Woody plants diversity and the associated ecosystem service across three contrasting forest management regime in Southwest Ethiopia

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Abstract

Coffee management intensification has simplified the stand structure and composition of woody plants in southwest Ethiopia. It is believed that a change in woody plant diversity could results in loss of ecosystem service. Nevertheless, information on the effect of coffee management intensification on ecosystem services is limited. The study aim to give an answer for whether forest modification to coffee agroforest brings about a loss in ecosystem services in southwest Ethiopia. The specific objectives were 1) to examine woody plant diversity across contrasting forest management regime 2) to explore changes in ecosystem services focusing on forest products 3) to examine the relationship between woody plants diversity and ecosystem services as perceived and used by local people. Mixed approaches were employed to collect the data. The forest was divided into three contrasting management regimes. Vegetation data were collected from 189 plots. Ethnoecological approach was employed to assess ecosystem services. Perceived local ecosystem services were collected from 136 individuals. The relationship between ecosystem services and diversity were estimated based on the use value approach. 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 simplify both the stand structure, woody plant composition and ecosystem services of the forest. Plant use value increases towards coffee agroforest. Coffee agroforest can serve as repository of diversity and ecosystem services in southwest Ethiopia.

Key words: Coffee forest, agroforest, use value, ethnoecology, managed forest

1. Introduction

Tropical forests are known for high diversity of many life forms, apparently supporting at least two-thirds of global terrestrial biodiversity (Lopez-Gomez et al. 2008, Gardner et al. 2009, Morris 2010, Sistla et al. 2016, Giam 2017). Studies have shown the conservation importance of tropical forest (Gardner et al. 2009, Hall et al. 2011). Human-forest interaction has gradually modified a natural forest to the interest of forest user (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). Agroforest in forested geographical region is evolved through modification of the natural forest (Berg et al. 2016, Gueze and Napitupulu 2017, Sayer and Margules 2017). Studies have shown the importance of agroforest 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 agroforest (Valencial et al. 2015).

Forest provides 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 service was introduced as a framework to analyze socioecological systems (Carpenter et al. 2009, Caceres et al. 2015). In 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 (MEA 2005, Ouko et al. 2018, Hong and Saizen 2019). The value of ecosystem service varies with the interest of local people (Caceres et al. 2015). For forest dependent community 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 agroforest can serve as the source of timber and non-timber forest products (Dawson et al. 2013, Tadesse et al. 2014).

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

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

All woody species are not equally important to the local people (Goncalves et al. 2016). Forest users intentionally promote certain woody species and discourage others based on the perceived value of the plant (Valencial et al. 2015). A study by Tadesse et al. (2014) found that factors related to biophysical and sociocultural determine the use value of ecosystem services. Apparant (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 property rights determine how the forest users value the ecosystem services of the forest.

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 service from the forest is 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 regime 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 forest, coffee forest and coffee agroforest 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 to the local people.

2. Material and Methods

2.1 Study area

The study was conducted at Belete forest, southwest Ethiopia (Figure 1). It is located at 45 km west of Jimma town. Geographically, it is found between 36^0 15' E and 36^0 45'E, and $7^0$30' N and $7^0$45'N. The study area is characterised by fragmented forest. The forest is one of a few remnant Afromontane moist evergreen forests in southwest Ethiopia. Belete forest has been under different forest management regime at different time (Russ 1944). The forest is a source of livelihoods for the local people living in and around the forest (Belay et al. 2013, Takahashi and Todo 2012, 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 were the major agricultural crops cultivated in the area. The most recent population data for the Shebe-Sombo district is the 2007 national population survey, which estimated the total population of Shebe-Sombo district as 129208 (male= 65414, F=63794). 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 Jimma zone. The population in and around Belete forest area was approximately 48772 individuals living in 11012 households (Cheng et al. 1998) and is expected to have gone up considerably since then.

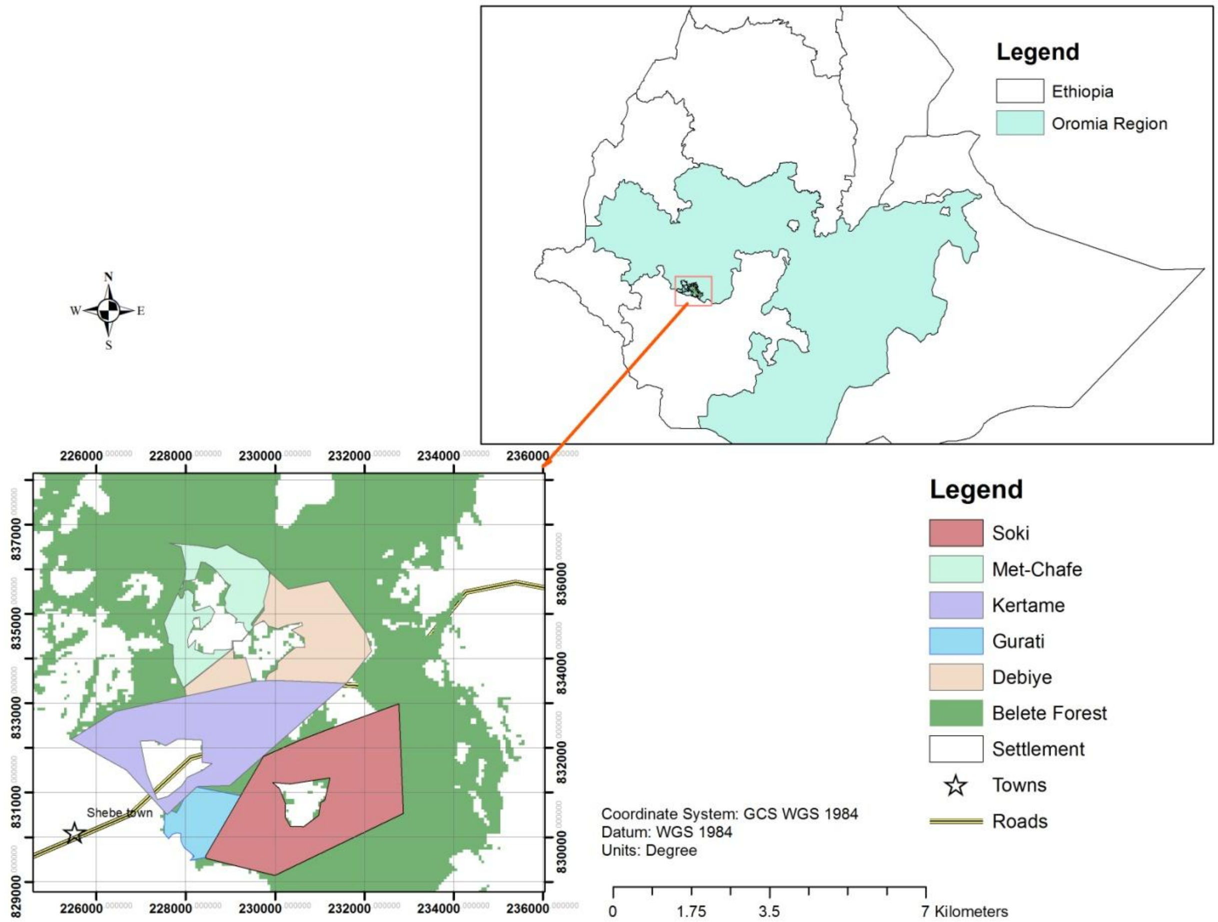

Figure 1**.** Map of Ethiopia with Oromia region, Jimma zone, location of study villages (sites)

2.2 Selecting villages and contextualising the three forest management regimes

We visited the study sites for three weeks to gain overall impression of the forest. Five study sites namely: Debiye, Meti-Chafe, Kerteme, Soki and Gurati were purposively selected both for their forest types, accessibility and because of forest users willingness to take part in this research. The researcher also took into account more than a decade past working experience to define as one containing the 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 of 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 management intensity over a time (Table 1).

Table 1. Description of contextualized three forest management regimes

Forest types	Description	Related literatures
Natural forest	Forest with its original structure and composition, comparatively less disturbed and utilized. There is no management intervention. It is supposed to be 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 communal basis and considered it a common pool 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 upper canopy. Coffee is intensively managed a minimum of seven years. The local people perceive it belongs to individual and use it privately.	Chenge et al. 1998, Geeraert et al. 2019, Labouisse et al. 2008 and Mertens et al. 2020

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). A plot size of 20 m by 20 m ($400m^2$) were laid systematically where the first plot is randomly or arbitrarily selected and the next locations 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 plot varies along the transect as a result of forest condition.

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

Woody species richness was computed for overall richness and woody plants with 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 400m^2 were converted into presence-absence data. Woody species richness is expressed as the number of species per each forest types: the coffee agroforest, coffee forest and natural forest (Magurran 2004, Magurran and McGill 2011).

To test the difference of diversity for three sample groups (coffee agroforest, coffee forest and natural forest) data were tested for normality and homogeneity of variance before the analysis. Where these 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 between 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 diameter greater than or equal to 10 cm. Shannon-Wiener index, Shannon Evenness and Simpson index were computed to compare the coffee agroforest, coffee forest and natural forest (Magurran 2004, Magurran and McGill 2011). 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 ith 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.

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

Ecological importance of woody plants were studied through the relative importance of the species IVI) (Cottam and Curtis 1956, Kacholi et al. 2014, Teketay et al. 2018, Asigbaase et al. 2019). It was computed based on 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 types, RD is the relative density calculated as the number of individual per ha, RF is the relative frequency calculated as the proportion of individual per forest types. Importance Value Index (IVI) was used as a proxy for a change in ecological important 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 a representative informants to 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). A potential participants were suggested by the forest user group committee. There was no payment for the participants except refreshment in a form of coffee and tea. The interview and discussion were carried out in the informants residential area because here the interviewee would be most relaxed and this has also been suggested by Dawson et al. (1993). The interview was held in local language (*Afaan Oromo* and sometimes *Amharic*) and the researcher took notes in English or translated into English soon after the discussion.

Resampling, and the concept of saturation and triangulation were used to reduce self bias selection and respondent bias, respectively. Resampling refers the selection of the right informant each time. The study activities were divided into case by case and participants were selected for each case. Data saturation refers the point where in-depth information is captured and there is no further new information obtained when interviewing a new respondent (Wray et al. 2007, Fusch and Ness 2015). Data triangulation refers 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. Effort was made to cross check collected data through informal discussion among the informants and analyzed normatively.

Free listing and semi-structured interviews were ethnoecological tools employed to generate data (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 4 to 6 individuals divided by age, either 18 to 35 years (youth) or greater than 35 years (old). During the interview process the groups were asked about their perception of the benefits of the forest in their livelihoods. The question asked was stated as what is/are the benefits of the forest in your surrounding? 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 rank the relative importance of each forest type out of 100. Initially it was thought to use beans for estimating the relative importance. Fortunately participated informants had grade and junior high school education and they wrote down on a paper. The relative importance was estimated based on percentage out of 100. The researcher distributed paper and played a facilitator role during the process.

Cited ecosystem services were grouped into provisioning, regulating, cultural and supporting ecosystems services as per millennium ecosystem assessment (MEA 2005). Provisioning ecosystem services were aggregated into major categories and a semi-structured checklist was prepared for further individual interview (Martin 1995).

A checklist for semi- structured interview 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)? Where do you collect them? A total of 136 forest users (107 males and 29 women) were interviewed. Furthermore 15 focus group discussions (5 groups old, 5 groups youth, 5 groups 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 minutes to 40 minutes 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 residual (Person residual= $(Observed - Expected)/\sqrt{Expected}$). Gardener (2014) stated a Pearson residual is normally distributed and a value of -2 as a significant.

The use value of woody plants was estimated based on 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 statement as following questions, Local name of a plant (1st, 2nd, 3rd,----------- 64th), 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 were not recorded) and Do you remove or maintain the plant in your coffee agroforest. A total of 96 forest users (85 man 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 were expressed as the total number of citation of uses. The number of use citation helped to order or rank the relative importance of woody plant species for specific uses. The number of uses were used to categorize woody plants into three categories generalist, specialist and versatile following Albuquerque et al. (2009). Woody plants were considered as specialist with at most 2 uses, generalist with at least 3 to 5 uses and versatile with more than 5 (Albuquerque et al. 2009). The number of woody species per use categories were used to categorize woody plants into three categories highly redundant(>75%), redundant (25% to 75%), not redundant (<25%) (Albuquerque et al. 2007). The concept of redundancy is adopted from ecological redundancy for utilitarian concept (Albuquerque et al. 2007). The concept refers to species with similar uses to distinguish from woody plant species with specific use (Albuquerque et al. 2007,Santoro et al. 2015). In forest resources use the presence of redundant species guarantees the resilience of a given system (Albuquerque et al. 2007,Santoro et al. 2015).

A change in provisioning ecosystem services across the coffee agroforest, coffee forest and natural forest were 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 $UV = \sum u/n$ 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 uses value 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 types (Andrade-Cetto and Heinrich 2011, Ouedraogo et al. 2014). A Kruskal Wallis H test was used to compare a difference in the ecosystem services (benefits) between the natural forest, coffee forest and coffee agroforest.

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

3. Result

3.1 Woody species richness and diversity

The result showed overall richness is decreasing 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 reduced almost by half in coffee agroforest. 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, Figure S1). Pair wise comparisons showed that richness was significantly greater in the natural forest compared to coffee forest and coffee agroforest (Figure S1).

The Shannon diversity indices of the natural forest, coffee forest and coffee agroforest, coffee forest and natural forest were 3.33, 3.42 and 3.07 respectively. Similarly, the Simpson diversity indices of the three forests were 0.92, 0.96 and 0.95 respectively. The result showed more diversity in coffee forest compared to natural forest and coffee agroforest. There was a significant difference in Shannon index and Simpson indices among the three forest types. One way ANOVA showed more diversity in coffee forest compared to coffee agroforest (H'= $F_{2,12}$=0.236, P<0.05, 1-D=$F_{2,12}$=0.004, P<0.05) (Table S1).

Table 2. Woody species richness and diversity in coffee agroforest, coffee forest and natural forest. Plot area 400m^2 (20m x20m).

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	*

3.2 Perceived Ecosystem Services

The findings showed that the local people value 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 categorised under provisioning ecosystem services. Coffee agroforest was acknowledged mainly for provisioning of managed coffee, timber and charcoal ecosystem services. Coffee forest was acknowledged for provisioning of non-timber forest products such as wild coffee, spice and pepper. Natural forest was acknowledged for regulating microclimate, increasing rainfall, wildlife habitat and honey production.

Table 3. Ecosystem services based on forest users perspective. The number in bracket indicates number of ecosystem services citations

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

Individual interviews result showed that forest users interact with 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 is harvested on an annual basis, fuelwood 2-3 times per week, liana occasional and construction materials every 2 to 3 years (simple construction) and 7 to 10 years (houses construction). The findings also showed that the relative importance of provisioning ecosystem services varies with time and technology.

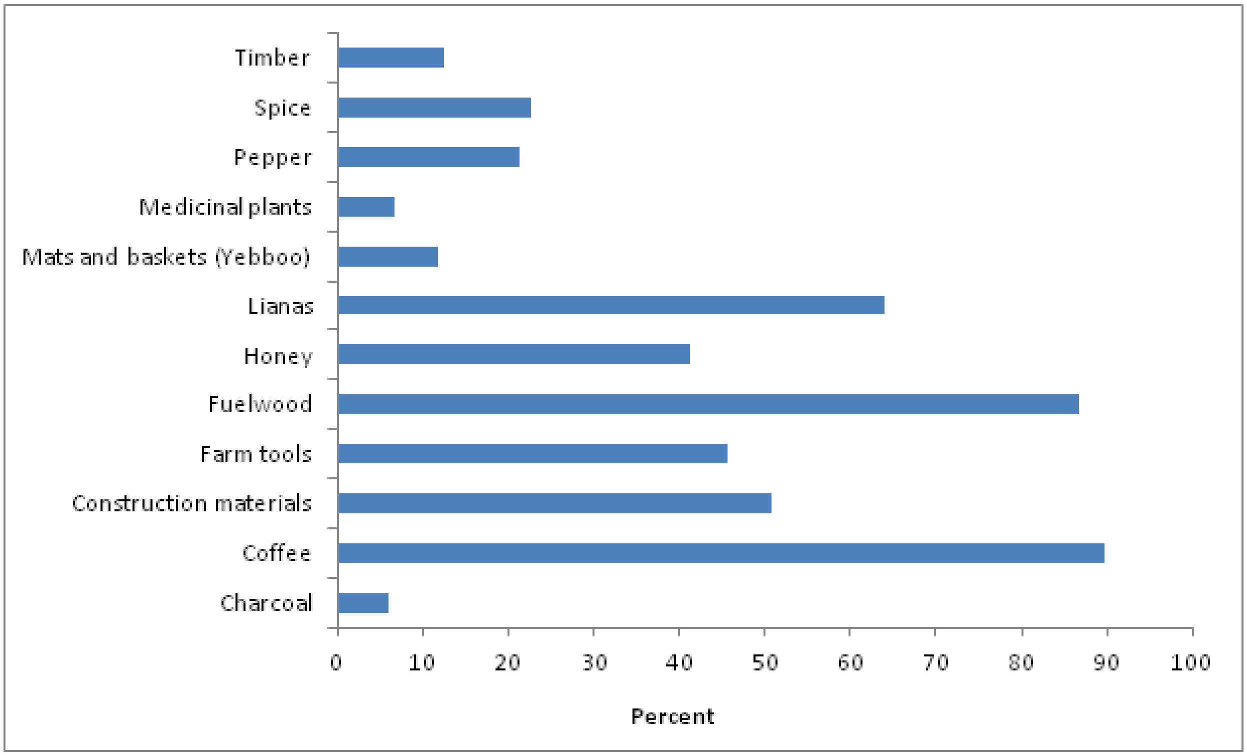

Figure 2. Proportion of forest users who reported actual uses of provisioning ecosystem services. The result showed an aggregated provisioning ecosystem services across all forest types.

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

Table 4. Local values of coffee agroforest, coffee forest and natural forest. The number of times forest users cited provisioning ecosystem services

Provisioning ecosystem services	Coffee agoforest	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

3.3 Relationship between woody species diversity and ecosystem services

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

Wood species used for fuelwood and construction materials were highly redundant, where as woody species used for mats and basket, timber, tool handle, farm tools and furniture were less redundant (Table S3).

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

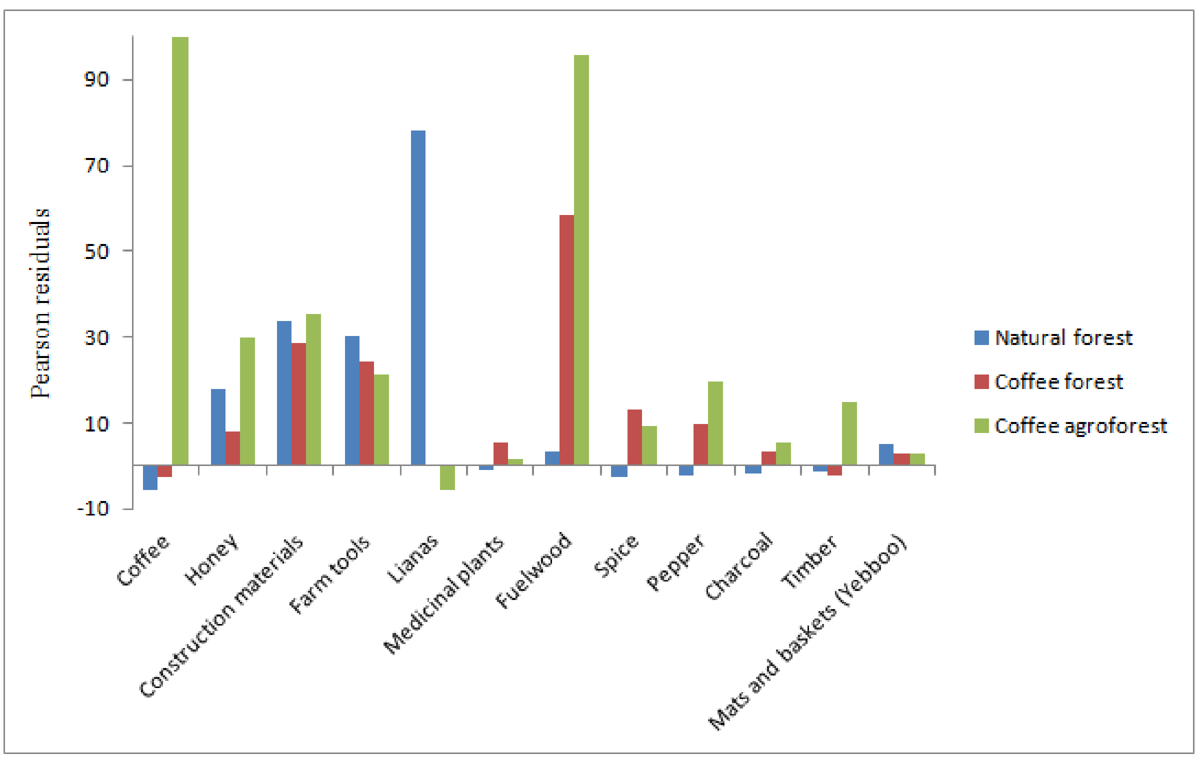

Figure 3. Actual provisioning ecosystem services use association with coffee agroforest, coffee forest and natural forest. A value of 2 was considered as the threshold of significant indicators

provisioning ecosystem services (Gardener 2014). Pearson residuals showed the association between use and forest type .

Coffee management intensification modifies the forest composition and structure through reducing the number of stems. Nevertheless, the use value of highly encouraged woody species such as *Albizia gummifera*, *Cordia africana*, *Milletia ferruginea* were decreased from coffee agroforest to natural forest. Whereas, the use value of those discouraged species such as *Chionanthus mildbraedii*, *Rothmannia urcelliformis* and *Oxyanthus speciosus* increased (Table S4). Figure 4. shows woody species abundance in the three forest management regime and coffee agroforest and associated use value. The result showed that both woody species abundance and total use value were lower in coffee agroforest compared to the natural forest and coffee forest. The relationship between woody species use value and ecological importance were tested using Spearman's correction. The Spearman's correlation showed a significant moderate positive correlation for 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 coffee agroforest ($r_s=0.625$, $P<0.01$).

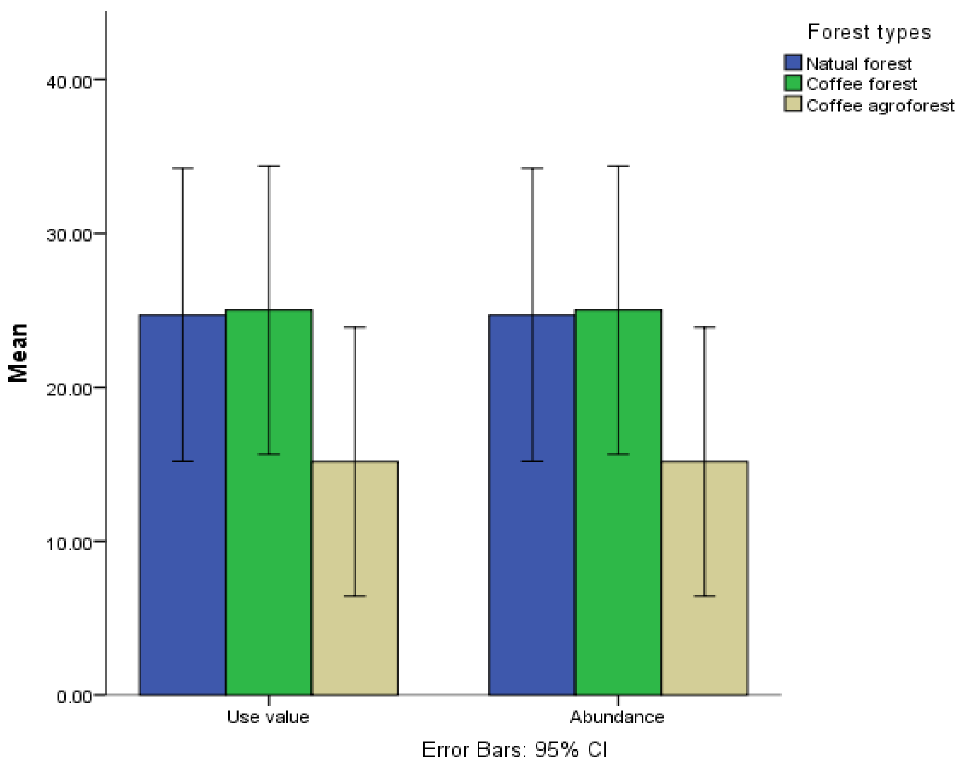

Figure 4. Woody species abundance and total use value in the natural forest, coffee forest and coffee agroforest

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 agroforest has great potential to conserve forest biodiversity (Ismail et al. 2014). Coffee management removed undergrowth or understory plant in coffee agroforest. Interest has grown in human managed landscapes in forest biodiversity conservation. Woody species diversity indicates the status of forest biodiversity under human management system. Species richness per plot (i.e. all woody plants recorded with abundance data) decreased from the natural to coffee forest to coffee agroforest.

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

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

We found that the Shannon diversity index of the natural forest, coffee forest and coffee agroforest were 3.33, 3.42 and 3.07 respectively. 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 coffee agroforest (i.e. 3.07) was found to be high (Magurran 2004, Arzamani et al. 2018). The Shannon diversity index result showed that coffee forest had the highest woody species diversity. The finding supports the intermediate disturbance hypothesis in that species diversity is maximum at an intermediate disturbance level (Bongers et al. 2009). Similarly a Simpson index of the coffee agroforest, coffee forest and natural forest were found to be 0.92, 0.96 and 0.95 respectively. Likewise the Simpson index result showed highest diversity in the coffee forest . Simpson diversity index ranges between 0 and 1. Simpson diversity index of a value 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

Forest is a source of livelihoods for local people (Ouedraogo et al. 2014). The study highlighted forest users perspective of ecosystem services provided by modified forest in general and the coffee agroforest, coffee forest and coffee agroforest in particular. Ecosystem services of the forest can be expressed as provisioning, regulating, supporting and cultural benefits of the forest (MEA 2005). Forest users reported these four major categories of ecosystems services. However, our findings showed that forest users value the provisioning ecosystem services of the forest more than other ecosystem services showing the local relative importance of the coffee agroforest to forest users. Seventeen out of twenty six freely listed forest ecosystem services were related to provisioning ecosystem services. Forest users interact with forest mainly for coffee and fuelwood collection and to a lesser extent for other forest products. Comparing the three forest types for most important forest products, forest users unequivocally value coffee agroforest the highest. This is because 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 forests are most used for provisioning ecosystem services. For example, a study from India shows traditional agroforest is a source of provisioning ecosystem services such fruit, timber, fuelwood, fodder and medicinal plants (Dhanya et al. 2014). Another study from south eastern Burkina Faso by Ouedraogo et al. (2014) has showed that provisioning services were the most cited ecosystem services.

The relative importance of provisioning ecosystem service 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 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 give greater priority to economic benefits of the forest than to ecological and social benefits of the forest. A study by Ango et al. (2014) shows coffee and honey were the most important cash generating ecosystem service to most forest users in southwest Ethiopia.

3.4.3 Relationship between woody species diversity and ecosystem services

Three types of plant uses were identified: Specialists, Generalist and Versatile (Albuquerque et al. 2009). Woody plants with at most two uses were grouped as specialist and 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 under specialist species. For example, two uses were reported for *Brucea antidysenterica* and *Dracaena steudneri*. *Alangium chinense, Albizia gummifera* and others were among generalist species. *Allophylus abyssinicus, Apodytes dimidiata, Olea welwitschii, Prunus africana* and *Syzygium guineense* and others had versatile uses (Albuquerque et al. 2009). More than 90% of the woody plants were used for fuelwood. Similarily 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 uses across the natural forest, coffee forest and coffee agroforest were studied through phytosociology (relative density, relative frequency, dominance) and use value. Woody plants were categorised into three categories highly redundant, redundant and less redundant based on specific uses with an arbitrary cut off points (Albuquerque and Oliveira 2007) greater than 75%, between 25% to 75% and less than 25% , respectively. These showed the benefit lost as a result of woody plant removal during coffee intensification. For instances, 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% available woody plant species. Similarly, redundant and less redundant showed that species uses could be obtained 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 commonly maintained with coffee agroforest. There was no coffee management practice such as weeding and cutting that 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 *Pouteria 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 from coffee agroforest such as *Bersama abyssinica, Brucea antidysenterica, Justicia schimperiana* and *Maesa lanceolata* had medicinal values. Lianas that are almost absent from coffee agroforest can be used for fuelwood, construction material (building material for traditional house, fencing and traditional beehive making), bee forage and as income through generating cash. *Schefflera abyssinica* was known as the well known honey tree for its popularity as bee forage. Coffee shade and multiple uses of woody species didn't justify the reason for encouraging some trees and discourage others in 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.

Coffee forest biodiversity has been receiving increasing attention for conservation. Some woody species are removed and others are maintained in coffee agroforest in southwest Ethiopia. Our study findings showed that woody species are encouraged in coffee agroforest not only for shade but also for other uses. *Albizia gummifera* and *Milletia ferruginea* are encouraged mainly for shade whereas *Cordia africana* and *Pouteria adolfifriederici* were encouraged for timber. *Diospyros abyssinica* was cited most for construction materials and *Polyscia fulva* was cited for traditional beehive making. *Schefflera abyssinica* was cited for bee forage. Forest users interact with forest for plant uses (Maroyi 2012). The present study findings showed that, although, 33 different uses of plants were identified only 3 to 5 were utilized most of the time. Fuelwood and construction materials were the main uses of woody plants. The potential uses of woody species are not implying the actual use of woody plants in most cases (Ahammad et al. 2019).

Woody plant uses citation show forest users have the knowledge but forest modification is a matter of immediate benefits priority. Literature has shown 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 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. Twleve different uses were reported for *Apodytes dimidiata,* whereas, the relative frequency of citation (RFC) was less than woody species with fewer number of uses for species such as *Cordia africana, Milletia ferruginea, Pouteria adolfi-friederici* and *Albizia gummifera.*

We study showed woody species availability and uses across the natural forest, coffee forest and coffee agroforest. Woody plants can be categorised into high redundant, redundant and less redundant based on specific uses per species. This shows the diversification of plant uses (Albuquerque et al. 2009) and has implications for woody plants conservation. Uses with highly redundant species reduce pressure on woody species whereas uses with less redundant species increase pressure on woody plants (Albuquerque & Oliveira 2007). Forest users reported that they use available dried woods 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 value 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 african*a is more abundant in coffee agroforest than coffee forest and natural forest. Similarly the shade value of woody plants is apparent in coffee agroforest.

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

3.5 Implication 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 forest to local people. Forest modification to coffee agroforest increases the actual use value and relative importance value of forest for timber and reduces the use value of non timber forest product and construction materials. Woody plant species that can be used for timber, traditional beehive, farm tool, tool handle, mats and basket 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 multidisciplinary approach in studying use and conservation of forest resources.

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Ethics Approval

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.

Declaration of competing interest

The authors declare no conflict of interest.

Data Availability

Data is available up on the request of corresponding author

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