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Examining the Impacts of Plantation Forests on Human and Plant Communities in the Ethiopian Highlands

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Home to 88 million people, the Ethiopian mountains are a highly heterogeneous landscape. The Afroalpine ecosystem is found above 3000 masl and is characterized by high levels of species diversity, rarity, and endemism. The objective of this article is to investigate impacts of plantation forests on both the human and plant communities of the Afroalpine zone. We use a case study of a community-based conservation area in the north central highlands, Guassa Community Conservation Area (Guassa), where plantation forests have been established since the 1970s. The study area covers about 78 km^2 ranging between 2600 and 3700 masl and largely belongs to the Afroalpine zone. We interviewed 100 residents of the 4 administrative regions closest to Guassa and conducted vegetation sampling of 70 quadrats along 2 transect lines. We found a roughly equal number of ecosystem services between native grassland and plantation forest. However, respondents reported 7 unique ecosystem services from the native grassland and only 3 unique ecosystem services from the plantation forest. Both native grassland and plantation areas were valued for their perceived ability to attract rain and provide habitat for wild animals. We recorded a total of 87 species belonging to 63 genera and 31 plant families across both vegetation types surveyed and a total of 19 endemic species. Of the plant families, Asteraceae had the highest species number. Although plantation forests support less diverse plant communities and provide fewer unique ecosystem services to human communities compared to native Afroalpine vegetation, they are still a valuable piece of the landscape mosaic.

Keywords: *native grassland; plantation area; ecosystem service; local community; plant diversity; community conservation area.*

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Introduction

The mountains of Ethiopia are home to more than 88 million people, 70% of the country's total population. The landscape is highly heterogeneous and includes the greatest extent of the iconic and rapidly disappearing Afroalpine ecosystem (Enquist et al 2019; UNDESA Population Division 2022). The Afroalpine ecosystem is found above 3000 masl and is characterized by high levels of species diversity, rarity, and endemism (Enquist et al 2019). Afroalpine pocket habitats form isolated "sky-islands" separated by extensive savannas, semideserts, agricultural areas, and other social-ecological barriers to species movement (Popp et al 2008; Gizaw et al 2013; Wondimu et al 2014; Mairal et al 2017). Afroalpine species are subject to high diurnal temperature variability, colloquially known as "summer every day and winter every night" (Hedberg 1964; Gehrke and Linder 2014). The vegetation displays remarkable adaptations to this harsh environment, with life forms such as tussock grasses, rosette plants, cushion plants, and sclerophyllous shrubs (Hedberg 1964). This landscape supports subsistence livelihoods for millions of people, as well as niche market-based economies for local honey and wild-harvested coffee (Senbeta and Denich 2006; Wakjira et al 2013).

Mountains worldwide are experiencing disproportionately intense and rapid warming compared to lowlands (Pepin et al 2015), and highland areas in Ethiopia are endangered by climate and land use changes (Stévart et al 2019). Many areas of the Ethiopian highlands appear to be shifting from a bimodal precipitation pattern to a unimodal distribution (Rosell 2011; Fashing et al 2014; Groth et al 2020), and the impact of the loss of early season rains on vegetation communities has yet to be seen. In some areas, native vegetation has been almost entirely substituted by agriculture and plantation forests of nonnative species, and the remaining patches of native vegetation have been damaged by unregulated wood gathering, livestock foraging, and other plant harvesting (Wassie et al 2005; Negash 2010). Soil erosion is considered the biggest problem in highland areas and is particularly pronounced when agricultural fields extend into marginal lands with steep slopes or cliffs and thin soils (Hurni 1988; Nyssen et al 2006; Haregeweyn et al 2017).

Plantation forests have long been used as a tool for soil and water conservation, particularly on steep hillsides, yet their history in Ethiopia is politically and socially complicated (Admassie 2000). More than 7000 ha were afforested within the study area (Guassa) during the socialist military Derg regime of 1974–1991, often against the will of local communities and with few to no benefits accruing to them (Admassie 2000). Large-scale planation development projects were also pursued by the African Development Fund and World Bank throughout this period (Pohjonen and Pukkala 1990). Following the overthrow of the Derg, many communities cut down these state-owned plantation forests, citing reasons such as anger toward the former government, uncertainty regarding plantation ownership, and a desire for personal profit (Admassie 2000). Since the 1990s, alternative approaches to afforestation have pursued smaller, privatized quadrats for individual and community woodlots, with the aim of increasing local benefits from plantation forests while reducing management conflicts (Jagger and Pender 2003; Meaza et al 2016).

Widespread debate continues over the social-ecological costs and benefits of plantation forests, particularly those using nonnative species like eucalyptus and cypress (Jagger and Pender 2003). There are many theorized benefits of site-appropriate tree plantation forests, such as ecosystem restoration (Hurni 1988; Bishaw 2001; Moges and Taye 2017) and increasing soil organic matter (Parrotta 1992; Hurni 1988). Economic benefits to local people have also been substantial (Meaza et al 2016). However, plantation forests are perceived to occupy otherwise valuable and limited cropland in Ethiopia, and certain species, like eucalyptus, are thought to deplete nutrients and water needed by agricultural crops (Jagger and Pender 2003). Exotic conifer species such as *Cupressus lusitanica* have been associated with low species richness and diversity in the understory compared to other plantation species (Lemenih et al 2004). Fast-growing species like eucalyptus also outcompete native tree species in some circumstances (Carnus et al 2006). Finally, concerns persist over the equitable utilization of plantation forest and *guassa* grass resources, as women and poor households may not benefit from projects as much as men and wealthy households (Gobeze et al 2009; Nigussie et al 2020). When the use of resources from the conserved area is restricted to certain days, women cannot compete with men equally; also, wealthy households can employ extra labor, which poor people cannot do.

The objective of this article is to investigate impacts of plantations on both human and plant communities in the Afroalpine zone. We use a case study of a community-based conservation area in the north central highlands, Guassa Community Conservation Area. We first conducted surveys and group interviews with local residents to understand how vegetation change (including the establishment of plantation forests) has impacted the subsistence and incomes of people in study area (Nigussie et al 2019). We then conducted vegetative sampling to understand how the plant communities differ among native Afroalpine grassland and exotic plantation forests. We hypothesized that native vegetation would have higher species diversity compared to plantation forests, but that plantation forests would offer a greater number of benefits to local people.

Methodology

Study site

Guassa Community Conservation Area (hereafter, Guassa) lies between 10°15′–10°27′N and 39°45′–39°49′E, 295 km northeast of Addis Ababa, the capital of Ethiopia (Figure 1). Guassa covers about 7800 ha and ranges from 2600 to 3700 masl. The average annual precipitation is 1650 mm, falling mainly within the *kiremt* season from June through September (Fashing et al 2014), with intermittent rains occurring in the *belg* season from February to April. The average monthly temperature of Guassa is 11.0°C (1.2°C SE) (Fashing et al 2014). Guassa is home to several endemic and endangered species, including the Ethiopian wolf (*Canis simensis*) and gelada monkey (*Theropithecus gelada*) (Ashenafi and Leader-Williams 2005). The name Guassa is taken from *guassa* grasses (*Festuca macrophylla*) that local people value for roofing, cord, building material, and forage (Steger et al 2020).

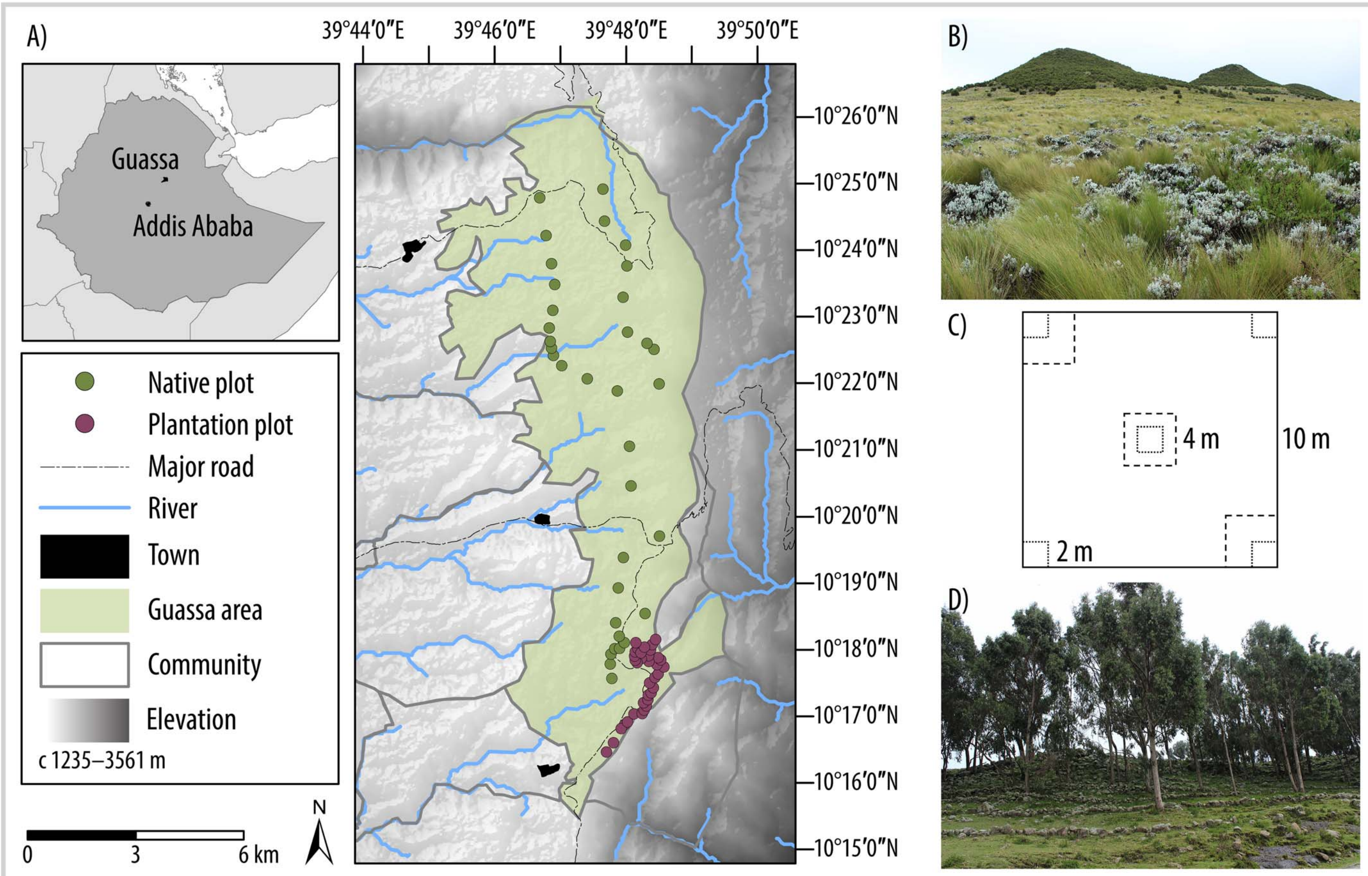
The Guassa management system has experienced major political and land management changes through its 400-year history. It was originally managed (c 1600–1974) through the local *Qero* system of communal management that limited access to the grasses (Ashenafi and Leader-Williams 2005). Changes then came rapidly, starting with the takeover of the imperial regime and Emperor Haile Selassie (1974). This was followed by a period of land restructuring through the military regime of the Derg (1974–1991). Then came a period of mixed government and community management (1991–2003), followed by increased nongovernmental organization leadership (2003–2012). A comanagement regime (2012–present) is currently used (Ashenafi and Leader-Williams 2005; Fischer et al 2014; Nigussie et al 2019; Steger et al 2020). As an important watershed and a sanctuary for flora and fauna, the Guassa site is receiving increasing attention from tourists, the Ethiopian government, researchers, and international conservation organizations (Welch 2017).

Plantation forests in this area vary in size depending on whether they were established as public soil and water regulator projects or as individual woodlots (Steger et al 2020). There is one large plantation, established by the Derg regime, that is largely contained within the conservation area, with a scattering of small woodlots (both private and public) in the land outside the conservation area. Our current comparison is based on the large plantation, as it represents a rare opportunity to study a long-term plantation site. Many of the plantation forests established by the Derg were destroyed by local communities in the 1990s in retribution for past state abuses (Admassie 2000). Eucalyptus (*Eucalyptus globulus*) and cypress (*Cupressus lusitanica*) are the dominant planted species.

Data collection and analysis methods

Socioeconomic surveys and group interviews: In December 2016, we designed and administered a survey to 100 respondents living in the 4 administrative regions closest to the Guassa area (25 respondents per region). All respondents were over 50 years of age so that they could reflect on changes to the conservation area and plantation forests throughout their lifetime. Respondents were

FIGURE 1 (A) Map of the Guassa Community Conservation Area and surrounding region. Quadrats in natural vegetation are marked with green points, and quadrats in plantation forest are marked with purple points. The inset map shows the location of Guassa in relation to Addis Ababa, the capital of Ethiopia. (B) Photograph of some natural vegetation types in Guassa. (C) Diagram of our quadrat sampling approach. (D) Photograph of plantation forest in Guassa. (Map, diagram, and photos by Cara Steger)



randomly selected, and open-ended questions were used to understand their perceived timeline of historical events and how they impacted local communities.

In March 2017, we conducted semistructured group interviews to recognize the ecosystem services associated with both native vegetation and plantation forest (Steger et al 2020). We conducted a group interview in each of the 9 administrative units around Guassa to avoid a biased perspective from people living closest to the Guassa area. We included a total of 106 participants across the 9 group interviews, with an average age of 41 years (ranging from 18 to 88 years). The combination of survey and group interviews allowed us to encompass a wide range of perspectives while also benefiting from rich, dynamic conversations (Gibbs 2012).

We analyzed surveys using descriptive statistics. We applied the software package ANTHROPAC (Borgatti 1996) to examine the ecosystem service data, calculating the comparative importance of each ecosystem service across the 9 communities interviewed.

Vegetation sampling: We conducted vegetation sampling in October and November 2016. We established 70 sampling quadrats along 2 transect lines in native grassland and plantation forest (Figure 1A), with 35 quadrats each in native vegetation (Figure 1B) and plantation forest (Figure 1D). The 2 transect lines were laid 500 m from one another. Quadrats on the native vegetation transect were established 200 m from each other, while quadrats in the plantation forest were established 100 m from each other due to the limited spatial coverage of plantation forests in the Guassa area. The size of each quadrat 10 m × 10 m for trees, 3 subquadrats (4 m × 4 m) for shrubs, and 5 subquadrats (2 m × 2 m) were laid down for ecological data collection (Figure 1C; BLM 1996).

All plant species in the quadrat were documented for the ecological analysis, and we collected and pressed any species we could not identify in the field. The relative cover of all species was recorded and converted to the modified Braun Blanquet scale values 1–9 (van der Maarel 1979). The collected plant specimens were pressed and brought to the National Herbarium in Addis Ababa University, where we consulted resident experts and databases of authenticated specimens to identify the species.

We used the Shannon–Wiener diversity index, species richness, and evenness (Krebs 1999; Magurran 2004; Erenso et al 2014; Wodaj et al 2016) to describe the plant species diversity of the native vegetation and the plantation site using the community ecology package (vegan, version 2.6-4) with RStudio 2022.12.0-353 software. The Shannon–Wiener diversity index was used because it considers both species evenness and richness and is not affected by sample size (Kent and Coker 1992). We used a two-sample t-test to check whether there was a statistically significant difference between native grass and plantation forest in terms of richness, diversity, and evenness.

TABLE 1 Locally defined land classes and their respective ecosystem services, ranked and aggregated across the 9 communities interviewed. Adapted from Steger et al (2020).

Class	Ranked ecosystem services	Relative salience (S score)	Overlap
Guassa grass	Roof thatch	1.00	
	Rope construction	0.83	Unique
	Grass for construction	0.62	
	Income	0.44	
	Sleeping mat	0.26	Unique
	Foder	0.22	
	Floor covering	0.18	
	Local materials	0.02	Unique
Guassa native area	Harvest of *guassa* grass	1.00	Unique
	Source of water	0.71	
	Shelter for wild animals	0.47	
	To attract tourists	0.33	Unique
	To attract rain	0.05	Unique
	Harvest other plants	0.04	Unique
Guassa plantation forest	House construction	1.00	
	Firewood	0.85	
	Income	0.72	
	Soil protection	0.50	
	Household items	0.41	
	Shelter for animals	0.31	
	To attract rain	0.24	
	Climate regulation	0.11	
	Forage	0.11	
	Fence construction	0.08	Unique
	Shade	0.07	
	Source of honey	0.03	
	Charcoal	0.02	Unique
	Increase groundwater	0.01	
	Beauty	0.01	

Note: A relative salience index (S score) was used to rank the items (in our case, ecosystem services) by their importance. Its value ranges from 0 to 1. The S score was calculated using the formula $S = (\Sigma((L - R_j + 1)/L))/N$, where L is the length of the list, R_j is the rank of item j in the list, and N is the total number of lists (Borgatti 1996).

Results

Impacts of plantation forest on human communities

Overall, respondents reported the establishment of plantation forests had been beneficial to both human and plant communities. Respondents reported a total of 15 ecosystem services that they derived from plantation forests, including timber for house construction, firewood, honey, and charcoal (Table 1). Plantation forest was also valued for its ability to increase the amount of groundwater in the area, though respondents specified that this was only for cypress and did not apply to eucalyptus plantations. One respondent reported, "If there was no planted forest, our lives would have been very difficult. In addition to its many benefits, it reduces the burden on natural grass land."

Respondents listed 6 ecosystem services for the Guassa area in general and 8 from the *guassa* grass specifically,

TABLE 2 Plant richness, diversity index (H'), maximum possible diversity index (H_{max}), and evenness for native grassland and plantation site (beta diversity).

Site	Richness	H'	H_{max}	Evenness
Native grassland	78	2.98	4.3	0.7
Plantation forest	48	2.20	3.8	0.6

which makes direct comparisons with plantation forest somewhat difficult. Grouping these together, we found a roughly equal number of ecosystem services across vegetation types. Native grassland was valued primarily as a source of *guassa* grass, which is the preferred roof covering in this region. *Guassa* grass is also used to make rope and other useful household items. Importantly, the Guassa area was used to provide firewood to local people until this practice was banned in 2010.

Respondents listed 7 ecosystem services that could be found only in the native grassland, whereas plantation forest provided only 3 unique ecosystem services. Both vegetation types were valued for the supposed ability to attract precipitation and for providing habitat for wild animals, as well as providing sources of cash income for local communities (Table 1).

Impacts of plantation forest on plant communities

We recorded a total of 88 species—86 within quadrats and 2 outside the quadrats but within the study site—belonging to 63 genera and 31 plant families (Appendix S1, *Supplemental material*, https://doi.org/10.1659/mrd.2023.00010.S1) across both vegetation types surveyed and 19 endemic species. We recorded 78 species from native grassland quadrats (Table 2). Of these, 38 species (48.7%) were recorded exclusively in the native grassland area. We recorded 48 species from the plantation area quadrats, 8 of which (16.7%) only existed in the plantation site. In total, 40 plant species were common to both the native vegetation and plantation sites. Of 31 plant families, Asteraceae had the highest number of plant species ($n = 31$), followed by Poaceae ($n = 9$), Rosaceae ($n = 4$), Cyperaceae ($n = 4$), and Polygonaceae ($n = 4$). These 5 families represent 60% of total species recorded from the area (Table 2).

The native grassland site had an average plant species richness of 11.6 species per quadrat (SD = 3.3), ranging from 6–18 species per quadrat. The plantation forest had a mean species richness of 9.91 species per quadrat, ranging from 3–18 species (SD = 3.2). The difference in number of species per quadrat across vegetation types was statistically significant ($t_{(68)} = 2.14$, $P = 0.04$). The Shannon–Weiner diversity index value (beta diversity) for native grassland was 2.98, while the index for plantation forest was 2.20. The difference in diversity index and evenness per quadrat (alpha diversity) across vegetation types was statistically significant ($t_{(53)} = 4.27$, $P < 0.001$ and $t_{(42)} = 4.62$, $P < 0.001$, respectively). Finally, the evenness for native grassland was 0.7, and evenness for plantation forest was 0.6 (Table 2).

We found 19 species (22% of total plant species) in the study area that are endemic to Ethiopia and Eritrea; 11 of these are unique to the Afroalpine zone (Table 3). Wodaj et al (2016) found only 9 endemic species in the conserved site. Three of these species has been evaluated for the International Union for Conservation of Nature's "Red List." The plantation forest had 12 endemic species, while the native grassland had 15 endemic species. Of these, 8 were shared across both vegetation types, leaving 7 endemic species unique to native grassland and 4 unique to the plantation forest.

Endemic species found in plantation forest and native grassland from this study were comparable to previous vegetation assessments in the area (Wodaj et al 2016). We confirmed endemism of each species using the Kew Royal Botanical Gardens Plants of the World portal. We confirmed whether species were unique to the Afroalpine zone using the Natural Database for Africa (Dagne 2011) and Gehrke and Linder (2014). We referred to the International Union for Conservation of Nature Red List of Threatened Species website (IUCN 2022) to check whether these species have been evaluated for threats to their continued sustainability. In most cases, it was difficult to find data regarding their threat status because the Red List assessment of Ethiopia was incomplete. The only Red List information currently available is for endemic trees and shrubs of Ethiopia (Vivero et al 2005) (Table 3).

Discussion

Our study investigated how plantation forests impact both the human and plant communities of the Afroalpine zone, using a case study of a community conserved area in the highlands of Ethiopia. We found that native grassland had higher species diversity than plantation forests. We also found that although plantation forests and native vegetation provide approximately equal numbers of ecosystem services to humans, native vegetation provides a higher number of unique ecosystem services that could not be found elsewhere. Still, people and plants derive unique benefits from plantation forests, which emphasizes the complementary role these planned vegetation types play in a heterogeneous landscape.

Plantation forests are increasingly important as a foundation of both timber and nontimber forest harvests throughout the world (Baral et al 2016; Elsasser et al 2021). Although many assume that plantation forests are inferior to natural forests in terms of ecosystem service provision, recent research indicates that this may be an artifact of inadequate monitoring over insufficient timescales (Baral et al 2016). The long-established plantation forests of our case study reveal that planted forests can provide levels of ecosystem services comparable to native vegetation.

In fact, well-planned and maintained plantations can alleviate the social, economic, religious, and ecological burden being placed on natural forests and other vegetation (Baral et al 2016). For example, plantation forests in Guassa provide a source for charcoal and firewood production, which is no longer available in the native grasslands due to

TABLE 3 Comparison of endemic plants found in current and previous ecological studies.

Species name	Plantation forest	Native grassland	Wodaj et al (2016)	Endemic (Natural Database for Africa [Dagne 2011])	Afroalpine (Gehrke and Linder 2014)	IUCN[a] Red List (Vivero et al 2005)
Alopecurus baptarrhenius S.M. Phillips	No	Yes	No	Yes	Yes	
Bidens pachyloma (Oliv. & Hiern) Cufod.	Yes	No	No	Yes	No	
Cineraria abyssinica Sch. Bip. ex A. Rich	Yes	No	Yes	Yes	Yes	
Cirsium dender Friis	No	Yes	No	Yes	No	
Cirsium schimperi (Vatke) C. Jeffrey ex Cufod.	No	Yes	No	Yes	No	
Conyza flabellata Mesfin	No	Yes	No	Yes	No	
Cynoglossum amplifolium Hochst. ex DC.	Yes	Yes	Yes	Yes	No	
Euryops pinifolius A. Rich.	Yes	Yes	Yes	Yes	Yes	Vulnerable
Festuca macrophylla Hochst. ex A. Rich.	Yes	Yes	Yes	Yes	Yes	
Festuca richardii E.B.Alexeev	Yes	Yes	No	Yes	Yes	
Inula confertiflora A. Rich.	Yes	Yes	No	Yes	No	Near threatened
Kniphofia foliosa Hochst.	Yes	Yes	Yes	Yes	Yes	
Lobelia rhynchopetalum Hemsl.	No	Yes	Yes	Yes	Yes	
Phagnalon abyssinicum Sch. Bip. ex Hochst.	Yes	No	No	Yes	Yes	
Plectocephalus varians (A. Rich) C. Jeffery ex Cufod.	Yes	Yes	Yes	Yes	Yes	
Senecio ochrocarpus Oliv. & Hiern	Yes	No	No	Yes	Yes	
Solanum marginatum L.f.	No	Yes	No	Yes	Yes	Least concern
Thymus schimperi Ronniger	Yes	Yes	Yes	Yes	Yes	
Urtica simensis Hochst. ex A. Rich.	No	Yes	Yes	Yes	No	

[a] IUCN, International Union for Conservation of Nature.

changes in management. Energy provisioning through firewood and charcoal is a critical ecosystem service for subsistence livelihoods (Mead 2005), and plantation forests can reduce deforestation pressures on native forests or shrublands.

In addition to the provision of ecosystem services, our results reveal that plantation forests can also support higher levels of endemic plants when considered as part of a landscape-scale mosaic. We found 4 endemic species in the plantation forest quadrats that were not present in the native Afroalpine vegetation. We suspect this may be due to a combination of factors: the higher soil moisture in plantation forests, lower light levels, and increased rates of litter and decomposition within forests due to reforestation. Plantation forest also provides many ecological benefits, such as changing nutrient cycling, increasing stability of soil carbon, improving soil moisture, and improving water quality (Cunningham et al 2015). Therefore, although our results support previous work that finds lower species diversity and richness in plantation forests versus native vegetation (Braun et al 2017; Rédei et al 2020), we would argue that plantation forests can still contribute to increased plant richness at a landscape scale (Lemenih 2006; Pawson et al 2013).

Our qualitative approach using interviews and group discussion provided robust results regarding the social history of the plantation. To understand the ecological differences between plantation and native grassland, quantitative methods were needed. The applied *t*-test revealed statistically significant differences. For example, the native grassland has greater plant richness, diversity, and evenness than the plantation area. This implies that planting trees has an impact on native plant species (Wang et al 2022). Plantation forest can also have either a positive or a negative impact on animals and faunal diversity (Hunter 1999; Wang et al 2022). This depends on management style and practices. If we plant solely exotic species, the impact is likely to be negative, whereas, if we plant mixed tree species, this has a positive influence on faunal diversity (Hunter 1999; Hartley 2002). However, we did not study the impact of the plantation forest on animals here.

Conclusions

This research contributes to ongoing debate about the impact of plantation forests on human communities, particularly in the heterogeneous cultural landscapes that characterize the Ethiopian highlands. Our results showed that local livelihoods are dependent upon plantation forests for a wide variety of ecosystem services, including cash income from niche products like honey, timber for housing, and energy from both firewood and charcoal provision. Negative perceptions of plantation forests, once widespread in this area, seem to have largely faded as smaller-scale plantation forests with targeted management have replaced large-scale government plantings.

Our results further contribute to ecological debate surrounding plantation forest impacts on plant communities. Although the plantation forests in our case study doubtless have lower plant diversity than native Afroalpine vegetation, they also provide an alternative habitat structure that enables higher plant diversity at the landscape scale. As precipitation patterns in the Ethiopian highlands continue to shift, the maintenance of long-term plantation forests may be a source of additional adaptive capacity for the plant communities of this region.

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Supplemental material

APPENDIX S1 Scientific and local names of total plant species recorded from Guassa conservation area.

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