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WOODY SPECIES DIVERSITY, REGENERATION AND SOCIOECONOMIC BENEFITS UNDER NATURAL FOREST AND ADJACENT COFFEE AGROFORESTS AT BELETE FOREST, SOUTHWEST ETHIOPIA

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Abstract

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The southwest Ethiopian Afromontane moist forests are recognized as one of the biodiversity hotspots as they are the centres of origin and domestication of Arabica coffee. But they are under threat due to deforestation and conversion to coffee farms. Coffee agroforests are believed to buffer the natural forest from these threats. The study was conducted to investigate the importance of coffee agroforest adjacent to Belete forest southwest Ethiopia. Vegetation data were collected from 68 plots (34 each) and socioeconomic data were collected from 136 households (68 each). The results showed that statistically, there were no significant differences between the natural forest and adjacent coffee agroforests in the species composition, species richness and Shannon diversity index of the woody species($P > 0.05$). The socioeconomic benefit result showed a number of forest products that are collected from the coffee agroforest. There were statistically significant differences between the natural forest and coffee agroforest in the forest income and the Simpson Diversification Index of the households ($p < 0.05$). Coffee agroforests contribute to the conservation of woody species through the retention of woody species and reducing pressure on the natural forest. Therefore, the socioeconomic benefits of coffee agroforests must take into account the conservation of woody species in linking the conservation and development arena.

Key words: diversity, forest incomes, conservation, Afromontane, southwest Ethiopia.

Introduction

A large proportion of the planet's land surface has been transformed as a result of conversion of the natural landscape for human use (Foley et al., 2005). The most practiced land-use changes threatening the tropical forests are the clearing of forests for subsistence agriculture, intensification of farmland productivity and expansion of urban centres (DeFries et al., 2004).

The southwest Ethiopian Afromontane moist forests are recognized as one of the biodiversity hotspots and are the centres of origin and domestication of Arabica coffee (Anthony et al., 2002) and supports diverse species of plants (Tadesse et al., 2014). Despite rapid forest destruction in Ethiopia, primarily, these moist forests are still the main natural production assets, since a great proportion of the population living close to the forest patches depends on the forest products (Stellmacher, 2008).

These remaining Afromontane forests have got much attention due to their ecological and economic importance. But they are under continuous change as the results of coffee management intensification (Schmitt et al., 2010; Tadesse et al., 2014) and are now modified to coffee agroforest that are mainly managed by smallholder farmers' (Aerts et al., 2011).

Despite the forest modification to coffee agroforest, many indigenous tree species are retained with it and has attracted much attention for woody species conservation (Tadesse et al., 2014). Recent study by Molla and Kessew (2015) has shown the significant contribution of traditional agroforestry towards addressing the conservation of indigenous tree species. Compared to large coffee plantation, the smallholder farmers' coffee farms have retained many woody species in southwest Ethiopia (Tadesse et al., 2014). Komar (2006) has also stated the greater conservation value of coffee agroforest. Currently, many conservation organizations have given due attention to coffee agroforests for the conservation of biodiversity and the livelihoods of smallholder farmers' (Gordon et al., 2007). Some studies have demonstrated the persistence high pressure on the natural forest (Didita et al., 2010; Gole et al., 2008). Coffee agroforest is a foreseen option among strategies proposed in reducing pressure on the remaining natural forest as a buffer zone.

The natural forest is the natural capital of the forest dependent households. Coffee agroforestry is a means of natural forest exploitation to get more benefits from the forest. Seemingly, coffee intensification results in a change in the woody species composition and regeneration status. As a result, one can notice a variation from the undisturbed natural forests to intensively managed coffee agroforest (Fisher et al., 2009). Study by Hundera et al. (2013) has revealed the vegetation composition, structure and regeneration difference due to coffee intensification in southwest Ethiopia. This has risen the notion of balancing conservation and development in human dominated land use system. Nevertheless, there is still an opinion that believes coffee agroforest is compatible with conservation in many ways. First there are different types of agroforests with different management intensity under different socioeconomic conditions (Wiersum, 2004). Secondly, coffee forests are nearby or adjacent to the natural forest (Moguel, Toledo, 1999).

Although there are many studies focusing on the Afromontane forest in southwest Ethiopia (Aerts et al., 2011; Hundera et al., 2013; Senbeta, Denich, 2006), literature that bring into attention the comparative analysis of woody species conservation and socioeconomic benefit is missing. The way the forest resources are used under coffee agroforests affect the woody species conservation. Hence, understanding the woody species diversity and socioeconomic benefits provides insights into resources use and conservation (Gomez-Baggethun et al., 2010). Therefore, this study was aimed at investigating the woody species diversity, regeneration status and socioeconomic benefits under natural forest and coffee agroforestry. The paper tries to answer the following research questions:

- Is there a major change in the species composition, structure, regeneration and diversity between a natural forest and coffee agroforestry?

- Do the households exploit coffee agroforest in a way that hinder the regeneration and conservation of woody species?

Material and methods

Description of study area

The study was conducted at Belete forest located in Shabe Sombo district, Jimma Zone, southwest Ethiopia. It is found along Jimma-Bonga main road at 50 km from Jimma town. Geographically, it is found between 7°30' and 7°45' N latitudes, 36°15' and 36°45' E longitudes. The altitude of the area ranges between 1300 to 3000 m above sea level (Cheng et al., 1998). The annual precipitation ranges from 1800 to 2300 mm with maximum rainfall between the months of June and September. The mean annual minimum and maximum annual temperature of the area ranges is 15 and 22 °C, respectively (Hundera, Gadissa, 2008).

Belete forest is part of Belete Gera National Forest Priority Areas in Ethiopia. The forest is part of the remnant moist evergreen Afromontane forest of southwest Ethiopia. For effective management, the forest is under participatory forest management since 2003, and currently, it is under the concession of Oromia Forest and Wildlife Enterprises. The total area of the forest is about 25,597.94 ha. The forest is dominated by trees like *Syzigium guineense*, *Olea welwitschii*, *Prunus africana* and *Pouteria adolfi-friederici*. This forest is among the forests that are rich in biodiversity (Schmitt et al., 2010). As a result, it has a great importance for biodiversity conservation and socioeconomic contribution.

Methods of data collection

Both vegetation and socioeconomic data were collected in 2016. Two stage sampling techniques were applied to collect the data. The forest was divided into natural forest and coffee agroforest. Fourteen (seven each) transect lines and a total of 68 plots (34 each) with an area of 20x20 m at a distance of 100 m between transect and within the plots were established to collect the vegetation data. Within the main plot, subplots of 10x10 and 5x5 m were nested for saplings and seedlings assessment, respectively. The starting point of the first transect line was located randomly. To avoid the edges effects, all the sample plots were established at least 50 m from the forest edges or roads inside the forest (Senbeta, Teketay, 2001). Total number of individuals for mature trees, saplings and seedlings were identified and counted within the main and subplots, respectively. Diameter at Breast Height (DBH) was measured for all woody species in the main plot for individuals with height ≥ 2 m and DBH ≥ 10 cm. Woody species with height ≤ 50 cm and DBH ≤ 10cm and height > 50 cm and DBH ≤ 10 cm were counted as seedlings and saplings, respectively (Kelbessa, Soromessa, 2008). Plant identification was carried out at the field with the help of Flora of Ethiopia and Eritrea (Edwards et al., 2000; Hedberg et al., 2006) and Useful Trees and Shrubs for Ethiopia (Bekele-Tesemma, 2007). Plant specimens were collected, pressed, dried and brought to Jimma University Department of Biology for further identification and deposition.

Natural forest and coffee agroforest are bordered by seven kebeles. Four kebeles (two for each) were selected randomly, Atro Gefere and Sombo Daru for the natural forest and Yanga Duguma and Sebeka Debye for coffee agroforestry. Socioeconomic information focusing on household characteristics, forest income in a form of non-timber forest products, forest products and forest utilization pattern was collected on the benefits of natural forest and coffee agroforestry through the household survey. Structured and semi structured questionnaire was prepared to collect the information. The sample size was determined using the formula following Barlett et al. (2001). Accordingly, a total of 136 households were calculated and proportionally allocated to the total number of households (Table 1). The interviewed households were selected randomly using the lottery approach.

T a b l e 1. Total number of households and sample size.

Name of Kebele	Total households	Sample size
Yanga Duguma	499	31
Sebeka Debye	694	43
Atero Gefere	540	33
Sombo Daru	467	29
Total HH	2200	136

Data analysis

Data on vegetation and socioeconomic benefits were analysed descriptively and tested by independent t-test using Microsoft Excel and the IBM SPSS version 20. The sufficiency of the total number of plots was checked by drawing species accumulation curve. Shannon diversity index, Sorensen's similarity index and Important Value Index were used to analyse vegetation data. The indexes were calculated using the formula following Magurran (2004).

Shannon diversity index:

$$H' = -\sum_{i=1}^{s} P_i \, lnP_i$$

where: H' = Shannon diversity index, Pi= proportion of individuals found in the ith species.

Sorensen's similarity index

$$S_s = \frac{2C}{(2C + A + B)}$$

where: Ss = Sorensen's similarity index, A = number of species in sample one, B = number of species in sample two, C = number of species common to both sample.

Important Value Index:

$$\text{IVI} = \text{Relative dominance} + \text{Relative frequency} + \text{Relative Abudance}$$

The regeneration status was decided based on the recruitment of seedlings, saplings and mature trees following Dibaba et al. (2014), as given below:

- good regeneration pattern when the number of Seedling > sapling > trees
- fair regeneration when the number of seedling outnumbers sapling and trees but sapling less than trees
- poor regeneration pattern when no individual in seedling and sapling stages but relatively many standing individual tree

Forest product diversity index, Simpson diversity index and Relative forest income were used to analyse the socioeconomic benefits under coffee agroforest and natural forest. Forest product diversity index was calculated adopting the Shannon diversity index as follow.

where: H' = Shannon's diversity index, S = total number of forest products collected, Pi = ni/N, the number of forest products as a proportion of the total number of forest products used, In = natural logarithm to base e.

$$(\text{H}') = -\sum_{1=i}^{s} \text{piln(pi)}$$

Simpson Diversity Index (SDI) was calculated using the formula following Illukpitiya and Yanagida (2010):

$$\text{SDI} = 1 - \sum_{i=1}^{N} p_i^2$$

where: Pi is the proportion of forest income from source i. Pi value varies from zero to one. If there is just one forest product type, Pi = one and hence, SDI = zero. As the number of sources increase, the shares (Pi) decline so that SDI approaches to one. SDI = zero implies specialization, whereas SDI = 1 implies diversification resource use types. According to Saha and Bahal (2010), the value of SDI always falls between zero and one. Households with most diversified incomes have the largest SID, and the less diversified incomes are associated with the smallest SDI.

Relative forest income was calculated by estimating the total volume of all types of forest products collected by a household and multiplied by the local market price of each of the products per unit volume. Relative Forest Incomes (RFI) is calculated as the proportion of total income originating from forest use and with total household income (Vedeld et al., 2007). Household annual income was estimated using the formula as has been used previously by Belay et al. (2013), Gobeze et al. (2009) and Tieguhong, Nkamgnia (2012).

$$\textit{Household Annual Income} = \sum \textit{Forest income} + \textit{Agricultural income} + \textit{Other incomes}$$

The total value products from crop production (I1), livestock products (I2), NTFPs (I3), off-farm activity (I4) and remittance (I5) then sums up to total household income (THI) and finally, relative forest income (RFI) that is calculated using the formula:

$$RFI = \frac{TFI}{THI} * 100$$

where: RFI = Relative forest income, TFI = Total forest income, THI = Total household income.

Results and discussion

Woody species composition of coffee agroforest and natural forest

Species accumulation curve levels first for coffee agroforest and then natural forest. It flattens at 25th for agroforestry and 28th for the natural forest (Fig. 1). The result shows the probability of getting new species is less. This implies that the total number of sample plots taken for the study were sufficient.

A total of 67 woody species belonging to 38 families were recorded. The natural forest accounts for 55 species belonging to 35 families, whereas the coffee agroforest accounts for 33 species belonging to 23 families (Appendix 2 and 3). The relative proportion of each families account for less than 10% in the natural forest and 12% in the coffee agroforest. Fabaceae was the family that accounts for the largest proportion, both in natural forest (7%) and coffee agroforest (12%). The Sorensen's similarity index showed that 47% of the total woody species recorded were found both in the natural forest and coffee agroforest. Although there were more species in the natural forest than agroforest, there were 5 woody species recorded only in the coffee agroforest, implying the importance of coffee agroforest for woody species conservation. The presence of 5 woody species in the coffee agroforest is probable due to overexploitation in the natural forest in the past. The finding supports the idea that the coffee

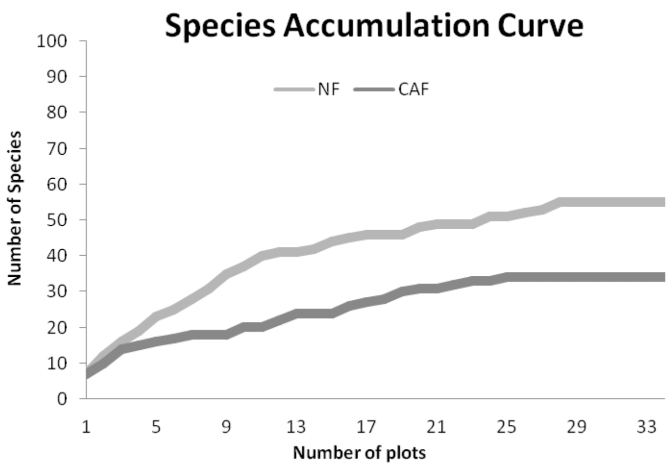

Fig. 1. Species accumulation curve of natural forest (NF) and coffee agroforests (CAF).

agroforest serves as a repository of native tree species as forest loss continues (Tadesse et al., 2014). The dominance of species belonging to the Fabaceae family might be attributed to the nature of species regeneration and coffee shade tree preference by the smallholder farmers.

During the assessment, trees, shrubs and lianas were recorded both in the natural forest and coffee agroforest. The proportion of trees, shrubs and lianas were 53, 31 and 16% in the natural forest and 73, 25 and 2% in the coffee agroforest. The proportion of trees, shrubs and lianas in the coffee agroforest shows the simplification of forest composition towards mature trees. This might be due to coffee management practices that discourage undergrowth (Hundera et al., 2013). The number of trees and lianas were significantly higher in the natural forest than the coffee agroforests ($p < 0.05$). The total number of shrubs recorded in the natural forest and coffee agroforest is not statistically significantly different ($p > 0.305$). Although the magnitude of woody species differ, coffee agroforest hold similar woody species in that trees, shrubs and lianas were recorded in the coffee agroforest.

The Importance Value Index (IVI) shows the top ten important woody species in the natural forest and coffee agroforests. It shows different species in the natural forest and coffee agroforest. Woody species with the highest IVI in the natural forest were *Syzygium guineense* (20%), *Croton macrostachyus* (14%), *Maytenus arbutiolia* (13%) and followed by other species. Whereas, woody species such as *Coffea arabica* (31%), *Millettia ferruginea* (30%) and *Albizia gummifera* (21.7%) and followed by other species were the species with higher IVI in coffee agroforest (Table 2).

Woody species richness and diversity

Species richness and diversity result showed that both the natural forest and coffee agroforest support many species. The Shannon's diversity index of the natural forest and coffee agroforest were H' = 3.79 and H' = 2.82, respectively. The species evenness for the natural forest and coffee agroforests were 0.95 and 0.81, respectively. Although the result shows more woody species richness and Shannon's diversity index under natural forest, the difference is not sta-

T a b l e 2. Importance value index of woody species under coffee agroforest and natural forest.

Natural forest		**Coffee agroforests**	
Scientific name	IVI	Scientific name	IVI
Syzygium guineense	20.03	*Coffea arabica*	30.90
Croton macrostachyus	13.59	*Millettia ferruginea*	29.60
Maytenus arbutiolia	13.42	*Albizia gummifera*	21.07
Olea capensis	13.19	*Ficus sycomorus*	18.71
Celtis africana	12.86	*Ficus vasta*	18.69
Pittosporum viridiflorum	12.29	*Cordia africana*	18.50
Teclea nobilis	11.34	*Bersema abyssinica*	16.06
Pouteria adolfi-friederici	10.05	*Ehretia cymosa*	15.07
Flacourtia indica	9.51	*Sapium ellipticum*	13.86
Ehretia cymosa	9.47	*Syzygium guineense*	12.36

Table 3. Diversity woody species in natural forest and coffee agroforests.

Forest site	Richness	Diversity	
		Shannon index	Evenness
Natural Forest	55	3.79	0.95
Coffee agroforests	33	2.82	0.81
p-value	0.134	0.826	0.50

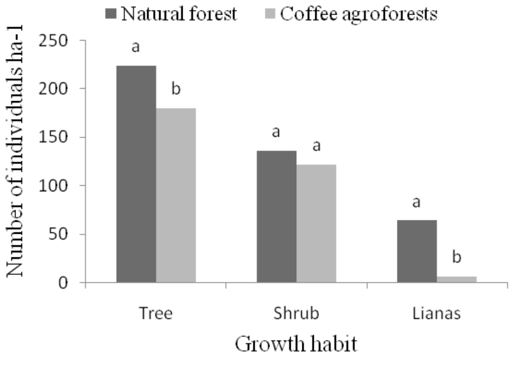

Fig. 2. Growth habit of woody species recorded in the natural forest and coffee agroforests.

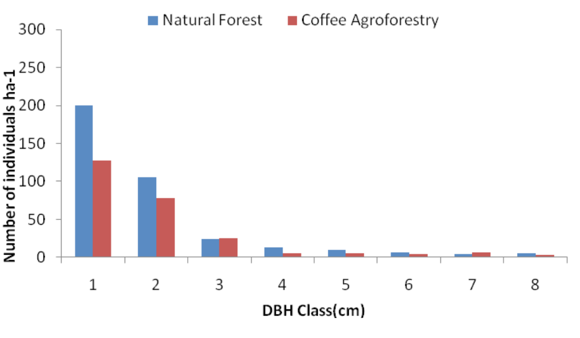

Fig. 3. Diameter class distributions of woody species in natural forest and coffee agroforests.
Notes: DBH class: 1 = 10–20 cm; 2 = 20–30 cm; 3 = 30–40 cm; 4 = 40–50 cm and 5 = 50–60 cm; 6 = 50–60 cm; 7 = 60–70 cm; 8 = > 80 cm.

tistical significant ($p > 0.05$) (Table 3). This might be due to land use history as most of the coffee agroforests are original natural forests. It indicates the importance of conservation of coffee agroforest. This study is in agreement with Tadesse et al. (2014) who reported 27 woody species in semi-forest coffee in south west of Ethiopia. Molla and Asfaw (2014) also reported 32 woody species in the enset based coffee agroforestry in the Midland of Sidama Zone in Ethiopia.

Regeneration under the coffee agroforest and natural forest

The diameter distribution of the individuals in the natural forest and coffee agroforest showed more or less inverted J-shape implying that there are greater number of individuals in the lower diameter class (Fig. 2). The larger diameter classes were dominated by *Pouteria adolfi-friederici, Ficus sycomorus, Prunus africana, Sapium ellipticum* and *Syzygium guineense species* (Fig. 3).

Table 4 shows the number of seedlings, saplings and trees under the natural forest and coffee agroforest. The result showed that overall, there are more number of seedlings than trees both in the natural forest and coffee agroforest. However, it differs from species to species. Regeneration category result showed that the largest proportion of species are under good regeneration under the natural forest and fair regeneration under the coffee agroforest (Fig. 4). No regeneration of *Olea welwitschii, Schefflera abyssinica, Prunus africana, Pouteria adolfi-friederici, Podocarpus falcatus* in the natural forest and *Ficus sycomorus, Prunus africana, Ficus vasta, Fagaropsis angolensis, Ekebergia capensis, Sapium ellipticum, Acacia abyssinica* in the coffee agroforest was recorded. The implication is that these species need attention in the future for conservation.

To compare species regeneration under the natural forest and coffee agroforest, the species recorded in both were selected. The result showed that a greater number of seedlings and saplings were recorded under the coffee agroforest. No regeneration of certain species were recorded both under the natural forest and coffee agroforest (Table 5). This implies that the absence of regeneration under the coffee agroforest is not always due to the practices, rather it might be attributed to the nature of the species regeneration.

Table 4. Number of seedlings, saplings and trees in the natural forest and coffee agroforest.

Growth stages	Natural forest	Coffee agroforests	P-value
	Density ha-1	Density ha-1	
Seedling	1950	1448	0.038
Sapling	579	424	0.034
Tree	458	424	0.207

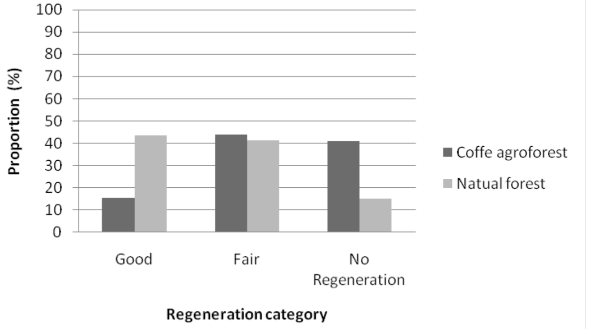

Fig. 4. Regeneration category of species in the natural forest and coffee agroforest.

Socio-economic Benefits

Diversity of forest products

Different forest products are collected from the coffee agroforest and natural forest. Figure 5 shows the major forest products that are collected from the forest. The largest proportion of households collect forest products that can be collected from the natural forest. The Shannon Diversity Index shows that there is no statistical significant difference between coffee agroforest and natural forest in the number of forest products that can be collected (Table

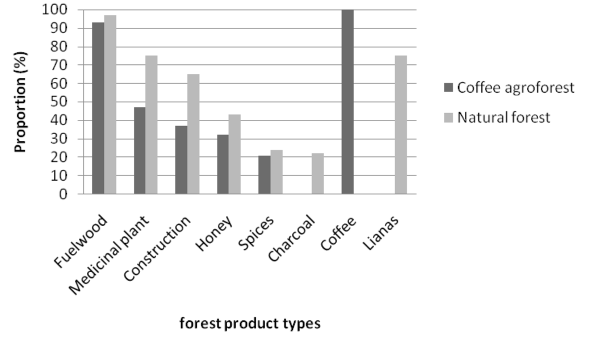

Fig. 5. Different forest products collected from coffee agroforest and natural forest.

T a b l e 5. Regeneration extent of species recorded both in the coffee agroforest and natural forest.

	Coffee agroforest			**Natural forest**		
	Seedlings	**Saplings**	**Trees**	**Seedlings**	**Saplings**	**Trees**
Albizia gummifera	+++	++	++++	+	+	++
Allophylus abyssinicus	++++++	-	++++	++	+	+++
Bersama abyssinica	+++++	+++	++++	++	++	+
Clausena anisata	-	-	+++	+	++	+
Cordia africana	+++	-	+++	-	+	++
Croton macrostachyus	-	++++	+++++	++	+	+++
Diospyros abyssinica	++++++	+++++	++++	+++	+	++
Dracaena afromontana	-	++++	-	++	+++	+
Ehretia cymosa	++++++	+++++	++++	+	+++	++
Ekebergia capensis	-	-	+++	-	+	++
Fagaropsis angolensis	-	-	++++	+++	+	++
Ficus sycomorus	-	-	+++	-	+	++
Maytenus arbutifolia	-	++++	-	+++	++	+
Millettia ferruginea	+++++	++++	++++	+++	++	+
Olea capensis	+++++	++++	++++	+++	++	+
Phoenix reclinata	-	-	++	-	-	+
Polyscias fulva	++++++	++++	+++++	+	++	+++
Prunus africana	-	-	++	-	-	+
Sapium ellipticum	-	-	+++	-	+	++
Syzygium guineense	-	++++	+++++	++	+	+++

Notes: - sign indicates no regeneration; + sign indicates regeneration and extent of regeneration.

T a b l e 6. Forest product types, relative importance and nature of dependence.

Study area	**Coffee agroforest**	**Natural forest**	**P-value**
Shannon's Diversity Index	4.18	4.16	0.799
Relative Forest Income	49	11	< 0.0001
Simpson Diversity Index	0.45	0.16	0.000

6). Household uses the forest as a source of income. The relative forest income from coffee agroforest account for 49% of the total household income. This is attributed to coffee, as it is highly linked to market to generate cash. The Simpsons Diversification Index shows that there is statistically significant difference between coffee agroforest and natural forest usage. Forest products' usage tends towards diversification and specialization for coffee agroforest and natural forest, respectively. The specialization of forest product use under the natural forest shows a shift from natural forest to other sources implying a reduction of pressure on the natural forest. The local communities do have different feelings towards the natural forest and coffee agroforest in terms of usage. About 90% of the respondents said that the natural forest is a common resource implying all have access to the forest. Whereas there is a restriction imposed to access the coffee agroforest (Fig. 6). The use rights, control rights and authoritative rights are the fundamental issues in forest governance (Sikor et al., 2017). Coffee agroforest has shown a sign of more control in forest resource use than the natural forest.

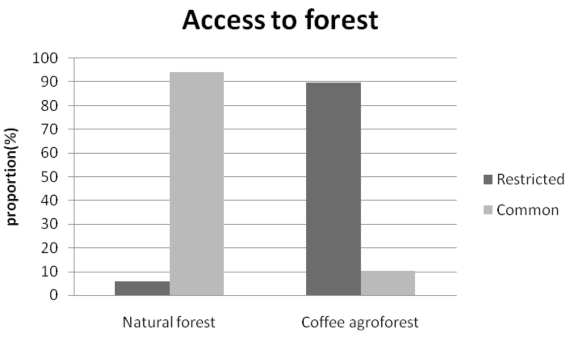

Fig. 6. Household response to access rights to the natural forest and coffee agroforest.

Conclusion

Forest of southwest Ethiopia has a vast ecological and economic importance, but due to human induced factors, there is a persistently high rate of biodiversity loss. There is a need of biodiversity conservation. The results of the present study confirm that the natural forest and coffee agroforests constitute larger proportions of woody species, which may be a reflection of the conservation of biodiversity. Coffee agroforests are conserving woody species through selective management practice in maintaining more species as shade of coffee and economically useful species. This implies that coffee agroforests indirectly contribute to the conservation of biodiversity through reducing pressure that would be exerted on natural forests, so coffee agroforests serve as a buffer zone in natural forest conservation. The study compared a consistent set of description of the characteristics of the forest product and diversification strategy. In the natural forest, household incomes show as specialized because more households are engaged in agricultural practise. However, coffee agroforestry shows that household income is diversified with high value product and is engaged in different activities. Different ways to address dependence on forest products incomes, in case of natural forest, the relationship between diversification and relative forest incomes indicates specialization. Therefore, dependence on agricultural and other incomes simply represents the utilization of the additional income opportunities that the forests provide less. Yet, coffee agroforestry, the relationship between diversification and relative forest incomes implies that it is diversified and is increasing with forest income. Therefore, coffee agroforestry provides different forest products incomes and reduces dependence from natural forest.

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