Osie, M., S. Nemomissa, S. Shibru, and G. Dalle. 2020. Trade-offs between benefits and costs of forest proximity: farmers' practices and strategies regarding tree–crop integration and ecosystem disservices management. *Ecology and Society* 25(4):36. https://doi.org/10.5751/ES-12100-250436

Research

Trade-offs between benefits and costs of forest proximity: farmers' practices and strategies regarding tree–crop integration and ecosystem disservices management

Mulatu Osie [1], *Sileshi Nemomissa* [2], *Simon Shibru* [3] *and Gemedo Dalle* [4]

ABSTRACT. The impact of ecosystem disservices is among the issues that farmers have to consider in management of livelihoods and local landscapes. We investigated distinct practices developed within local communities in tree–crop integration and strategies to offset disservices. Forty-eight transects (24 at ≤1 km and 24 at ≥3 km from forest edges) were laid in the study sites. Woody and crop species were recorded from a total of 150 homegardens and farm fields along the 48 transects. In addition, farmers (n = 384) were interviewed using a semistructured questionnaire to assess their land-use practices and management strategies to counter ecosystem disservices. Data were analyzed using a linear mixed effects model of the statistical program R. A total of 72 woody and crop species belonging to 40 families were recorded. The mean number of woody species increased near to the forest. Wild mammals, such as olive baboons, bush pigs, warthogs, vervet monkeys, and porcupines were common crop raiders. Farmers used fences, guarding, noise, scare devices, and smoke to scare away crop-raiding animals. To protect beehives in the forest fragments, they have developed indigenous skills such as dusting ashes, spraying indigenous repellant suspensions, and destroying the nests of raiding ants. A biological control mechanism was also used by farmers where they cut part of the nest of *Crematogaster* sp. (locally called "Penie") and glue it onto the trunk of trees with beehives. *Crematogaster* sp. safeguard the beehives from raiding ants as part of their efforts to protect their own nests. We recommend both ecological and socioeconomic studies in order to augment farmers' strategies to balance disservices and corresponding management practices across the landscapes.

Key Words: *beehives; Crematogaster; crop raiding; Ethiopia; farmers' strategies; Kafa biosphere*

INTRODUCTION

Forest patches and trees in mosaic agricultural landscapes provide many ecosystem services for smallholder farmers (Ricketts 2004, Millenium Ecosystem Assessment (MA) 2005, van Damme and Kindt 2012). Alongside of these provisions, ecosystem functions produce some disservices (defined here as "functions of an ecosystem resulting in unwanted and economically harmful effects on human well-being") (Escobedo et al. 2011, von Döhren and Haase 2015, Lyytimäki 2015). The concept of ecosystem disservices has been used in different studies as negatively impacting nuisances, such as pests (Lemessa et al. 2013, Ango et al. 2014) and food insecurity (Zhang et al. 2007), biological hazards, such as diseases (Chevalier et al. 2016), human and livestock predations (Vailshery et al. 2013), allergies caused by pollen, volatile organic compounds, and other pollutants (Escobedo et al. 2011), and geophysical hazards, such as floods (Dunn 2010), noise pollution (Basner et al. 2014), and heat stress and storms (Xu et al. 2016). The concept has also been used in studies of crop raiding by wild mammals and the effect of ants on honeybees negatively impacting the livelihoods of smallholder farmers, particularly those in close proximity to forests (Lemessa et al. 2013). Forest-dwelling wild mammals, such as baboons, monkeys, bush pigs, porcupines, chimpanzees, and elephants, have been identified as significant crop raiders causing substantial damage to cereals, root crops, and fruits in different regions of Africa (Seifu and Beyene 2014). Such crop loss poses a serious problem, resulting in food shortages for many farmer households living near to forests (Hill 2000, Fungo 2011). Furthermore, crop raiders caused substantial indirect costs, such as labor for guarding and negative effects on children's schooling (Kleijn et al. 2006, Ango et al. 2014, Byg et al. 2017).

Ants attack beehives and negatively affect the livelihoods of smallholder farmers. They are also the most important enemies of honeybees, causing serious problems for the honey production sector (Hansen and Klotz 2005, Petit and Burel 2006, Stamps and Groothuis 2010). Studies have shown that forests are preferred nesting and foraging sites for ants (Andersen et al. 2006, Philpott et al. 2006, Schultheiss and Nooten 2013) because forests have structurally complex habitats with abundant litter, higher amounts of coarse, dead woody debris, sufficient humidity, cold climate, high soil organic matter, and fewer disturbances (Chala et al. 2012, Desalegn 2015).

In response to these ecosystem disservices, farmers have invented various indigenous management strategies against crop raiders and ants that differ spatially in relation to damage types and intensities (Lemessa et al. 2013, Ango et al. 2014, von Döhren and Haase 2015). However, these management actions carried out to mitigate the impact of crop raiders may lead to habitat modifications, e.g., tree clearance, which in turn impact on other ecosystem processes and result in loss of biodiversity (Zahawi and Augspurger 2006, Zhang et al. 2007, van Damme and Kindt 2012, Swanepoel et al. 2017).

Despite the influence of ecosystem disservices at close forest proximity on their agricultural production systems and livelihoods, farmers integrate trees into their croplands (Zahawi and Augspurger 2006, Ango et al. 2014, Mohammed and Asfaw

[1]Arba Minch University, [2]Department of Plant Biology and Biodiversity Management, College of Natural Sciences, Addis Ababa University, Addis Ababa, Ethiopia, [3]Department of Biology, College of Natural and Computational Sciences, Arba Minch University, Arba Minch, Ethiopia., [4]Center for Environmental Science, Addis Ababa University, Addis Ababa, Ethiopia

2015) and they retain forests and woodlands. Tree–crop integration (defined here as "managing some multipurpose natural/planted tree species at different settings of their land plots together with introduced crops") is among the basic activities of farmers and needs thorough analysis to determine how it contributes to farmers' livelihoods in terms of domestic consumption and as a source of income (Harvey 2000, Tolera et al. 2008). Furthermore, farmers allow multipurpose trees to grow inside their croplands and manage them with their crops (Posada et al. 2000, Harvey et al. 2011). These trees, which grow from the soil seedbank of croplands, if located at required sites within the cultivated field, are protected by farmers and managed according to their traditional agroforestry practices (Perfecto et al. 1996, Schroth et al. 2004, Harvey et al. 2006, Ruelle 2014). Farmers account for yield loss in their decision for growing crops near to and far from forest sites. But they continue to grow crops that are regularly attacked by raiders because they either lack alternative crops less prone to attack or have developed different protection mechanisms (Lemessa et al. 2013, Mohammed and Asfaw 2015).

Various studies have shown that farmers managed trees in and around homesteads and on agricultural lands to obtain various benefits (Harvey 2000, Zahawi and Augspurger 2006, Tolera et al. 2008), such as live fences (Chaco 2003, Francesconi 2006, Pulido-Santacruz and Renjifo 2011), grazing lands (Posada et al. 2000, Harvey et al. 2006, 2011), and shade trees for coffee production (Perfecto et al. 1996, Schroth et al. 2004, Ango et al. 2014). However, these studies have not explicitly addressed the influence of forest proximity and farmers' knowledge and practices to balance ecosystem disservices and conservation. They ignore the aspects of the influence of forest proximity on farmers' crop production system and management strategies to overcome crop loss due to wildlife raiders that play key roles in balancing between ecosystem disservices and forest conservation. Our approach tried to address this question and provides alternative insights into farmers' knowledge and skills for tree–crop management and ecosystem disservices trade-offs at various forest proximities.

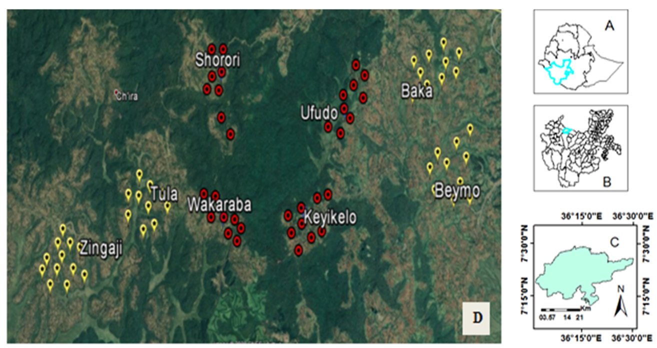
Based on the reconnaissance survey of our study sites and earlier studies elsewhere (Hill 2000, Kleijn et al. 2006, van Damme and Kindt 2012, von Döhren and Haase 2015, Sinare et al. 2016, Byg et al. 2017, Swanepoel et al. 2017), we assumed that the major crop raiders in the area are vervet monkeys (*Cercopithecus aethiops*), warthogs (*Phacochoerus africanus*), bush pigs (*Potamochoerus larvatus*) and porcupines (*Hystrix cristata*). Several studies have shown that greater crop damage was found near to rather than far from the forest (e.g., Fungo 2011, Linkie et al. 2007, Lemessa et al. 2013, Ango et al. 2014). We also expected greater crop damage in close proximity to rather than far from forests in our study landscape. Although crop damage by wildlife substantially affects the livelihoods of a large number of smallholder farmers, their indigenous analytical management practice is still relatively poorly understood, and little is known about farmers' attitudes regarding the trade-off between ecosystem disservices and conservation. Thus, we hypothesize that: (1) There are significant differences in tree–crop integration and crop raiding for farmers living near to and far from the forests. As a result, we expect that the management strategies of local communities increase as distance to the forest decreases. (2) Farmers have indigenous strategies to avoid beehive raiding by ants. We tested these hypotheses by investigating tree–crop composition in 150 homegardens, farmlands, and farm boundaries (referred as geometric borders of cropped areas) at different distances from the forest edges in a pair-wise design. In addition, we conducted a semistructured questionnaire to investigate farmers' knowledge and practices in managing crop raiders and ant-mediated damages on beehives.

METHODS

Study Area

The study was conducted in Gimbo district (Fig. 1), Kafa Zone, southwestern Ethiopia, which is located about 461 km southwest of Addis Ababa. It is situated between 07° 23'N to 07° 49' N latitude and 36° 00'E to 36° 47'E longitude with altitudinal range of 500 to 3300 m a.s.l. The study area is characterized by a variety of landforms resulting in a highly diverse climate, soil, and vegetation. Topographically, the area is characterized by a complex system of highlands, steep valleys, and large flatlands, which drop to the lowlands in the South.

Fig. 1. Study area map produced from Landsat images taken in 2018 and 2019. (A) map of Ethiopia; (B) map of Ethiopian Southern Nations, Nationalities, and Peoples' Region; (C) map of Gimbo district; (D) study sites; red markers denote residences near to forest and yellow markers denote residences far away from the forest.



The area has a long rainy season (March–October) and receives a mean annual rainfall ranging from 1710 mm to 1892 mm (Nature and Biodiversity Conservation Union [NABU] 2017). The dry months are December–February. The annual mean temperature is 19.4°C with average maximum and minimum temperatures of 27.5°C and 10.1°C, respectively (Socioeconomic Profile of Gimbo District [SePGD) 2018, *unpublished data*).

The moist afromontane forests of the area have diverse animal and plant assemblages (Friis et al. 2010). The black and white colobus monkey (*Colobus guereza*) is the main feature in the forests of the study area. *Syzygium guineense*, *Olea welwitschii*, *Millettia ferruginea*, *Pouteria adolfi-friedericii*, and *Schefflera abyssinica* are the dominant trees species (NABU 2017). The forests provide provisional ecosystem services, i.e., common spices such as *Aframomum corrorima* and *Piper capense* grow naturally across the landscape and are harvested by the local communities.

The forest area is an important freshwater reservoir for the Gojeb River, which is a tributary of Baro-Akobo Basin.

Sampling Design

Forests, farmlands, settlements, and other landscape features of our study area were identified using Google Earth (Ango et al. 2014) followed by a reconnaissance survey made from 2–6 September 2018. Subsequently, eight sites were identified; four sites (Baka, Beymo, Tula, and Zingaji) are far from (≥3 km) forest edges (Lemessa et al. 2013), and the other four sites (Kayikela, Shorori, Ufudo, and Wakaraba) are near to (≤1 km) the forests. Accordingly, we laid a total of 48 transects (six in each selected study site). The length of each transect line is from 2–3 km with 1 km width on each side of the transect. Subsequently, we selected 150 homegardens (defined here as a homestead area for growing and cultivating plants, although its composition varies considerably in size and crop diversity among farms), farmlands (referred as farm fields for plants cultivated and grown on a large scale), farm boundaries, and riparian areas, (75 at near to and 75 far from forest edges) along all 48 transects to collect data on woody and crop species diversity. All landscapes and homegardens were visited with the permission of local administrative bodies and homegarden owners.

Woody and Crop Species Data Collection

All woody and crop species were recorded by their vernacular and scientific names and identified in the field by using the *Flora of Ethiopia and Eritrea* (Hedberg and Edwards 1989, Edwards et al. 1995, Hedberg et al. 2004). Plant specimens were pressed and dried, and field identifications were confirmed at the National Herbarium of Ethiopia, Addis Ababa University. Authenticated specimens' replicates were deposited both in the National Herbarium of Ethiopia and in the Botany laboratory of Arba Minch University with their specific identification/reference number. In addition, a semistructured interview questionnaire was conducted focusing on tree and crop management.

Data Collection Regarding Farmers' Knowledge of Management of Ecosystem Disservices and Tree–Crop Integration

We conducted a semistructured questionnaire that was translated to the local language (Kafi nono) to explore data on farmers' practices of tree–crop integration, the most susceptible crop types, type of raiders attacking crops regularly, beehive raiding by ants, and management strategies of the communities to minimize crop loss. Accordingly, we sampled a total of 384 farmers (193 near to and 191 far from the forests) by following Kothari (2004). Key informant interviews and focus group discussions (FGD) were used to validate the collected data. The key informants (n = 10) were identified through snowballing and are mostly elder farmers. All of them have been recognized to be knowledgeable with regard to specific issues of land use and forest cover changes, tree–crop integration, types of wild animals affecting their livelihoods by raiding crops, and indigenous management strategies. Moreover, a total of seven FGD were conducted with 32 informants (women (n = 12) and men (n = 20)) in separate and mixed groups of seven to ten participants. Each group was composed of model farmers, farmers' representatives, development agents, district agricultural officers, and NABU experts, which were sampled systematically. The major issues discussed were the strategies about how farmers manage trees and crops and types of ecosystem disservices and management practices. We carried out repeated field walks with farmland owners to verify and collect additional data. The data were collected from September to November 2019.

Statistical Analyses

The variation in tree–crop integration among homegardens was analyzed by both the mean number of species per homegarden and the cumulative number of species for all transects near to and far from forest edges using a linear mixed effects model (the lme-package) of the statistical program R (R Development Core Team 2010, Ango et al. 2014). As categorical variables, we used distance from the forest edges (near to and far from), the interaction between main factors, and altitude as fixed factors and transect pair (each pair consisting of one transect near to and one far from forests) as random factor (Lemessa et al. 2013). In addition, we tested if the species composition differed for all transects/homegardens near to and far from forest edges with a multiresponse permutation procedure using Bray-Curtis dissimilarity index in the vegan-package of R (Oksanen et al. 2011). Crop raiding as a function of distance from the forest and ant-mediated impacts were analyzed with independent samples t-test. Similarly, we analyzed farmers' responses at near to and far from the forests with Pearson's Chi-square test. One-way ANOVA and Kruskal-Wallis tests were computed to see the variations at $P < 0.005$ and $P < 0.001$ with farmers' responses to crops and beehive raiding at different distances from the forests.

Ethical Issues

The study was approved by the Arba Minch University, Ethiopia. Written permissions for the study were obtained from Bureaus for Kafa Zone Administration, Gimbo District Administration, Environment Protection and Forestry, Agricultural and Natural Resources Development through a brief explanation of objective of the study. Verbal consent was obtained from the selected households prior to interviews.

RESULTS

Farmers' Strategies in Tree–Crop Integration

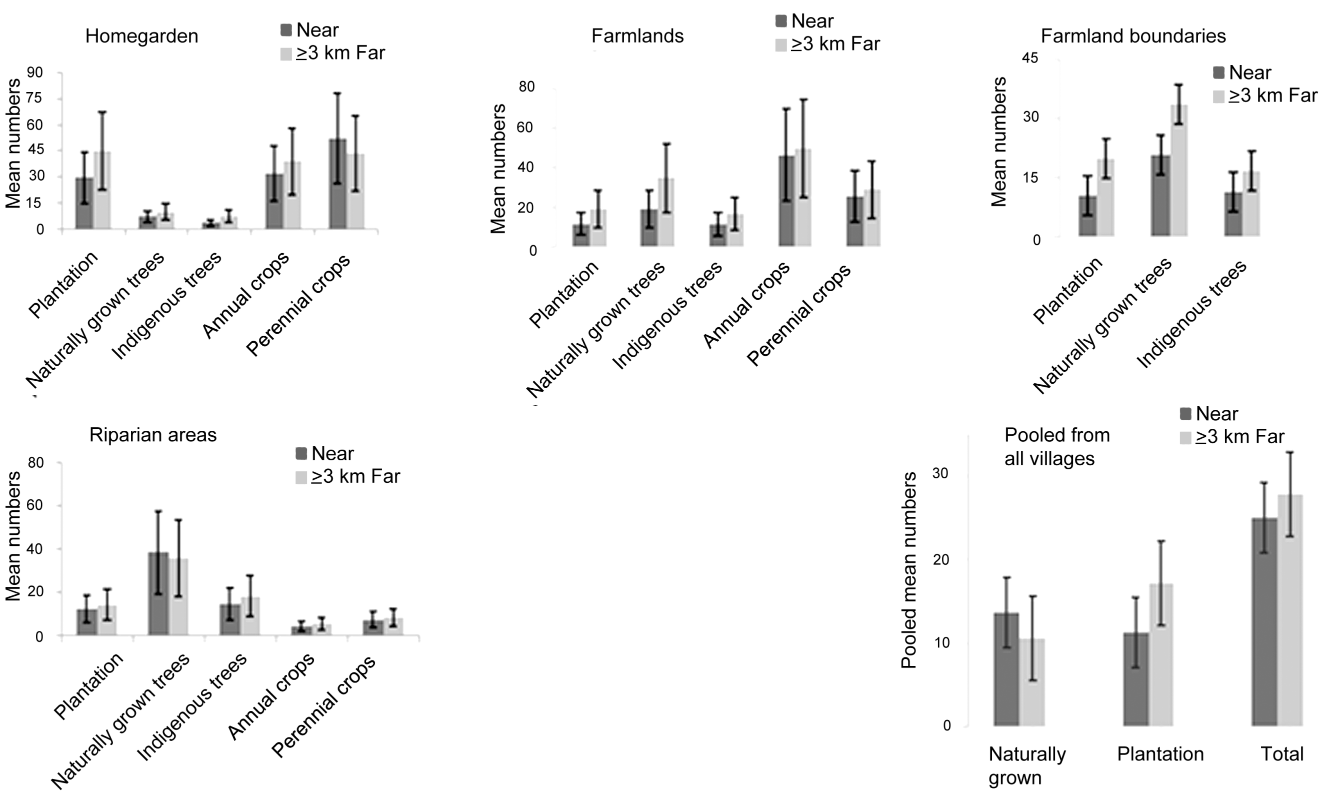
A total of 72 species of both woody plants and crops belonging to 40 families were identified (Appendix I). The mean number of species per farm plot was 31.04 (range, 1.3–83.7) near to and 27.3 (1.3–89.4) far from forest edges, and the difference was statistically significant at $P < 0.001$. *Ensete ventricosum* was the most frequent food crop grown across the landscape. Roots crops (e.g., *Solanum tuberosum)*) were mostly cultivated far from forests. Farmers noted that root crops were the most susceptible to crop raiders, and therefore, there is a tendency to cultivate less of these crops near to forests.

We found significant variations in mean numbers of tree species and food crops in the homegardens, inside farmlands, along the farm boundaries, and in riparian areas (defined here as a buffer zone not appropriate for crop cultivation) along the transects near to and far from forest edges (Fig. 2). The difference was statistically significant at $P < 0.005$ (Table 1). More perennial crops were recorded in the homegardens and farmlands far from forest edges. Perennial fruits, such as *Citrus sinensis*, *Persea americana*, and *Mangifera indica*, were less commonly cultivated in close proximity to the forests. In addition, more annual crops were found in the homegardens far from the forest edges (Fig. 2).

Table 1. Multiple comparisons of woody species and food crop integration near to and far from the forest. *P* values are from linear mixed effect models.

Types of Trees and crops	Mean percentage of trees/crops per landscape features in the study sites												
	Homegardens			Farmlands			Farm boundaries			Riparian areas			
	Near	Far	SE	Near	Far	SE	Near	Far	SE	Near	Far	SE	*P* value
Planted trees	17.3	36	0.05	8.3	1.3	0.05	2.7	8.3	0.08	9.2	7.3	0.05	< 0.05
Naturally grown trees	4.3	2.8	0.03	34.1	21.7	0.03	32.7	22.3	0.03	21.3	37.5	0.06	< 0.001
Annual crops	58.5	23.6	0.04	64.9	44.1	0.03	7.3	4.3	0.05	1.6	1.2	0.04	< 0.05
Perennial crops	18.3	61.2	0.03	13.1	6.4	0.05	35.1	8.4	0.03	1.9	3.1	0.02	< 0.05

Fig. 2. Mean numbers of tree species and food crops recorded in homegardens, inside farmlands, along farmland boundaries, and in riparian areas. The statistical interpretations of the patterns are found in the text. Error bars are standard error. The sample size is found in Table 2.



Trees in the coffee agroecosystem of southwestern Ethiopia were categorized by farmers as either plantations (referred to, in this case, as cultivated woody plants in contrast to naturally grown trees) or naturally grown in the homegardens, farmlands, along farmland boundaries, and in riparian areas. The distribution pattern of trees varied significantly in these areas. We found a greater number of plantations in the homegardens and along farmland boundaries in study sites, and the differences were significant near to and far from the forests (Fig. 2). More plantations were recorded in the homegardens and along the farmland boundaries in Baka, Beymo, Tula, and Zingaji, whereas fewer plantations were found in the farmlands and riparian areas. Furthermore, naturally growing trees were abundant near to the forests ($P < 0.001$; Fig. 3A, B, C). Planted or naturally growing trees exhibited less variation near to and far from forests in riparian areas (Fig. 3D; $P < 0.07$).

In all study sites, greater tree–crop integration was recorded in the homegardens and farmlands, but they were generally fewer in the riparian areas (Table 1). Results of the present study indicate that farmers used a number of criteria to integrate trees with crops. Among these, access to seedlings, farm size (Table 2), fast growth, multiple-use values (Table 3), and drought resistance were described as principal. In FGD and interviews, farmers pointed out that tree–crop integration trees such as *Millettia ferruginea* and *Albizia gummifera* were the most preferred as shade for *Coffea arabica*. The reasons they mentioned were that the leaves of these trees were thin, small, and light, having no impact on coffee trees when they fell off; these trees were chosen because they allow a sufficient amount of light to reach the crop. Farmers also integrated trees in farmlands with *Eragrostis tef*, *Vicia faba*, and *Zea mays*. As well, trees such as *Cordia africana*, Schefflera

Table 2.. Average size (in ha) and number of the investigated fields at different proximities from the forest edges: N = study sites near to the forest edge; F = study sites far from forest edge.

Study sites	Average size (in ha), number of selected fields and standard error of mean (SE)														
	Homegardens			Crop fields			Farm boundaries			Riparian areas			Total		
	Area	No.	SE	Area	No.	SE	Area	No.	SE	Area	No.	SE	Area	No.	SE
Baka (F)	0.36	6	0.05	0.38	6	0.06	0.32	4	0.05	0.35	3	0.08	0.33	19	0.04
Beymo (F)	0.31	5	0.07	0.34	6	0.03	0.32	3	0.04	0.33	3	0.05	0.36	17	0.05
Kayikelo (N)	0.43	7	0.03	0.39	7	0.07	0.37	4	0.02	0.40	4	0.03	0.34	21	0.06
Shorori (N)	0.38	5	0.04	0.34	6	0.05	0.32	3	0.06	0.31	3	0.06	0.38	17	0.02
Tula (F)	0.34	6	0.06	0.35	6	0.04	0.32	3	0.03	0.31	3	0.04	0.34	18	0.03
Ufudo (N)	0.36	6	0.08	0.33	5	0.08	0.31	3	0.05	0.36	4	0.07	0.34	19	0.05
Wakaraba (N)	0.33	5	0.05	0.33	6	0.05	0.33	4	0.08	0.33	3	0.05	0.33	18	0.04
Zingaji (F)	0.42	7	0.03	0.38	6	0.03	0.36	4	0.03	0.33	4	0.06	0.35	21	0.02
Sites near to forest edge	0.36	23	0.04	0.34	23	0.03	0.32	15	0.05	0.31	14	0.04	0.35	75	0.03
Sites far from forest edge	0.33	24	0.03	0.34	24	0.05	0.31	14	0.03	0.32	13	0.02	0.33	75	0.04
Total	0.32	47	0.04	0.33	47	0.03	0.32	29	0.04	0.31	27	0.03	0.34	150	0.03

Fig. 3. Mean numbers of naturally grown and planted tree species per study site, recorded (A) in homegardens, (B) in crop fields, (C) along farm boundaries, and (D) in riparian areas. The statistical interpretations of the patterns are found in the text. Error bars are standard error. The sample size is found in Table 2.

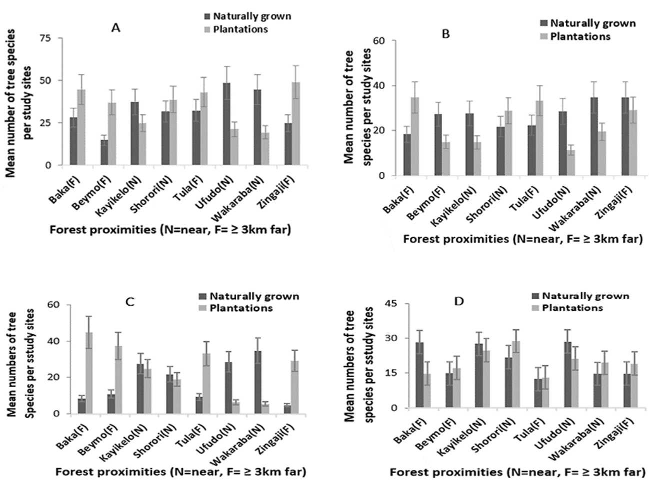
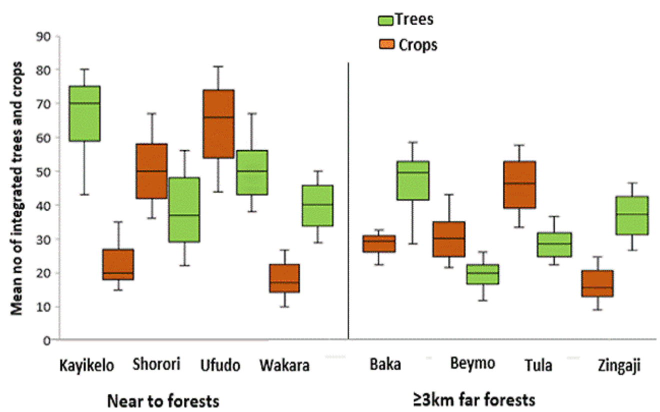


Fig. 4. Mean numbers of integrated tree and crop species at the study sites. The statistical interpretations of the patterns are found in the text. The sample size is found in Table 2.



abyssinica, *Ficus sycomorus*, and fruit plants, e.g., *Citrus sinensis*, *Persea americana*, and *Mangifera indica* are integrated with *Sorghum bicolor* and *Pisum sativum*. From this study, we found that the knowledge of integrating multipurpose trees with crops has been acquired from parents, communities, or lifelong experiences (Table 4). Despite some discrepancies, the patterns of treeU–crop integration were generally similar in study sites near to and far from forest edges, and the difference was not statistically significant (Fig. 4; $P > 0.05$).

Ecosystem Disservices and Management Practices

The results of this study indicate that crop raiding by large wild mammals was greater near to forest edges and was less prevalent far from the forests (Fig. 5A, Table 5). Olive baboons, bush pigs, warthogs, vervet monkeys, and porcupines were often listed by farmers as crop raiders, especially in the homegardens and farmlands near to forests; their effects are less common far from forests (Table 6).

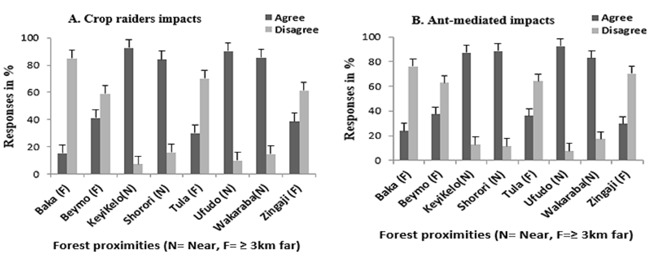
There were differences on the effects of crop-raiding animals near to and far from forests. In FGD and interviews, most farmers (71.9%) near to the forest perceived the damage caused by bush pigs, baboons, and vervet monkeys as severe (a loss of more than a tenth of total yield). Some farmers (24.5%) living far from forest edges have reported similar crop damage, mainly by bush pigs and vervet monkeys. This difference is statistically significant ($P < 0.001$; Table 6).

When farmers were asked how to minimize the risk of crop damage by wild mammals, they listed several indigenous strategies such as guarding, smoking, shouting from different directions, chasing away the animals directly, or using dogs, fencing, and scare devices (e.g., scarecrows) in homegardens and at the edge of farmlands (Table 7). As well, children and women participate in chasing away the raiders from both homegarden and field crops

Table 3. Results of preference ranking of trees based on multiple use-values exercised by key informants (KI) and focus group discussants (FGD). Scores in the table indicate ranks given to multipurpose trees based on their use-values (highest number (10) was given for the tree species which informants thought most-preferred in its use-values, and the lowest number (1) was given for its least-preference). The highest total scores were the most-preferred tree species by the farmers. Letters A-J represent KI and FGD.

Tree Species	Key informants and focus group discussants labeled A–J										Total score	Rank
	A	B	C	D	E	F	G	H	I	J		
Millettia ferruginea	8	7	6	10	9	7	10	9	6	8	80	2
Albizia gummifera	6	5	10	7	5	8	8	5	9	10	73	3
Cordia africana	4	9	5	4	6	9	4	8	7	4	60	6
Eucalyptus spp.	3	3	4	5	3	1	3	2	3	1	28	8
Schefflera abyssinica	7	4	3	9	7	5	9	7	8	7	63	5
Persea americana	5	6	9	6	4	4	5	4	4	5	52	7
Mangifera indica	9	8	7	3	8	6	6	6	5	6	64	4
Coffea arabica	10	10	8	8	10	10	7	10	10	9	92	1
Croton macrostachyus	2	1	1	2	2	3	2	3	2	2	20	9
Ficus sycomorus	1	2	2	1	1	2	1	1	1	3	15	10

Fig. 5. Farmers' responses regarding (A) crop raiding and (B) ant-mediated impacts at specific forest proximities: a high degree of raiding in homegardens near to forest edges (Kayikela, Shorori, Ufudo, and Wakaraba) and relatively little raiding far from the forest edges (Baka, Beymo, Tula, and Zingaji). The statistical interpretations of the patterns are found in the text. Error bars are standard error. The sample size is found in Table 3.



during the day. Men usually patrol homegardens by shouting and using torches to protect their crops from bush pigs and porcupines. However, farmers explained that guarding their crops during the night had health effects such as cold and lack of sleep.

Farmers have developed different management strategies, such as dusting ash under trees with beehives, plastering the trees with plastic materials, finding and killing the queen ant, or destroying the ant nests to reduce ant attacks on beehives (Table 7). They also spray trees with suspensions of garlic and *Eucalyptus* leaves as a repellent. Another innovative strategy is the use of a biological control mechanism where they cut part of the nests of *Crematogaster* sp. and glue it to trees where beehives are located. These species attack beehive-raiding ants.

Beehive raiding by ants was greater in the forest and near to the forest than far from forests (Fig. 5B, Tables 5 and 6; $P < 0.001$). Moreover, independent samples t-test results showed that there was significant difference in the responses of farmers to the impacts of ants near to the forest ($M = 2.27$, $SD = 0.624$) and far from the forest ($M = 2.34$, $SD = 0.657$; $t = 0.866$, df =382, $P = 0.002$). The magnitude of the differences in the means was very small ($\eta^2 = 0.00196$). Despite, the great effect of ants on beehives, most farmers still believe that the benefits obtained from the forests outweigh the costs from disservices due to ants. They invented different strategies (Table 7) to mitigate ant attacks on beehives that are significantly different near to and far from forests ($P < 0.001$).

DISCUSSION

Farmers' Strategies in Tree–Crop Integration

Most of the studies concerning forest ecosystems focus on the benefits and inventories of services (Cerdán et al. 2012, Lemessa et al. 2013, Ruelle 2014, Mohammed and Asfaw 2015). Harvey (2000), Zahawi and Augspurger (2006), and Tolera et al. (2008) have reported various benefits of forests such as live fences (Chaco 2003, Francesconi 2006, Pulido-Santacruz and Renjifo 2011), grazing lands (Posada et al. 2000, Harvey et al. 2006, 2011), and shade trees for coffee production (Perfecto et al. 1996, Schroth et al. 2004, Ango et al. 2014). However, these studies have not explicitly addressed the influence of forest proximity and management practices on the associated disservices. They ignore the aspects of the influence of forest proximity on agricultural production systems and management strategies. Our interdisciplinary investigation provides alternative insights about farmers' knowledge and management practices regarding trade-offs/disservices at varying forest proximities. Below, we first discuss the pattern of farmers' knowledge and practices in tree–crop integration, and subsequently, crops and honeybee raiders and local management strategies.

Our findings show that (1) statistically significant variations of tree species and food crops were observed in the homegardens, inside farmlands, along the farmland boundaries, and in riparian areas along the transects near to and far from forest edges; (2) more tree species were recorded in homegardens, along boundaries of farmlands, and in riparian areas compared with inside farmlands (Fig. 2); (3) more plantations were found far from the forest edges whereas there are more naturally grown tree species near forests (Fig. 3A, B, C); 4) farmers' integration of trees

Table 4. Farmers' responses regarding the source of knowledge about integrating trees with crops in their farmlands near to and far from forests. *P* values are from chi-square tests.

Sources of knowledges	Near to forest edges						Far from the forest						Grand total	*P* value
	Agree		Disagree		Total		Agree		Disagree		Total			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	
Parents	188	48.2	5	2.1	193	50.3	168	43.8	43	11.2	191	49.7	384	> 0.05
Formal education	12	44.5	181	5.7	193	50.3	64	16.7	127	33.1	191	49.7	384	> 0.05
Community	174	45.3	19	4.9	193	50.3	138	35.9	53	13.8	191	49.7	384	< 0.001
Life experiences	158	41.2	35	9.1	193	50.3	172	44.8	21	5.5	191	49.7	384	< 0.001

Table 5. Farmers' responses regarding the challenges posed by crop raiding by wild animals and beehives attacked by ants as ecosystem disservices near to and far from forests. *P* values are from chi-square tests.

Types of disservices	Near to forest edges						Far from the forest						Grand total	*P* value
	Agree		Disagree		Total		Agree		Disagree		Total			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	
Crop raiding	185	48.2	8	2.1	193	50.3	53	13.8	138	35.9	191	49.7	384	< 0.001
Ant attacks on honeybees	171	44.5	22	5.7	193	50.3	64	16.7	127	33.1	191	49.7	384	< 0.001

Table 6. Farmers' responses regarding the types of crop and honeybee raiders along the transects near to and far from forests. *P* values are from chi-square tests.

Raiders	Target of raid	Near to forest edges				Far from the forest edges				Total	*P* value
		Agree		Disagree		Agree		Disagree			
		No.	%	No.	%	No.	%	No.	%	No.	
Bush pigs	Crops	174	45.3	19	4.9	78	20.3	113	29.4	384	< 0.05
Baboons		182	47.4	11	2.9	94	24.5	97	25.2		< 0.001
Warthogs		166	43.2	27	7.0	62	16.1	129	33.6		< 0.05
Porcupines		157	40.9	36	9.4	38	9.9	153	39.8		> 0.05
Ants	Honeybees	179	46.6	14	3.6	92	23.9	99	25.8	384	< 0.001

Table 7. Farmers' responses regarding indigenous management strategies for ecosystem disservices at different proximities to forests. *P* values are from chi-square tests.

Types of disservices	Indigenous management strategies	Near to forest edges				Far from the forest edges				Total	*P* value
		Agree		Disagree		Agree		Disagree			
		No.	%	No.	%	No.	%	No.	%	No.	
Crop raiding by wild mammals	Guarding	188	48.9	5	1.3	154	40.1	37	9.6	384	< 0.001
	Smoking	185	48.2	8	2.1	103	26.8	88	22.9		< 0.001
	Shouting	145	37.8	48	12.5	79	20.6	112	29.2		> 0.05
	Scare devices	156	40.6	37	9.6	68	17.7	123	32.0		> 0.05
	Fencing	172	44.8	21	5.5	112	29.2	79	20.6		< 0.001
Honeybee raiding by ants	Dusting ash	138	35.9	55	14.3	59	15.4	132	34.4	384	< 0.001
	Plastering	98	25.5	95	24.7	47	12.2	144	37.5		> 0.05
	Destroying nests	171	44.5	22	5.7	134	34.9	57	14.8		< 0.001
	Repellents	123	32.0	70	18.2	99	25.8	92	23.9		> 0.05
	Crematogaster sp.	174	45.3	19	4.9	179	46.6	12	3.1		< 0.001

with crops both near to and far from the forest edges did not exhibit statistically significant patterns (Fig. 4); and (5) farmers' knowledge of tree–crop integration is passed down from older generations and communities, or results from lifelong experience.

Farmers in our study area commonly integrate trees with crops in their farm plots based on the multiple-use values (van Damme and Kindt 2012, Ruelle 2014, Mohammed and Asfaw 2015). These are mostly multipurpose indigenous plant species, including shade trees (*Millettia ferruginea* and *Albizia gummifera*), fuel or timber plants (*Eucalyptus* spp., *Cordia Africana*), bee hiving trees (*Schefflera abyssinica* and *Ficus sycomorus*), fruit plants (*Citrus* spp., *Persea americana* and *Mangifera indica*) integrated with *Coffea arabica* and other food crops such as *Eragrostis tef*, *Vicia faba*, *Zea mays*, *Sorghum bicolor*, and *Pisum sativum*. Furthermore, other studies (e.g., Cerdán et al. 2012, Ruelle 2014) have shown that *Croton macrostachyus*, *Olea europaea*, *Cuspidata* sp., and *Cordia africana* were commonly integrated with food crops in farm landscapes in northern Ethiopia and other areas of the country (Mohammed and Asfaw 2015). Whereas the integration of fruit plants into the homegardens of smallholder farmers is a new source of income, Aregawi et al. (2018) have reported that about 35% of the household income is generated by fruits and vegetables cultivated in homegardens in Tigray, Ethiopia.

A number of criteria are used by the farmers to integrate trees with crops. These are farm size, fast growth, compatibility, multiple-use values, drought resistance, and access to seedlings. Among these, farm size was indicated as one of the determinant factors. We observed that some farmers often had several plots and more land, allowing them to plant more trees in addition to food crops than those with smaller-sized farms. These farmers use their entire land to grow food crops even though they were interested in growing a greater number of trees as well. Similar results were reported from Brazil and Kenya (Cerdán et al. 2012, van Damme and Kindt 2012). It was found that farmers prefer to plant more trees in areas that are not productive, including very steep slopes, along farm boundaries, and beside their homes and in riparian areas. The same trend was reported in southern and northwest Ethiopia (Ruelle 2014, Mohammed and Asfaw 2015).

Ecosystem Disservices and Management Practices

Crop raiding

Crop raiding by wild mammals negatively influences the livelihoods and food security of smallholder farmers (Escobedo et al. 2011, Fungo 2011, von Döhren and Haase 2015, Lyytimäki 2015, Xu et al. 2016). Farmers in our study have reported that olive baboons, bush pigs, warthogs, vervet monkeys, and porcupines were the major crop raiders posing the most serious threat to their livelihoods, particularly near forests rather than on sites far from forests ($P < 0.001$) (Fig. 5, Table 4). This result corroborates several studies from many landscapes across Uganda, Cameroon, and Ethiopia (Hill 2000, Weladji and Tchamba 2003, Seifu and Beyene 2014). In particular, farmers living adjacent to the forest edges estimated more than a quarter of their crop yield was lost. Furthermore, more than 40% of food production was being lost globally to pests, pathogens, and weeds; pest impacts occur for the most part at close proximity to the forest (Kleijn et al. 2006). Similarly, Zhang et al. (2007) reported that agricultural pests cause significant economic losses to smallholder farmers worldwide.

In our study, the majority of the informants (82.3%) agreed that the extent of crop raider impacts decreases as distance from the forest increases because the forests provide protection for these animals. Farmers near to forests claim more yield loss due to crop-raiding animals than those living far from forests (Weladji and Tchamba 2003, Fungo 2011, Lemessa et al. 2013, Seifu and Beyene 2014, von Döhren and Haase 2015). This loss is beyond their management strategies (mainly guarding), and it was common to hear such stories in villages along forest edges (van Damme and Kindt 2012, Ango et al. 2014). Diurnal crop raiders, such as olive baboons, common monkeys, and warthogs, are less common far from forests than near to forests because the latter provides easy protection for them when chased away. Similar findings were reported by other studies (Hill 2000, Sinare et al. 2016). Furthermore, the incidences of crop damage from warthogs are greater near to forested areas in southern Ethiopia (Byg et al. 2017). On the other hand, bush pigs and porcupines travel longer distances from forests for crop raiding than olive baboons, and their nocturnal behavior makes management strategies by farmers more difficult. Naughton-Treves (1997) reported similar findings, i.e., that protecting crops from bush pigs even at long distances from the forest edge was found to be difficult due to their nocturnal behavior.

Farmers have reported that the problem of crop raiding by wild animals was severe on early and late-cultivated crops, which corroborates previous studies (Kleijn et al. 2006, Seifu and Beyene 2014). The reason is that crop raiding is not spread over many fields, and thus the damage in any particular field is maximized (Naughton-Treves 1997 Lemessa et al. 2013). Swanepoel et al. (2017) have reported that the lack of integration in cultivation time and types of crops as well as lack of cooperative approaches will heighten crop damage by raiders. Moreover, there was a significant spatial variation, with crops adjoining forest edges more susceptible than those away from forest edges. Similar results were reported by several other studies (e.g., Hill 2000, von Döhren and Haase 2015, Sinare et al. 2016) from Uganda, Burkina Faso, and France. Crop raiding not only caused loss of food crops but also caused substantial indirect costs, such as additional labor for guarding and negative effects on children's schooling (Ango et al. 2014, Shackleton et al. 2016).

Although farmers were challenged by crop raiders, they have developed their own management strategies, including fences, guarding, noise, scare devices, and smoke, to minimize such ecosystem disservices (Naughton-Treves 1997, Weladji and Tchamba 2003, Escobedo et al. 2011, Fungo 2011, Seifu and Beyene 2014, Lyytimäki 2015, Xu et al. 2016). Although farmers in the study area have used different management strategies, they reported that olive baboons and vervet monkeys are intelligent enough to adapt to human behavior easily and became less afraid of children and scare devices, making protection of crops less effective and more challenging (see also Lemessa et al. 2013, Ango et al. 2014). In line with this, Shackleton et al. (2016) underlined that farmers should adopt appropriate indigenous management practices to reduce crop loss by raiders.

Ant-Mediated Ecosystem Disservices

Farmers in our study area have reported that ants raid their beehives, affecting honey production. Similar problems have been reported from the northern part of Ethiopia and elsewhere (Hansen and Klotz 2005, Andersen et al. 2006, Petit and Burel 2006, Desalegn 2015). There are multiple ecosystem disservices originating in forests, such as pests, predators, parasites, honey badgers, birds, spiders, snakes, lizards, and wax moths. But ants pose direct constraints on the productivity of beehives because they attack honeybees to steal the honey. Previous studies have also reported that ants were the most important enemies of honeybees, and they are considered to be a serious problem for the honey production sector (e.g., Stamps and Groothuis 2010, Schultheiss and Nooten 2013).

Farmers have reported that ants enter the beehives and feed on the honey, brood, and pollen, and destroy the bee wax, causing the bees to abscond; they even feed on young bees and can destroy the entire bee colony. Our results corroborate previous studies (Hansen and Klotz 2005, Andersen et al. 2006). Desalegn (2015) found that ants have attacked 40% of honeybee colonies, in addition to eating honey and pollen.

Beekeeping is a tradition of the Kafa community of the study area, and 90.3% of farmers use predominantly traditional methods of apiculture, i.e., they place beehives inside forests permanently (Chala et al. 2012). We recorded that more beehives inside/near to forests were attacked by ants than those far from forests (Andersen et al. 2006). This is due to the presence of structurally complex habitats with abundant litter, having higher amounts of coarse, dead woody debris, sufficient humidity, cold climate, high soil organic matter, and often less disturbed shaded areas in forests (Petit and Burel 2006, Desalegn 2015). These complex habitats provide nesting sites for the ants. Abiotic factors, such as soil properties, daily temperature variations, humidity, and wind, and biotic drivers such as the structure of plant communities, determine local ant assemblage (Petit and Burel 2006, Stamps and Groothuis 2010, Schultheiss and Nooten 2013). Furthermore, the availability of food resources determines the severity of ant foraging behavior (Andersen et al. 2006, Stamps and Groothuis 2010). In our study area, the farmers practice coffee agroforestry in forests, where there are abundant nesting sites for ants, thus explaining the severity of the attacks on beehives by ants. Philpott et al. (2006) reported that ants prefer coffee and cacao forests due to physiological and ecological factors.

Farmers have reported that there is a temporal variation in attacks on beehives by ants. The most severe attacks occur from the beginning of October to December, during the drought season. During hot days, ants forage individually (Stamps and Groothuis 2010, Schultheiss and Nooten 2013), carrying out severe attacks on beehives (Desalegn 2015) and they also exhibit dynamic foraging behavior, with worsening effects on beehives (Andersen et al. 2006). Furthermore, our results corroborate previous studies where ants were found to exhibit predatory behavior due to levels of coarse woody debris, food availability, litter depth, and soil temperature (Hansen and Klotz 2005, Petit and Burel 2006).

Farmers use different management strategies, such as dusting ashes, spraying indigenous repellant suspensions, and destroying the nests of raiding ants to minimize ant attacks on beehives. A biological control mechanism was also used by farmers, where they cut part of a nest of *Crematogaster* sp. (locally called "Penie") and glue it to the trunk of trees with beehives. *Crematogaster* sp. safeguard the beehives from the raiding ants as part of their efforts to protect their own nests (Desalegn 2015). The observed higher prevalence of beehive attacks near to the forests is due to abundant nesting sites for the ants. As distance from the forest increases, nesting sites of ants decrease, resulting in fewer attacks on beehives. Therefore, more transplantation of *Crematogaster* nests were observed near to than far from forests to reduce ant attacks on beehives (Chala et al. 2012).

CONCLUSIONS

Farmers have acquired the knowledge of integrating multipurpose trees with crops from past generations, their communities, or their own lifelong experiences. They integrate trees with crops selectively and strategically based on the multiple-use values. Although ecosystem services predominate, forests do produce a number of disservices. Even with spatial variation, ecosystem disservices could influence local livelihoods and the crop production system of farmers, particularly at close proximity to the forests. Crop raiding and ant-mediated impacts on beehives were found to be the major ecosystem disservices in our study area. However, farmers continue to live there because they have developed their own strategies to mitigate these ecosystem disservices. We recommend both ecological and socioeconomic studies in order to augment farmers' strategies to trade-offs between ecosystem disservices, traditional coping mechanisms, and biodiversity conservation.

Declaration of Competing Interest

The authors declare no conflicts of personal, commercial, political, academic, or financial interest. There was no disagreement in authorship. Authors made substantial contributions to the intellectual content from conceptualizing and designing the study to submission for publication. Authors also confirm that this work is entirely original, has not been published elsewhere, nor is it currently under consideration for publication elsewhere, and referenced words and/or ideas of others have been appropriately cited or quoted.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12100

Acknowledgments:

We would like to thank Arba Minch University for the financial support. Our thanks also go to Offices for Kafa Zone Administration, Gimbo District Administration, and Natural Resources Development for their administrative support. We sincerely thank informants for their hospitality and willingness to share information during the data collection. We thank Meseret Mulu, Getachew Gebregziabher, Takele Gebre, and Asfaw Maro for their unreserved assistance in data collection. All of these field assistants were hired from our study areas for a short period of time to assist in the field work for the purpose of data collection only. We appreciate the anonymous reviewers for their constructive comments.

Data Availability:

The data that support the findings of this study are available from the Open Science Framework: https://Osf.io/gwp85.

LITERATURE CITED

Andersen, A. N., T. Hertog, and J. C. Z. Woinarski. 2006. Long-term pre exclusion and ant community structure in an Australian tropical savanna: congruence with vegetation succession. *Biogeography* 33:823–832. https://doi.org/10.1111/j.1365-2699.2006.01463.x

Ango, T., L. Börjeson, F. Senbeta, and K. Hylander. 2014. Balancing ecosystem services and disservices: smallholder Farmers' use and management of forest and trees in an agricultural landscape in Southwestern Ethiopia. *Ecology and Society* 19(1): 30. https://dx.doi.org/10.5751/ES-06279-190130

Aregawi, G., M. Tahitay, and K. Tsemri. 2018. Sustainable agriculture for improved food security in Tigray, Ethiopia. *Irish Aid and UK Aid Publishing Agency* 12 (4): 21–29.

Basner, M., W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, and S. Stansfeld. 2014. Auditory and non-auditory effects of noise on health. *The Lancet* 383:1325–1332. https://doi.org/10.1016/S0140-6736(13)61613-X

Byg, A., P. Novo, M. Dinato, A. Moges, T. Tefera, B. Balana, T. Woldeamanuel, and H. Black. 2017. Trees, soils, and warthogs: Distribution of services and disservices from reforestation areas in southern Ethiopia. *Forest Policy and Economics* 84:112–119. https://doi.org/10.1016/j.forpol.2017.06.002

Cerdán, C. R., M. C. Rebolledo, G. Soto, B. Rapidel, and F. L. Sinclair. 2012. Local knowledge on impacts of tree cover on ecosystem services in smallholder coffee production systems. *Agricultural Systems* 110:119–130. https://doi.org/10.1016/j.agsy.2012.03.014

Chaco, M. 2003. *Tree cover and live fences in a fragmented landscape in Rı´o Frı´o, Costa Rica.* Thesis, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.

Chala, K., T. Taye, D. Kebede, and T. Tadele. 2012. Opportunities and challenges of honey production in Gomma District of Jimma Zone, south-west Ethiopia. *Agricultural Extension and Rural Development* 4(4): 85–91.

Chevalier, V. F. Courtin, H. Guis, A. Tran, and L. Vial. 2016. Climate change and vector-borne diseases. Pages 97–108 *in* E. Torquebiau, editor. *Climate change and agriculture worldwide*Éditions Quae, Versailles,, France. https://doi.org/10.1007/978-94-017-7462-8_8

Desalegn, B. 2015. Honeybee diseases and pests research progress in Ethiopia—a review. *African Journal of Insects* 3(1):93–96.

Dunn, R. R. 2010. Global mapping of ecosystem disservices: the unspoken reality that nature sometimes kills us. *Biotropica* 42 (5):555–557. https://dx.doi.org/10.1111/j.1744-7429.2010.00698.x

Edwards S, S. Demissew, and I. Hedberg. 1995. *Flora of Ethiopia and Eritrea. Volume 6: Hydrocharitaceae to Arecaceae.* The National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden.

Escobedo, F. J., T. Kroeger, and J. E. Wagner. 2011. Urban forests and pollution mitigation: analyzing ecosystem services and disservices. *Environmental Pollution* 159:2078–2087. https://dx.doi. org/10.1016/j.envpol.2011.01.010 https://doi.org/10.1016/j.envpol.2011.01.010

Francesconi, W. 2006. Bird composition in living fences: potential of living fences to connect the fragmented landscape in Esparza, Costa Rica. *Tropical Resources Bulletin* 25:38–40.

Friis, I. B., S. Demissew, and P. van Breugel. 2010. *Atlas of the potential vegetation of Ethiopia.* The National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden.

Fungo, B. 2011. A review of crop raiding around protected areas: nature, control and research gaps. *Environment Restoration* 5:87–92.

Hansen, L. D., and J. H. Klotz. 2005. *Carpenter ants of the United States and Canada.* Comstock Publishing Associates, Ithaca, New York, USA.

Harvey, C. A. 2000. Colonization of agricultural windbreaks by forest trees: effects of connectivity and remnant trees. *Ecological Applications* 10:1762–1773. https://doi.org/10.1890/1051-0761(2000)010[1762:COAWBF]2.0.CO;2

Harvey, C. A., A. Medina, D. Merlo Sánchez, S. Vílchez, B. Hernández, J. C. Saenz, J. M. Maes, F. Casanoves, and F. L. Sinclair. 2006. Patterns of animal diversity associated with different forms of tree cover retained in agricultural landscapes. *Ecological Applications* 16:1986–1999. https://doi.org/10.1890/1051-0761(2006)016[1986:POADID]2.0.CO;2

Harvey, C. A., C. Villanueva, H. Esquivel-Mimenza, R. Gomez, M. Ibrahim, M. Lopez, J. Martinez, D. Munoz, C. Restrepo, J. C. Saenz, J. Villacis, and F. L. Sinclair. 2011. Conservation value of dispersed tree cover threatened by pasture management. *Forest Ecology and Management* 261(10):1664–1674. https://dx.doi.org/10.1016/j.foreco.2010.11.004

Hedberg, I., and S. Edwards, editors. 1989. *Flora of Ethiopia and Eritrea. Volume 3. Pittosporaceae to Araliaceae.* The National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden. https://doi.org/10.1007/978-94-009-0285-5_104

Hedberg, I., Friis, I., and S. Edwards, editors. 2004. *Flora of Ethiopia and Eritrea. Volume 4, Part 2. Asteraceae (Compositae).* The National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden. https://doi.org/10.1007/978-94-009-0285-5_104

Hill, C. M. 2000. Conflict of interest between people and baboons: crop raiding in Uganda. *International Journal of Primatology* 21:299–315. https://doi.org/10.1023/A:1005481605637

Kleijn, D., R. A. Baquero, Y. Clough, M. Díaz, J. de Esteban, F. Fernández, D. Gabriel, F. Herzog A. Holzschuh, R. Jöhl, E. Knop, A. Kruess, E. J. P. Marshall, I. Steffan-Dewenter, T. Tscharntke, J. Verhulst, T. M. West, and J. L. Yela. 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. *Ecology Letters* 9:243–254. https://doi.org/10.1111/j.1461-0248.2005.00869.x

Kothari, C. R. 2004. *Research methodology: methods and techniques.* Second edition. New Age International Ltd., Delhi, India.

Lemessa, D., K. Hylander, and P. Hambäck. 2013. Composition of crops and land-use types in relation to crop raiding pattern at different distances from forests. *Agriculture, Ecosystems and Environment* 167:71–78. https://doi.org/10.1016/j.agee.2012.12.014

Linkie, M., Y. Dinata, A. Nofrianto, and N. Leader-Williams. 2007. Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. *Animal Conservation* 10:127–135. https://doi.org/10.1111/j.1469-1795.2006.00083.x

Lyytimäki, J. 2015. Ecosystem disservices: embrace the catchword. *Ecosystem Services* 12:136–136. https://doi.org/10.1016/j.ecoser.2014.11.008

Millennium Ecosystem Assessment (MA). 2005. *Ecosystems and human well-being: synthesis.* Island Press, Washington, D.C., USA.

Mohammed, H., and Z. Asfaw. 2015. *Smallholder farmers' perceptions, attitudes, and management of trees in farmed landscapes in Northeastern Ethiopia.* Feed the Future: the U.S. Government's Global Hunger and Food Security Initiative, Washington, D.C., USA.

Nature and Biodiversity Conservation Union (NABU). 2017. Kafa Biosphere Reserve—southwest Ethiopia. *Development Research* 63:1–14.

Naughton-Treves, L. 1997. Farming the forest edge: vulnerable places and people around Kibale National Park, Uganda. *Geographic Reviews* 87:27–46. https://doi.org/10.2307/215656

Oksanen, J., F. Guillaume Blanchet, R. Kindt, and P.Legendre. 2011. Vegan: Community Ecology Package. R package version 2. 0-0. https://CRAN.R-project.org/package=vegan

Perfecto, I., R. A. Rice, R. Greenberg, and M. E. van der Voort. 1996. Shade coffee: a disappearing refuge for biodiversity. *BioScience* 46(8):598–608. https://dx.doi.org/10.2307/1312989

Petit, and Burel. 2006. Connectivity in fragmented populations: *Abax parallelepipedus* in a hedgerow network landscape. *Comptes Rendus de l'Academie des Sciences, Series III* 321:55–61. https://doi.org/10.1016/S0764-4469(97)89626-6

Philpott, S., M. Perfecto, and I. J. Vandermeer. 2006. Effects of management intensity and season on arboreal ant diversity and abundance in coffee agroecosystems. *Biodiversity and Conservation* 15:139–155. https://doi.org/10.1007/s10531-004-4247-2

Posada, J. M., T. M. Aide, and J. Cavelier. 2000. Cattle and weedy shrubs as restoration tools of tropical montane rainforest. *Restoration Ecology* 8:370–379. https://doi.org/10.1046/j.1526-100x.2000.80052.x

Pulido-Santacruz, P., and L. M. Renjifo. 2011. Live fences as tools for biodiversity conservation: a study case with birds and plants. *Agroforestry Systems* 81:15–30. https://dx.doi. org/10.1007/s10457-010-9331-x https://doi.org/10.1007/s10457-010-9331-x

R Development Core Team. 2010. *A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. [online] URL: https://www.gbif.org/tool/81287/r-a-language-and-environment-for-statistical-computing

Ricketts, T. H. 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conservation Biology* 18:1262–1271. https://doi.org/10.1111/j.1523-1739.2004.00227.x

Ruelle, M. L. 2014. *Human-plant ecology of an Afromontane agricultural landscape: diversity, knowledge, and food sovereignty in Debark, northern Ethiopia.* Dissertation, Cornell University, Ithaca, New York, USA.

Schroth, G., G. da Fonseca, C. A. Harvey, C. Gascon, H. L. Vasconcelos, and A.-M. N. Izac. 2004. *Agroforestry and biodiversity conservation in tropical landscapes.* Island Press, Washington, D.C., USA.

Schultheiss, P., and S. S. Nooten. 2013. Foraging patterns and strategies in an Australian desert ant. *Austral Ecology* 38:942–951. https://doi.org/10.1111/aec.12037

Seifu, M., and F. Beyene. 2014. Local livelihoods and institutions in managing wild-life ecosystems: the case of Babile elephant sanctuary in Ethiopia. *Nature Conservation* 22(6):559–569.

Shackleton, C. M., S. Ruwanza, and G. K. S. Sinasson. 2016. Unpacking Pandora's box: understanding and categorizing ecosystem disservices for environmental management and human wellbeing. *Ecosystem* 19:587–600. https://doi.org/10.1007/s10021-015-9952-z

Sinare, H., L. J. Gordon, and E. E. Kautsky. 2016. Assessment of ecosystem services and benefits in village landscapes: a case study from Burkina Faso. *Ecosystem Services* 21(16):141–152. https://doi.org/10.1016/j.ecoser.2016.08.004

Stamps, J., and T. G. G. Groothuis. 2010. The development of animal personality: relevance, concepts and perspectives. *Biological Reviews* 85:301–325. https://doi.org/10.1111/j.1469-185X.2009.00103.x

Swanepoel, L. H., C. M. Swanepoel, and P. R. Brown. 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: are we asking the right questions? *Plos One* 12(4): e0176621. https://doi.org/10.1371/journal.pone.0174554

Tolera, M., Z. Asfaw, M. Lemenih, and E. Karltun. 2008. Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agriculture, Ecosystems and Environment* 128:52–58. https://dx.doi.org/10.1016/j.agee.2008.05.001

Vailshery, L. S., M. Jaganmohan, and H. Nagendra. 2013. Effect of street trees on microclimate and air pollution in a tropical city. *Urban Forestry and Urban Greening* 12:408–415. https://doi.org/10.1016/j.ufug.2013.03.002

van Damme, P., and R. Kindt. 2012. Ethnobotanical methods. Pages 28–36 *in*I. A. K. Dawson, C. E. Harwood, J. Beniest, and R. H. Jamnadass, editors. *Agro-forestry tree domestication: a primer.* World Agroforestry Centre (ICRAF), Nairobi, Kenya.

von Döhren, P., and D. Haase. 2015. Ecosystem disservices research: a review of the state of the art with a focus on cities. *Ecosystem Indicators* 52:490–497. https://doi.org/10.1016/j.ecolind.2014.12.027

Weladji, R. B., and M. N. Tchamba. 2003. Conflict between people and protected areas within the Bénoué wildlife conservation area, North Cameroon. *Oryx* 37(1):72–79.

Xu, Z., G. Fitzgerald, Y. Guo, B. Jalaludin, and S. Tong. 2016. Impact of heatwave on mortality under different heatwave definitions: a systematic review and meta-analysis. *Environment International* 89:193–203. https://doi.org/10.1016/j.envint.2016.02.007

Zahawi, R. A., and C. K. Augspurger. 2006. Tropical forest restoration: tree islands as recruitment foci in degraded lands of Honduras. *Ecological Applications* 16:464–478. https://doi.org/10.1890/1051-0761(2006)016[0464:TFRTIA]2.0.CO;2

Zhang, W., T. H. Ricketts, C. Kremen, K. Carney, and S. M. Swinton. 2007. Ecosystem services and disservices to agriculture. *Ecological Economics* 64:253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024

Appendix I. *Tree- crop integration in their farmlands along transects of different distances to the forest. The mean frequency shows how often the trees and crop types appeared per homegardens.*

	Farm Plot		Family	Mean frequency (%) at Near to forests	Mean frequency (%) at Far from forests	P-Value
Scientific Name	Amharic Name	Local Name				
Pittosporum viridiflorum	Weyil	Shollo	Pittosporaceae	53.1	32.4	0.36
Cordia africana	Wanza	Di'o	Boraginaceae	37.6	25.1	0.07
Ficus vasta	Warka	Melo	Moraceae	41.9	38.2	0.66
Millettia ferruginea	Birbira	Bibero	Fabaceae	74.2	78.7	1
Sapium ellipticum	Arboji	Shedo	Euphorbiaceae	36	17.3	0.17
Croton macrostachyus	Bisana	Wago	Euphorbiaceae	44.3	22.8	0.23
Ficus sycomorus	Shola/Hemba	Chapero	Moraceae	28.5	23.6	0.49
Albizia gummifera	Sesa	Chato	Fabaceae	58.3	61.2	0.8
Prunus africana	Tikur inchet	Ommo	Rosaceae	11.6	5.3	0.5
Phoenix reclinata	Zembaba	Yebo	Arecaceae	8.3	1.3	1
Olea welwitschii	Yedamat weyra	Yaho	Oleaceae	34.1	11.7	0.47
Schefflera abyssinica	Getema	Buto	Araliaceae	64.9	24.1	0.63
Ficus sur	Shola	Charo	Moraceae	13.1	6.4	1
Vernonia amygdalina	Grawa	Grawo	Asteraceae	8.3	14.6	0.06
Erythrina brucei	Korch	Kolacho	Fabaceae	5.7	18.3	0.35
Maesa lanceolata	Qelewa	Chago	Myrsinaceae	32.7	2.3	0.09
Vernonia auriculifera	Gujo/Birawa	Dengirato	Asteraceae	27.3	24.3	0.9
Polyscias fulva	Yezinjero wenber	Karesho	Araliaceae	35.1	8.4	0.41
Brucea antidysenterica	Omme	Nuqasho	Simaraubaceae	17.3	15.3	0.65
Bersama abyssinica	Afajeshign	Boqqo	Francoaceae	9.2	7.3	1
pinus radiata	Pinus	Chido	Pinaceae	1.3	37.5	0.65
Pinus patual	Pinus	Chido	Pinaceae	1.6	21.2	0.17
Schefflera volkensii		Komo	Araliaceae	6.9	3.1	0.28
Lepidotrichilia volkensis	Trichilia	Shahiyo	Meliaceae	32.3	2.7	0.4
Hagenia abyssinica	Koso	Kosho	Rosaceae	26.2	1.1	0.45
Galinira coffeoides	Buna mesay	Dido	Rubiaceae	12.6	0	1
Allophylus Abyssinicus	Embis	She'o	Sapindaceae	37.1	0	0.23
Pouteria adolfi-friederici	Qerero	Shongo	Sapotaceae	27.3	1.8	0.22
Syzygium guineense	Dokima	Yino	Myrtaceae	21.4	4.7	0.94
Ricinus communis	Gulo	Qobo	Euphorbiaceae	17.5	9.4	1
Ilex mitis	Yemisir qefo	Ketto	Aquifoliaceae	8.6	2.4	0.24
Podocarpus falcatus	Zigiba	Tido	Podocarpaceae	13.4	1.6	0.15
Trilepisium madagascariense	Juya	Gebo	Moraceae	23.8	4.1	0.37
Celtis africana	Qawut	Ufo	Ulmaceae	9.4	0	1
Ocotea kenyesis	Derersa	Najo	Lamiaceae	17.4	3.9	0.68
Eucalaptus globulus	Nech bahir zaf	Neche barzafo	Myrtaceae	56.8	59.4	1

Eucalaptus camaldalensis	Key bahir zaf	Chele barzafo	Myrtaceae	43.1	52.3	0.21
Eucalyptus citriodora	Yeshito bahirzaf	barzafo	Myrtaceae	27.3	37.4	0.74
Juniperus procera	Tsid	Chido	Cupressaceae	54.7	57.3	1
Coffea arabica	Buna	Buno	Rubiaceae	83.7	64.4	0.43
Mangifera indica	Mango	Mango	Anacardiaceae	33.9	32.1	0.21
Persea americana	Avocado	Abokato	Lauraceae	71.5	64.2	0.01
Annona senegalensis	Gishixa	Gishxo	Annonaceae	8.4	11.3	0.68
Rhamnus prenoides	Gesho	Gesho	Rhamnaceae	24.2	5.7	0.59
Justicia schimperiana	Sensel	Gilbano	Acanthaceae	9.1	14.7	0.17
Euphoribia abyssinica	Qulqual	Qakero	Euphorbiaceae	37.4	39.1	0.61
Sesbania sesban	Sesibania	Sasibaniyo	Fabaceae	14.1	24.8	1
Arundinaria alpina	Qerkeha	Shinato	Poaceae	32.6	28.5	0.49
Citrus sinensis	Birtukan	Birtukano	Rutaceae	27.2	32.6	0.02
Citrus aurantiifolia	Lomi	Lomo	Rutaceae	8.4	17.3	0.41
Eragrostis tef	Tef	Gaasho	Poaceae	29.6	31.4	0.36
Vicia faba	Baqela	Ato	Fabaceae	48.2	53.9	0.19
Zea mays	Beqolo	Baaro	Poaceae	67.3	71.4	0.28
Phaseolus vulgaris	Adenguare	Gobo	Fabaceae	39.1	36.8	0.31
Pisum sativum	Ater	Atero	Fabaceae	47.4	51.3	0.62
Sorghum bicolor	Mashila	Yango	Poaceae	32.7	37.4	0.37
Hordeum vulgare	Gebs	Sheqo	Poaceae	38.4	46.3	0.19
Brassica oleracea	Gomen	Shano	Brassicaceae	69.4	72.1	0.27
Daucus carota	Karot	Karoto	Apiaceae	7.2	11.5	0.68
Manihot esculenta	Kasava	Qiido	Euphorbiaceae	53.1	57.6	0.03
Catha edulis	Chat	chato	Celastraceae	33.6	36.5	0.27
Afromomum corrorima	Kororma	Ogio	Zingiberaceae	41.1	17.6	0.22
Allium sativum	Nech Shinkurt	Duqusho	Alliaceae	38.6	37.4	1
Allium cepa	Key Shinkurt	Amarto	Alliaceae	29.5	32.1	0.38
Cucurbita pepo	Dubba	Buqo	Cucurbitaceae	35.2	37.7	0.53
Lycopersicon esculentum	Timatim	Timatimo	Solanaceae	21.5	34.5	0.84
Solanum tuberosum	Dinich	Doqo	Solanaceae	27.6	41.8	0.03
Ensete ventricosum	Enset	Uxo	Musaceae	69.3	89.4	0.36
Musa spp.	Muz	Muzo	Musaceae	37.5	39.3	0.25
Ananas comosus	Ananas	Ananaso	Bromeliaceae	10.2	17.5	0.16
Saccharum officinarum	Shenkora	Agedo	Poaceae	8.5	21.8	0.27