ORIGINAL ARTICLE

Agroforestry, Indigenous Tree Cover and Biodiversity Conservation: A Case Study of Mount Elgon in Uganda

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Abstract

Addressing interconnected social and environmental issues, including poverty, food security, climate change, and biodiversity loss, requires integrated solutions. Agroforestry is a sustainable land use approach with the potential to address multiple issues. This study examined the tree cultivation behavior of smallholder farmers in the Mt. Elgon region of Uganda. We examined the proportion of indigenous tree species added to or removed from agricultural land and the reasons for farmers' decisions in this regard. We found that farmers overwhelmingly planted exotic species, limiting the possible benefits for the conservation of biodiversity from a suggested re-greening of the region. Indigenous trees were cultivated in low numbers and dominated by a handful of species. Opportunities to help farmers increase the number and variety of indigenous trees on their land were found among smaller-scale coffee farmers and in the protection of natural forests from which indigenous trees propagate into the wider landscape.

Keywords Biodiversity conservation · Coffee agroforestry · Indigenous trees · Uganda

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Résumé

Il faut des solutions intégrées pour bien adresser les problèmes sociales et environnementales connectés, tels que la pauvreté, la sécurité alimentaire, le changement climatique, et la perte de la biodiversité. L'agroforesterie est un approche d'utilisation durable de la terre, qui a le potentiel d'adresser des problèmes multiples. Cet étude examine le comportement des petits exploitants dans la région du Mont Elgon au Uganda, dans la cultivation des arbres. Nous avons examiné la proportion d'espèces d'arbres indigènes qui a été ajouté ou enlevé aux terrains agricoles, et les motivations des agriculteurs dans leurs décisions. Nous avons trouvé que les agriculteurs majoritairement plantent des espèces exotiques, ainsi limitant les possibles bénéfices issues de la conservations de la biodiversité, suggérés par une possible reverdissement de la région. Les arbres indigènes sont peux nombreux à être cultivés, et ils ne comptent qu'une poignée d'espèces parmi eux. Les opportunités pour aider les agriculteurs, augmentant le nombre et la variété d'espèces indigènes sur leurs terres, sont possibles surtout parmi les petits exploitants de la cultivation du café, et dans la protection des forets naturels, depuis lesquelles les espèces d'arbres indigènes se diffusent dans le paysage.

Introduction

Climate change and biodiversity loss are emerging as two of the greatest environmental challenges facing humanity (IPBES 2019; IPCC 2014; Pörtner et al. 2021), and political efforts to address these and other environmental challenges are increasing (CBD 2018; UNFCCC 2015). With governments having pledged to meet the Sustainable Development Goals by 2030 (UNFCCC 2015), there is an increasing demand for integrated policies that offer significant synergies and minimize trade-offs in the pursuit of this complex and demanding agenda. In this context, land use approaches, such as sustainable agriculture, are policy options that are growing in prominence as part of national and international strategies to address multiple challenges (EU 2016; UNCCD 2014). The form of sustainable land use, which is the focus of this study, is agroforestry. The impacts of forest clearance have been closely studied for decades. The global forest area has declined by ~ 20% since 1850, contributing to ~ 90% of the greenhouse gas emissions due to land use change during that period (Prentice et al. 2001). Tropical forests alone have been estimated to house two-thirds of the world's organisms (Raven 1988), making their protection a priority for conservationists. Deforestation, which usually occurs to create more farmland, is also considered a critical driver of land degradation (UNCCD 2017). However, relatively limited attention has been given to the conservation of biodiversity in areas that have been cleared of forest for human use but may still hold a substantial number of trees. Uganda has experienced severe deforestation. Uganda's forest cover declined from 4.9 to 1.8 million hectares between 1990 and 2015, with the biggest decline of trees on private land (MWE 2016).

Agroforestry, which includes the integration of trees into farming systems, is a promising way to address multiple social, economic, and environmental goals, including increasing farm productivity, improving water management, mitigating and adapting

to climate change, and bolstering biodiversity conservation (FAO 2017). It is a traditional practice in numerous regions, and it is now widely promoted by governments and non-governmental organizations. In some regions, including East Africa, farmers often plant exotic species of trees because of their perceived superior growth rates, high fruit yields, or compatibility with other crops. However, the inclusion of exotic trees in agroforestry can occur at the expense of indigenous species, which play important roles in biodiversity conservation through the conservation of the species themselves, providing habitat and food for other species, and by reducing harvesting pressure in nearby natural forests (Burghardt et al. 2010; Forister et al. 2015).

This study aimed to increase knowledge of the tree cultivation behavior of smallholder farmers using a case study in the Mt. Elgon region of Uganda. The study area lies close to Mt. Elgon National Park. While other studies have examined the pressures that the local population places on biodiversity within the park (Sassen 2014; Scott 1998), this paper is a contribution to gauging the potential for biodiversity conservation in the farmland area beyond its boundary. We asked farmers in the region for details of their tree cultivation practices, including the planting, protection, and removal of trees, over a 3-year period. In addition, we asked about their motivations behind the species that they selected and where the trees were located.

Our goal was to gain insights into the on-the-ground processes adopted by farmers, with a focus on the prevalence of exotic trees and their impact on the number and diversity of indigenous species present. We also aimed to gain insights into farmer decision-making, rather than eliciting preferences, which may not be reflected in future behavior. Specifically, this study aimed to determine whether and why farmers have planted exotic trees at the expense of indigenous species, whether and why farmers have retained indigenous trees on their land, whether farmers would like to have more indigenous trees on their land, and what factors hinder the cultivation of indigenous trees on their land. The first two questions explore the drivers of farmers' decision-making with regard to the selection of tree species and the land use resulting from the selection of these tree species. However, the third question aims to uncover the potential for development policies or farm extension services to increase the conservation value of agroforestry by promoting indigenous tree species. For practical reasons, a survey was used instead of a longitudinal tree inventory study. Therefore, the findings of this research have limitations. However, it is hoped that the findings can help direct further inquiry and inform sustainable land use policies that take advantage of the synergies between practicing agroforestry and conserving biodiversity.

The remainder of this article is organized as follows: the next section presents the methodology, including a description of the study area and survey design, and the methodological limitations of this study. This is followed by two sections dedicated to the presentation and discussion of the results. The last section concludes.
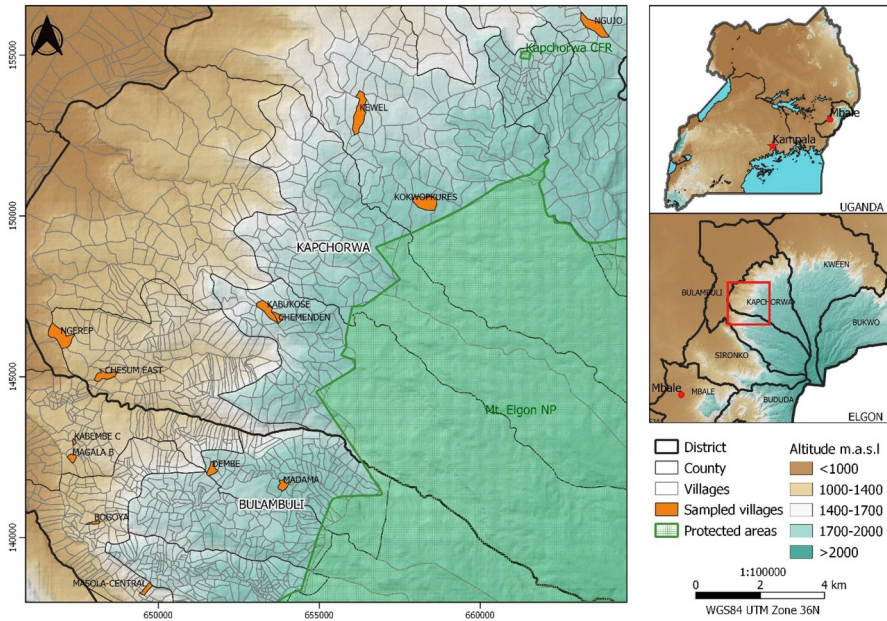
Fig. 1 Location of the study area within Uganda, Mt. Elgon area (top right), districts of the study area (Bulambuli, Kapchorwa) (down right), and study site with sampled villages across altitude bands

Methodology

Study Area

The research was conducted in coffee-growing areas of the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda, near the border with Kenya. The research sites were selected as they fall within the areas of high conservation priority and areas where a significant number of households practice agroforestry (Dave et al. 2019; IUCN 2016). The study area lies on the western slopes of Mt. Elgon, from about 1000 to 2000 masl (see Fig. 1). The mean annual rainfall of the area ranges from about 1200 to 1800 mm, with the mean annual temperatures of 18 °C to 23 °C (Gram et al. 2018). The rural economy is dominated by smallholder agriculture on intensively farmed plots of food crops, such as banana and maize, and cash crops of primarily coffee. Coffee–banana intercropping is common, while much coffee is also grown under shade trees. Several government agencies and non-government organizations have undertaken rural development programs in the region, including the promotion of agroforestry techniques. Natural vegetation was largely cleared from the immediate study area several decades ago. However, the study area lies within the Mt. Elgon transboundary management area for conservation, which is centered on national parks that protect the high mountain on both sides of the frontier (Gram et al. 2018).

Survey Design

The field work was conducted in May 2019. Sampling was performed using a multi-stage approach, which began with the selection of seven sub-counties across the two districts where *Coffea arabica* is widely cultivated. Villages in the sub-counties were stratified by altitude, and 13 villages from different altitude bands were randomly selected. A minimum of 12 households were selected randomly from each village using household lists provided by village chairpersons. The households were mobilized by local extension officers and village chairpersons. Data were obtained using a survey questionnaire. To ensure that respondents were able to comprehend the survey questions, the survey was translated into vernacular i.e., Lumasaaba in Bulambuli district and Kupsabiny in Kapchorwa district. A team of 12 local enumerators, gender disaggregated into six men and six women, were carefully selected, trained, and supervised by the researchers to conduct all the interviews. Data was collected electronically using tablets based on the Open Data Kit (ODK) platform and then uploaded to an online server on a daily basis by the enumerators. All selected households were visited in their homesteads to conduct the face-to-face interviews. A total of 161 respondents provided information for this study, including 142 men and 19 women.

The enumerators asked the respondents to name and quantify the trees that their household had planted, protected (i.e., allowed to grow in situ after germinating naturally), or removed in the previous three years. The respondents were also asked where on their land trees were planted, protected, and removed and why they made decisions to plant, protect, and remove trees. Where respondents provided names in local languages for the tree species recorded, where possible, the local names were matched with scientific names using an identification guide to the trees of Uganda (Katende et al. 1995). Gaps were filled in consultation with botanists. The data were coded according to species and category (exotic, indigenous, or unknown). In addition, household heads were asked a range of questions about their socioeconomic conditions. Values for the tree cultivation variables were also computed for each household so that they could be analyzed together with the socioeconomic data. Enumerators gathered data for some variables that may explain the patterns of tree cultivation: the main cash crop, area of land cultivated, and altitude.

In addition to the survey, eight focus group interviews were held in four different villages: four with men and four with women. Each group consisted of between five and nine adults. The participants were selected and mobilized by field facilitators and local leaders from villages that were not included in the household survey. The focus group discussion was structured around a set of neutrally phrased questions. The participants of the focus group discussions were asked about the species of trees that had become more or less common during the period that the participants had lived in the village, which was potentially a much longer period than that covered in the survey, as well as the reasons for these changes. They were also asked about the history of forest clearance, the impacts of climate change on trees in the area, and their own decision-making regarding trees.

Methodological Limitations

Gathering quantitative data about tree cultivation patterns using a questionnaire raises issues with regard to accuracy. This is because the respondents are unlikely to accurately recall all the relevant actions taken during a given period. Therefore, a short timeframe of 3 years was selected to minimize this effect. The socioecological conditions in the study area also make this approach defensible. Given the low standard of living and the intensity of land use in the area, families are likely to think carefully about whether to plant or remove trees. Similarly, small farm sizes indicate that the number of these decisions is limited, which helps recall. While the survey gathered data about the trees that were added to and removed from the landscape, there is a possibility that the respondents answered these questions in different ways. The participants of the focus group discussions indicated that there were no issues surrounding tree tenure rights that would make people reluctant to discuss tree falling on their own land. However, it is possible that respondents were more reticent about tree removal or less interested to provide details of it. Therefore, results involving this data are interpreted with caution.

The identification of the tree species named by the respondents was challenging. A total of 41 species or groups of closely related species were recorded and positively identified. However, another 27 tree names provided in local languages or English could not be identified conclusively and were recorded as "unknown". In addition, it appeared that some respondents used at least one local name to identify two different *Ficus* species. Local dialects further complicated the picture. Consequently, this important group of at least three species was grouped as *Ficus* spp. Similarly, *Albizia* species were grouped as *Albizia* spp., and *Pinus* species were grouped as *Pinus* spp. While *Eucalyptus grandis* was commonly recorded, some respondents only identified the genus. Therefore, the presence of other *Eucalyptus* species and hybrids cannot be excluded, and all *Eucalyptus* species were grouped as *Eucalyptus* spp. As each of the four groups described above is exclusively either indigenous or exotic, the loss of species-level information had a limited impact on the analysis, which was focused on the comparison of the two categories, namely, indigenous, and exotic. Furthermore, most of the tree names that could not be matched with scientific names occurred only once. The Online Appendix presents the list of species recorded and their classification.[1]

Results

Tree Cultivation and Removal

The respondents reported 426 plantings of tree species or species groups over the 3-year period. Exotic species or species groups accounted for 63% of all cases,

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[1] Recommended further reading on indigenous and scientific kinds by Ludwig (2017), as suggested by an anonymous reviewer.

Table 1 Tree species most frequently planted on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda

Species	#cases	% of total
Eucalyptus spp.*	101	24.0
Cordia africana	59	14.0
*Persea Americana**	51	12.0
*Grevillea robusta**	44	10.0
Ficus spp.	44	10.0
*Mangifera indica**	20	4.7
Unknown	19	4.5
Markhamia lutea	16	3.8
*A. heterophyllus**	16	3.8
*Cupressus lusitanica**	9	2.1
*Ricinus communis**	7	1.6
Maesopsis eminii	7	1.6
Pinus spp.*	5	1.2
*Citrus sinensis**	5	1.2

Excludes species that account for less than 1% of cases. Exotics are indicated by an asterisk

indigenous species or species groups accounted for 33% of cases, and unknown species accounted for the remaining 4% of planted species. Table 1 presents the most frequently planted species or groups over the 3-year period. Exotics dominate in terms of the absolute numbers of trees planted. The respondents reported planting a total of 21,950 trees, of which 90% were exotic species, compared with 6.4% indigenous trees. *Eucalyptus* spp. alone accounted for 75% of the total number of trees planted. *Eucalyptus* and two other key exotics, *Grevillea robusta* and *Pinus* spp., together represent 84.9% of all planted trees.

The respondents allowed trees that had germinated naturally to continue growing in situ (referred to as "protected") in 235 cases. In contrast to the situation for planted trees, 62% of cases of protected trees were indigenous species, 32% were exotic species, and 6% were unknown species. Indigenous *Ficus* spp., *Cordia africana*, and *Markhamia lutea* accounted for 48% of all cases (Table 2). The absolute number of trees allowed to grow naturally was 1276. The proportion of indigenous and exotics among them, 64% and 30%, respectively.

There were 661 cases of trees of individual species or species groups that were added to farms as either planted or protected trees over the 3-year period. Of these, 52% were exotic species; 43%, indigenous species; and 5%, unknown species. In total, 23,226 trees were planted or protected. Of these trees, exotics accounted for 87%, and indigenous species accounted for 9.3%. *Eucalyptus* spp. dominate the trees that were planted and protected (Table 3).

When the respondents were asked why they had planted each species of tree, they provided between one and seven reasons, indicating the multiple ecosystem services provided by trees. While firewood and timber were both mentioned in most cases, fruit/food was a more important reason given for planting exotic trees, whereas indigenous species were more often planted for shade, soil fertility,

Table 2 Most frequently protected tree species on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda

Species	#cases	% of total
Ficus spp.	45	19.0
Cordia Africana	42	18.0
*Persea Americana**	33	14.0
Markhamia lutea	25	10.0
Unknown	13	5.5
*Mangifera indica**	12	5.1
*Artocarpus heterophyllus**	11	4.7
*Ricinus communis**	8	3.4
Croton macrostachyus	6	2.6
Schefflera volkensii	5	2.1
Albizia spp.	5	2.1
Sesbania sesban	4	1.7
*Psidium guajava**	4	1.7
Vangueria apiculata	3	1.3
Spathodea campanulata	3	1.3

Excludes species that account for less than 1% of cases. Exotics are indicated by an asterisk

Table 3 Cases and numbers of tree species most commonly added to smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda

Species	#cases	% of total	#trees	% of total
Eucalyptus spp.*	103	16.0	16,510	71.0
Cordia africana	101	15.0	784	3.4
Ficus spp.	89	14.0	620	2.7
*Persea Americana**	84	13.0	395	1.7
*Grevillea robusta**	44	6.7	1137	4.9
Markhamia lutea	41	6.2	421	1.8

Exotics are indicated by an asterisk

and erosion control (Table 4). Cultural or esthetic reasons played a minimal role in driving decisions to plant trees. The respondents provided a similar number and balance of reasons for allowing trees to grow naturally on their land.

The respondents reported 184 cases of tree species removal. Exotic species were removed in 60% of cases, indigenous species were removed in 37% of cases, and 3% of cases were unknown species. In total, 2421 trees were removed. This is about 10% of the total number of trees that were added to farms. This finding could reflect an increase in the number of trees in the landscape, underreporting of removals, or both of these factors (see methodology and discussion sections). Of the removed trees, 91% were exotics, and 8.7% were indigenous trees. The most frequently removed species over the 3-year period are presented in Table 5. The proportion of exotic and indigenous species among the trees removed is

Table 4 Reasons for planting exotic or indigenous trees on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda (n = 161 respondents)

Reasons	Exotic species		Indigenous species	
	#cases	% cases	#cases	% cases
Fruit/food	100	37.0	0	0.0
Timber	159	59.0	83	60.0
Charcoal	4	1.5	5	3.6
Firewood	188	70.0	92	66
Medicine	2	0.7	3	2.2
Fodder	14	5.2	14	10.0
Bee forage	4	1.5	4	2.9
Shade	68	25.0	75	54.0
Windbreak	51	19.0	25	18.0
Erosion control	17	6.3	22	16.0
Soil fertility	10	3.7	59	42.0

Table 5 Cases and numbers of tree species most frequently removed from smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda (n = 161 respondents)

Species	#cases	% of total	#trees	% of total
*Eucalyptus spp.**	63	34.0	1723	71.0
Cordia Africana	33	18.0	73	3.0
*Grevillea robusta**	21	11.0	375	16.0
Ficus spp.	21	11.0	49	2.0
*Persea Americana**	18	9.8	64	2.6
Markhamia lutea	7	3.8	55	2.3

Exotics are indicated by an asterisk

similar to the proportion of trees added to farms, suggesting that balance is maintained between the cover of exotic and indigenous tree species that have been planted.

The respondents reported removing trees in 184 cases, mostly to harvest timber (64% of 118 cases) and firewood (60% of 110 cases), followed by leaving space, light, and water for crops (13% of 24 cases) and other trees (7% of 13 cases). The findings for exotic and indigenous species were similar, with the exception that the respondents more often removed indigenous trees than exotic trees (19% vs. 10% of cases) to provide space, light, and water for other crops, showing how exotic trees grown in woodlots do not compete with other crops.

Of the 161 respondents, 129 (80%) said that they would like more trees on their land, and they provided 192 cases of species that they would like to have more of. Of these cases, 68% were exotic species; 29%, indigenous species; and ~3%, unknown species. For individual species, the popularity of *Eucalyptus* spp. was equal to that of the trees planted (23%). The frequency with which respondents identified three other important exotic species, *Grevillea robusta*, *Pinus* spp., and *Cupressus lusitanica*, was higher than the number of trees planted, whereas the

Table 6 Obstacles to planting desired tree species on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda (*n* = 161 respondents)

Obstacle	#cases	% of total
Availability of seeds/seedlings	100	52.0
Price of seeds/seedlings	72	38.0
Lack of land	41	21.0
Lack of labor	7	3.6
Lack of knowledge	6	3.1
Weather hazards	6	3.1

Table 7 Planting locations broken down by exotic and indigenous species on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda (*n* = 161 respondents)

Location	Exotic species		Indigenous species	
	#cases	% cases	#cases	% cases
Inside fields	131	49.0	114	82.0
Farm or field boundary	115	43.0	56	40.0
Home compound	53	20.0	14	10.0
Woodlot	43	16.0	2	1.4
Soil conservation bunds/river bank	22	8.2	0	0.0
Unproductive land	6	2.2	1	0.7
Fruit orchard	1	0.4	0	0.0

preference for key indigenous species *Cordia africana* and *Ficus* spp. was less than that of the frequency with which these trees are planted. When the respondents were also asked what prevented them from planting more of the trees they wanted, the findings for exotic and indigenous species were broadly similar (Table 6).

Where Trees were Cultivated

The respondents reported that they had mostly planted trees in their fields and on boundaries. Compared with indigenous species, exotic species were more often planted in woodlots, around the home, and along soil conservation bunds or riverbanks to control erosion (Table 7). Exotic species, such as *Eucalyptus* spp., were prominent in woodlots for producing timber and firewood, and fruit trees were preferred near the household. However, indigenous species, such as *Cordia africana* and *Ficus* spp., were planted inside fields to provide shade for coffee crops.

When the respondents were asked where on their land they had allowed trees that germinated naturally to grow in situ, we found that in more than 80% of instances, trees of a given species were allowed to grow inside a field. Other important locations were field/farm boundaries (29%) and around the home (12%). This pattern was similar for both exotic and indigenous species.

Table 8 Where trees were removed on smallholder farms in the Kapchorwa and Bulambuli districts of the Mt. Elgon subregion of eastern Uganda ($n = 161$ respondents)

Location	Exotic species		Indigenous species	
	#cases	% cases	#cases	% cases
Inside fields	131	49.0	114	82.0
Farm or field boundary	115	43.0	56	40.0
Soil conservation bunds/river bank	22	8.2	0	0.0
Woodlot	43	16.0	2	1.4
Home compound	53	20.0	14	10.0

Overall, trees were most commonly removed from within fields (59% of cases) and from around the boundary of a field or farm (41%). Woodlots were also important locations for the removal of germinating trees (12.5%). Indigenous species were more likely than exotics to be removed from fields, whereas exotics were more likely than indigenous species to be removed from woodlots (Table 8).

Farmer Attributes and Behavior

Associations between household level tree data and socioeconomic variables were examined to explore the drivers of the cultivation patterns described above. The distributions of the variables relating to the number of species of trees planted, protected, and removed per household were examined to identify appropriate statistical tests. While some variables showed an approximately normal distribution, many other variables did not. As discussed, the data may also have been subject to inaccurate respondent recall. Furthermore, the values for household tree cultivation variables are often small, with many zero values. As the data did not meet all the assumptions for parametric statistical analysis, the findings below were derived solely from non-parametric techniques.

An analysis of the main cash crops grown found that coffee and banana were grown by 82% and 13% of the households, respectively. An independent Mann–Whitney U test found significant differences in five variables between the groups of farmers growing coffee and banana crops: plantings of indigenous species ($p < 0.01$), total plantings ($p < 0.01$), cases of indigenous species protected ($p < 0.01$), cases of indigenous species added to farms ($p < 0.001$), and cases of all trees added to farms ($p < 0.01$). The mean and median numbers of plantings of indigenous species by coffee farmers were 1 and 2, respectively, which were higher than the 0.33 and 0 plantings, respectively, for banana farmers. Coffee farmers protected indigenous species in a mean of 1.01 and a median of 1 case, whereas banana farmers only protected indigenous species in a mean of 0.38 and a median of 0 case. Thus, coffee farmers more frequently added indigenous species and more species overall to their land than banana farmers. In terms of the absolute numbers of trees, the two groups differed significantly in the same ways: indigenous trees planted ($p < 0.01$), indigenous trees protected ($p < 0.01$), and indigenous trees added ($p < 0.01$). Coffee

farmers planted several times more indigenous trees than banana farmers (mean and median of 10.27 and 3 compared with 1.9 and 0, respectively) and protected more indigenous trees (mean and median of 5.44 and 2 compared with 1.33 and 0, respectively). Consequently, coffee farmers planted or protected about three-and-a-half times more indigenous trees than banana farmers (mean and median of 15.7 and 7 compared with 3.24 and 2, respectively).

The mean area cultivated by the farmers surveyed was 1.5 ha. While three farmers worked 12 ha or more, the vast majority (96%) cultivated less than 2.8 ha. There was no positive correlation between the land area and the number of species planted, and there was only a weak relationship between the land area and the absolute number of trees planted. When a more homogeneous sample was created of 129 farmers (80% of farmers) growing coffee as their main cash crop and cultivating less than 2.8 ha to further examine this relationship, no linear correlation was detected. However, the results suggest that even the coffee farmers with quarter an hectare of land cultivate as many species of tree as those with 1.6 to 2.4 ha of land. The absolute number of trees planted was lower for those farmers with less than half an hectare of land, but it did not increase uniformly as the cultivated area increased, suggesting that extra land is used disproportionately for crops rather than trees.

The altitude of the sampled farms ranged from 1199 to 2096 m. The altitude data were grouped into 100-m bands to examine their distribution. Two roughly equally populated groups were created: the first comprise farms lying between 1300 and 1500 m, and the second comprise farms lying between 1900 and 2100 m. The Kruskal–Wallis test found significant differences between the groups in two variables: the number of cases where indigenous species were protected ($p < 0.01$) and the absolute number of indigenous trees protected ($p < 0.05$). The number of cases where indigenous species were protected was higher in the lower-altitude group (mean and median of 1.06 and 1 compared with 0.68 and 0 cases, respectively, for the higher-altitude group). Similarly, the lower-altitude group protected a mean and median of 5.39 and 3 indigenous trees compared with 3.44 and 0 trees, respectively, for the higher-altitude group. These findings could indicate that farmers at lower altitudes allow more indigenous species to grow to protect crops, such as coffee, which benefit from shade, particularly at lower altitudes where temperatures are higher.

Discussion

Extent of Tree Cover

The data gathered for this study suggest that the number of tree cover is increasing in the study area, as farmers reported nine times more trees being added to the land than being removed. If this sample is representative of the extensive coffee-growing areas around Mt. Elgon, then it suggests that a "re-greening" could be underway in a region where the loss of natural forests has been a pressing concern (Norgrove and Hulme 2006; Sassen 2014). However, as discussed above, this finding must be interpreted with caution. In particular, it is possible that the respondents have underreported the removal of trees, making the net number of trees added to the landscape,

which was reported as a mean of 129 per household, appear larger than it is in reality. As already mentioned, checking this finding against other sources is a challenge, because to the best of our knowledge, no large-scale longitudinal studies of the evolution of tree cover have been conducted outside of the mountain's protected areas. Further, remote imaging techniques are yet to be applied reliably on farmland at this scale (Zomer et al. 2014).

The suggestion that the number of tree cover is increasing is given nuance by the impressions gained during the group interviews. Population increases, land hunger, subdivision, and the cutting down of remnant forest trees without replacement were prominent reasons given for the decline of rare indigenous tree species over the longer term. Meanwhile, the data on where trees were planted or removed shows the importance of woodlots for exotic species. This indicates that the expansion of woodlots could outweigh declines in some indigenous species in and around croplands. This does not necessarily mean that the overall tree density in fields and along boundaries has declined. The largest number of plantings of exotic species, which usually involved planting a small number of trees, took place in and around fields and near homes. This reflects the importance of exotic fruit trees, such as *Persea americana* and *Mangifera indica*, for household food security but also the practice of many families in the region of growing a few trees of fast-growing species, such as *Eucalyptus* spp. and *Grevillea robusta*, for firewood, construction materials, and other purposes for private use or for sale from various points on their land.

Fruit trees contribute not only to nutrition security but also to food security. Due to their extensive and deep root systems, fruit trees are less sensitive to droughts compared to annual staple crops and provide a harvest even when staple crops fail. Not only during droughts, but especially during pre-harvest periods of annual staples characterized by food shortages, the fruits of some fruit tree species may be ready for harvest to serve as emergency food or to be sold, thus contributing to food and nutrition security (Kehlenbeck et al. 2013). According to Kehlenbeck et al. (2013), a year-round supply of fruit can be achieved by combining site-specific portfolios of different exotic and indigenous fruit species for cultivation.

Within croplands, the findings suggest that tree cultivation is influenced by land use. Farmers growing coffee as their main cash crop added more trees to their land, especially indigenous species, compared with farmers relying more on banana. This could reflect a growing need, driven by climate change and acknowledged by participants in the group interviews, to provide more shade for coffee crops. This creates a dilemma for many farmers through their dependence on banana for food, which is often intercropped with coffee.

Composition of Tree Cover

This study indicates that about 80% of the trees added to farmland in the study area during the 3-year period were just three exotic species: *Eucalyptus* spp., *Grevillea robusta*, and *Pinus* spp. This finding was reinforced by the focus group discussions: each focus group identified *Eucalyptus* spp. and *Grevillea robusta* among the species that had increased in number in recent years. The interviewees suggested that

ecosystem services, such as timber and fuelwood, which are currently provided by the principal exotic species, were previously supplied by slower-growing indigenous species, strengthening the evidence that exotic species have displaced their indigenous counterparts in the landscape in recent years. Still, the similar proportions of exotic and indigenous species among trees being added to the land (87.3% and 9.3%, respectively) and among those being removed (90.7% and 8.7%) suggest that while exotic species have clearly become dominant in the landscape, their share of total tree cover may be stabilizing at this high level. This, in turn, implies that the overall position of indigenous trees is also stable but precarious. Species richness, even within the indigenous category, is equally limited. *Cordia africana*, *Ficus* spp. (which includes at least three individual species), and *Markhamia lutea* trees have been planted on farms.

There were some small positive findings for indigenous species. First, indigenous trees were prominent among the trees that were allowed to naturally grow. The relatively wide range of indigenous species that farmers protect, especially where coffee is the primary cash crop, is keeping tree diversity alive in the landscape. This diversity depends on natural propagation, where seeds are carried by birds, animals, wind, or water in farmland to new sites where they may germinate. The continuation of these processes depends on the presence of relevant biotic vectors and a sufficient population of a given species of tree in the landscape to sustain pollination rates and genetic diversity (Dawson et al. 2013). In the case of Mt. Elgon, concerns on illegal wood cutting and depletion of biodiversity in the Mt. Elgon National Park raise a question about the long-term viability of some of the less-numerous forest species, which are currently present in small numbers in the wider landscape. The second positive finding for indigenous species richness is that the proportion of cases where they were planted or protected (43.1%) is relatively large compared with that of absolute numbers of trees added to the landscape (9.3%). This indicates that the indigenous trees present are more widely spread among farms, adding to species richness on smaller scales.

Drivers

Farmers' decision-making about trees was dominated by economic motives. The reasons provided for planting or protecting trees almost exclusively concerned the provision of material or agricultural benefits. Esthetic and cultural reasons played a negligible role, and they were mentioned in just 1.8% of cases. While fuel and timber were the primary reasons for adding both exotic and indigenous trees to farmland, notable in the data was the prominent role of exotic species in providing fruit or food in 37% of cases, whereas no indigenous trees were planted to provide fruit or food. This reflects the importance of *Persea americana* and *Mangifera indica* for food security on these farms. If indigenous fruit trees were once popular, they appear to have been almost entirely displaced by their exotic counterparts. Where indigenous species have been added to the landscape, they are more likely than exotics to have been planted to provide shade, soil fertility, and erosion control. This highlights the awareness and appreciation of farmers for the ecosystem services that

species, such as *Ficus* spp., provide to sustain the productivity of their land. This likely helps explain the persistence of some indigenous species in the landscape.

The data on tree cultivation and altitude indicates that farmers lower down the mountain protect more indigenous trees than those further up. This suggests the willingness to increase tree cover to buffer climate-sensitive crops, such as coffee, from higher temperatures at lower altitudes. The non-linear relationship between farm size and tree cultivation suggests that, once a household's needs for services, such as firewood and fruit, have been met, there is a diminishing incentive to plant more trees, even if space is available. As a consequence, it is possible that smaller farms have a higher density of tree cover than larger farms. This implies that population increases, and the subdivision of land could, at least when larger parcels are split, potentially spur an increase in tree cover on a landscape scale. Several group interviewees stated that some farmers were uprooting coffee plants and replacing them with banana crops and woodlots. The reason provided for this shift was partly the perceived lack of government support for coffee production. Given that this study found that coffee farmers tend to host higher indigenous tree diversity on their land than those relying more on banana, this conversion from coffee to banana crops could be a factor behind the dominance of exotic species observed in the study area.

Opportunities to Encourage Increased Tree Cover and Tree Species Diversity

Our findings suggest several opportunities for policy makers to support farmers in maintaining tree cover and tree species diversity in the region. First, four out of five respondents said that they would like to have more trees on their land. Surprisingly, the low availability of seeds/seedlings and their affordability were more often cited as obstacles than the shortage of land. This suggests that programs to supply seedlings of a range of species, especially indigenous ones, at subsidized prices could successfully enhance tree diversity on farms. This impression is reinforced by the proportionally higher number of trees being planted on small-sized farms. World Agroforestry (ICRAF), in collaboration with Uganda's National Forestry Resources Research Institute (NaFORRI), has established a central nursery in Mbale town to produce high-quality germplasm for the establishment of on-farm participatory trials under the Trees for Food Security Project (T4FS) in the Mt. Elgon region. The nursery also serves as a Rural Resource Center (RRC), providing training and providing tree planting materials to local communities to encourage on-farm tree production. RRCs are community-managed centers where farmers can access information on low-cost, high-quality planting materials, learn new technologies for tree planting and management, and have the opportunity to network with other farmers, the private sector, and government agencies (Odoi et al. 2019).

While exotic species remain in high demand, each household has also protected, on average, at least one naturally growing tree on their land during the 3-year period. As this study has demonstrated, in most cases (62%), an indigenous species has been protected. This demonstrates the willingness of local families to harness the low-cost benefits of trees that grow from naturally occurring seedlings. As already mentioned, the maintenance of viable populations of as many indigenous tree species as

possible within the landscape, including in nearby protected areas, as well as populations of the vertebrates that disperse their seeds is key to ensuring that this source of indigenous trees is sustained.

Several strands of evidence suggest that supporting coffee farmers in the region will have positive impacts on tree cover and its indigenous components, as coffee farmers wish to have more indigenous trees on their land. Our focus group discussion and survey data suggested that coffee farmers are aware that their crops need shade and that they need to provide more shade at lower, warmer altitudes, a need that is likely to increase as a result of climate change. According to Bunn et al. (2015) and Laederach et al. (2017), climate change affects Arabica coffee most at lower altitudes, as they are exposed to higher temperatures, prolonged drought, and higher water and heat stress. Supporting coffee farmers could also reduce the reliance of farmers on banana food crops, which makes them reluctant to include more shade trees.

Conclusions

This study sought to determine whether smallholder farmers engaged in agroforestry practices in the Mt. Elgon region of Uganda are planting exotic trees at the expense of indigenous species, whether farmers have retained indigenous trees, whether farmers would like to have more indigenous trees on their land, and what obstacles farmers face to having more indigenous trees on their land. Based on the data gathered, it can be tentatively concluded that the widespread planting of exotic trees for timber, firewood, and food is increasing the overall tree cover in the study area. The more common exotic species, such as *Eucalyptus grandi*s, are prominent in agroforestry strategies promoted and adopted in the Mt. Elgon area and beyond. These exotic species have substantially displaced the indigenous species that provided a similar set of goods and services in the past. However, there is little indication in the findings of this study to suggest that such a displacement will continue. Rather, it is possible that this process has been largely completed and that the prevalence of indigenous trees and species is stabilizing at a low level. Continual or periodic surveying into the future is required to confirm or refute this.

Indigenous species still play an important role, especially as companion trees on coffee farms where they provide shade, enhance soil fertility, and conserve moisture in ways that are appreciated by farmers. However, the cultivation of indigenous species is dominated by just three species and species groups (*Cordia africana*, *Ficus* spp., and *Markhamia lutea*), indicating that other indigenous trees are now rare in the landscape. The promotion and popularity of *Cordia africana* in the area could even be contributing to the decline of other already scarce indigenous species. Most farmers want more trees on their land. While exotic species are still the most popular, there is also a demand for indigenous species. However, it seems that the poor availability of seeds and seedlings at affordable prices holds farmers back from cultivating more indigenous trees. It is therefore important to promote an alternative system that incorporates the efforts of the government, the private sector, communities, and individuals to invest in tree seed and seedling production while ensuring

the availability and accessibility of affordable, quality tree seed and seedlings. The strength of these findings, especially with regard to the evolution of overall tree cover, is limited by the reliance of the study on the ability of smallholder farmers to accurately recall the trees that they have added and removed from their land.

Given the importance of indigenous trees to biodiversity conservation, policy makers can ensure the implementation of four measures to make it easier for farmers to include more indigenous trees of a wider range of species on their land by extending support to small-scale coffee farmers, making planting materials for a variety of indigenous tree species available at subsidized prices, monitoring the impacts of climate change and advising farmers on how indigenous vegetation can be employed to mitigate its impacts, and effectively managing protected areas as reservoirs of genetic material and refuges for the vectors essential to natural tree propagation.

Further research could strengthen the insights gained here into the cultivation of indigenous trees by smallholder farmers in the Mt. Elgon region and elsewhere. In particular, tree inventories taken at regular intervals could improve our understanding of trends in the frequency of indigenous trees in this landscape. In addition, ecological network analysis of vegetation in settled and protected areas in the region could identify indigenous tree species of conservation value and concern, and economic analysis could be employed to establish the potential value of these species to local livelihoods, the key services they provide, and the level and form of any subsidies required to promote their adoption in farmlands instead of exotic species.

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