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The role of traditional coffee management in forest conservation and carbon storage in the Jimma Highlands, Ethiopia

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ABSTRACT

Ethiopia has lost 90% of its forest extent. Remnant patches in the southwest are often semi-forest coffee (SFC), a system whereby coffee is managed beneath the canopy. Here, we (1) quantify aboveground live carbon (AGC) stored by trees in SFC and other land use types in the Jimma Highlands; and (2) determine coffee farmers' preference for canopy shade trees, and the resulting differences in carbon storage. We surveyed twenty coffee farmers and assessed thirty-one 1-ha vegetation plots across a 23.6-km transect. The most preferred shade species were *Albizia gummifera*, *Acacia abyssinica*, *Millettia ferruginea* and *Cordia africana*, which together accounted for 42% AGC in SFC and 12% in natural forests. These species had broad size class distributions, while the least preferred had scant representation in lower size classes. SFC stores significantly more AGC (61.5 ± 25.0 t ha^{-1}, mean ± SE) than woodland, pasture and cropland, significantly less than plantation and slightly less than natural forest (82.0 ± 32.1 t ha^{-1}). If SFC was converted to cropland, then 59.5 t ha^{-1} would be released, at a social cost of US$2892–4225 ha^{-1}. Carbon-payment schemes (e.g. REDD+) may, therefore, play a role in conserving these forests and associated biodiversity and livelihoods into the future.

KEYWORDS
Agroforestry; biodiversity conservation; *Coffea arabica*; coffee shade trees; deforestation; forest degradation; land use change; semi-forest coffee; REDD+

1. Introduction

During the last four decades, cumulative CO_2 emissions from forest loss and other land use changes have increased by 45% (IPCC 2014). By early this century (2000–2005), tropical deforestation accounted for 7–14% of global anthropogenic CO_2 emissions (Harris et al. 2012), with commensurate impacts on the global climate system and biodiversity, as well as more localised impacts on ecosystem goods and services such as hydrological functioning,

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soil conservation and forest products. In Ethiopia, the areal coverage of closed canopy forests has been reduced by around 90%, from 45 million ha at the beginning of the twentieth century to 4 million ha in 2013 (Teferi et al. 2013). Deforestation in Ethiopia continues, albeit at a slower rate (1.0–1.5% y^{-1}; Lemenih & Woldemarian 2010). Particularly in the southwest of the country, many remnant forest patches coincide with sites of traditional coffee farming and, to a lesser extent, sacred forest groves (Denu & Belude 2012).

Traditional coffee farming is an example of agroforestry, whereby shrubs and trees are combined with crops and/or livestock generating economic, environmental and social benefits (USITC 2005; Tadesse et al. 2014a; Vanderhaegen et al. 2015). One-fifth of the global population depends directly upon products and services obtained from agroforestry, a system that covers at least a billion hectares globally (Nair et al. 2009). Due to the carbon retained in trees, shrubs and soils, agroforestry has potential to offset greenhouse gas emissions from conversion to more intensive forms of land use (IPCC 2014), particularly in the case of traditional coffee farming, which typically retains a high degree of canopy cover and associated carbon (Tadesse et al. 2014a; Vanderhaegen et al. 2015; De Beenhouwer et al. 2016).

Coffee farming in Ethiopia has an exceptionally long history: *Coffea arabica* is native to the Jimma Highlands in the southwest, a region that hosts the highest genetic diversity of coffee on Earth, and that is recognised globally for its broader biodiversity value (Mittermeier et al. 2004). Four coffee management systems have been described in Ethiopia: wild coffee, semi-forest coffee, garden coffee and plantation coffee (Teketay 1999). In the wild coffee system, coffee berries are directly harvested from wild plants in the natural forest, while semi-forest coffee (henceforth, SFC) refers to the coffee management system whereby the canopy trees are thinned, the ground vegetation is removed and empty spaces are enriched by transplanting naturally regenerating seedlings of coffee (Teketay 1999). In the process of thinning, the farmers retain the canopy trees of their preference for shade provision and remove the rest. Garden coffee is established under shade as well as in open places with area coverage of <3 ha (Teketay 1999), while plantation coffee refers to the coffee management system in which improved technologies such as selection of varieties, shade tree regulation, fertilisation, weed and pest control are applied. Coffee provides economic benefits both locally and nationally, and it is Ethiopia's leading export (45% of total exports, US$190 million in 2003) contributing 5% to GDP and nearly 10% of government revenue (USITC 2005).

Among these four coffee management systems, wild and SFC retain the greatest degree of canopy cover, and thus have the greatest potential in terms of global benefits such as carbon storage (Tadesse et al. 2014a; Vanderhaegen et al. 2015; De Beenhouwer et al. 2016) and the conservation of forest-dependent species (Aerts et al. 2010). In Ethiopia, SFC accounts for approximately one-quarter of the coffee production area (Teketay 1999), and for approximately 20% of the total production, with an estimated average yield of 400–500 kg ha^{-1} compared with 450–570 kg ha^{-1} for plantation coffee (Teketay 1999).

Semi-forest coffee involves periodic, partial clearance of the shrub layer, with the purpose of promoting coffee yields beneath a closed canopy of preferred shade-providing indigenous tree species. This traditional system of forest use has thereby preserved the canopies of large numbers of (modified) forest patches (Hylander et al. 2013), while forests elsewhere in Ethiopia have given way to less carbon-rich land covers (Aerts et al. 2010). For coffee growers, all canopy trees are not equally preferred. Tree species with flat and wider canopies are preferred by the coffee growers for shade provision, and the coffee shrubs/trees are believed to give better yield under the canopy of these trees (Muleta et al. 2011). Ecosystem goods and services associated with SFC include timber and non-timber forest products (Chilalo & Wiersum 2011; Senbeta et al. 2013; Tadesse et al. 2014b), regulation of soil moisture and nutrient content and soil fertility (Grossman et al. 2006), biodiversity conservation (Vanderhaegen et al. 2015; De Beenhouwer et al. 2016) and carbon storage (Aerts et al. 2010; Tadesse et al. 2014a; Vanderhaegen et al. 2015; De Beenhouwer et al. 2016).

The amount of carbon stored in a coffee forest varies depending on management intensity. For example, compared to nearby natural forests, SFC systems have been reported to retain 50–62% (Tadesse et al. 2014a) and 48–65% (Vanderhaegen et al. 2015) of carbon storage, with a number of stems ha^{-1} (DBH > 10 cm) of 64% in Yeki and Decha (Tadesse et al. 2014a), and 32–51% in Gera and Garuke, with ca. 331 stems ha^{-1} around Jimma (Vanderhaegen et al. 2015). Supporting coffee growers in their sustainable management of Ethiopia's remnant forest patches could represent a cost-effective option for climate change mitigation and conservation of canopy tree species. To support such a mechanism, it is critical to understand the amount of carbon stored by SFC, relative to degraded natural forest (hereafter simply called 'natural forest') [1] as a baseline (invariably degraded), and to alternative forms of land use, as well as farmers' preference for canopy shade tree species.

The objectives of this study were to: (1) quantify aboveground live carbon (AGC) in the Jimma Highland's SFC, compared with carbon stored in nearby natural forests and other common land use/land cover types (woodland, pasture, cropland and plantation forest); (2) determine coffee farmers' preferences for canopy shade trees and the consequences of this for carbon storage and tree species composition.

2. Methods

2.1. Study region

The study was conducted along a 23.6-km transect in the Jimma Highlands of southwest Ethiopia (Figure 1), a region famous for contributing *C. arabica* to the world and part of the Eastern Afromontane Biodiversity Hotspot (Mittermeier et al. 2004). The Highlands are a

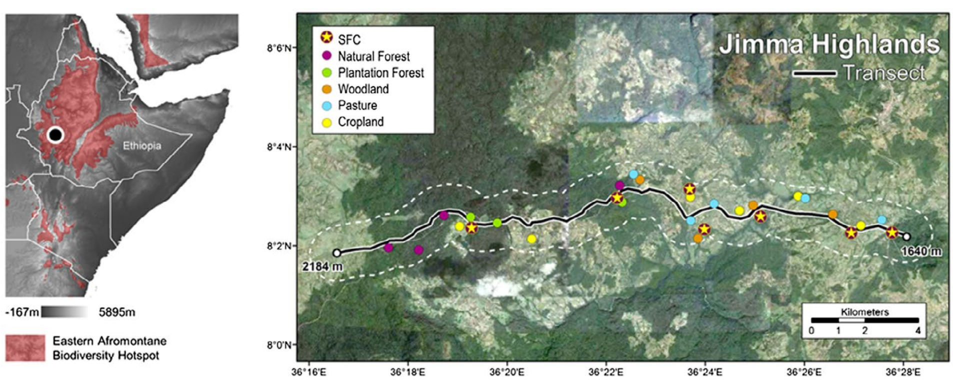

Figure 1. Distribution of vegetation plots (1 ha) along a 23.6-km transect plus 1 km buffer in the Jimma Highlands, southwest Ethiopia. The transect spans the districts of Gumay and Setema, within the Eastern Afromontane Biodiversity Hotspot. Source: Background image is from Google Earth (SPOT, 23/10/2014; copyright CNES/Astrium, DigitalGlobe).

mosaic of SFC, natural forest, woodland, pasture and cropland, both with scattered trees, and exotic species plantation. Using Spot5 satellite images acquired in 2008, the transect was selected to traverse each of these six land use/land cover types, spanning an elevational gradient from 1640 m to 2184 m (Figure 1).

Natural (i.e. unmanaged) forests and woodlands are surrounded by villages and are used as common pools for provision of timber, fire wood, poles and vines for construction, and as a result are degraded. Woodland are characterised mainly by *Acacia abyssinica*, *Combretum spp*., *Entada abyssinica* and *Terminalia schimperiana*. Natural forest is mainly composed of *Apodytes dimidiata*, *Millettia ferruginea*, *Ficus sur* and *Chionanthus mildbraedii* (Appendix 1). Cropland (of mainly teff, maize and sorghum) and pastureland are characterised by scattered trees. Exotic tree plantations include *Grevillea robusta*, *Pinus patula*, *Eucalyptus camaldulensis* and *Cupressus lusitanica*. According to the local communities, these tree species plantations were started in early 1980s by the state. SFC is mainly composed of *Albizia gummifera*, *Croton macrostachyus*, *Acacia abyssinica*, *Millettia ferruginea, Ehretia cymosa* and *Cordia africana* (Appendix 2). Coffee, the main cash crop in the transect, is harvested mainly from SFC, with only a negligible amount of wild harvesting or garden coffee and no coffee plantations.

Southwest Ethiopia is the wettest region of the country; the study transect receives mean annual rainfall of 1900 mm (range, 1500–2200 mm yr^{-1} over the period 1981–2013. The transect typically experiences eight consecutive wet months (>100 mm $month^{-1}$, March–October), with the heaviest rains falling from May to September (>200 mm $month^{-1}$) and one short dry season from November to February. The mean annual temperature is 20.1 °C at the lower end of the transect, and 17.5 °C at the highest. Daily minima (coolest month) and maxima (warmest month) are in the ranges 8.2–10.1 and 26.7–30.3 °C, respectively, depending on altitude. The soils are volcanic in origin, with slightly acidic pH (5.1–6.4), and texture consisting clay (33–39%), sand (30–38%) and silt (26–31%).

2.2. Vegetation surveys

We surveyed thirty 1-ha vegetation plots, placed at random intervals along the transect (plus 1 km buffer), such that the number of plots per land use type was approximately proportional to the area covered by that land use (Figure 1). This resulted in seven plots in SFC (mean elevation = 1777 m, range in elevation 1532–2143 m), four in natural forest (2101 m, 1782–2226 m), four in woodland (1709 m, 1590–1859 m), five in pasture (1681 m, 1533–1792 m), six in cropland (maize, sorghum and teff; 1825.33 m, 1519–2120 m) and four in plantation forest (*Eucalyptus camaldulensis*, *Grevillea robusta* and *Pinus patula*; 2086 m, 1926–2191 m). One of the plantation plots was found to have been recently cut, with no woody stems at the time of the surveys, and so was excluded from further analyses.

Each stem with diameter at breast height (DBH, 1.3 m) ≥ 10 cm was measured and identified to species level. Voucher specimens were deposited at the National Herbarium (ETH), Addis Ababa University. For growth abnormalities such as large buttresses or multiple stems, we followed Rainfor protocols (Phillips et al. 2009). To calculate tree heights, we measured the angle from the observer to the top of tree using a clinometer, and the distance from the observer to the tree at breast height using a Digital Laser Distance Measurer (DLR130 K). Tree height was then obtained using standard trigonometric relationships.

2.3. Carbon calculations

We used the revised non-destructive allometric equation described by Chave et al. (2014) to estimate the aboveground live biomass (AGB, kg) contained within each tree, given as a function of DBH (cm), height (H, m) and wood specific gravity (ρ, g cm^{-3}):

$$\mathrm{AGB} = 0.0673 \times \left(\rho D^2 H\right)^{0.976}$$

Aboveground live carbon (AGC) was estimated at 50% of AGB (Chave et al. 2014). Wood specific gravity was obtained at species level from the Global Wood Density database (Chave et al. 2009), taking the mean over records for a species, preferring records from tropical Africa where available (otherwise the tropics, otherwise all available records). In three instances, no species-specific records were available, and so we used mean density values from the respective plots.

Differences in AGC within and between land use types were investigated using one-way analysis of variance. We conducted Tukey's post hoc test to determine the difference between SFC and other land use types.

2.4. Elevation

Differences in the elevational distribution of land use types along our study transect (Figure 1) could potentially confound our inference of how much AGC is retained in SFC plots compared with natural forest plots, with the latter having a higher mean elevation (1777 m vs. 2101 m). AGC in tropical forests typically decreases with elevation, due to temperature and productivity gradients (Girardin et al. 2010), although mid-elevation peaks in AGC have also been observed, potentially driven by a combination of respiration, photosynthesis and disturbance (Marshall et al. 2012). Assuming decreasing AGC with elevation, AGC retained in SFC compared with natural forest could be exaggerated. To test for this effect, we regressed AGC against elevation within each of these forest types.

2.5. Farmers' preference for coffee shade trees

Based on the recommendations of local development agents, employed by the government to advise farmers, 20 coffee growers were selected from communities in Ageyo, Difo and Setema villages located along the transect. The coffee growers were asked to identify the most important shade trees (whose seedlings are allowed to grow to maturity). Preference rankings ranged from one (most preferred) to eight (least preferred), with equal scores allowed where no preference was given between competing species.

To investigate the impact of farmers' preferences for certain shade species on forest composition, now and in the future, we plotted AGC and stem density across five DBH classes (10–30 cm, 30–50 cm, 50–70 cm, 70–90 cm, >90 cm) and compared the results between SFC and natural forest. Mean rank and AGC for each shade tree of preference were analysed using the R statistical software (R Core Team 2014).

3. Results and discussion

3.1. Carbon storage by land use type

Analysis of variance showed significant differences in AGC storage within all land use types ($F_{23,5} = 22.548$, $p < 0.001$). The largest mean value for AGC storage was for plantation forest, the smallest was for farmland covered by annual crops (Figure 2). Tukey's multiple comparison tests showed significant difference in AGC storage between SFC and all other land uses except natural forest (Table 1). SFC (61.5 ± 25.0 SE) stored significantly more AGC than woodland (12.9 ± 7.6 SE), pasture (2.5 ± 2.7) and cropland (2.0 ± 0.8), significantly less than plantation forest (152.3 ± 56.81), and less than natural forest (82.0 ± 32.1), although 95% confidence intervals for the latter comparison spanned zero (Table 1).

Comparing AGC across the elevation ranges of SFC and natural forest plots, we detected no trend in either case (SFC: $R^2 = 0.0001$, regression coefficient = 0.0037; natural forest: $R^2 = 0.004$, regression coefficient = 0.009), suggesting that the difference in AGC between these forest types is unlikely to be confounded by temperature (productivity) gradients. Plantation forests were found to store 60% more carbon than SFC.

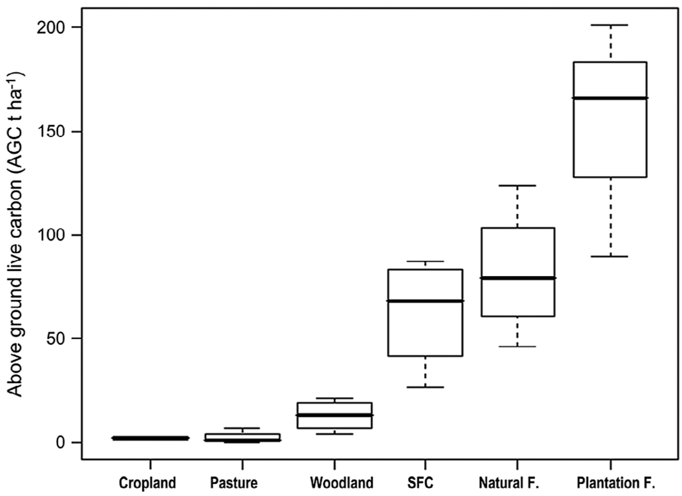

Figure 2. Boxplot comparison of aboveground live carbon storage across land use/land covers types. Whiskers extend up to 1.5 times the interquartile range from each box.

Table 1. Mean differences in aboveground live carbon (AGC), between SFC and other forms of land use (positive values indicate more carbon in SFC). Tukey's multiple comparison tests show significant difference in AGC between SFC and all other land uses except natural forest.

				95% Confidence interval	
LULC	Δ AGC (t ha^{-1})	Std. error	*p*-value	Lower	Upper
Natural	−20.50	15.18	0.755	−67.61	26.60
Woodland	48.66	15.18	0.040	1.55	95.77
Pasture	59.02	14.18	0.004	15.01	103.03
Cropland	59.50	13.48	0.002	17.68	101.31
Plantation	−90.72	16.71	0.000	−142.59	−38.86

The 25% difference in AGC stored by SFC, compared with natural forests, is smaller here than reported elsewhere in southwest Ethiopia, for Yeki and Decha forests (38–50%; Tadesse et al. 2014a) and Gera forest (48% for Vanderhaegen et al. 2015 and 38% for De Beenhouwer et al. 2016). Compared with the nearby natural forests, the SFC in our study retains more carbon than most traditional agroforests elsewhere in the world (cf. Kirby & Potvin 2007; Kessler et al. 2012). If not on sacred grounds, managed for coffee or protected by the State, forests and woodlands are used as common pools for the (increasingly unsustainable) provision of timber and non-timber products (fire wood, poles, forage and thatch). By comparison, SFC systems are proactively managed and protected by local communities, thus maintaining the long-term integrity of canopy tree cover and associated carbon stocks (Tadesse et al. 2014a).

Soil organic carbon pool is affected by land use types in the Jimma Highlands of Ethiopia (Vanderhaegen et al. 2015). Disturbance and management intensities cause variation in the amount of carbon stored in the soil (De Beenhouwer et al. 2016). We expect small difference in the belowground carbon storage between forest and SFC systems in our study transect, because in both cases, soil organic layer is left almost undisturbed. On the contrary, the conversion of forest and SFC to cropland greatly affects the top soil, which is rich in organic matter and hence depletes the carbon stored in the organic layer.

As the centre of diversity for *C. arabica*, a number of forest patches in southwest Ethiopia have so far been spared cropland encroachment. In many cases, SFC systems have persisted without major intervention from the State (e.g. protected areas) because they are valued locally and nationally for their coffee. However, there is a tendency among the coffee growers to convert forest and SFC to plantation coffee in southwest Ethiopia, due to higher coffee yields in the latter system (Tadesse et al. 2014b). In the same region, there is another trend which is to convert SFC to cropland and pasture when the market price of coffee drops (D. Denu personal observation). As the human population continues to rise and land becomes scarcer, there is thus an increasing risk that SFC be converted to other agricultural systems, more productive on the short term such as plantation coffee, or more essential than SFC for the livelihood of local people such as cropland or pasture.

If such livelihood pressures were to cause the coffee growers along our study transect to convert their land to cropland or pasture, we estimate that ca. 59 t ha^{-1} would be released as greenhouse gas emissions into the atmosphere. Estimates of the social costs of carbon – i.e. the cost of the physical impacts of climate change resulting from carbon release – range from US$ 49 t^{-1} to US$ 71 t^{-1} (mean values from Tol 2008). Accordingly, the social cost associated with the conversion of one hectare of SFC would be between US$ 2892 and US$ 4225.

To counterbalance the risk of SFC being converted, one important step would be the international recognition of their value in terms of climate change mitigation through the carbon sequestered and stored in their biomass (Tadesse et al. 2014a; Vanderhaegen et al. 2015), as well as in terms of their contribution to local livelihoods (Chilalo & Wiersum 2011; Senbeta et al. 2013; Tadesse et al. 2014b) and global biodiversity (Vanderhaegen et al. 2015; De Beenhouwer et al. 2016).

3.2. Forest composition and shade tree preference

In the SFC, 10 species contributed 85% of AGC, while 10 families contributed 97%. The remaining 16 plant families recorded in SFC were each represented by just few small stems (<30 cm DBH).

The top four preferred shade trees reported by farmers were, in descending order of mean preference, *Albizia gummifera*, *Acacia abyssinica*, *Millettia ferruginea* and *Cordia africana* (Table 2). The farmers rated the first three especially highly (mean ranks, 1.35–1.65; range, 1–4) due to their flat canopy cover and the perceived quality of coffee yield beneath. *C. africana* was also reported as an important shade tree (mean rank, 2.4; range, 1–4) and was preferred by some farmers due to its valuable timber. The farmers' preference for coffee shade trees was in line with the abundance of tree species in the coffee plots: *A. gummifera* (abundance = 15.4 stems ha^{-1}), *A. abyssinica* (4.29 stems ha^{-1}), *M. ferruginea* (11.14 stems ha^{-1}), *C. africana* (14.43 stems ha^{-1}). Combined, these four species contributed 42% (26.1 ± 5.2 t ha^{-1}) of the aboveground carbon in SFC, compared with 12% (9.9 ± 5.7 t ha^{-1}) in natural forests (Table 2).

Table 2. Coffee farmers' (N = 20) preference rankings for canopy shade trees and the mean contributions of these species to aboveground live carbon (AGC) in natural forest (natural) and in semi-forest coffee system (SFC).

			AGC (mean t ha^{-1})		AGC (mean %)	
Species	Rank mean	Rank range	SFC	Natural	SFC	Natural
Albizia gummifera	1.35	[1, 2]	14.62	6.48	23.76	7.90
Acacia abyssinica	1.40	[1, 2]	4.29	0.00	6.97	0.00
Millettia ferruginea	1.65	[1, 3]	3.09	3.04	5.02	3.71
Cordia africana	2.40	[1, 4]	4.10	0.36	6.66	0.44
Croton macrostachyus	3.70	[2, 5]	9.68	1.63	15.73	1.99
Celtis africana	4.10	[2, 7]	1.60	6.61	2.60	8.06
Ficus mucuso	4.75	[3, 6]	7.31	0.00	11.87	0.00
Dracaena steudneri	7.05	[6, 8]	4.15	0.00	6.75	0.00

Croton macrostachyus and *Celtis africana* were ranked lower by most farmers (mean ranks, 3.7–4.1; range, 2–7), while *Dracaena steudneri* and *Ficus mucuso* were reported to be the least preferred shade trees (mean ranks, 4.75–7.05; range, 3–8), although a few large stems contributed substantially to carbon storage in some plots, particularly in the case of *F. mucuso* (51.2 AGC t ha^{-1} in a single plot; Table 2).

For each of the top six shade species in SFC, distributions of stem density across DBH size classes followed laterally inverted J-curves (Figure 3(a)), indicative of healthy regeneration. This is consistent with results obtained from a number of studies conducted on natural forests of Ethiopia (Alemu et al. 2015). This pattern was less clear in the natural forest plots, where the density of *C. africana* peaked at 30–70 cm DBH (Figure 3(b)). For *F. mucuso* and *D. steudneri*, the pattern was reversed, with saplings in SFC outnumbered by older trees – evidence of suppressed recruitment (selective removal of saplings) by coffee farmers.

The results of our coffee farmers' survey are in broad agreement with previous studies (Teketay & Tegineh 1991; Muleta et al. 2011). All 20 of those interviewed ranked the Ethiopian endemic *M. ferruginea* in the top three shade species. Two other species ranked similarly highly were *A. gummifera* and *A. abyssinica*, both from the same plant family (Fabaceae). Each of these species has a natural capacity for nitrogen fixation, due to symbiotic associations between their roots and rhizobia, improving soil fertility for the coffee shrubs, although broad and flat canopy cover was perceived by the farmers to be the main reason for improved coffee yield. In agreement with a study by Muleta et al. (2011) in the Yayu Hurumu and Bonga forests, the fourth most preferred shade species was *Cordia africana*. This is a multi-purpose tree, providing good shade for coffee and also high-quality timber. It is widely used for

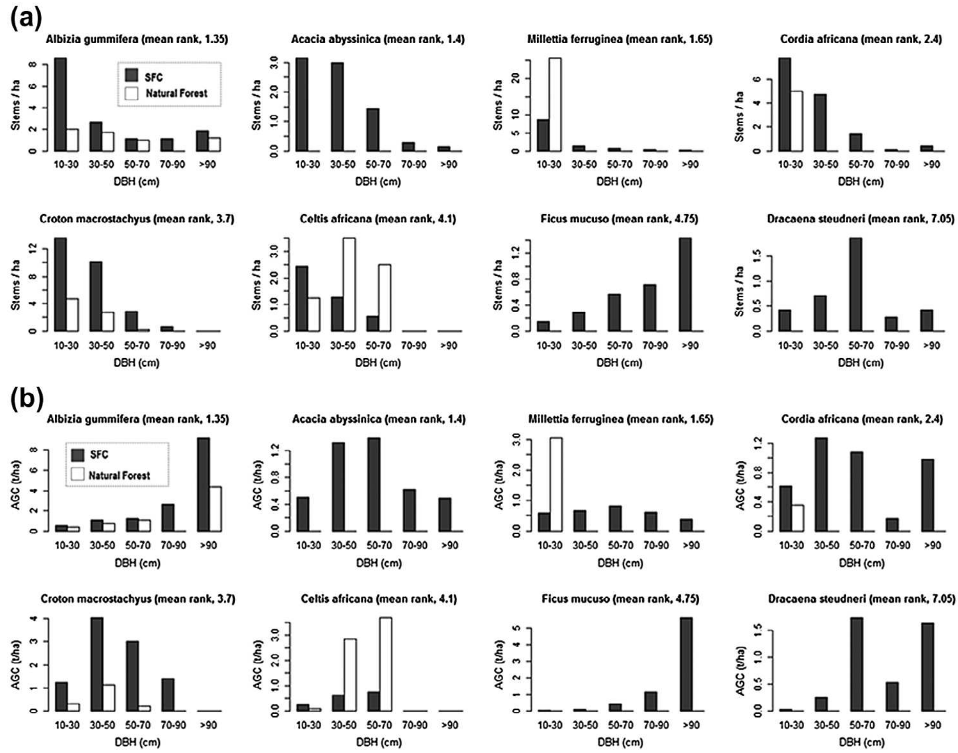

Figure 3. Stem density (a) and aboveground live carbon (b) across DBH size-class distributions of canopy trees. Grouped bars compare semi-forest coffee and natural forest. Species are ordered by coffee farmers' mean preference rankings (see Table 2).

making doors and window frames, cabinets, mortars and beds. The farmers stressed the importance of *C. africana* as an alternative source of income, which explains its relative abundance even in cropland.

4. Conclusion and recommendations

Agroforestry systems have received increased attention as potentially cost-effective options for climate change mitigation due to their importance in carbon storage and sequestration (IPCC 2014), whilst also maintaining livelihoods (Chilalo & Wiersum 2011). Ethiopia's SFC retains 75% of the carbon stored in natural forests, but it retains significantly more long-term carbon stocks than alternative forms of agricultural land use (pasture and cropland). Coffee farmers' stated preference for certain shade tree species, especially in the family Fabaceae, is translated by the high contribution of these species to AGC in SFC. The same species have a much lower contribution to AGC in natural forests, suggesting historical selection by farmers either of specific sites adapted to coffee-growing because they were naturally rich in these species, or of saplings of these species which were/are not cut during conversion and maintenance of the SFC. Size-class distributions of stems in our plots suggest that such management is still ongoing.

To ensure the continued role of SFC in the retention of carbon, conservation of biodiversity and provision of local livelihoods, we suggest the development of a mechanism by which farmers could be compensated for yield losses or for failures in the market price of coffee. This would reduce the risk of conversion of SFC to cropland or pasture by farmers. SFC retains a high degree of canopy cover with trees measuring up to 40 m high, and therefore meets the minimum requirements to be classify as 'forest' (canopy cover 10–30%, tree height 2–5 m) as set out by the UNFCCC in the context of the Kyoto protocol. Carbon-payment schemes such as REDD + may, therefore, play a role in conserving these forests and associated ecosystem services, biodiversity and livelihoods into the future.

Note

1. Natural forests are invariably degraded in the study area.

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Disclosure statement

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Appendix 1.Tree species composition, density, basal area, biomass and AGC in natural forest

S. No	Species name	Density ha^{-1}	BA ha^{-1}	AGB ha^{-1}	AGC t ha^{-1}
1	*Albizia gummifera*	6	1.468	12969.943	6.485
2	*Allophylus abyssinicus*	9.25	0.199	1055.136	0.528
3	*Apodytes dimidiata*	33.75	3.007	28304.042	14.152
4	*Bersama abyssinica*	9.25	0.276	1830.371	0.915
5	*Brucea antidysenterica*	0.25	0.002	4.521	0.002
6	*Canthium oligocarpum*	2.5	0.047	241.070	0.121
7	*Celtis africana*	7.25	1.139	13217.262	6.609
8	*Chionanthus mildbraedii*	25.25	0.566	3320.070	1.660
9	*Cordia africana*	5	0.114	716.890	0.358
10	*Croton macrostachyus*	7.75	0.441	3255.595	1.628
11	*Ekebergia capensis*	0.25	0.265	2311.696	1.156
12	*Ficus sur*	13.25	4.800	39503.647	19.752
13	*Ficus sycamoras*	0.5	0.072	451.633	0.226
14	*Galiniera saxifraga*	32	0.473	1784.668	0.892
15	*Macaranga capensis*	7.5	0.894	4613.892	2.307
16	*Maytenus arbutifolia*	1.5	0.022	76.492	0.038
17	*Millettia ferruginea*	25.5	0.561	6080.975	3.040
18	*Nuxia congesta*	1	0.067	423.607	0.212
19	*Olea welwitschii*	0.5	0.583	6405.312	3.203
20	*Oxyanthus speciosus*	0.5	0.004	13.484	0.007
21	*Phoenix reclinata*	2.5	0.062	335.571	0.168
22	*Podocarpus falcatus*	1.75	0.112	766.283	0.383
23	*Polyscias fulva*	0.5	0.170	521.779	0.261
24	*Prunus africana*	2	0.487	4928.804	2.464
25	*Psychotria orophila*	1	0.010	26.418	0.013
26	*Rothmania ulceriformis*	1.25	0.028	141.412	0.071
27	*Schefflera abyssinica*	6	2.224	11683.004	5.842
28	*Syzygium guineense*	28	1.930	16169.976	8.085
29	*Teclea noblis*	8.5	0.103	620.346	0.310
30	*Trichilia dregeana*	1	0.102	785.577	0.393
31	*Vangueria apiculata*	1.25	0.010	53.693	0.027
32	*Vepris dainellii*	15	0.258	1445.505	0.723
	Total	257.5	20.497	164058.671	82.029

Appendix 2.Tree species composition, density, basal area, biomass and AGC in SFC

S. No	Species name	Density ha^{-1}	BA ha^{-1}	AGB ha^{-1}	AGC t ha^{-1}
1	*Acacia abyssinica*	8.000	1.067	8586.187	4.293
2	*Albizia gummifera*	15.429	3.601	29236.632	14.618
3	*Allophylus abyssinicus*	1.429	0.065	385.950	0.193
4	*Apodytes dimidiata*	0.143	0.063	539.645	0.270
5	*Bersama abyssinica*	1.571	0.030	150.453	0.075
6	*Bridelia micrantha*	0.286	0.017	85.534	0.043
7	*Celtis africana*	4.286	0.373	3207.317	1.604
8	*Chionanthus mildbraedii*	1.000	0.017	68.742	0.034
9	*Clausena anisata*	2.000	0.022	57.610	0.029
10	*Cordia africana*	14.429	1.656	8209.625	4.105
11	*Croton macrostachyus*	27.286	2.780	19363.558	9.682
12	*Diospyros abyssinica*	2.000	0.293	2642.940	1.321
13	*Dracaena steudneri*	3.714	1.167	8306.061	4.153
14	*Ehretia cymosa*	14.857	0.432	1746.161	0.873
15	*Ekebergia capensis*	0.429	0.005	21.621	0.011
16	*Ficus mucuso*	3.143	2.284	14613.039	7.307
17	*Ficus sur*	1.571	0.621	3492.005	1.746
18	*Ficus thonningii*	1.286	0.378	1939.923	0.970
19	*Ficus vasta*	0.571	0.611	3546.745	1.773
20	*Flacourtia indica*	0.143	0.015	94.125	0.047

(*Continued*)

Appendix 2. *(Continued).*

S. No	Species name	Density ha^{-1}	BA ha^{-1}	AGB ha^{-1}	AGC t ha^{-1}
21	*Galiniera saxifraga*	0.286	0.003	8.755	0.004
22	*Grewia ferruginea*	0.143	0.001	3.395	0.002
23	*Maesa lanceolata*	1.000	0.026	102.211	0.051
24	*Maytenus arbutifolia*	0.143	0.046	220.473	0.110
25	*Millettia ferruginea*	11.143	0.743	6185.767	3.093
26	*Phoenix reclinata*	0.143	0.008	30.313	0.015
27	*Pittosporum viridiflorum*	0.143	0.001	3.835	0.002
28	*Podocarpus falcatus*	0.143	0.009	38.425	0.019
29	*Polyscias fulva*	0.286	0.058	181.505	0.091
30	*Prunus africana*	0.714	0.279	2428.957	1.214
31	*Rothmania urcelliformis*	0.429	0.011	54.004	0.027
32	*Sapium ellipticum*	1.000	0.389	3427.273	1.714
33	*Schefflera abyssinica*	0.571	0.230	1329.353	0.665
34	*Schrebera alata*	0.143	0.015	73.324	0.037
35	*Syzygium guineense*	0.286	0.088	587.377	0.294
36	*Terminalia schimperiana*	0.143	0.011	32.808	0.016
37	*Trichilia dregeana*	0.714	0.065	427.333	0.214
38	*Trilepisium madagascariense*	0.571	0.079	553.481	0.277
39	*Vangueria apiculata*	1.000	0.011	46.176	0.023
40	*Vepris dainellii*	4.286	0.145	788.204	0.394
41	*Vernonia amygdalina*	1.714	0.039	186.460	0.093
42	*Vernonia auriculifera*	1.143	0.013	46.269	0.023
	Total	129.714	17.768	123049.573	61.525