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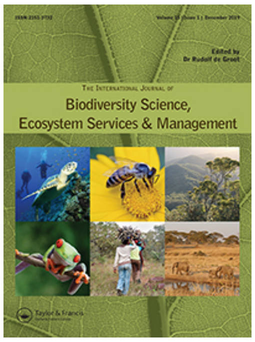

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Woody plant use and management in relation to property rights: a social-ecological case study from southwestern Ethiopia

Girma Shumi[a], Ine Dorresteijn[a,b], Jannik Schultner[a], Kristoffer Hylander[c], Feyera Senbeta[d], Jan Hanspach[a], Tola Gemechu Ango[e] and Joern Fischer[a]

[a]Faculty of Sustainability, Leuphana University, Lüneburg, Germany; [b]Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands; [c]Department of Ecology, Environment and Plant Sciences, Stockholm University, Stockholm, Sweden; [d]College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia; [e]Department of Human Geography, Stockholm University, Stockholm, Sweden

ABSTRACT

Many people in less developed countries depend on woody plants, but sustainable management of woody plants often remains a challenge. We assessed people's use, perceived property rights and management of woody plants in farmland and forests in a landscape of southwestern Ethiopia. We interviewed 180 households and surveyed woody plants in 192 plots. We found that 95 species were used for eleven major purposes. The majority of plants (52) were used for house construction followed by farming tools (42), fuelwood (38) and honey production (37). These benefits were sourced from farmland, forest with coffee management and forest without coffee management. Our study found that local people perceived land tenure security and tree use rights to be limited, especially for forests. We found abundant regeneration of the most widely used tree species in all land use types. However, some of these species, including important pole and timber species, appeared to be overharvested in forests. To improve biodiversity outcomes and sustainable use, it would be beneficial to recognize local people's diverse needs for woody plants and grant them appropriate property rights. Conservation policies should encompass the entire landscape and empower local farmers to proactively manage tree populations while providing safeguards against overuse.

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Introduction

Biodiversity provides supporting (e.g. nutrient cycling and primary production), provisioning (e.g. food, timber, fuel, fresh water), regulating (e.g. climate and water regulation) and cultural (e.g. spiritual experience, recreation, education) ecosystem services that are essential for human wellbeing (MA 2003; Díaz et al. 2018). Within this context, woody plants provide many important services that are directly or indirectly associated with particular species (Díaz et al. 2006). Especially in less wealthy countries, many people directly depend on woody plants for their daily lives (Rasmussen et al. 2017; Reed et al. 2017). However, the sustainable management of woody plants and their services for long-term human wellbeing remains a challenge.

The sustainable management and maintenance of woody plant species and their associated ecosystem services are influenced by numerous direct drivers (i.e. activities directly causing changes in woody species) as well as indirect drivers (i.e. underlying circumstances that prevent the maintenance of woody plants) (Geist and Lambin 2002; Hosonuma et al. 2012). Direct causes of woody plant species declines include land conversion for agriculture and agricultural intensification, logging, fuelwood collection and cattle grazing (Foley et al. 2005; Asner et al. 2009; Lewis et al. 2015), as well as commercial forest management (e.g. for oil palm in Southeast Asia; Edwards et al. 2014 and coffee in Ethiopia; Hundera et al. 2013; Geeraert et al. 2019). These direct causes, in turn, are linked to indirect drivers such as demographic pressure and certain property rights, policies and markets, all of which influence local people's ability to maintain woody plants and associated benefits (Lambin et al. 2001; Geist and Lambin 2002; Díaz et al. 2015). Understanding such complex links between nature and people can be facilitated through taking a social-ecological systems perspective (e.g. Bennett et al. 2015). Social-ecological systems are systems with strong and close links between people (the social system) and environmental processes (the ecological system) (Berkes et al. 2003; Folke 2006; Fischer et al. 2012). In such systems, among others, questions that require investigation relate to the ways in which people use different species of woody plants; how property rights impede or facilitate the use and conservation of woody plants; and whether species are managed sustainably or not. To the best of our knowledge, such interrelated issues have not been investigated to date via focusing on

CONTACT Girma Shumi girmasd@gmail.com
Supplementary data for this article can be accessed here.

local people at the same time as considering the forest-agriculture mosaic from a landscape ecological perspective (e.g. Balvanera et al. 2014; Isbell et al. 2017; Díaz et al. 2018).

Globally, several billion people rely on woody plants for their livelihoods (Kaimowitz and Sheil 2007; Reed et al. 2017) with, for example, between 1.3 and 2.4 billion people using wood for house construction and cooking, respectively (FAO 2014). The benefits people obtain from woody plants are numerous and may involve both direct and indirect services associated with particular plant species (Díaz et al. 2006). These benefits are important to meet basic needs and mitigate income insufficiency of rural households (FAO 2014; Reed et al. 2017). Among others, trees and shrubs provide food, timber, fuelwood, shelter, farming tools (such as yolks and beams), fodder, and medicine (FAO 2014; Iiyama et al. 2014). Woody plants also contribute to indirect benefits such as hosting agricultural crop pollinators or enhancing soil fertility, water infiltration and flood protection (FAO 2014; Rasmussen et al. 2017).

Despite such important benefits, human land use has been a major driver of biodiversity loss, influencing all taxa including woody plants (e.g. Keenan et al. 2015; Barlow et al. 2016; IPBES 2018). In this regard, unsustainable use of woody plant species, such as overharvesting or the inability to maintain these species, can be driven by direct causes (see above). It can also be attributed to indirect causes (see above), predominantly to imperfect resource governance or local people's ill-defined property rights (e.g. Ostrom 2009; Chazdon 2018). Property rights, whether enforced by the government (de jure) or the community (de facto), govern the rights to access and use a resource (e.g. land, woody plants or forest), maintain it, exclude others, and transfer these rights to others (Schlager and Ostrom 1992). In this context, local people's ability to effectively take on a stewardship role for the woody plants they depend on can be undermined by unclear or absent property rights (Ostrom and Nagendra 2006; Ostrom 2009; RRI 2017). Consequently, unclear property rights may negatively affect forest management. This, in turn, can alter forest structure, and species composition and diversity (Bergès et al. 2013; Johann and Schaich 2016; McClellan et al. 2018). For example, in Ethiopia, a lack of clear property rights has been observed to affect tree retention and management by rural households (Mekonnen 2009). Likewise, conservation policies that prohibit the use of indigenous timber species have discouraged farmers from planting and conserving these species (Kassa et al. 2011; Lemenih and Kassa 2014).

In the context of our study, especially use rights and land tenure security were important aspects of property rights. Specifically, use rights define the ways in which a person is allowed to utilize a given plot of land for cultivating subsistence crops or for livestock grazing, or the resources available from it, e.g. woody plants (Crewett and Korf 2008; Crewett et al. 2008). Such use can be extractive (e.g. collection of firewood) or non-extractive (e.g. suspension of beehives for honey production). For land tenure security, we specifically assessed people's perception thereof, and we thus refer to perceived tenure security as an indicator of how safe local people feel that they will be able to use a particular plot of land continuously into the future (e.g. without fearing that the land may be taken away by the authorities) (e.g. see Arnot et al. 2011).

Although both the uses of tree species as well as issues of property rights have received some research attention (see above), to date, such work has rarely been linked to ecological field data on the distribution, abundance, and demographic profiles of trees (e.g. the classification of individual trees of a population into different size classes). Such data are important, however, to give an indication of which species are maintained sustainably, and which are not. A given species can be recognized as a sustainably managed species if it has viable population despite the extraction of goods and services (Charnley and Poe 2007; Kuhlman and Farrington 2010). For example, natural populations of tree species typically have many small individuals followed by progressively fewer older aged individuals (an inverted J-shaped distribution of tree diameters). This indicates successful regeneration as well as maintenance of increasingly older aged individuals, ensuring future recruitment capacity and sustainable use of the species (Wakjira 2006; Mwavu and Witkowski 2009). In contrast, unsustainably managed tree species often have a discontinuous pattern of tree diameter distributions. This indicates that certain size classes are missing or that regeneration may be insufficient to replace existing adults. Two key reasons for unsustainable demographic profiles are overharvesting (Mwavu and Witkowski 2009); and management that prevents natural tree regeneration (Fischer et al. 2009).

For this study, we focused on a social-ecological system in southwestern Ethiopia as a case study. Here, the rural community depends heavily on woody plants for their basic needs from forests and farmland (Ango 2016; Dorresteijn et al. 2017). According to the constitution of the Federal Democratic Republic of Ethiopia (FDRE) (1995), the state owns all land and its resources, including forests, and local communities have limited use rights (Crewett et al. 2008). In addition, current forest management and private investment policies may further undermine people's perceived tenure security (Lemenih and Kassa 2014; Tura 2018). Nevertheless, some communities still continue to apply customary use rights to their local forests (Wakjira and Gole 2007). The Ethiopian government has also issued land use certificates for farmland and some coffee plots (mainly for plots rehabilitated from farmlands) since 1998, to improve farmer's tenure security and also to facilitate land tax collection (Deininger et al. 2008). Most recently, the government has identified the protection and rehabilitation of degraded forests for ecosystem services provision as key for its green economy development strategy (FDRE 2011). It has also enacted a new forest law (Proclamation No. 1065/2018; FDRE 2018), which recognizes private forest development and ownership, and participatory forest management that may further improve local people's woody plant use, including the possibility for controlled timber extraction. This constitutes a considerable shift in government policies on forest management but currently still lacks translation into regulations to be effective.

Drawing on the rationale outlined above, we aimed to:

(1) Assess local people's uses of woody plant species, segregated by different purposes and sources (e.g. farmland versus forest);
(2) Uncover how people perceived their land tenure security, woody plant use rights and sense of ownership and management responsibility in forest and farmland; and
(3) Investigate population viability of the most widely used tree species in forest and farmland.

Methods

Study area

The study was conducted in subsistence-dominated rural landscapes of six *kebeles* (the lowest administrative unit) located in the Gera, Gumay and Setema districts of Jimma Zone, Oromia Regional State, southwest Ethiopia (Figure 1). The *kebeles* were selected to span a gradient in forest cover, ranging from 11% to 84% within a *kebele* (Figure 1(c,d)) (for specific details see Shumi et al. 2018). The region is characterised by a mosaic of forest, farmland (arable land, grazing land and homegardens) and settlements. The forest in the area is moist evergreen Afromontane forest, and part of the Eastern Afromontane Biodiversity Hotspot. The dominant tree species in the forest include *Olea welwitschii, Pouteria adolfi-friederici, Schefflera abyssinica, Prunus africana, Albizia spp., Syzygium guineense*, and *Cordia africana* (Cheng et al. 1998). Coffee (*Coffea arabica*) is native to the forest and grows naturally at altitudes between 1000 and 2000 m above sea level (Schmitt 2006; Senbeta et al. 2014).

Coffee is widely promoted at altitudes between 1500 and 1800 m asl, within its ecological optimum, and is generally grown under a canopy of native shade trees (Teketay 1999). Agriculture, including cropping and livestock keeping, is the main source of livelihoods. The largest ethnic group in the region is the Oromo, while Amhara, Kefficho and Tigre people are minorities.

Data collection

Household survey

We assessed local people's woody plant uses and perception of their property rights in two steps. We first conducted an exploratory pilot study from July to September 2015 to obtain a basic understanding of people's use of woody plants and their sources. We used open-ended questionnaires in the six *kebeles* and interviewed a total of 72 households. For this, 12 households were randomly selected from satellite images in each *kebele*, without prior information about these households.

Second, we conducted the main study from February to March 2017 using questionnaires consisting of primarily closed questions. The questionnaire was structured into four main sections: general background information on the household; uses and preferences of woody plant species by source (farmland, forest with coffee management, forest without coffee management, government plantation forest; see Table S1); tree/forest use rights and sense of ownership; and land tenure security and tree/forest management (for details, see Appendix S1). Based on the pilot study and existing literature (Wakjira and Gole 2007; Ango 2016) we categorized woody plant uses into 11 major classes (Table 1).

We interviewed 180 randomly selected households (30 per *kebele*, including renewed interviews with the 12 households of the pilot study plus 18 additional households). The 18 additional households from each *kebele* were selected in the same way as those for the pilot study. The respondents were household heads or their spouses. All respondents remained anonymous to protect their privacy. Before a given interview, we introduced the objectives of our study and informed interviewees about procedural aspects such as the voluntary nature of participation in the interview.

Woody plant survey

We surveyed woody plants in the same six *kebeles* where we conducted the household surveys, from November 2015 to January 2016, and April to May 2017. Prior to the plant surveys, using ArcGIS 10.2, we determined the proportion of farmland and forest within each *kebele* using a land cover map generated via supervised image classification of a RapidEye satellite image from 2015 using ArcGIS 10.2. Then, we randomly selected a total of 192 survey plots, distributed across the six *kebeles* (ranging from 25 to 43 plots per *kebele*). Of these, we assessed 72, 1-ha circular plots in farmland (53 and 19 plots in arable land and grazing land, respectively) and 120, 20 m by 20 m plots in forests and homegardens (63, 46, and 11 plots in forest without coffee management, forest with coffee management, and homegarden, respectively). We used different plot sizes in farmland

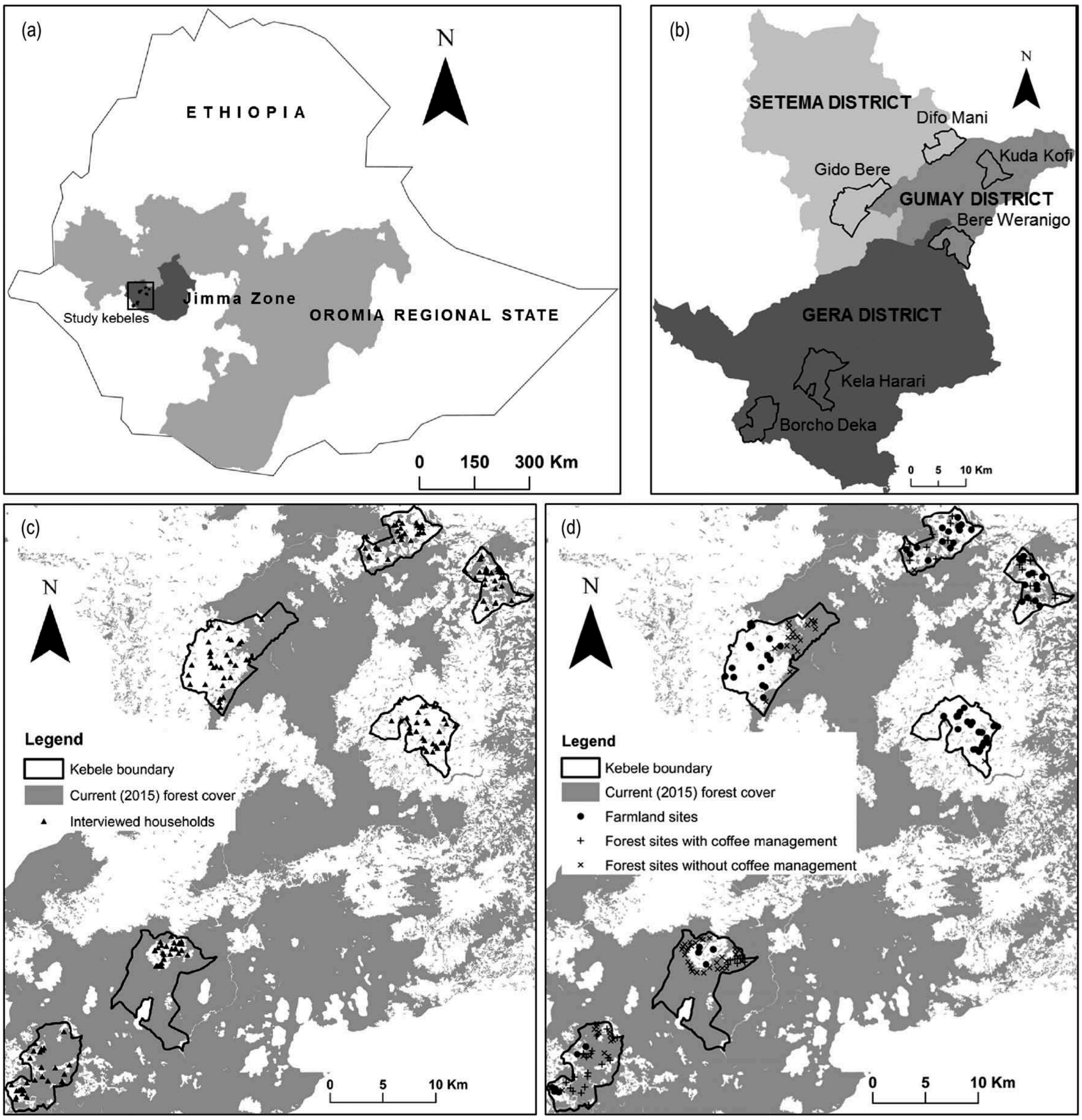

Figure 1. (a) Study area (square) in jimma zone, Ethiopia; (b) the six *kebeles*: Difo Mani and Gido Bere in Setema district, Bere Weranigo and Kuda Kofi in Gumay district, and Borcho Deka and Kela Harari in Gera district; (c) interviewed households (black triangles); and (d) woody plant survey points: in farmland (black circles), in forest with coffee management ('+' sign), and in forest without coffee management ('x' sign). In (c) and (d) grey colour represents current forest cover.

Table 1. Overview of the uses of woody plants in southwest Ethiopia in terms of ecosystem services, and their description and importance for meeting basic human needs. Woody plant use classification to basic human needs follows FAO (2014).

Ecosystem service	Specific use	Description and importance
Provisioning and/or cultural	Fuelwood	Firewood and charcoal used for cooking, heating and lighting. Helps to satisfy physiological, safety and security needs.
	Fences	Dried or live woody fences. Satisfy safety and security needs.
	Farming tools	Wooden handles, yolks and beams etc. used for ploughing, i.e. cultivating subsistence crops. Help to fulfil physiological, safety and security needs.
	Honey production	Plants used for beehive making and suspension, and bee flora. Helps to fulfil physiological and cultural needs.
	House construction	Sticks and wood (other than poles and timber) used to build houses' walls and roofs. Satisfies physiological, safety and security needs.
	Household utilities	Wooden household items, e.g. coffee table and chairs. Helps to satisfy cultural needs.
	Poles and timber	Wood prepared used for construction and carpentry, e.g. poles for wall and roof reinforcement, timber for doors and furniture. Help to satisfy physiological, safety, security and cultural needs.
	Medicine	Plant parts used for treating people and livestock. Helps to meet physiological, safety, security and cultural needs.
	Animal fodder	Plant parts browsed by livestock, or cut and fed to livestock. Helps to fulfil physiological, safety and security needs.
	Coffee shade	Planted or maintained trees for coffee shading. Helps to fulfil physiological, safety, security and cultural needs.
Regulating	Soil fertility	Planted or maintained trees supporting soil fertility. Helps to fulfil physiological, safety, security and cultural needs.

and forest because of very different densities in trees, as well as for logistic reasons (1-ha plots would not be feasible in dense forest; e.g. see Sheil et al. 2003). We did not survey plantation forests because they are even-aged forests often planted with exotic trees, and managed almost exclusively by the government. In our later analysis, due to sample sizes, we usually generalised land use types to the level of 'farmland', 'forest with coffee management', and 'forest without coffee management'.

In each study plot, all individuals of tree and shrub species with a height ≥1.5 m were recorded. We also measured and recorded diameter at breast height (DBH) of all individuals with DBH ≥ 5 cm. We identified plants that were readily identifiable in the field. For species that were difficult to identify in the field, specimens were collected, pressed, dried and transported to the National Herbarium at Addis Ababa University for identification. Nomenclature follows the Flora of Ethiopia and Eritrea (Flora of Ethiopia & Eritrea 1989–2006).

Data analysis

Socioeconomic data analysis

The socioeconomic data consisted of two major datasets. The first dataset covered a household's background information, uses and preferences of woody plants and their sources, i.e. the land use type from which the household collected and used woody plants. We summarized the characteristics of respondents by calculating averages (e.g. for age) or proportions (e.g. percentage of respondents native to the area). With respect to the *specific purposes* of a given woody species, we determined the total number of species used by local people for all purposes, total number of species for each purpose, and number of purposes of a species. Furthermore, we identified species of particularly low replaceability, by calculating the 'redundancy' of species for a given purpose. To this end, first, we determined the number of commonly used species for each purpose. Here, we used ≥30 households as a threshold to define commonly used species for a given purpose. Second, for each purpose, we determined the redundancy of common species (i.e. the number of readily available commonly used alternative species) and total redundancy (i.e. the total number of alternative species for a given purpose). In addition to looking at the specific purposes of particular species, we also defined the most widely used tree and shrub species in the landscape, *regardless of the purpose* they served. For this, first, we determined the total number of households that used a species for one or more purposes. Then, we determined the upper quartile (the top 25%) of the frequency of households mentioning the species mostly. Then, we identified these species as the most widely used species in the landscape. Finally, we determined the proportion of households visiting each major source for woody plant use.

The second dataset consisted of local people's perceived and actual land tenure security, woody plant use rights, sense of ownership and management responsibility. Perceived land tenure security was determined from information on whether household respondents felt that they had tenure security for the land from which they procured woody plant benefits. In addition, we established whether respondents held a land ownership certificate for the land from which they sourced woody plants. We also determined the percentage of respondents who believed they had wood extractive use rights from a given source of woody plants. Finally, we determined the percentage of respondents who felt a sense of ownership and responsibility to protect and manage woody plants in the source from which they obtained woody plant benefits.

Woody plant data analysis

We investigated the abundance of all woody plant species, and the DBH size class distributions of naturally regenerating widely used tree species, separately by pooling all plots within each of the three sources (farmland, forest with and without coffee management). For each tree species, we categorized individuals into diameter classes. To determine DBH profiles, we calculated total numbers of individuals of a tree species in each diameter class across all study plots by source. We then visually categorized DBH distribution profiles, grouping profiles of similar shape. Finally, we determined the percentage of species exhibiting a particular profile shape in each source.

Results

Characteristics of the respondents

Respondents were on average in their forties and 82% of them were male (Table S2). The average household size of respondents was six; 48% of the respondents were illiterate, and 79% of respondents were native to the area (Table S2). All respondents had homegardens, 94% used arable land, 73% used private grazing land and additionally, 24% accessed communal grazing land (Table S2). Fifty-seven percent of the respondents used inherited forest with coffee management; 13% owned forest with coffee management legally granted by the *kebele* authority; and 15% of respondents used inherited forest without coffee management. Fifty-two percent of the respondents had access to communal forest without coffee management. Almost none of the respondents accessed government plantation forest (Table S2).

Use and preference of woody plants and their sources

Of 158 recorded tree and shrub species (Table S3), local people used 90 species, including 17 exotic species (Table S4). They reported that they also used five additional tree and shrub species, which did not occur in the studied plots (Table S4). With respect to the total number of species for each purpose, 52 species were used for house construction, 42 for farming tools, 38 for fuelwood, 37 for honey production, and 11 for poles and timber (Table 2, Table S4). Species used for animal fodder, household utilities, medicine, poles and timber, and soil fertility had few readily available alternatives (≤2 species; Table 2). The most versatile species, i.e. species with the highest number of different uses, were *Croton macrostachyus, Vernonia amygdalina, Cordia africana, Millettia ferruginea, Pouteria adolfi-friederici, Vernonia auriculifera* and *Syzygium guineense* (Table 3, Table S4). Of all locally used species, 17 trees and 4 shrub species were identified as the most widely used species, i.e. each of these species were mentioned to be used by ≥67 respondents regardless of the number purposes they served in the landscape (Table 3). Of these species, *Erythrina brucei, Ehretia cymosa, Ocimum lamiifolium, Chionanthus mildbraedii, Cordia africana, Albizia* spp., and *Croton macrostachyus* were used most extensively.

Except for plants from government plantation forest, respondents used woody plants from all major sources (Table 4). About 90% of households visited forests with coffee management for farming tools, fuelwood and household utilities, and 86% for poles and timber. All households visited farmland for fences, and 87% for house construction, and 83% for medicine. Eighty-one percent of households visited forests without coffee management for farming tools, and 65% for house construction and fuelwood (Table 4).

Perceived land tenure security, use rights and sense of ownership and management

Although 93% of respondents had a farmland use certificate, only 36% felt they had farmland tenure security (Figure 2). Forty-five percent of respondents had a land use certificate for a plot of land (mainly converted from farmland) with coffee management, and for such a plot of land, only 25% of respondents felt they had land tenure security. Virtually none had an individual or communal forestland use certificate or felt they had secure tenure for forest without coffee management (Figure 2). The percentage of respondents who felt they had wood extractive use rights varied by source, i.e. land use type, and the type of extractive use (Table 5). Ninety-eight and eighty-nine percent of respondents perceived that they had wood extractive use rights for sourcing house construction wood from farmland and forest with coffee management, respectively (Table 5). In contrast, for household utilities and particularly for poles and timber, respondents perceived that extractive use rights were much more limited from all land use types (Table 5). 83 and seventy-eight percent of respondents felt a sense of woody plant ownership in farmland and in forest with coffee management, respectively. Likewise, 96% and 90% of respondents felt a sense of woody plant management responsibility in farmland and in forest with coffee management, respectively. In contrast, only 19% of respondents felt a sense of ownership over and 12% a management responsibility for the woody plants in forest without coffee management (Table 5).

Woody plant abundance and population structures

A total of 158 (including one unidentified) species of trees and shrubs, representing 50 families, were recorded from all plots (Table S3). Of these, *Vernonia auriculifera*,

Table 2. Use of woody plants, total number of species for each use, number of commonly used species (i.e. by at least 30 households), the redundancy of a commonly used species with commonly preferred alternatives and with non-commonly preferred alternatives, and total redundancy of a commonly preferred species with all species. Note that individual species may be used for multiple purposes (see Table S4).

Use	Total number used species	Number of commonly used species	Redundancy of a commonly used species with commonly used alternative species	Redundancy of a commonly used species with non-commonly used alternative species	Total redundancy
House construction	52	8	7	44	51
Farming tools	42	10	9	32	41
Fuelwood	38	9	8	29	37
Honey production/beehives	37	13	12	24	36
Fences	36	8	7	28	35
Medicine	25	2	1	23	24
Coffee shade	23	6	5	17	22
Household utilities	21	3	2	18	20
Soil fertility	18	2	1	16	17
Animal fodder	17	1	0	16	16
Poles and timber	11	2	1	9	10

Table 3. List of the most widely used woody plant species (i.e. each species mentioned to be used by ≥67 households for one or more purposes) in the landscape. Note that *Albizia* spp. stands for *Albizia gummifera* and *Albizia schimperiana*, and *Eucalyptus* spp. for more than two species of *Eucalyptus*; major source: fl = farmland, fwcm = forest with coffee management, fwocm = forest without coffee management. Small tree treated as a tree for this study.

Scientific name	Local name	No. of uses of species	No. of households preferred a species	Species category or mode of regeneration	Major source	Habit (Growth form)
Albizia spp.	Ambabbessa	7	152	Generalist	fl, fwcm, fwocm	Tree
Chionanthus mildbraedii	Gagamaa	3	154	Forest specialist	fwcm, fwocm	Tree
Coffea arabica	Buna	5	68	Forest specialist	fl, fwcm, fwocm	Small tree
Cordia africana	Waddessa	8	153	Generalist	fl, fwcm, fwocm	Tree
Croton macrostachyus	Bakkannissa	9	151	Pioneer	fl, fwcm, fwocm	Tree
Ehretia cymosa	Ulaagaa	5	160	Generalist	fl, fwcm, fwocm	Small tree
Erythrina brucei	Beroo	5	176	Planted	fl	Tree
Eucalyptus spp.	Baargamoo	6	143	Planted	fl	Tree
Euphorbia abyssinica	Adaamii	4	116	Planted	fl	Tree
Ficus sur	Harbuu	7	88	Generalist	fl, fwcm, fwocm	Tree
Galiniera saxifrage	Simararuu	3	84	Forest specialist	fl, fwcm, fwocm	Small tree
Justicia schimperiana	Dhummugaa	3	76	Generalist	fl, fwcm, fwocm	Shrub
Millettia ferruginea	Astiraa	8	133	Forest specialist	fl, fwcm, fwocm	Small tree
Ocimum lamiifolium	Dammaakkasse	1	158	Pioneer	fl	Shrub
Olea welwitschii	Bayaa	7	110	Forest specialist	fwcm, fwocm	Tree
Pouteria adolfi-friederici	Qararoo	8	105	Forest specialist	fwcm, fwocm	Tree
Rytigynia neglecta	Miixoo/Miixoo adii	4	80	Forest specialist	fl, fwcm, fwocm	Shrub
Syzygium guineense	Baddeessa	8	67	Forest specialist	fl, fwcm, fwocm	Tree
Teclea nobilis	Hadheessa/ Mitrii	2	81	Forest specialist	fwcm, fwocm	Small tree
Vernonia amygdalina	Ebicha	9	148	Generalist	fl, fwcm, fwocm	Shrub
Vernonia auriculifera	Reejii	8	103	Pioneer	fl, fwcm, fwocm	Shrub

Table 4. Extractive use of woody plants and percentage of households engaged in their extraction, in the major land use types of farmland (n = 180), forest with coffee management (n = 114), forest without coffee management (n = 97) and plantation (n = 180).

	% Households visiting major source for use of woody plants			
Use	Farmland	Forest with coffee management	Forest without coffee management	Plantation (governmental)
House construction	87	74	65	0
Farming tools	67	94	81	1
Fuelwood	74	93	65	1
Honey production – beehives	46	62	58	0
Fences	100	74	57	0
Medicine	83	54	38	1
Household utilities	53	90	51	0
Animal fodder	38	27	20	0
Poles and timber	39	86	44	0

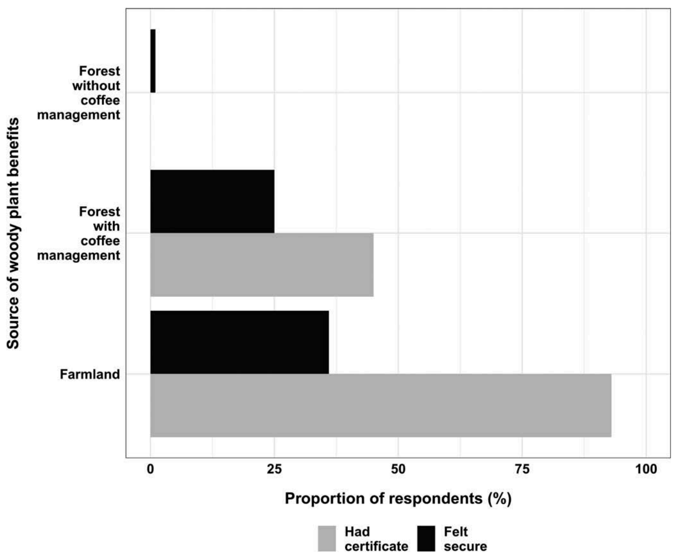

Figure 2. Proportion of respondents who had actual (a land use certificate) and perceived tenure security to main sources (i.e. land use types) of woody plant benefits. Note that for farmland n (the number of respondents) = 180; forest with coffee management: n = 114; and forest without coffee management: n = 97.

Table 5. Percentage of respondents who felt they had woody plant extractive use rights, sense of ownership and management responsibility for each source. Farmland (n = 180), forest with coffee management (n = 114), forest without coffee management (n = 97) and plantation (n = 180).

Source	% Respondents who felt they had extractive use rights for wood for			% Respondents who felt sense of ownership	% Respondents who felt management responsibility
	House construction	House utilities	Poles and Timber		
Farmland	98	36	4	83	96
Forest with coffee management	89	28	4	78	90
Forest without coffee management	65	21	3	19	12
Plantation (governmental)	0	0	0	0	1

Erythrina brucei, Acanthus sennii were abundant in farmland; *Coffea arabica, Maytenus arbutifolia, Vernonia auriculifera* in forest with coffee management; and *Dracaena afromontana, Chionanthus mildbraedii* and *Justicia schimperiana* in forest without coffee management (Table S3). Unlike species used for honey production, farming tools, and fuelwood, species used for poles and timber (an extractive use with few readily available alternative species; Table 2) had low abundance in the landscape (Table S3; Table S4).

Naturally regenerating widely used tree species were nine (including the two *Albizia* species) in farmland and 13 in forests (Fig. S1; Table 3). Of these, poles and timber tree species were three in farmland, and four in forests (Fig. S2; Table S4). The population profiles of these most widely used tree species were categorized into one of the three major distribution profiles in a given type of source (Figure 3). The first profile indicated a *healthy population structure* characterized by many individuals in lower size classes followed by progressively fewer individuals in larger size classes, as illustrated, for example, by *Milletia ferruginea* in farmland (Figure 3(a)). This profile was exhibited by 90% of the most widely used tree species in farmland, by 75% species in forest without coffee management, and by 55% of species in forest with coffee management (Figure 4(a)). The second diameter profile had *selectively removed individuals* in some age classes, typified by a species with many individuals in the lowest size class followed by fewer individuals in lower and/or intermediate size classes and proportionally more individuals in larger size classes, as illustrated, for example, by *Syzygium guineense* in forest with coffee management (Figure 3(b)). This distribution was demonstrated by 30% species in forest with coffee management, and by 10% of species in forest without coffee management. However, this distribution was not found in farmland (Figure 4(a)). The third diameter profile indicated *poor regeneration and lack of old trees*, characterised by a species with few individuals in both small and large size classes, as illustrated, for example, by *Olea welwitschii* in forest with coffee management (Figure 3(c)). This profile was exhibited by 15% of species in both types of forest, and 10% in farmland (Figure 4(a)). Diameter distribution profiles of the most widely used tree species also varied in different sources by the type of purposes of the species, especially for poles and timber species (Figure 4(b)). Population profiles of poles and timber species were much less healthy in forests than in farmland (Figure 4(b)). Especially in forest without coffee management, only 25% of poles and timber species exhibited a healthy population structure (Figure 4(b)).

Discussion

Ensuring landscape sustainability via integrated land management for biodiversity and ecosystem services is an important priority for human societies (Wu 2013; Kremen and Merenlender 2018). However, many obstacles prevent farmers from actually practicing sustainable land management, including ill-defined property rights (RRI 2017; Kremen and Merenlender 2018). In biodiverse landscapes of southwestern Ethiopia, we found that many species of woody plants were used to generate benefits for the wellbeing of rural households, sourced from different land use types across the landscape including farmland, forest with and forest without coffee management. However, we also found a low perception of tenure security and extractive use rights, particularly for poles and timber species. Specifically, we found that local people's perceived tenure security was higher for farmland, for which the majority also held land use certificates, but that it was much more limited for forest without coffee management. We also found that the perceived insecure land tenure and limited use rights, particularly for forest without coffee management, reduced the sense of ownership and responsibility to manage and conserve woody plants. Ecologically, we found that most of the widely used tree species had good regeneration throughout the landscape, including in farmland. From a sustainable use and management perspective, however, we found that some of these tree species, including important species that provide poles and timber, appeared to have been overharvested in forests, especially in forest with coffee management. In the following we discuss our findings in detail, focusing on the importance of woody plants for rural livelihoods and woody plant management in relation to property rights in different land use types.

Trees and shrubs are essential for the livelihoods of rural households (Kaimowitz and Sheil 2007; Rasmussen

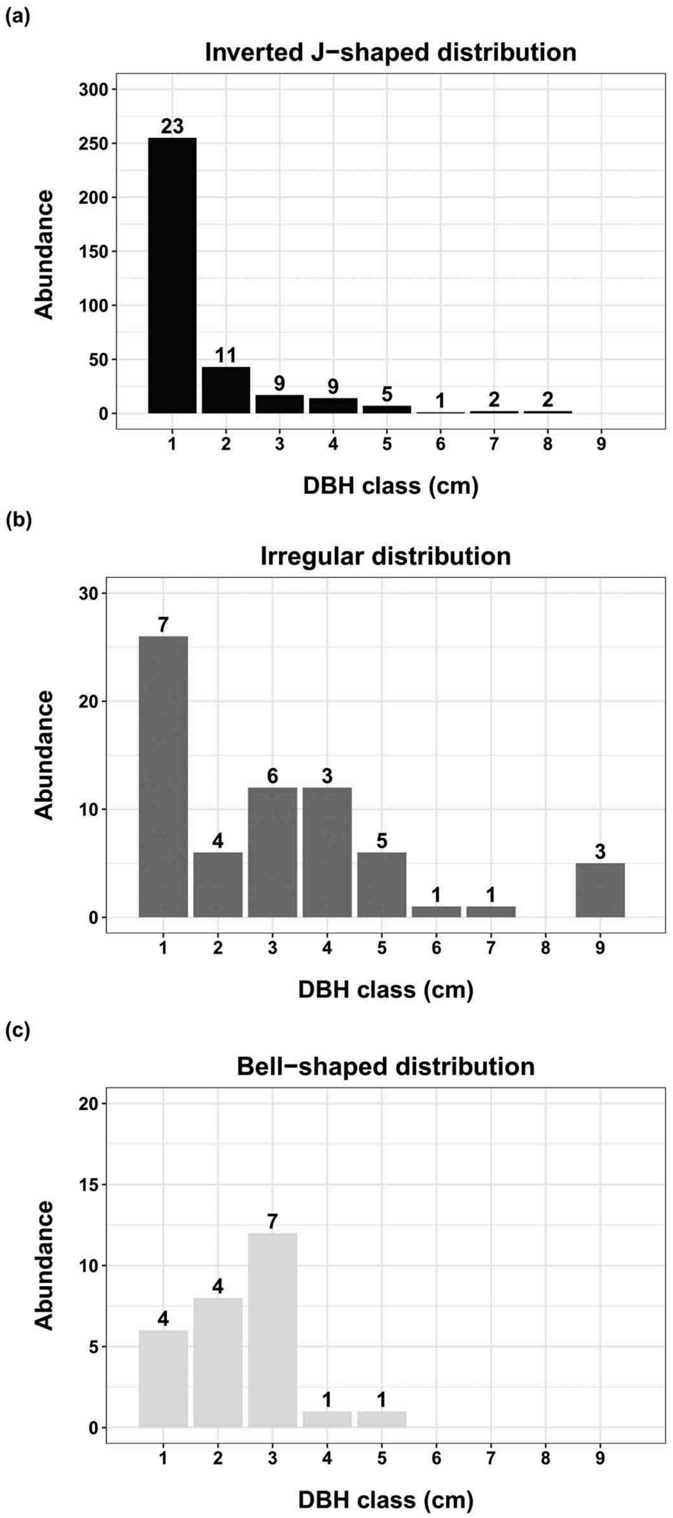

Figure 3. Typical DBH class distribution profiles of the most widely used tree species. (a) Inverted J-shaped distribution (healthy population profile; dark shaded), exemplified by Millettia ferruginea from farmland; (b) irregular distribution (selective removal population profile; dark grey shaded), exemplified by Syzygium guineense from forest with coffee management; and (c) bell-shaped distribution (poor regeneration and lack of old trees population profile; light grey shaded), exemplified by Olea Welwitschiii from forest with coffee management. DBH classes are: 1 = <5 cm; 2 = 5.1–10 cm; 3 = 10.1–20 cm; 4 = 20.1–30 cm; 5 = 30.1–40 cm; 6 = 40.1–50 cm; 7 = 50.1–60 cm; 8 = 60.1–70 cm; and 9 = >70 cm. Numbers above bars refer to the number of plots in which individuals in the size class occurred.

et al. 2017; Reed et al. 2017). Our findings revealed the importance of many species for local people's livelihoods in southwestern Ethiopia. Tree and shrub species provided fuelwood, medicine, construction materials, household utilities, farming tools, fences, poles and timber, animal fodder, honey production, coffee shade and soil fertility improvement, which are vital for the subsistence of rural farmers (FAO 2014; Reed et al. 2017). Our findings are consistent with other studies, for example by Faye et al. (2011) in five regions of Burkina Faso,

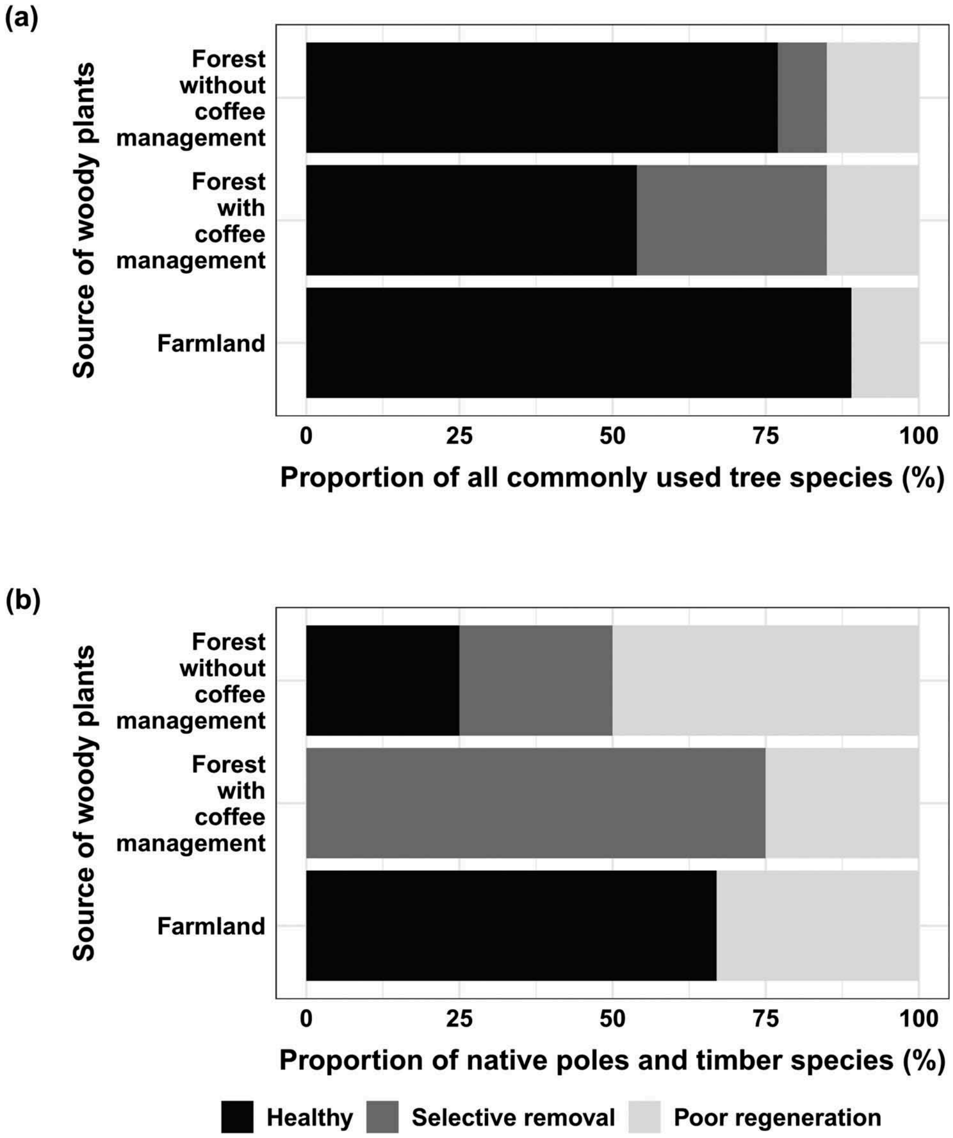

Figure 4. (a) Proportion of all naturally regenerating commonly used tree species with healthy population profile (dark shaded); with selective removal population profile (dark grey shaded); and with poor regeneration and lack of old trees population profile (light grey shaded) in major land use types, i.e. sources of woody plant benefits. (b) Proportion of the most widely used native poles and timber species with healthy population profile (dark shaded); with selective removal population profile (dark grey shaded); and with poor regeneration and lack of old trees population profile (light grey shaded) in major land use types. Note that there were three native species (Cordia africana, Ficus sur, and Syzygium guineense) from which poles and timber were produced in farmland; and four (Cordia africana, Ficus sur, Pouteria adolfi-friederici, and Syzygium guineense) in forests (see Table 3 and Fig. S2).

Mali, Niger and Senegal, and by Quandt (2016) in Tanzania, who demonstrated a similar level of social significance of trees and shrubs for rural livelihoods. Likewise, a study by Iiyama et al. (2014) corroborated that the majority of rural households (>90%) in sub-Saharan Africa still depend on fuelwood for cooking. Reed et al. (2017) also showed that trees and shrubs increase crop yields when integrated and managed properly.

Our findings further confirmed local people's reliance on a range of different sources, including farmland, forest with and forest without coffee management. This multifunctionality of the landscape is in agreement with Reed et al. (2017) and Kremen and Merenlender (2018), who emphasised the need to integrate trees and forest patches within rural landscapes for improved livelihoods and biodiversity conservation. Interestingly, our findings highlighted that local people appreciated landscape multifunctionality, rather than seeing biodiversity conservation and extractive uses of the environment as mutually exclusive (Fischer et al. 2017; Jiren et al. 2017). In this context, multifunctional landscapes are landscapes that concurrently fulfil basic needs such as food, wood and cultural needs, while also contributing to biodiversity conservation (O'Farrell and Anderson 2010; Wu 2013; Kremen and Merenlender 2018).

From a property rights perspective, land is a vital livelihood asset and its accessibility has many implications for rural people and land management (e.g. Tura 2018; Kremen and Merenlender 2018). Beside forests, the smallholder farmland matrix in southwestern Ethiopia harbours many trees and shrubs, including both retained and planted species (Ango 2016; Jara et al. 2017). Perhaps surprisingly, our findings revealed healthy population structures in farmland for nearly all of the most widely used tree species, including poles and timber species. Here, unlike in other parts of the world, such as Australia (Fischer et al. 2009) or Romania (Hartel et al. 2013), our findings showed successful regeneration and preservation of successively aged individuals. Possible reasons could be relatively low intensity use of the agricultural landscape, including the existence of small patches of trees, coffee shrubs under shade trees, homegardens and live fences in or around pastures and small fields (Ango 2016; Jara et al. 2017). In addition, the relatively secure perceived tenure in farmland may also provide an incentive for farmers to sustainably retain and manage trees in farmland (Yami and Snyder 2015; McClellan et al. 2018).

In contrast to farmland, our findings for forest with coffee management showed discontinuous population structures for the majority of the most widely used tree species, particularly for timber species. These species regenerated successfully but individual trees in older age classes were extracted quite heavily, and potentially at unsustainable levels. Here, the likely reasons could be (i) the perceived insecure tenure and limited use rights, particularly of timber species; as well as (ii) intensive use pressure on this forest, especially for coffee production. From a property rights perspective, our findings are consistent with other studies indicating that a lack of clear property rights can negatively influence local people's stewardship role for the ecosystems and woody plants they depend on (Mekonnen 2009; RRI 2017). For example, studies by Kassa et al. (2011) and Lemenih and Kassa (2014) in Ethiopia indicated that a lack of timber use rights negatively affected local people's native timber tree species maintenance in the forest. In our study area, a local farmer asked: 'Why would I retain a *Cordia africana* tree, a highly valued timber species, in my forest with coffee management, which I then cannot use?' (pers. comm.). Indeed, of the three studied sources, forest with coffee management was used most widely for highly extractive uses (Table 4), suggesting that strong use pressure led to the discontinuous population structures of species in coffee forest (Wakjira 2006; Mwavu and Witkowski 2009). Moreover, forest with coffee is typically actively managed by local people for coffee production (Teketay 1999; Schmitt et al. 2010). As shown in other studies (e.g. Hundera et al. 2013; Kumsa et al. 2016), such management entails farmers frequently removing young and intermediate-sized trees, so as to avoid competition with coffee (Geeraert et al. 2019). This was also the typical pattern found in our study; that many species, including the most widely used tree species, had low numbers of small and intermediate-sized trees despite abundant regeneration. Hence, unclear property rights, coffee production and extensive use pressure in this forest together most likely lead to unsustainable population structures.

Similarly to forest with coffee management, our findings for forest without coffee management also revealed a discontinuous population structure of some species, and especially of timber species. A possible reason could be local people's ill-defined property rights (perceived insecure tenure for forest lands, limited woody plant use rights, low sense of ownership and management responsibility), as revealed in our study (cf. Schlager and Ostrom 1992; Johann and Schaich 2016; RRI 2017). A likely additional reason is that illegal timber extraction has increased in the area in recent years due to the provision of licenses for metal and woodwork as a strategy to create job opportunities for young people (pers. comm. with metal and woodwork micro-enterprises in Gera district). This is at odds with conservation-oriented forest policies that prohibit the use of timber species (Lemenih and Kassa 2014). Thus, despite some conservation-oriented policies, our findings suggest that even important tree species are not effectively protected in this forest at present.

Notably, the observed disturbed population structures in our study, particularly of timber species, were different from population structures that have been reported in community managed forests elsewhere in Ethiopia, where forest land tenure, use rights and management decisions are negotiated and devolved to the community by the government. For instance, Gobeze et al. (2009) confirmed natural population structures of tree species in the community managed Bonga coffee forest, in a broadly similar environment to that studied here. Studies by Takahashi and Todo (2012; 2017) on participatory forest management (PFM) and community managed forest in Gera, one of the three southwestern Ethiopian districts we studied, showed reduced rates of deforestation and improved tree density as compared to forest without such management. Similarly, Yietagesu (2013) demonstrated that commercial timber species were effectively maintained in community managed forest in southeastern Ethiopia. Comparisons with studies from areas where PFM schemes exist thus suggest that local people's woody plant retention and sustainable use may more generally be influenced by perceived and actual property rights. Therefore, given the high reliance of local people on nature but also ongoing mismanagement, any future biodiversity and ecosystem service management strategy needs to consider and balance landscape-specific social and ecological benefits and costs.

Conclusion

Understanding and adopting effective and integrated biodiversity conservation and ecosystem service management remains a challenge. By using a social-ecological system perspective for the biodiverse landscapes of southwestern Ethiopia, we revealed complex and strong links between nature and people across the landscapes. More specifically, our study showed local people's reliance on several woody plant species for their livelihoods, and the existing multifunctionality of rural landscapes. However, we found that local people's perceived tenure security and woody plant use rights were limited in forest with and without coffee management. Ecologically, our study found most of the commonly used tree species to successfully regenerate throughout the landscape, including in farmland. Nevertheless, some of these useful tree species appeared to be overharvested in forests, particularly in forest with coffee management. Our findings highlight the importance of woody plants for rural households, but that local people's ill-defined property rights may adversely affect the maintenance of woody plants in forests. In this regard, recent changes in the national forest law that permit forest use, management and development by local community, may be helpful but need to be translated into specific regulations (e.g. see Vos and Meekes 1999). Proper implementation of these policies could improve local people's perceived property rights, woody plant use, potentially including controlled extraction and management of species needed for pole and timber production. Such development may then also lead to a more sustainable, inclusive development of the multifunctional southwestern Ethiopian landscapes. To strengthen existing synergies between biodiversity and people in southwestern Ethiopia and other similar landscapes, we therefore suggest to: (1) recognize local people's livelihood needs of woody plants and their property rights to land, including the right to use and manage woody plants, and (2) design conservation policies that engage and empower local people while also provide safeguards against overuse of woody plants in forests and that encompass the entire landscape mosaic including farmland.

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ORCID

Kristoffer Hylander http://orcid.org/0000-0002-1215-2648

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