaceae	9. Shrub	2, 3, and 4	6
28	Loomii	*Citrus aurantifolia*	Rutaceae	1. Fruit trees	1, 2, and 7	6
29	Maangoo	*Mangifera indica*	Anacardiaceae	1. Fruit trees	1 and 7	29
30	Marga Veetiivaar			9. Grass	6. Soil conservation	31
31	Mishingaa	*Sorghum bicolor*	Poaceae	8. Cereals	1. Food	38
32	Mixaaxisa	*Ipomoea batatas*	Convolvulaceae	5. Root and tuber	1 and 7	19
33	Muuzii	*Musa acuminata*	Musaceae	1. Fruit trees	1 and 7	56
34	Paappayyaa	*Carica papaya*	Caricaceae	1. Fruit trees	1 and 7	11
35	Qobboo	*Ricinus communis*	Euphorbiaceae	7. Pulse	3 and 7	15
36	Qoccinee			9. Climber	1. Food	3
37	Qoccoo/Enset	*Ensete ventricosum*	Musaceae	5. Root and tuber	1. Food	197
38	Qoricha bofaa			9. Shrub	2. Medicine	6
39	Qullubbii	*Allium sativum*	Alliaceae	9. Spice	2, 7, and 8. Spice	31
40	Raafuu Habashaa	*Brassica carinata*	Brassicaceae	6. Vegetables	1. Food	151
41	Raafuu Maraa	*Brassica oleracea*	Brassicaceae	6. Vegetables	1 and 7	56
42	Rigaa arbaa	*Bridelia micrantha*	Euphorbiaceae	9. Shrub	3. Fuelwood	4
43	Sasbaaniyaa	*Sesbania sesban*	Fabaceae	9. Shrub	3 and 6	32
44	Shonkoora Agadaa	*Saccharum officinarum*	Poaceae	9. Industrial crop	1 and 7	146
45	Shunkurtii	*Allium cepa*	Alliaceae	9. Spice	1 and 7	16
46	Turungoo	*Citrus medica*	Rutaceae	1. Fruit trees	1 and 7	3
47	Waddeessa	*Cordia africana*	Boraginaceae	2. Timber trees	3, 4, and 7	8
48	Xeenaaddaam	*Ruta chalepensis*	Rutaceae	9. Spice	2. Medicine	14
49	Zayituunaa	*Psidium guajava*	Myrtaceae	1. Fruit trees	1. Food	5
50	Zinjibila	*Zingiber officinale*	Zingiberaceae	9. Spice	2, 7, and 8. Spice	72

Table A3. Species Compositions of Plantation Coffee System.

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
1	Abbayyii	*Maesa lanceolata*	Myrsinaceae	4. Shade trees	2, 3, 5, and 6	7
2	Baargamoo Diimaa	*Eucalyptus camaldulensis*	Myrtaceae	2. Timber trees	3, 4, and 7	9
3	Bakkanniisa	*Croton macrostachyus*	Euphorbiaceae	4. Shade trees	2, 6, and 9	13
4	Buna	*Coffea arabica*	Rubiaceae	9. Cash crop	1 and 7	965
5	Ceekaa	*Calpurnia aurea*	Fabaceae	9. Shrub	3. Fuelwood	9
6	Dambii	*Ficus thonningii*	Moraceae	4. Shade trees	3, 4, 5, and 6	3
7	Dhummuugaa	*Justicia schimperiana*	Acanthaceae	9. Shrub	2, 3, 4, and 6	6
8	Eebicha	Vernonia amygdalina	Asteraceae	3. Forage	2, 3, 5, and 6	20
9	Gatamaa/Gagamaa	*Olea welwitschii*	Oleaceae	2. Timber trees	2, 3, 4, and 9	1
10	Geeshoo	*Rhamnus prinoides*	Rhamnaceae	9. Shrub	1 and 7	5
11	Gizaawwaa	*Withania somnifera*	Solanaceae	9. Shrub	2 and 3	14
12	Giraaviiliiyaa/Muka qawwee	*Grevillea robusta*	Proteaceae	2. Timber trees	2, 3, 4, 7, and 9	4
13	Harbuu	*Ficus sur*	Moraceae	4. Shade trees	1, 3, and 5	3
14	Hoomii	*Prunus africana*	Rosaceae	2. Timber trees	2, 3, 4, and 7	2
15	Indoodee	*Phytolacca dodecandra*	Phytolaccaceae	9. Climber	2 and 8, purification	2
16	Laaftoo	*Acacia sieberiana*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	15
17	Mukarbaa/Ambabbeessa	*Albizia gummifera*	Fabaceae	4. Shade trees	9. Shade	12
18	oogiwoo/koroolimaa	*Ethiopian candimon*		9. Spice	7 and 8. Spice	41
19	Oobdaa	*Ficus vasta*	Moraceae	4. Shade trees	3, 5, 6, and 9	5
20	Qararoo	*Acokanthera schimperi*	Apocynaceae	2. Timber trees	3 and 4	9
21	Qolaadii	*Mimusops kummel*	Sapotaceae	4. Shade trees	3, 4, and 9	4
22	Qomanyoo	*Brucea antidysenterica*	Simaroubaceae	9. Shrub	2 and 3	1
23	Reejjii	*Vernonia rueppellii*	Asteraceae	4 and 9. Shrub	3, 6, and 9	36
24	Sesbania	*Sesbania sesban*	Fabaceae	9. Shrub	3, 4, 5, 6, and 9	42

Table A3. *Cont.*

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
25	Sondii	*Acacia lahai*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	5
26	Sootalloo	*Millettia ferruginea*	Fabaceae	4. Shade trees	2, 3, and 6	6
27	Ulaagaa	*Ehretia cymosa*	Boraginaceae	4. Shade trees	2, 3, and 4	6
28	Waddeessa	*Cordia africana*	Boraginaceae	2 and 4	3, 4, 5, 7, and 9	12

Table A4. Species Compositions of Semi-Forest Coffee Production System.

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
1	Abbayyii	*Maesa lanceolata*	Myrsinaceae	4. Shade trees	2, 3, 5, and 6	5
2	Agamsa	*Carissa spinarum*	Apocynaceae	9. Shrub, climber	1, 3, and 5	13
3	Akuukkuu	*Oncoba spinosa*	Flacourtiaceae	4. Shade trees	3. Fuelwood	10
4	Alalee	*Albizia grandibracteata*	Fabaceae	4. Shade trees	3, 4, and 6	5
5	Alaltuu	*Salix subserrata*	Salicaceae	9. Shrub	3 and 4	8
6	Ambabbeessa/mukarbaa	*Albizia gummifera*	Fabaceae	4. Shade trees	9. Shade	13

Table A4. *Cont.*

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
7	Ambaltaa	*Entada abyssinica*	Fabaceae	4. Shade trees	2, 3, and 6	7
8	Baddannoo	*Balanites aegyptiaca*	Balanitaceae	2. Timber trees	1, 2, 3, and 4	3
9	Baddeessaa	*Syzygium guineense*	Myrtaceae	2. Timber trees	1, 3, and 4	4
10	Bahaa	*Strychnos spinosa*	Loganiaceae	4. Shade trees	3, 4, 5, 6, and 9	6
11	Bakkanniisa	*Croton macrostachyus*	Euphorbiaceae	4. Shade trees	2, 6, and 9	22
12	Bosoqa	*Sapium ellipticum*	Euphorbiaceae	2. Timber trees	3, 5, 6, and 9	4
13	Botoroo	*Stereospermum kunthianum*	Bignoniaceae	9. Shrub	3. Fuelwood	13
14	Buna	*Coffea arabica*	Rubiaceae	9. Cash crop	1 and 7	1018
15	Burquqqee	*Acacia nilotica*	Fabaceae	9. Shrub	3. Fuelwood	9
16	Cayii	*Celtis africana*	Ulmaceae	2. Timber trees	3 and 4	2
17	Ceekaa	*Calpurnia aurea*	Fabaceae	9. Shrub	3. Fuelwood	85
18	Dambii	*Ficus thonningii*	Moraceae	4. Shade trees	3, 5, and 6	6
19	Dhangaggoo	*Rhoicissus tridentata*	Vitaceae	9. Herb	1 and 6	32
20	Dhoqonuu	*Grewia ferruginea*	Tiliaceae	9. Shrub, climber	4. Construction	16
21	Doggomaa	*Croton macrostachyus*	Euphorbiaceae	2. Timber trees	3 and 4	4
22	Doqoo			2. Timber trees	3, 4, and 9	3
23	Gatamaa/Gagamaa	*Olea welwitschii*	Oleaceae	2. Timber trees	2, 3, 4, and 9	2
24	Geeshoo	*Rhamnus prinoides*	Rhamnaceae	9. Shrub	1 and 7	6
25	Gizaawwaa	*Withania somnifera*	Solanaceae	9. Shrub	2 and 3	3
26	Gursadee			9. Shrub	2. Medicine	12
27	Harangamaa	*Maerua aethiopica*	Capparidaceae	9. Climber	8. Live fence	23
28	Harbuu	*Ficus sur*	Moraceae	4. Shade trees	1, 3, and 5	2
29	Harooressa	*Grewia bicolor*	Tiliaceae	2. Timber trees	3 and 4	8
30	Heexoo/Koosoo	*Hagenia abyssinica*	Rosaceae	2. Timber trees	2, 3, and 6	8
31	Hoomii	*Prunus africana*	Rosaceae	2. Timber trees	2, 3, 4, and 7	3

Table A4. *Cont.*

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
32	Incinnii	*Sesbania sesban*	Fabaceae	9. Climber	4 and 8	53
33	Indoodee	*Phytolacca dodecandra*	Phytolaccaceae	9. Climber	2. Medicine	19
34	Kombolcha	*Maytenus arbutifolia*	Celastraceae	9. Shrub	8. Live Fence	25
35	Kosorruu/sokorruu	*Acanthus pubescens*	Acanthaceae	9. Shrub	3. Fuelwood	35
36	Laaftoo	*Acacia sieberiana*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	14
37	Lolchiisaa	*Bersama abyssinica*	Melianthaceae	2. Timber trees	2, 3, and 4	3
38	Lookoo	*Diospyros abyssinica*	Ebenaceae	2. Timber trees	2, 3, and 4	8
39	Oobdaa	*Ficus vasta*	Moraceae	4. Shade trees	3, 5, 6, and 9	4
40	oogiwoo/koroolimaa	*Ethiopian candimon*		9. Spice	7 and 8. Spice	56
41	Qararoo	*Acokanthera schimperi*	Apocynaceae	2. Timber trees	3 and 4	4
42	Qolaadii	*Mimusops kummel*	Sapotaceae	4. Shade trees	3, 4, and 9	5
43	Qomanyoo	*Brucea antidysenterica*	Simaroubaceae	9. Shrub	2 and 3	3
44	Reejjii	*Vernonia rueppellii*	Asteraceae	4 and 9. Shrub	3, 6, and 9	44
45	Rigaa arbaa	*Bridelia micrantha*	Euphorbiaceae	9. Shrub	8, brush	12
46	Saacoo/too	*Erica arborea*	Ericaceae	4. Shade trees	3, 4, and 9	3
47	somboo	*Ekebergia capensis*	Meliaceae	2. Timber trees	2, 3, 4, and 9	3
48	Sondii	*Acacia lahai*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	7
49	Sootalloo	*Millettia ferruginea*	Fabaceae	4. Shade trees	2, 3, and 6	7
50	Ulaagaa	*Ehretia cymosa*	Boraginaceae	4. Shade trees	2, 3, and 4	4
51	Ulmaayii			9. Shrub	2, 3, and 8, teeth brush	20
52	Urgeessaa	*Premna schimperi*	Lamiaceae	9. Shrub	2, 3, and 4	6
53	uuyyuu/Muka gurraacha			2. Timber trees	3, 4, and 9	2
54	Waddeessa	*Cordia africana*	Boraginaceae	2 and 4	3, 4, 5, 7, and 9	8
55	Waleensuu	*Erythrina abyssinica*	Fabaceae	9. Shrub	3 and 4	6
56	Xaaxessaa	*Rhus natalensis*	Anacardiaceae	9. Shrub	2, 3, and 4	5

Table A5. Species Compositions of Annual Crop Production System.

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
1	Abbayyii	*Maesa lanceolata*	Myrsinaceae	4. Shade trees	2, 3, 5, and 6	1
2	Ambabbeessa/mukarbaa	*Albizia gummifera*	Fabaceae	4. Shade trees	9. Shade	2
3	Baargamoo Diimaa	*Eucalyptus camaldulensis*	Myrtaceae			3
4	Bahaa	*Strychnos spinosa*	Loganiaceae	4. Shade trees	3, 4, 5, 6, and 9	4
5	Bakkanniisa	*Croton macrostachyus*	Euphorbiaceae	4. Shade trees	2, 6, and 9	7
6	Barbaree	*Capsicum annuum*	Solanaceae			176
7	Boqqolloo	*Zea mays*	Poaceae	8. Cereals	1. Food	14850
8	Bosoqa	*Sapium ellipticum*	Euphorbiaceae	2. Timber trees	3, 5, 6, and 9	1
9	Botoroo	*Stereospermum kunthianum*	Bignoniaceae	9. shrub	3. Fuelwood	1
10	Buna	*Coffea arabica*	Rubiaceae	9. Cash crop	1. Food	40
11	Burtukaana	*Citrus sinensis*	Rutaceae	9		1
12	Caatii	*Catha edulis*	Celastraceae	9		6
13	Cadaa	*Euphorbia tirucalli*	Euphorbiaceae			33
14	Dabaaqula/Buqqee	*Dabaaqula/Buqqee*	Cucurbita pepo			4
15	Dafee/Boloqqee	*Phaseolus vulgaris*	Fabaceae			477
16	Dambii	*Ficus thonningi*	Moraceae	4. Shade trees	3, 5, and 6	1
17	Dhangaggoo	*Rhoicissus tridentata*	Vitaceae	9. Herb	1 and 6	16
18	Dinnicha Oromoo	*Plectranthus edulis*	Lamiaceae			13
19	Eebicha	*Vernonia amygdalina/schimperi*	Asteraceae	3. Forage	2, 3, 5, and 6	9
20	Geeshoo	*Rhamnus prinoides*	Rhamnaceae	9. Shrub	1 and 7	5
21	Giraaviiliyaa/Muka Qawwee	*Grevillea robusta*	Proteaceae			26
22	Harangamaa	*Maerua aethiopica*	Capparidaceae	9. Climber	8. Live fence	3

Table A5. *Cont.*

S. Number	Local Name/s of the Plant/Crop Species	Scientific Name	Family Name	Plant/Crop Typology 1. Fruit trees 2. Timber trees 3. Forage 4. Shade trees 5. Root and tuber 6. Vegetables 7. Pulse 8. Cereals 9. Others, specify	Purpose of the Plants/Crops in the System: 1. Food 2. Medicine 3. Fuelwood 4. Construction 5. Fodder 6. Soil conservation 7. Income generation 8. Others 9. Shade	Abundance of the species in the system
23	Harbuu	*Ficus sur*	Moraceae	4. Shade trees	1, 3, and 5	1
24	Hoomii	*Prunus africana*	Rosaceae	2. Timber trees	2, 3, 4, and 7	2
25	Indoodee	*Phytolacca dodecandra*	Phytolaccaceae			10
26	Kaashimiirii	*Conyza stricta*	Asteraceae			1
27	Laaftoo	*Acacia sieberiana*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	2
28	Lolchiisaa	*Bersama abyssinica*	Melianthaceae	2. Timber trees	2, 3, and 4	1
29	Loomii	*Citrus aurantiifolia*	Rutaceae			1
30	Maangoo	*Mangifera indica*	Anacardiaceae			5
31	Marga Veetiivaar					33
32	Mishingaa	*Sorghum bicolor*	Poaceae	8. Cereals	1. Food	2218
33	Mixaaxisa	*Ipomoea batatas*	Convolvulaceae	5. Root and tuber	1 and 7	34
34	Muuzii	*Musa acuminata*	Musaceae			7
35	Oobdaa	*Ficus vasta*	Moraceae	4. Shade trees	3, 5, 6, and 9	2
36	Paappayyaa	*Carica papaya*	Caricaceae			3
37	Qobboo	*Ricinus communis*	Euphorbiaceae			7
38	Qomanyoo	*Brucea antidysenterica*	Simaroubaceae	9. Shrub	2 and 3	1
39	Raafuu Habashaa	*Brassica carinata*	Brassicaceae			66
40	Reejjii	*Vernonia rueppellii*	Asteraceae	4 and 9. Shrub	3, 6, and 9	7
41	Sasbaaniyaa	*Sesbania sesban*	Fabaceae			11
42	somboo	*Ekebergia capensis*	Meliaceae	2. Timber trees	2, 3, 4, and 9	1
43	Sondii	*Acacia lahai*	Fabaceae	4. Shade trees	3, 4, 5, 6, and 9	1
44	Sootalloo	*Millettia ferruginea*	Fabaceae	4. Shade trees	2, 3, and 6	2
45	Waddeessa	*Cordia africana*	Boraginaceae	2 and 4	3, 4, 5, 7, and 9	4
46	Waleensuu	*Erythrina abyssinica*	Fabaceae	9. Shrub	3 and 4	1
47	Zayituunaa	*Psidium guajava*	Myrtaceae	1. Fruit trees	1 and 7	3

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