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EDITED BY
Anurag Dhyani,
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Duzce University, Türkiye
Aabid Hussain Mir,
Government of Jammu & Kashmir, India

*CORRESPONDENCE
Zerihun Kebebew
kebzerh@gmail.com

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Woody plants diversity and the associated provisioning ecosystem services across three contrasting forest management regimes in Southwest Ethiopia

Zerihun Kebebew [1,2]* and Claire Ozanne [1]

[1]Department of Life Sciences, University of Roehampton, London, United Kingdom, [2]Department of Natural Resources Management, Jimma University College of Agriculture and Veterinary Medicine, Jimma, Ethiopia

Woody plants are a source of provisioning ecosystem services. Coffee management impacts forest composition, structure, and diversity. We studied the effect of coffee management intensification on woody plants and their associated provisioning ecosystem services under three contrasting forest management regimes in southwest Ethiopia. The study employed mixed approaches (vegetation assessment and ethnoecological study) to collect the data. Woody plants were collected from 189 plots and perceived local ecosystem services were identified by 136 individuals through an ethnoecological approach. The total number of woody plants recorded in the natural forest, coffee forest, and coffee agroforest was 971, 945, and 521 respectively. Species richness in natural forest, coffee forest, and coffee agroforest were 57, 54, and 53 respectively. The local people perceived 17 different provisioning ecosystem services collected from the three forest types. The result showed that there is a positive relationship between the diversity and use value of woody plants across the three forest management regimes. Coffee management intensification simplifies the stand structure, woody plant composition, and ecosystem services of the forest. Plant use value increases in coffee agroforests. Coffee agroforests can serve as repositories of diversity and ecosystem services in southwest Ethiopia.

KEYWORDS
coffee forest, agroforest, use value, ethnoecology, managed forest

1 Introduction

Tropical forests are known for a high diversity of many life forms, supporting at least two-thirds of global terrestrial biodiversity (Lopez-Gomez et al., 2008; Gardner et al., 2009, Morris et al., 2014; Sistla et al., 2016; Giam, 2017). Studies have shown the conservation importance of tropical forests (Gardner et al., 2009; Hall et al., 2011). Human–forest interaction has gradually modified a natural forest to the interest of forest users (Waltert et al., 2005; Tscharntke et al., 2011; Ismail et al., 2014; Vallejo-Ramos et al., 2016; Mukul and Saha, 2017; Milheiras et al., 2020). Agroforests in forested geographical regions have evolved through the modification of natural forests (Berg et al., 2016; Gueze and Napitupulu, 2017; Sayer and Margules, 2017). Studies have shown the importance of agroforests in use and conservation of forest biodiversity (Bhagwat et al., 2008; Mukul and Saha, 2017; Udawatta et al., 2019). Management intensity determines the richness and diversity of woody species in coffee agroforests (Valencia et al., 2014).

Forests provide goods and services to local people, collectively known as ecosystem services (Ouko et al., 2018; Gouwakinnou et al., 2019; Hong and Saizen, 2019). The concept of ecosystem services was introduced as a framework to analyze socioecological systems (Carpenter et al., 2009; Cáceres et al., 2015). In Millennium Ecosystem Assessment (MEA) (2005), ecosystem services are defined as the benefits that the local people obtain from the forest. Four major groups of ecosystem services are suggested: provisioning services, regulating services, cultural services, and supporting services (Millennium Ecosystem Assessment (MEA), 2005, Ouko et al., 2018; Hong and Saizen, 2019). The value of ecosystem services varies with the interest of the local people (Cáceres et al., 2015). For forest-dependent communities, the natural forest is mainly valued for the provision of ecosystem services such as timber and non-timber forest products (Wiersum and Endalamaw, 2013; Ouko et al., 2018). In areas where the natural forest is lost or degraded, agroforests can serve as a source of timber and non-timber forest products (Dawson et al., 2013; Tadesse et al., 2014).

Woody plants are a major source of ecosystem services, including timber and non-timber forest products, that are critical to the livelihoods of local people (Bucheli and Bokelmann, 2017; Bukomeko et al., 2019; Shumi et al., 2021). Local people value the importance of forests in view of the ecosystem services provided by woody plants (Ango et al., 2014; Obayelu et al., 2017; Shumi et al., 2019). Studies have shown a positive relationship between diversity and ecosystem services of woody plants (Shumi et al., 2021). The diversity, composition, and structure of woody plants are simplified in coffee agroforests, leading to a loss of biodiversity and ecosystem services (Millennium Ecosystem Assessment (MEA), 2005).

Previous studies have applied land use and land cover as a proxy for the assessment of a given ecosystem service (Rasmussen et al., 2016; Tolessa et al., 2017; Habtamu et al., 2018). This has helped researchers to assess and quantify the value of ecosystem services (Tshewang et al., 2019). However, there is a shortcoming in the method of quantifying the actual use and perceived value of ecosystem services of the forest (Rasmussen et al., 2016; Ahammad et al., 2019). The social dimension of ecosystem service assessment reflects the values, priorities, and the interests of local people (Cáceres et al., 2015; Tshewang et al., 2019). Cáceres et al. (2015) has portrayed the value of ecosystem services from the perspective of different social actors. Local people appreciate forests for the diverse products and benefits they obtain from the forest (Bengston, 1994; Nordlund and Westin, 2011; Obayelu et al., 2017).

All woody species are not equally important to local people (Goncalves et al., 2016). Forest users intentionally promote certain woody species and discourage others based on the perceived value of the plant (Valencia et al., 2014). A study by Tadesse et al. (2014) found that biophysical and sociocultural factors determine the use value of ecosystem services. Apparent (i.e. dominance and availability) species are assumed to be the most useful plants to the users (Tunholi et al., 2013; Gueze et al., 2014; Goncalves et al., 2016). Shumi et al. (2019) have stated that property rights determine how forest users value the ecosystem services of forests.

Although coffee management practices have created multifunctional socioecological production land units (i.e., coffee agroforests) (Wiersum, 2010), intensive coffee management is degrading the natural forest, resulting a change in woody species composition and diversity across the management gradient (Hundera et al., 2013). Obtainable ecosystem services from the forests are expected to be reduced or lost (Tadesse et al., 2014). The value of coffee agroforest in providing important ecosystem services is less studied in southwest Ethiopia. We studied a forest with contrasting management regimes with the overall aim of assessing the relationship between the diversity and ecosystem services of woody plant species in southwest Ethiopia. The specific objectives of the study were 1) to examine woody plant diversity in natural forests, coffee forests, and coffee agroforests; 2) to explore changes in ecosystem services, focusing on the use value of plants; 3) to examine the relationship between woody plant diversity and ecosystem services for the local people.

2 Materials and methods

2.1 Study area

The study was conducted at Belete forest, southwest Ethiopia (Figure 1). It is located 45 km west of Jimma town. Geographically, it is found between 36° 15' E and 36° 45'E, and 7° 30' N and 7° 45'N. The study area is characterized by fragmented forest. The forest is one of a few remnants of Afromontane moist evergreen forests in southwest Ethiopia. Belete forest has been under different forest management regimes at different times (Russ, 1944). The forest is a source of livelihood for the local people living in and around the forest (Belay et al., 2013; Takashi and Todo, 2013; Belay et al., 2013). At the moment, the forest is under participatory forest management with 44 forest user groups organized to protect and use the forest. Coffee, khat (*Catha edulis*), cereal crops, and vegetables are the major agricultural crops cultivated in the area. The 2007 national population survey estimated the total population of Shebe-Sombo district to be 129,208 (men=65,414; women=63,794). The population density was 168.8 people per km^2, which is less than the population density of 184.2 people per km^2 of the Jimma zone. The population in and around the Belete forest area was approximately 48,772 individuals living in 11,012 households (Cheng et al., 1998) and is expected to have gone up considerably since then.

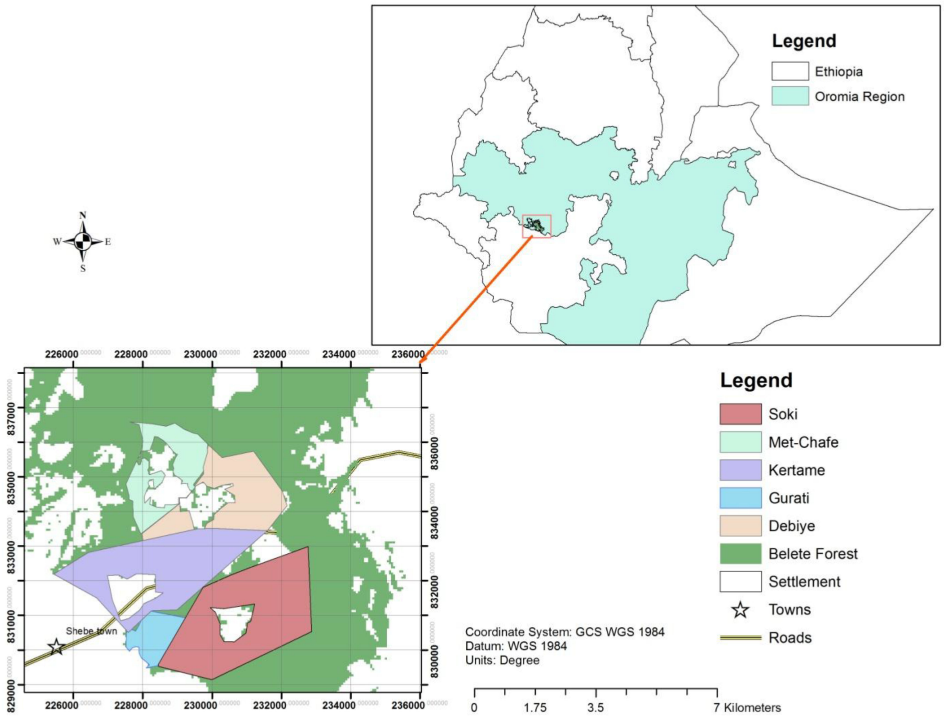

FIGURE 1
Map of Ethiopia with Oromia region, Jimma zone, location of study villages (sites).

2.2 Selecting villages and contextualizing the three forest management regimes

We visited the study sites for 3 weeks to gain an overall impression of the forest. Five study sites namely: Debiye, Meti-Chafe, Kerteme, Soki, and Gurati were purposely selected both for their forest types and accessibility and because of forest users' willingness to take part in this research. We also took into account more than a decade of past working experience to classify the study area into three levels of forest management: coffee agroforest, coffee forest, and natural forest.

Forest ethnoecological classification was the starting point to contextualize the three contrasting forest management regimes. The state of the art in the literature was used to define forest management characteristics as: coffee agroforest, coffee forest, and natural forest. The three forest types, coffee agroforest, coffee forest, and natural forest, for the purpose of the study portray the same forest under three levels of management intensity over time (Table 1).

2.3 Methods of data collection and analysis

2.3.1 Vegetation data collection and analysis

We collected vegetation data from 189 plots (each 63 plots) based on the plot-based vegetation assessment protocol as mostly used in many studies in southwest Ethiopia (Senbeta and Denich, 2006; Schmitt et al., 2010; Hundera et al., 2015). Plots of 20 m by 20 m (400 m^2) were laid out systematically where the first plot was randomly or arbitrarily selected and the next locations were spaced homogeneously throughout the survey. We selected coffee agroforest first and then coffee forest and natural forest subsequently along the transect line. The distance between the plots varied along the transect as a result of forest conditions.

TABLE 1 Description of the three contextualized forest management regimes.

Forest types	Description	Related literature
Natural forest	Forest with its original structure and composition, comparatively less disturbed and utilized. There is no management intervention. It is supposed to be a conservation zone.	Cheng et al., 1998; Schmitt et al., 2010 and Mertens et al., 2020
Coffee forest	A disturbed forest due to extraction of forest products and undergrowth removal around wild coffee. Usually, the local people use it on a communal basis and considered it a common pool of resources	Cheng et al., 1998; Labouisse et al., 2008 and Wiersum et al., 2008
Coffee agroforest	A modified natural forest for coffee production. The forest is under intensive coffee management practices such as undergrowth removal, transplanting coffee seedlings, and reduction of the upper canopy. Coffee is intensively managed for a minimum of 7 years. The local people perceive that it belongs to individuals and use it privately.	Cheng et al., 1998; Geeraert et al., 2019, Labouisse et al., 2008 and Mertens et al., 2020

Data were analyzed using the most commonly used metrics to estimate diversity such as richness, the Shannon–Wiener index, and the Simpson index. This is because richness is affected by sample size, the Shannon–Wiener index is affected by rare species, and the Simpson index is affected by common species, hence, the parallel use of these diversity measures is a general practice in ecological study (Yeom and Kim, 2011; Morris et al., 2014).

Woody species richness was computed for overall richness and included woody plants with a diameter greater than or equal to 10cm from recorded vegetation data in the coffee agroforest, coffee forest, and natural forest. We computed richness per plot for each forest type (coffee agroforest, coffee forest, and natural forest). All woody species recorded within 400 m^2 were converted into presence–absence data. Woody species richness is expressed as the number of species per forest type (Magurran, 2004; Magurran and McGill, 2011).

To test the difference of diversity for the three sample groups (coffee agroforest, coffee forest, and natural forest), data were tested for normality and homogeneity of variance before the analysis. Where these conditions were met, one-way analysis of variance (ANOVA) was used to compare diversity between the three forest types. When the assumptions were violated, the non-parametric Kruskal–Wallis H test was employed to compare the woody species richness among the three forest types. Data were organized in Microsoft Excel, and analyzed in SPSS version 25 and PAST software 3.24.

Diversity analysis was conducted for woody species with a diameter greater than or equal to 10 cm. The Shannon–Wiener index, Shannon evenness, and the Simpson diversity index were computed to compare the coffee agroforest, coffee forest, and natural forest (Magurran, 2004; Magurran and McGill, 2011). The Shannon–Wiener index (H') was calculated as:

$H' = -\sum_{i=1}^{s} pi * \ln pi$, where pi is the proportion of individuals found in the i^{th} species and ln is the natural logarithm.

Shannon evenness (E') was calculated as $E' = \frac{H}{\ln s}$ where H is Shannon diversity and S is the number of species.

The Simpson diversity index (1-D) was calculated as $1 - D = \sum pi^2$ where pi is the proportion of individuals found in the i^{th} species. Data were organized in Microsoft Excel and imported to be analyzed in SPSS version 25 and PAST software 3.24.

The ecological importance of woody plants was studied through the relative importance of the species (Cottam and Curtis, 1956; Kacholi, 2014; Teketay et al., 2018; Asigbaase et al., 2019). It was computed based on the basal area, frequency, and density of woody plants (Cottam and Curtis, 1956; Asigbaase et al., 2019; Kunwar et al., 2020) with the equation $IVI = DO + RD + RF$, where DO is the relative dominance calculated as basal area per forest type, RD is the relative density calculated as the number of individual per ha, RF is the relative frequency calculated as the proportion of individuals per forest type. The Importance Value Index (IVI) was used as a proxy for a change in the ecological importance of the coffee agroforest, coffee forest, and natural forest during coffee management intensification. The higher the value, the greater the importance of woody species in the forest.

2.3.2 Ethnoecological data collection and analysis

Ethnoecological data collection started with consulting the forest user group committee. It was guided by generating the required information rather than recruiting representative informants from the whole population. In this regard, purposive or convenience sampling was used to recruit the informants (Martin, 1995; Tongco, 2007; Longhurst, 2016; Kunwar et al., 2020). Potential participants were suggested by the forest user group committee. There was no payment for the participants except refreshment (coffee and tea). The interview and discussion were carried out in the informants' residential area because here the interviewee would be most relaxed, as has been suggested by Dawson et al. (1993). The interview was held in the local language (*Afaan Oromo* and sometimes *Amharic*) and the researcher took notes in English or translated them into English soon after the discussion.

Resampling and the concepts of saturation and triangulation were used to reduce self-bias selection and respondent bias, respectively. Resampling refers to the selection of the correct informant each time. The study activities were divided on a case-by-case basis and participants were selected for each case. Data saturation refers the point where in-depth information is captured and there is no new further information obtained when interviewing a new respondent (Wray et al., 2007; Fusch and Ness, 2015). Data triangulation refers to collecting data from multiple sources (Wray et al., 2007; Fusch and Ness, 2015). Albuquerque et al. (2017) suggested a mix of methods to triangulate ethnoecological data. An effort was made to cross-check collected data through informal discussion among the informants and data were analyzed normatively.

Ethnoecological data were collected through free listing and semi-structured interviews (Albuquerque et al., 2017; Furusawa et al., 2014; Dorji et al., 2019). Prior to free listing, the informants were briefed on the objective of the study. They were asked about the three types of forest identified for the study and all participants were in a position to distinguish coffee agroforest, coffee forest, and natural forest. Eight focus group discussions were undertaken with groups of forest users from four sites consisting of four to six individuals divided by age, either 18 to 35 years old (youth) or greater than 35 years old (old). During the interview process, the groups were asked about their perception of the benefits of the forest in their livelihoods. The questions asked were "What is/are the benefits of the forest in your surroundings?" and "Which forest type is more important to suggested forest benefits?". The groups listed the general ecosystem services of the forest they have experienced in their surroundings and ranked the relative importance of each forest type out of 100. Participating informants had grade and junior high school education and they wrote down their answers on paper. The relative importance was estimated as a percentage. The researcher distributed the paper and played a facilitator role during the process.

Cited ecosystem services were grouped into provisioning, regulating, cultural, and supporting ecosystem services as per the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment (MEA), 2005). Provisioning ecosystem services were aggregated into major categories and a semi-structured checklist was prepared for further individual interviews (Martin, 1995).

A checklist for semi-structured interviews was prepared based on the preliminary findings of the free listing. The checklist included but was not limited to questions such as “Do you collect forest product x (local name of the product)?” and “Where do you collect them?” A total of 136 forest users (107 men and 29 women) were interviewed. Furthermore, 15 focus group discussions (5 “old” groups, 5 “youth” groups, and 5 groups of women) were conducted to assess the relative importance of provisioning ecosystem services and forest types (coffee agroforest, coffee forest, and natural forest). The size of a group varied between 4 to 5 individuals. The duration of an interview and a focus group discussion differed case by case (an hour for focus group discussion and 30 mins to 40 mins for an interview).

The proportion of citations and ranking were used to organize and analyze the relative importance of provisioning ecosystem services and forest types (Martin, 1995). Indicators of forest products were used to associate forest products with the coffee agroforest, coffee forest, and natural forest (Gardener, 2014). The association was estimated based on Pearson residuals (Pearson residual = $(Observed - Expected)/\sqrt{Expected}$). Gardener (2014) stated that a Pearson residual is normally distributed and a value of −2 was designated as significant.

The use value of woody plants was estimated based on the number of citations. Woody species recorded during the inventory were organized and listed for use value estimation.

Semi-structured interviews were conducted to assess the uses of woody plants. Forest users were asked, but not limited to, the following questions: “Local name of a plant (1^{st}, 2^{nd}, 3^{rd},————64^{th})”, “Do you know the species x (local name of the plant)?”, “What is/are the uses of the plant?” (The use of planted coffee in coffee agroforest was not recorded), and “Do you remove or maintain the plant in your coffee agroforest?”. A total of 96 forest users (85 men and 11 women) were interviewed. Previous studies by Gueze et al. (2014) and Soares et al. (2017) employed similar approaches to assess the uses of plants. The number of uses were calculated from use categories of woody species developed by Albuquerque and Oliveira (2007) and Albuquerque et al. (2009). The number of woody plant uses was expressed as the total number of citations of uses. The number of use citations helped us to order or rank the relative importance of woody plant species for specific uses. The number of uses was used to categorize woody plants into three categories, namely, generalist, specialist, and versatile, following Albuquerque et al. (2009). Woody plants were considered specialist with at most two uses, generalist with at least three to five uses, and versatile with more than five (Albuquerque et al., 2009). The number of woody species per use category was used to categorize woody plants into three categories: highly redundant (>75%), redundant (25% to 75%), or not redundant (<25%) (Albuquerque and Oliveira, 2007). The concept of redundancy was adopted from the utilitarian ecological redundancy concept (Albuquerque and Oliveira, 2007). The concept refers to species with similar uses to distinguish from woody plant species with specific uses (Albuquerque and Oliveira, 2007, Santoro et al., 2015). In forest resource use, the presence of redundant species guarantees the resilience of a given system (Albuquerque and Oliveira, 2007; Santoro et al., 2015).

A change in provisioning ecosystem services across the coffee agroforest, coffee forest and natural forest was assessed based on plant use value (Phillips and Gentry 1993; Castaneda and Stepp, 2007; Andrade-Cetto and Heinrich, 2011; Faruque et al., 2018). Use value was calculated as where u refers the number of uses mentioned by forest users and n refers the total number of forest users interviewed (Phillips and Gentry 1993; Faruque et al., 2018). The total use values of the coffee agroforest, coffee forest, and natural forest were calculated as the summation of the use value of all woody species recorded within each forest type (Andrade-Cetto and Heinrich, 2011; Ouedraogo et al., 2014). The Kruskal–Wallis H test was used to compare differences in the ecosystem services (benefits) between the natural forest, coffee forest, and coffee agroforest.

Relative frequency citations (RFC) were used as the consensus on woody species that were retained or removed from the coffee agroforest. Relative frequency citations were expressed as the number of times a particular species was mentioned as being retained divided by the total number of interviewees (Faruque et al., 2018). One way of understanding the effect of forest modification for coffee production is to relate ecologically important woody species and the uses of woody species (Gueze et al., 2014). Spearman’s rank correlation was conducted to investigate the relationship between the availability of woody species and plant uses (Sop et al., 2012; Gueze et al., 2014). Woody species availability across the coffee agroforest, coffee forest, and natural forest was based on phytosociological metrics (relative density, relative frequency, and dominance) (Albuquerque et al., 2009). Ethnoecological data were summarized descriptively (Jalilova and Vacik, 2012; Ahammad et al., 2019) using Microsoft Excel and imported to SPSS version 25 for the non-parametric analytical Spearman’s rank correlation test.

3 Results

3.1 Woody species richness and diversity

The results showed overall richness decreased from natural forest to coffee forest and coffee agroforest (Table 2). The number of species recorded in the natural forest, coffee forest, and coffee agroforest were 57, 54, and 53 respectively. The abundance of woody plants was reduced almost by half in the coffee agroforest. A comparison of the three forest types showed a significant difference in woody species richness (Kruskal–Wallis test ($\chi^2(2)$= 90.1, P<0.05 (Table 2, Supplementary Figure S1). Pair-wise comparisons showed that richness was significantly greater in the natural forest compared to the coffee forest and coffee agroforest (Supplementary Figure S1).

The Shannon diversity index of the natural forest, coffee forest, and coffee agroforest, was 3.33, 3.42, and 3.07, respectively. Similarly, the Simpson diversity index of the three forests was 0.92, 0.96, and 0.95, respectively. The result showed that there was more diversity in the coffee forest compared to the natural forest and coffee agroforest. There was a significant difference in the Shannon diversity index and Simpson diversity index among the three forest types. One-way ANOVA showed that there was more diversity in the coffee forest compared to the coffee agroforest (H’=

TABLE 2 Woody species richness and diversity in coffee agroforest, coffee forest, and natural forest. Plot area 400 m^2 (20 m x 20 m).

Parameters	Natural forest	Coffee forest	Coffee agroforest	P-value
Individuals	971	945	521	**
Richness	57	54	53	*
Richness (Dbh>=10cm)	47	49	48	ns
Shannon diversity index (H')	3.33	3.42	3.07	*
Evenness (J)	0.86	0.87	0.79	ns
Simpson diversity index (1-D)	0.95	0.96	0.92	*

* significant; ** highly significant; ns, not significant.

$F_{2,12}$ = 0.236, P<0.05,1-D=$F_{2,12}$ = 0.004, P<0.05) (Supplementary Table S1).

3.2 Perceived ecosystem services

The findings showed that the local people valued the forest for multiple benefits such as provisioning, supporting, regulating, and cultural ecosystem services. A total of 26 ecosystem services were acknowledged by forest users (Table 3), of which 69% were categorized as provisioning ecosystem services. The coffee agroforest was acknowledged mainly for the provision of managed coffee, timber, and charcoal ecosystem services. The coffee forest was acknowledged for the provision of non-timber forest products such as wild coffee, spice, and pepper. The natural forest was acknowledged for regulating microclimate, increasing rainfall, wildlife habitat, and honey production.

The individual interview results showed that forest users interact with the forest mainly for coffee (90%), fuelwood (87%), liana (64%), and construction materials (51%) (Figure 2). Major non-timber forest products such as wild coffee, spice, pepper, and mats and baskets (*Yebboo*) were becoming less used. Coffee was harvested on an annual basis, fuelwood 2–3 times per week, liana occasionally, and construction materials every 2 to 3 years (simple construction) or 7 to 10 years (house construction). The findings also showed that the relative importance of provisioning ecosystem services varies with time and technology.

Forest users reported that the coffee agroforest was mainly a source of coffee, fuelwood, timber, and other benefits (Table 4). Forest users occasionally move to the coffee forest and natural forest only for a few ecosystem services such as honey production, lianas, and, to some extent, construction materials and farm tools. The actual use of provisioning ecosystem services indicates the relative importance of the coffee agroforest over the coffee forest and natural forest.

TABLE 3 Ecosystem services based on forest users' perspective.

Ecosystem services	Description	Frequency citation (%)
Provisioning (17)	Wild coffee, Managed coffee, Spice, Honey, Construction materials, Fuelwood, Timber, Liana, Farm tools, Medicinal plants, Pepper, Charcoal, Wild edible plants, Mats and baskets (*Yebboo*), Furniture, Beehive material, Fodder	69
Supporting (6)	Bee forage, Grazing, Placing beehive, Protect soil erosion, Wildlife habitat, Coffee land	23.1
Regulating (2)	Regulate microclimate, Increase rainfall	7.7
Cultural (1)	Walking/Recreation	3.8

The number in bracket indicates the number of ecosystem service citations.

3.3 Relationship between woody species diversity and ecosystem services

A total of 33 different uses were associated with recorded woody species (Supplementary Table S2). A single ecosystem service could be obtained from multiple sources. The result showed that most of the woody species were generalist and versatile species.

The wood species used for fuelwood and construction materials were highly redundant, whereas the woody species used for mats and baskets, timber, tool handles, farm tools and furniture were less redundant (Supplementary Table S3).

Coffee is positively associated with the coffee agroforest and negatively associated with the natural forest and coffee forest. Fuelwood, honey, construction materials, and farm tools were positively associated with the coffee agroforest, coffee forest, and natural forest. Lianas were positively associated with the natural forest and negatively associated with the coffee agroforest. Timber was positively associated with the coffee agroforest. Non-timber forest products such as spice, pepper, and mats and baskets were positively associated with the coffee agroforest and coffee forest (Figure 3).

Coffee management intensification modifies the forest composition and structure by reducing the number of stems. Nevertheless, the use value of highly encouraged woody species such as *Albizia gummifera*, *Cordia africana*, and *Milletia ferruginea* decreased from coffee agroforest to natural forest. In contrast, the use value of those discouraged species such as *Noronhia mildraedii, Rothmannia urcelliformis*, and *Oxyanthus speciosus* increased (Supplementary Table S4). Figure 4 shows woody species abundance in the three forest management regimes and associated use value. The result showed that both woody species

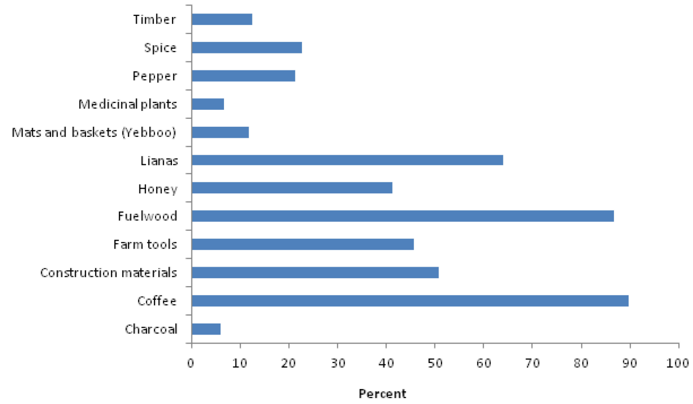

FIGURE 2
The proportion of forest users who reported actual use of provisioning ecosystem services. The result shows aggregated provisioning ecosystem services across all forest types.

abundance and total use value were lower in the coffee agroforest compared to the natural forest and coffee forest. The relationship between woody species use value and ecological importance was tested using Spearman's correlation. Spearman's correlation showed a significant moderate positive correlation for the natural forest and coffee forest, respectively (r_s=0.312, P<0.05; r_s=0.435, P<0.01) and a significant positive strong correlation for the coffee agroforest (r_s=0.625,P<0.01) (Figure 5).

3.4 Discussion

3.4.1 Woody species richness and diversity

Woody plant diversity and availability are determinant factors in plant usage (Soares et al., 2017). The current status of forest biodiversity varies with intensity of land use (Chazdon et al., 2009; Phillips et al., 2017). Coffee production is one form of land use that modifies the natural forest. Coffee agroforests have great potential to conserve forest biodiversity (Ismail et al., 2014). Coffee management removes undergrowth or understory plants in coffee agroforests. Interest has grown in human-managed landscapes in forest biodiversity conservation. Woody species diversity indicates the status of forest biodiversity under human management systems. Species richness per plot (i.e., all woody plants recorded with abundance data) decreased from the natural forest to the coffee forest to the coffee agroforest.

In contrast to our expectations, woody species with a diameter greater than or equal to 10cm richness decreased from the coffee agroforest towards the natural forest. Higher numbers of woody species were found in the coffee forest and coffee agroforest than the natural forest. Silvicultural practices that encourage tree species in the coffee agroforest were maintaining desired trees and not clearing the seedlings of desired tree species. These contributed a greater number of pioneer species such as *Albizia gummifera*, *Milletia ferruginea*, and *Cordia africana* in the coffee agroforest. The higher species richness in the coffee agroforest compared to the natural forest was attributed to land use history and other factors related to the environment rather than silvicultural treatment. Studies have shown land use history affects woody plant species richness (Shumi et al., 2018; Kumsa et al., 2016; Arnell et al., 2019). As stated in literature four decades ago (McCann, 1997), Belete forest was under logging, implying the removal of timber tree species from the natural forest. Commercial logging was not carried out in the coffee agroforest. Moreover, coffee management practices involve slashing understory plants to create vacant space for planting coffee and avoid competing vegetation, as well as the thinning or stem reduction of canopy trees. The reduction of bigger trees (DBH >=10cm) is carried out to remove heavy shade on coffee plants. But the higher number of trees with a DBH greater than 10cm in the coffee agroforest implies the removal of understory plants for coffee intensification. The bigger trees (DBH>=10cm) are scattered and so there is no need to reduce the canopy trees. Decuyper et al. (2018) has stated that forest utilization in southwest Ethiopia has a greater effect on the undergrowth plants than on the canopy tree species. According to Decuyper et al. (2018), a coffee forest has canopy

TABLE 4 Local value of the coffee agroforest, coffee forest, and natural forest.

Provisioning ecosystem services	Coffee agroforest	Coffee forest	Natural forest
Charcoal	8	5	0
Coffee	121	3	0
Construction materials	43	34	39
Farm tools	28	29	35
Fuelwood	105	65	10
Honey	36	12	22
Lianas	1	5	83
Mats and baskets (*Yebboo*)	6	5	7
Medicinal plants	4	7	1
Pepper	24	13	1
Spice	13	16	0
Timber	18	0	1

The number of times forest users cited provisioning ecosystem services.

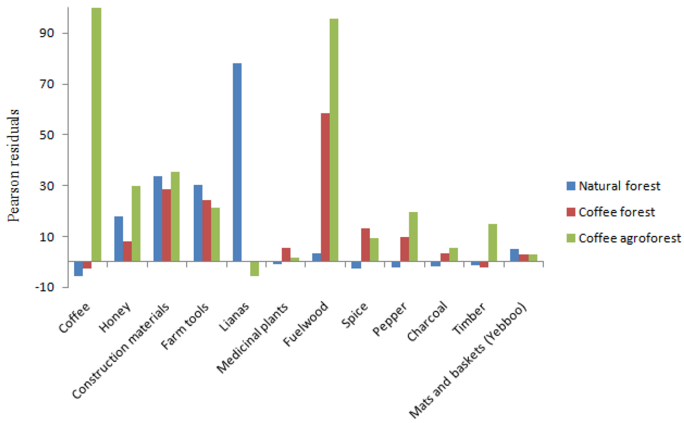

FIGURE 3
Actual provisioning ecosystem services use association with the coffee agroforest, coffee forest, and natural forest. A value of 2 was considered the threshold of significant provisioning ecosystem services (Gardener, 2014). Pearson residuals show the association between use and forest type.

openness as when the undergrowth plants are removed the gaps created are sufficient for coffee and there is no need for further thinning of canopy trees. Existing bigger trees left *in situ* result in a coffee agroforest containing a greater number of woody plants. Natural forest modification to coffee agroforest has contributed to a reduction in commercial logging in coffee agroforests because commercial logging does not take place here.

The current study findings show that many woody species are maintained in coffee agroforests. Study findings from Mexico by Valencia et al. (2014) showed lower species richness in a coffee agroforest at the plot level and comparable species richness at the landscape level compared to an adjacent natural forest.

We found that the Shannon diversity index of the natural forest, coffee forest and coffee agroforest was 3.33, 3.42, and 3.07, respectively. The Shannon diversity index usually ranges between 1.5 and 3.5, and rarely surpasses 4.5 (Bibi and Ali, 2013; Travlos et al., 2018). The Shannon diversity index of the coffee agroforest

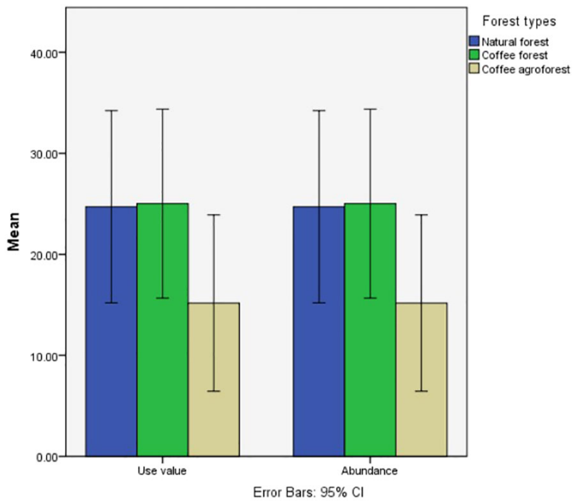

FIGURE 4
Woody species abundance and total use value in the natural forest, coffee forest, and coffee agroforest.

(i.e., 3.07) was found to be high (Magurran, 2004; Arzamani et al., 2018). The Shannon diversity index result showed that the coffee forest had the highest woody species diversity. The finding supports the intermediate disturbance hypothesis in that species diversity is highest at an intermediate disturbance level (Bongers et al., 2009). Similarly, the Simpson diversity index of the coffee agroforest, coffee forest, and natural forest was found to be 0.92, 0.96, and 0.95 respectively. Likewise, the Simpson diversity index result showed the highest diversity in the coffee forest. The Simpson diversity index ranges between 0 and 1. The Simpson diversity index value of 0 shows similarity within a community and a value of 1 shows diversity (Bibi and Ali, 2013; Travlos et al., 2018; Atsbha et al., 2019). The present study finding shows high diversity across the three forest management regimes.

3.4.2 Ecosystem services

The forest is a source of livelihood for local people (Ouedraogo et al., 2014). Our study highlighted forest users' perspectives of ecosystem services provided by modified forests in general and the coffee agroforest, coffee forest, and natural forest in particular. Forest ecosystem services can be expressed as provisioning, regulating, supporting, and cultural benefits of the forest (Millennium Ecosystem Assessment (MEA), 2005). Forest users reported these four major categories of ecosystem services. However, our findings showed that forest users value the provisioning ecosystem services of the forest more than the other ecosystem services, showing the local relative importance of the coffee agroforest to forest users. In total, 17 out of the 26 freely listed forest ecosystem services were related to provisioning ecosystem services. Forest users interact with the forest mainly for coffee and fuelwood collection and to a lesser extent for other forest products. Comparing the three forest types with regard to the most important forest products, forest users unequivocally value the coffee agroforest the highest. This is because the coffee agroforest is a source of managed coffee. A previous study in southwest Ethiopia by Tadesse et al. (2014) showed that coffee is valued highly for its high cash value. Studies from other areas have also shown that

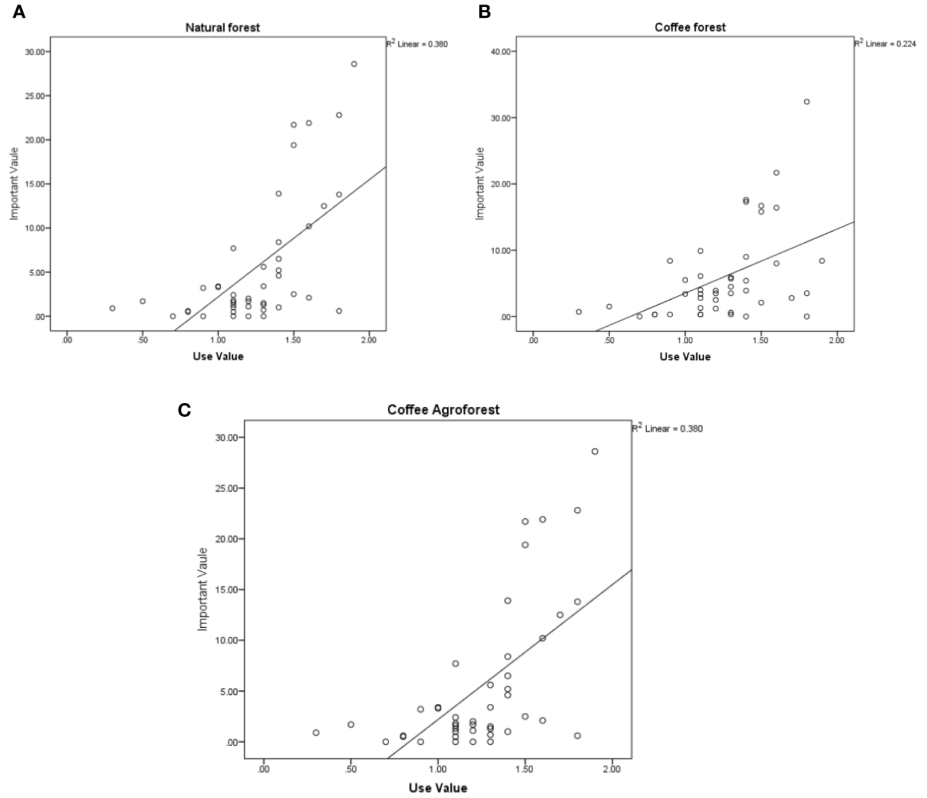

FIGURE 5
Relationship between plant use value and Important Value Index across three contrasting forest management regimes: **(A)** natural forest; **(B)** coffee forest; **(C)** coffee agroforest.

forests are most used for provisioning ecosystem services. For example, a study from India showed that a traditional agroforest was a source of provisioning ecosystem services such as fruit, timber, fuelwood, fodder, and medicinal plants (Dhanya et al., 2014). Another study from southeastern Burkina Faso by Ouedraogo et al. (2014) showed that provisioning services were the most cited ecosystem services.

The relative importance of provisioning ecosystem services and the forest types showed the value of those services and their sources to forest users. Most provisioning ecosystem services were extracted for subsistence use from the coffee agroforest. An interesting finding of the study is that there is a difference in potential and actual ecosystem services of the forest. Forest users gave greater priority to the economic benefits of the forest than to the ecological and social benefits of the forest. A study by Ango et al. (2014) showed that coffee and honey were the most important cash-generating ecosystem service for most forest users in southwest Ethiopia.

3.4.3 Relationship between woody species diversity and ecosystem services

Three types of plant uses were identified: specialist, generalist, and versatile (Albuquerque et al., 2009). Woody plants with at most two uses were grouped as specialist and those with three to five uses were grouped as generalist. Woody plants with more than five uses were grouped as versatile species (Albuquerque et al., 2009). Only a few woody species were grouped as specialist species. For example, two uses were reported for *Brucea antidysenterica* and *Dracaena steudneri*. *Alangium chinense, Albizia gummifera*, and others were among the generalist species. *Allophylus abyssinicus*, *Apodytes dimidiata, Olea welwitschii, Prunus africana, Syzygium guineense*, and others had versatile uses (Albuquerque et al., 2009). More than 90% of the woody plants were used for fuelwood. Furthermore, more than 80% and 50% of woody plants were used for construction and medicinal value, respectively.

Woody plant diversity and availability are determinant factors in plant usage (Soares et al., 2017). Availability and plant use across the natural forest, coffee forest, and coffee agroforest were studied through phytosociology (relative density, relative frequency, and dominance) and use value. Woody plants were categorized into three categories, namely, highly redundant, redundant, and less redundant, based on specific uses with arbitrary cut-off points (Albuquerque and Oliveira, 2007) greater than 75%, between 25% and 75%, and less than 25%, respectively. These showed the benefit lost as a result of woody plant removal during coffee intensification. For instance, the benefit that derived from a specific sources (i.e., woody plant species) might be lost along with tree removal. High redundancy showed that specific uses could be obtained from more than 75% of the available woody plant species. Similarly, redundant and less redundant showed that species uses could be obtained from between 25% to 75%, and less than 25% of available woody plant species respectively.

Some of the woody species were highly encouraged in coffee agroforest; as a result many woody species were commonly maintained in the coffee agroforest. There was no coffee management practice such as weeding and cutting that would discourage these plant species from the system. Their seedlings were encouraged to grow by removing competing grasses around them. Woody species such as *Milletia ferruginea* and *Albizia gummifera* were highly encouraged for coffee shade whereas *Cordia africana* and *Aningeria adolfi-friederici* were some of the highly encouraged woody species for timber. *Cordia africa* is widely used in the area for making furniture. Woody species that are mainly discouraged in the coffee agroforest, such as *Bersama abyssinica, Brucea antidysenterica, Justicia schimperiana* and *Maesa lanceolata*, had medicinal values. Lianas, which are almost absent from the coffee agroforest, can be used for fuelwood, construction material (building material for traditional houses, fencing, and traditional beehive making), bee forage, and as income through generating cash. *Astropanax abyssinica* is known as the honey tree for its popularity as bee forage. Coffee shade and multiple uses of woody species did not justify the reason for encouraging some trees and discourage others in the coffee agroforest. For instance, eight uses were mentioned for *Clausena anisata and Calpurnia aurea* where highly encouraged coffee shade trees *Albizia gummifera* and *Diospyros abyssinica* had five and four uses, respectively.

Coffee forest biodiversity has been receiving increasing attention for conservation. Some woody species are removed and others are maintained in coffee agroforests in southwest Ethiopia. Our study findings showed that woody species are encouraged in coffee agroforests not only for shade but also for other uses. *Albizia gummifera* and *Milletia ferruginea* are encouraged mainly for shade whereas *Cordia africana* and *Aningeria adolfifriederici* were encouraged for timber. *Diospyros abyssinica* was cited most for construction materials and *Polyscia fulva* was cited for traditional beehive making. *Astropanax abyssinica* was cited for bee forage. Forest users interact with the forest for plant use (Maroyi, 2012). The present study findings showed that although 33 different uses of plants were identified, only three to five were utilized most of the time. Fuelwood and construction materials were the main uses of woody plants. The potential uses of woody species do not indicate the actual use of woody plants in most cases (Ahammad et al., 2019).

Woody plant use citations show that forest users have the knowledge but forest modification is a matter of immediate benefit priority. The literature has shown that location, locally available resources, and plant knowledge increases the use and conservation of forest biodiversity (Pieroni and Soukand, 2018). Plant uses are also one form of the forest biodiversity conservation model (Albuquerque et al., 2009). The specialist, generalist, and versatile uses of woody plants indicate the importance of woody plants and their conservation value. Twelve different uses were reported for *Apodytes dimidiata*, whereas, the relative frequency of citation (RFC) was less than woody species with a fewer number of uses such as *Cordia africana, Milletia ferruginea, Aningeria adolfi-friederici*, and *Albizia gummifera.*

We showed that woody species availability and uses differ across the natural forest, coffee forest, and coffee agroforest. Woody plants can be categorized into high redundant, redundant and less redundant categories based on number of specific uses per species. This shows the diversification of plant use (Albuquerque et al., 2009) and has implications for woody plant conservation. The use of highly redundant species reduces pressure on woody species whereas use of less redundant species increases pressure on woody plants (Albuquerque and Oliveira, 2007). Forest users reported that they use available dried wood and branches of woody plants for fuelwood instead of specific woody species for fuelwood. The study findings also showed there was a change in most use values during forest modification to coffee production. Nevertheless, coffee agroforest increased the shade and timber use value of woody species. The well-known timber tree *Cordia africana* is more abundant in the coffee agroforest than in the coffee forest and natural forest. Similarly, the shade value of woody plants was apparent in the coffee agroforest.

A previous study by Gueze et al. (2014) in the Bolivian Amazon on the relationship between the Importance Value Index and useful value tree species showed a positive relationship between the Importance Value Index and overall use value. Kunwar et al. (2020) reported a weak relationship between plant use value and phytosociological indicators in Nepal. Our findings showed that there are moderate positive correlations between the Importance Value Index and overall woody plant use value for the natural forest and coffee forest and a strong positive correlation for the coffee agroforest.

3.5 Implications for forest management

The findings of the study have implications for the use and conservation of forest resources in southwest Ethiopia. Ignoring local value and perspectives of forest use has a negative impact on the sustainable forest management approach. Local people value the three types of forest differently and their management differ accordingly. Coffee agroforest is an area where the local people undertake silvicultural practices. The assumption that there is a reduction in woody plant species richness and diversity needs reconsideration to take into account the actual use value and relative importance of the forest to local people. Forest modification to coffee agroforest increases the actual use value and relative importance value of the forest for timber and reduces the use value of non-timber forest products and construction materials. Woody plant species that can be used for timber, traditional beehives, farm tools, tool handles, and mats and baskets are limited and need conservation priority in coffee agroforest. Coffee management removed non-timber forest products including spice, pepper, and liana and the conservation of plant species that supply non-timber forest products in coffee agroforest needs special attention. Our findings can help to establish a foundation for sustainable forest management. The findings also showed the importance of a multidisciplinary approach in studying the use and conservation of forest resources.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The research for this project was submitted for ethics consideration under the reference LSC 18/233 in the Department of Life Sciences and was approved under the procedures of the University of Roehampton's Ethics Committee on 11.04.18. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the study was conducted in rural area where many people can read and write. So, it was decided to obtain informed oral consent.

Author contributions

ZK: Writing – original draft, Writing – review & editing. CO: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2024.1382843/full#supplementary-material

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