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Biodiversity And Livelihoods In Southwestern Ethiopia: Forest Loss And Prospects For Conservation In Shade Coffee Agroecosystems

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A dissertation submitted in partial satisfaction
of the requirements for the degree of

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by

Getachew Tadesse Eshete

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Table of Contents

LIST OF FIGURES

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

LIST OF TABLES

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

LIST OF APPENDICES

ABSTRACT

Biodiversity and livelihoods in southwestern Ethiopia: Forest loss and prospects for conservation in shade coffee agroecosystems

By

Getachew Tadesse Eshete

The Ethiopian southwest is a global origin for *Arabica* coffee which is the second most traded global commodity after petroleum; and the most important agricultural commodity for Ethiopia. The region is also a global center of crop domestication and diversification with ancient and diverse social and agricultural systems, languages, and cultural groups. People have been here possibly longer than anywhere on Earth and have longer history of interactions with their natural environment, so they rely principally on these agro-ecosystems for a range of goods and services. The forest remnants represent some of the last remnants for the nation and the world's only habitat that retain diverse wild *Arabica* coffee populations.

However, deforestation and land-use changes have been key drivers of degradation of biodiversity and ecosystem services in the region as in many tropical regions. But, the extent, patterns and drivers of deforestation at local scales in the context of broader socio-ecological dynamics remain poorly understood, although such studies are important for biodiversity conservation and sustainable use of forest resources. I explored land-use changes and forest loss in southwest Ethiopia over the last 40 years (Chapter 1), and the prospects for conserving biological diversity (Chapter 2) and ecosystem services (Chapter 3) in coffee landscapes. Over 40 years,

more than 50% of the forest cover has been lost or converted to small-scale and large-scale coffee, *Eucalyptus* and tea plantations as well as other annual croplands. Deforestation rates varied in space and time as a function of the complex and interacting effects of local socio-cultural processes, and external policy and demographic pressures that influenced socio-ecological feedbacks locally.

To understand the effects of deforestation and fragmentation on biodiversity, I examined patterns of woody plant diversity in the remaining forests, and studied the potential and limitations of conserving native biodiversity in coffee agroforests. There are four types of shade coffee production systems (wild, semi-wild, small-scale garden and plantation coffee) in the region. The wild and semi-wild (small-scale) shade coffee systems retain more native woody biodiversity than large-scale coffee plantations. Although over 60% of woody species and associated biodiversity can be conserved in these shade coffee systems depending on management and the species, some species such as understory shrubs and herbs, slow-growing large trees and lianas cannot persist. While traditionally diverse coffee agroforests can retain some components of native biodiversity, these agroforests are also facing intensification and conversion to working landscapes that support less biodiversity.

In order to reduce deforestation and intensification and conserve biodiversity in these forests and coffee agroforests, it is essential to promote local ecosystem benefits to millions of people living in these ecosystems. I used socio-ecological and market surveys to assess the local benefits of forest-based ecosystem services in both forests and coffee farms, and the prospects for coffee agroforestry systems to provide complementary ecosystem services under current land-use trajectories in the region. My findings show that over 60% of provisioning services can be maintained in coffee landscapes while most of the cultural, regulating and supporting services will have to be provided by the forest remnants. Therefore, both forest remnants and low-intensity coffee landscapes are critical for the persistence of both biodiversity and ecosystem services in the region. This implies that losing these forests to coffee means losing important components of biodiversity and ecosystem services as well as sources for coffee shade tree diversity and for the coffee crop itself. Alternatively, we also cannot lose low-intensity and semi-wild coffee from these landscapes without losing considerable biodiversity and ecosystem services, since coffee is now a large part of these landscapes and forests are becoming scarce.

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CHAPTER ONE

Policy and demographic factors alter deforestation patterns and socio-ecological processes in southwest Ethiopian coffee agroecosystems

By

Getachew Tadesse Eshete

Abstract

Deforestation and land-use changes are the primary drivers for the loss of biodiversity and ecosystem services in tropical regions. The extent, patterns and drivers of deforestation at local scales in the context of broader socio-ecological dynamics remain poorly understood in some tropical regions, although such studies are important for biodiversity conservation and sustainable use of forest resources. We used the case of rapidly changing landscapes in southwest Ethiopia and estimated the basic rates of land-cover changes over a 37-year period and to explore variations in space and time. We obtained LANDSAT images (from 1973, 1987, 1995, 2001, and 2010) to estimate rates of land-cover changes. In order to understand the extent of local and regional drivers and socio-ecological feedbacks locally, I combined the remote sensing analyses with (1) interviews with local people on the extent and drivers of landscape changes during this period, and (2) the effects of historic resettlement and management that varied between two districts (Yeki and Decha). Our results show that more than half of the study area's forests were lost; there is an increase in forest fragmentation and agricultural lands increased considerably. Patterns of deforestation varied with biophysical and social variables including elevation, road infrastructure and population density. Most of the remnant fragments are concentrated at higher elevations, and in areas where more traditional groups and cultural practices remained. Annual deforestation rates were two times higher in Yeki district (2.1%) than in Decha (1.1%) during the same period. Higher deforestation rates in Yeki between 1973 and 1987 are correlated with the 1984/5 onset of major national resettlement and resulting demographic pressure. Conversely, forests have been maintained in some areas regardless of population growth due to traditional forest-based livelihoods in Decha as well as recent forest conservation programs. Local people corroborated the high rates of deforestation and drivers of forest loss including policy and demographic drivers and market opportunities. I conclude that deforestation rates vary in space and time as a function of the complex and interacting effects of local socio-cultural changes and external policy and demographic pressures that influence local responses to the loss of forests and forest resources in the region. Local feedbacks reflect responses to the effects of deforestation on biodiversity, ecosystem services and livelihoods as a result of socio-cultural and economic changes. Our findings underscore the need for forest conservation efforts to consider local and regional processes that influence human-environment interactions.

1. Introduction

Human-environment interactions involve modification of the biophysical character of landscapes (i.e. land-cover) through the socio-economic employment of land (i.e. land-use) (Meyer & Turner 1992). The dominant type of land-use/cover in a region is mainly the result of human-environment interactions explained by prevailing socioeconomic, cultural and environmental processes with multiple trajectories and feedbacks in the landscape (Lambin *et al*. 2003). Any major landscape change is therefore the result of changes in such interactions driven by socioeconomic and policy changes to meet material and non-material needs (Dale *et al*. 2000; Haines-Young 2009).

Humans have modified their environment for millennia, although rates of land-use and land cover change have been unprecedented during the last 50 years and disproportionate compared to rates of historic land-use changes (Metzger *et al*. 2006). These trends are particularly severe in ancient landscapes of southwest Ethiopia known for long-standing and intimate interactions between indigenous people and their landscapes (Reusing 2000; Stellmacher 2007).

With current annual deforestation rates nationally (2,000 $km^2 yr^{-1}$), forest cover in Ethiopia diminished from 40% in the early 20^{th} C, to 16% in the 1950s, and to <3% recently (McCann 1997). Consequently, the largest forest ecosystems became limited to southwest highlands and the adjacent lowlands we considered for this study, although these remnants have also been under unprecedented land-cover changes (see map, Figure 1). The forests in this region belong to the Eastern Afromontane biodiversity hotspot known for 75% endemism in vascular plant species (White 1981; Burgess *et al*. 2005; Birdlife International 2012). Within Ethiopia, where about 40% the original habitat for the hotspot is found, the large majority of moist Afromontane vegetation and biodiversity occurs in southwest Ethiopia. These forests are the global origin for *Arabica* coffee, where wild populations with high genetic diversity coffee occur in addition to a range of timber and non-timber forest products that vitally support the livelihoods of most people in the region (Gole 2003; Kassahun 2006, Bongers & Tennigkeit 2010).

1.1 Drivers and consequences of landscape changes

Landscape change drivers involve (1) endogenous socio-ecological forces such deforestation and agricultural expansion, and/or (2) exogenous socioeconomic factors such as market demand, land-use policy and resettlement (Lambin & Meyfroidt 2010). The first are mostly proximate causes (logging, agricultural expansion, fuel-wood and charcoal production) occurring at household, or community level that directly affect land-cover. Local drivers are buttressed by underlying drivers (demographic, cultural, policy factors) unmanageable by local communities (Blaikie & Brookfield 1987; Lambin *et al*. 2003).

Patterns of deforestation and land-cover changes can also be associated with (1) biophysical factors such as elevation and slope gradients, and (2) socio-economic and demographic factors such as roads (physical access to forests), population density, and human management or protection of forests (Hayes *et al*. 2002; Laurance *et al*. 2002; Muller & Zeller 2002; Steininger *et al*. 2001; Mukwada 2009). Therefore, sustainable land management requires the understanding of where in the landscape high deforestation occurs in addition to exploring broader demographic and policy drivers of land-cover changes. For instance, the expansion of agricultural land by smallholders in tropical regions (Lambin *et al*. 2003) particularly in sub-Saharan Africa (MEA 2005) is exacerbated by economic and policy changes, and demographic drivers.

Deforestation could result in habitat loss and degradation that affect biodiversity and ecosystem services (Foley *et al*. 2005; Haines-Young 2009; Polansky *et al*. 2011). Deforestation not only affects habitat size but also causes fragmentation through increasing edge and isolation of patches, and by decreasing size and connectivity of patches.

Globally, there has been a shift from swidden cultivation to more intensive cultivation (Foley *et al*. 2005) driven by policy and demographic drivers and market opportunities although changes to more intensive practices can cause permanent deforestation, biodiversity loss, soil erosion and loss of soil nutrients (van Vliet *et al*. 2012). Landscape changes can have socioeconomic effects including increased risk from and vulnerability to drought, climate change, poverty, and socio-cultural perturbations (Lambin *et al*. 2003). Such changes are shifting production practices locally such as conversion from traditional forest-based livelihoods, fallowing and shifting cultivation to more intensive cultivation.

1.2 Political-economic and ecological processes in southwest Ethiopia

Deforestation is not only an outcome of increasing demand for more agricultural land induced by population growth and poverty locally but also a result of broader changes in the political economy of a region (Blaikie & Brookfield 1987; Perrings 2000; Adger *et al*. 2001). Both the above-mentioned local (proximate) and underlying (national) processes occur at our study landscape in southwest Ethiopia. We (1) examined the major drivers correlated with patterns of deforestation and land-use changes using satellite data and socio-ecological surveys, and (2) compared impacts of resettlement and forest conservation on deforestation, using two districts of contrasting demographic and forest management histories.

The contrasting histories of the two districts, Yeki and Decha, give us the opportunity to explore how land-use change can be influenced by different drivers under different demographic and management regimes. In the 1950s and 1960s, Yeki district used to be dominated by indigenous Majangir and Shako peoples who predominantly practiced shifting cultivation and hunting-gathering (Stauder 1971). On the other hand, indigenous peoples in Decha district had a long history of sedentary cultivation practices with high use of non-timber forest products. Generally, indigenous people in Yeki district are less dominant (58.9%) than they are in Decha and surrounding districts (84%) (CSA 2008).

In pre-1974 Ethiopia, land-tenure was complex and diverse, and included church, kinship, serfdom, private, communal, village, and state land-holding regimes (Rahmato 2009). After the national 1974 land-to-the-tiller proclamation that homogenized the pre-existing diverse ownership regimes, the state nationalized land throughout Ethiopia including both study districts. The state redistributed land and allowed local communities (farmers) to farm cultivated or cultivable land using usufruct rights. This resulted in the disruption of the pre-existing ownership regimes, in creating land-tenure insecurity, and in the weakening the traditional forest management systems that may have aggravated deforestation. With the formalization of usufruct rights, many traditionally owned and managed forests were converted to state ownership. This might have led to rivalry and conflict, which was aggravated by inefficient state forest conservation programs that did not fully involve communities (Ostrom & Nagendra 2006; Stellmacher 2007).

Probably the most interesting historical event after these land-tenure changes that increased demographic pressure and competition for agricultural land was a resettlement program in 1984/5 that occurred as a national response to the Ethiopian famine crisis (Clay & Holcomb 1985). The major resettlement scheme was prevalent in Yeki, but not in Decha district. The environmental impact of resettlement through rapid land-cover changes and forest degradation has been documented in tropical forest regions (Peres 2012) although its impact can vary from region to region.

After resettlement, the most noticeable drivers of deforestation were associated with the Ethiopian political regime change in 1991. This regime change led to liberalization policies and land redistribution to new families with further deforestation, agricultural expansion and intensification. Ethiopia's Agricultural Development-led Industrialization Policy after the 1990s provided extension and credit programs that encouraged intensive farming practices and farmland expansion (Gebreselassie 2006).

Reichhuber & Requate (2007) outlined three conflicting interests of land-use in coffee landscapes of southwest Ethiopia (1) conversion of coffee forests to small-scale agricultural land (2) managing forests to support semi-forest coffee production, and (3) forest protection through limiting access to forest products. Rather than strict forest preservation, recently, new forest management approaches such as Participatory Forest Management programs have been introduced to many regions in Ethiopia and to Decha district to involve local communities in forest conservation while promoting direct forest benefits to them aimed to ensure food security and alleviate poverty (Winberg 2010) through regulated access that promote sustainable use. However, Participatory Forest Management was not introduced to Yeki district.

Therefore, major changes in policy, demographic and socioeconomic conditions occurred during the last four decades in both or either one of the districts we studied (Table 1). We investigated whether these changes affected rates of forest loss in the region. Much land-use change research in tropical regions focuses on estimating rates of deforestation, but we also sought to address the effects of socioeconomic and cultural drivers on forest loss rates (Uriarte *et al*. 2009) in space and time. Although some of these drivers were generally described (Gole 2003; Argaw 2005), there are no known studies in this region that examined the effects of these drivers superimposed with actual rates of deforestation across larger temporal scales. Studies on local rates of deforestation and its effect on fragmentation are similarly few and less detailed (Reusing 2000; Wakjira 2007). Here, we addressed forest cover changes and transitions to other land-uses (coffee farms, settlements, cultivated fields and plantations) and related effects on fragmentation patterns from 1973 to 2010. Finally, we explored spatial correlates of deforestation along elevational and slope gradients and in relation to roads and settlement to help identify conservation priorities for the area.

1.3 Traditional ecological knowledge and perceptions on landscape changes

Understanding land-use changes requires local people's perceptions and decision-making on environmental changes (i.e. environmental cognitions) as a form of social–ecological feedbacks (Meyfroidt 2012). These feedbacks depend on how land-use changes affect ecosystem services and livelihoods, and how local people perceive these changes (Ostrom 2009; Uriarte *et al*. 2009). Traditional ecological knowledge represents cumulative memory and adaptive skills (Bélair *et al*. 2010) developed from complex and interacting socioeconomic and biophysical processes (Gadgil *et al*. 1993; Matthews and Selman 2006; Maro 2011). As major land managers, local people can provide comprehensive information on the socio-cultural and environmental changes in their landscapes (Pisanelli *et al*. 2012). This knowledge enables societies to closely examine and understand complex environmental processes, and to monitor and adapt with ecosystem changes and deal with uncertainties in changing landscapes (Colding *et al*. 2003; Olsson *et al*. 2004; Folke 2006).

High dependence of forests for various ecosystem services may have shaped the way people perceive forests and the status of forest-cover changes in southwest Ethiopia. Incorporating such knowledge and practices is useful in planning and decision-making for sustainable land management (Maro 2011), and for detailed understanding of drivers, processes and consequences on land-use changes. Local perceptions on land-use changes in southwest Ethiopia have been poorly understood; and hence we studied the extent and drivers of landscape changes as perceived by local communities during the past 40 years.

2. Methods

2.1 The study area

We studied two major regions of contrasting demographic and land-use histories: (1) Yeki, and (2) Decha (including adjacent forested villages) districts in southwest Ethiopia (Figure1). Yeki district has high population density (223 persons km^{-2}) with both indigenous people and settlers. In this district, there has been rapid land-use transition from shifting cultivation and hunting-gathering practices to intensive cultivation. Settlers who belong to various ethnic groups and who came after 1984/5 from the highly populated regions of central Ethiopia to the region mostly engaged on intensive cultivation practices than indigenous people. In contrast, Decha has lower population density (79 persons km^{-2}) with longer history of cereal cultivation and dominated by indigenous people who depend on various NTFPs (SUPAK-S 2009; Central Statistical Authority of Ethiopia, CSA 2012). Both regions are generally human-dominated agricultural landscapes with Yeki being 33.3 % rain-fed mosaic villages (villages with a mix of trees and crops), and 67% residential rain-fed mosaics (mix of trees and rain-fed cropland with substantial human populations), while Decha being 10% rain-fed mosaic villages and 90% rain-fed villages and forests (villages dominated by rain-fed agriculture and forests) (Ellis & Ramankutty 2008). From 1990s to 2010, population density of Yeki was more than doubled to 205 persons km^{-2} compared to lower increase in Decha region (36-45 persons km^{-2}) (CSA 2012).

2.2 Data collection and image processing

We studied the land-cover dynamics in southwest Ethiopia using (1) remote sensing, (2) ground truthing, (3) fragmentation analysis, and (4) socio-ecological surveys based on local ecological knowledge and perceptions about land-use changes. We acquired satellite images (Land Remote-Sensing Satellite System LANDSAT 1, 5, 7 and Enhanced Thematic Mapper) from USGS (http://glovis.usgs.gov); and French Remote-Sensing Satellite (SPOT) 2007 and toposheets from Ethiopian Mapping Authority. For the spatiotemporal analysis of change detection, all of the images acquired were from dry seasons, i.e., between December and February (Table 2) to minimize atmospheric haze and cloud cover. The multispectral images allowed us to map different land-use and land-cover units over time. We used 1973 image as a reference since no earlier images were available, and we could not know the pre-1973 extent of forests in the region that has always been inhabited. The year 1973 also precedes the major political changes and land re-distribution scheme in Ethiopia that induced much of the subsequent landscape changes in the region. Later images were from 1987 coincided with major resettlement in the region; from 1995 following after regime change in 1991; from 2001 that coincided with conservation programs; and finally from 2010 to compare with recent land-cover (Table 1).

The major steps we used for image classification and change detection were (1) collecting the training samples, (2) generating a signature file, (3) executing the maximum likelihood classification tool, and (4) post-classification processing. We also used geospatial analytical tools in ArcMAP 10 to identify and classify land-use types, and depict changes in land-cover types over time and calculate rates of deforestation. For the image classification, we used ERDAS Imagine 9.3 and a toolbar introduced at ArcGIS 10 with spatial analyst and image analysis extensions.

We used supervised classification technique with ground-truthing information (GPS landmarks), classified the images using polygons that characterize distinct sample areas in land-use types. Then, we used these sampling points for accuracy assessment and change detection. We used reference images (SPOT 2007, geoprocessed recent Google Earth images) to support our ground-truthing surveys. Elevation, slope, and geographic coordinate data were collected for each sampling point. Elevation and slope data for each land-cover zones were calculated using Shuttle Radar Topography Mission layers in ArcToolbox in ArcMAP 10. We obtained population density data between 1990 and 2010 from the database in the Center for International Earth Science Network, Columbia University (2007). We digitized toposheets and interpreted the images using ERDAS Imagine 9.2 (raster graphics editor). Specific areas of change and change rate were calculated for the change detection, along with spatial distribution of changed types and accuracy assessment. We also used (Normalized-Difference-Vegetation-Index (NDVI) analysis to assess vegetation cover changes across time and space.

2.3 Fragmentation analysis

Fragmentation indices were calculated using FRAGSTATS 4.1 (McGarigal *et al*. 2010) based on various area, edge, core and neighbor indices at patch and landscape levels (Table 3). FRAGSTATS is a spatial pattern analysis program for categorical maps representing the landscape mosaic model of landscape structure (McGarigal *et al* 2012). We set edge length core area to 600 m; search radius and threshold distance to 1km each; and edge depth was set to 450 m.

2.4 Socio-ecological surveys

To understand the various drivers of deforestation and associated local and regional socio-ecological feedbacks, we compared time-series satellite data with socio-ecological survey data using local perceptions about land-use/cover dynamics across space and time. Using semi-structured interviews (n=105) and focus groups (n=11) from villages that were representative of the different patterns of landscape changes, we collected data on major changes and associated drivers at farm and landscape levels across time. We collected about farm-level and landscape-level changes in coffee farms and forest fragments using semi-structured interviews. The socio-ecological data was then correlated with the rates of deforestation as well as the reported proximate (increasing demands for agricultural land) and ultimate drivers (resettlement, market incentives and policy changes) where I coded the local responses about the drivers as proximate and underlying causes following Lambin *et al*. (2003) description about drivers of land-cover changes .

2.5 Data Analyses

We determined annual deforestation rates using a recent and standardized index, $P = \frac{100}{t_2 - t_1} \ln \frac{A_2}{A_1}$ where P is annual percentage of forest loss, and A_1 and A_2 are the amount of forest cover at time t_1 and t_2 respectively (Puyravaud 2003). In order to evaluate the accuracy of the final maps, post classification accuracy assessment for the major land-cover classes was calculated based on overall, user‘s and producer‘s accuracy (Congalton 1991). For the change detection, we computed NDVI, $NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}$ where NIR and VIS are near-infrared and red (visible) reflectances (bands) respectively. Using zonal statistics in the Arctool box, we calculated the mean slope, elevation, and population density of forests and non-forested working landscapes to examine whether deforestation patterns were associated with topography and demographic pressure in the landscape. We then compared for any effects of elevation, slope, roads and population density on deforestation patterns using chi-square tests.

In order to examine the effects of resettlement and protection on forest cover, we used before-after-control-impact (BACI) observational experiment with the resettlement on Yeki that included forest loss rates between 1973 and 1995; and participatory forest management and forest conservation on Decha that included forest loss rates between 1996 and 2010. We used ANOVA, and non-parametric t-tests for comparing the effects of these drivers on forest loss rates between the two regions.

3. Results

3.1 Forest cover declined by more than 50% and became more fragmented

Overall classification accuracy for the thematic classes from 1973 to 2010 varied from 74.2 to 83.3 %, based on our 362 ground control points from the different land-cover types (Table 4). The mean Kappa coefficient (K_{hat} =0.8) indicated a strong agreement between the ground truth and the classified land-use classes. The NDVI analysis of 2010 images showed that coffee farms had generally lower average NDVI values that ranged from 0.19 to 0.55 (mean=0.47) than forests, which ranged from 0.36 to 0.65 (mean=0.5) ($F_{2,193}$=19.06, $p<0.001$).

Overall forest cover across the two districts declined rapidly to only 45% of the 1973 cover remaining by 2010. Forest loss was accompanied by expansion of agricultural lands and settlements (238%), and coffee farms (280%) compared to their corresponding size in 1973. Consequently, the landscape changed from forest-dominated (73% forests) to non-forest dominated (32% forests) during the last four decades (Table 4). Annual deforestation rates were mainly the highest (P=3.0%) between 1973 and 1995, and from 1995 to 2001 (P=2.5%). The major land-use changes also included 30% reduction of the grazing lands; and 282% expansion of agriculture and settlement areas.

Mean deforestation rate in Yeki (P= 2.1%) over the last 40 years was higher than in Decha (P =1.1%). Only 48.7% of Yeki forests that existed in 1973 remained by 2010 compared to 71.7% in Decha (Figure 2). Yeki landscapes have been modified from forest dominated (66% forests) to non-forest dominated (32% forests). The highest annual deforestation in Yeki was between 1973 and 1987 (5.4%); and highest annual expansion in cultivated farms and settlement areas in this district occurred between 1987 and 1995. Changes in croplands were accompanied by the expansion of coffee farms between 1973 and 1987, and between 2001 and 2010. The overall forest dominance by cover in Decha landscape decreased from 55% to 39% from 1973 to 2010. Rates of deforestation in Decha were the highest (1.9%) with high annual forest loss rates while the largest annual expansion of non-forested areas occurred between 1995 and 2001 (Table 4).

In addition to decline in forest cover, deforestation resulted in increased forest fragmentation. Fragmentation increased the number of patches, patch isolation, and landscape division. But it decreased patch size, cohesion and core area, and the percentage of forest area contained in the largest patch (Table 5). Total core area of the forest fragments have largely decreased between 1973 and 2010, to about 30% of the 1973 size in both regions. The patch size of forests in Yeki and Decha showed the highest declines between 1973 and 1987 to respective 10% and 13% compared to the mean values of 1973 fragments. Between 1973 and 2010, fragmentation diminished mean patch size of forests in Yeki and Decha by 84% and 81%, and total forest core area by 68% and 61% respectively. Fragmentation of Yeki was greater than Decha region based on overall indices (χ^2_6=13.7, p=0.03). Many smaller patches have been lost between 2001 and 2010 along with a substantial decrease in the number of patches in both regions (Table 5).

3.2 Effects of topography, roads and population on deforestation patterns

Forest remnants occurred at elevations ranging from 826 m to 2531 m (Table 6). However, forests were dominant (74%) at higher elevations between 1500 and 2000 m which comprised 50% of the total area of the landscape (Tables 6). Larger fragments were common with increase in elevation (r^2 =0.04, p=0.047). Elevation affected patterns of deforestation in both Yeki (172.6, df = 3, p <0.001) and Decha districts (χ^2_3= 9.3, p=0.026). Patterns of deforestation were also affected by slope in both Yeki (χ^2_3=24.1, p<0.001) and Decha (χ^2_3=109, p<0.001). Generally, forests in Decha occurred on more steep slopes and a wider range of slopes (mean $14^o \pm 6^o$, range 0^o to 48^o) than in Yeki (mean $6^o \pm 5^o$, range 0^o to 40^o). Finally, percentage of forest cover increased from 17.5 % around 1 km to 30% around 5 km away from roads (Table 7). Hence roads had significant effects on deforestation rates (χ^2=4.4, p=0.04). **Yeki had more roads 143 m/km^2 than Decha and its surrounds 74 m/km^2.**

Population density estimates of Yeki was generally higher (223 persons/km^2) than Decha and its surrounds (79 persons/km^2). The 2010 estimates were lower around forests in Yeki than around non-forested areas (Figure 3). In Yeki, regions where forests remained between 1990 and 2010 showed less increase in population density (90 persons km^{-2}) than did non-forested areas (settlement, croplands and coffee farms) which had higher population density. In contrast, population density in Decha was higher in forested regions than in non-forested areas between 1990 and 2010. The relative differences between non-forested and forested population density in Yeki and Decha were significant between 1990 and 2010 ($\chi^2=5.4$, $p=0.02$).

In addition to spatial differences in deforestation rates between the two districts, there were also distinct patterns through time – accelerations and slowdowns in forest loss rates. There was significant association of the onset of resettlement policies with accelerating in forest cover loss rates in Yeki district compared to areas that experienced low resettlement in Decha (Wilcoxon non-parametric test, $\chi^2=16.3$, $p<0.001$). Onset of forest protection efforts was associated with reduced deforestation rates in Decha districts relative to the same time period in Yeki district, which experienced low onset of forest protection efforts between 2000 and 2010 (Wilcoxon non-parametric test, $\chi^2=10.1$, $p<0.001$) (Figure5).

3.3 Local perceptions on deforestation drivers and socio-ecological feedbacks

The majority (95%) of interviewed households reported decreased forests and grazing lands, and increased coffee farms and plantations (Figure4). A few respondents (5%) described increase in forests and grazing lands. Over 89% of households described a significant decrease or absence of fallowing between 1980s and 1990s, which was attributed to rapid land-use conversion and shortage of farmland with the growing population. This trend overlapped with the period when intensive production and oxen plowing became more common. Respondents reported that the largest expansion of cultivated fields and settlements occurred after the (1) 1974 land-tenure changes, (2) 1984/5 major resettlement that followed rapid agricultural expansion, and (3) 1991 regime changes that followed local land grab, and land redistribution along with large-scale agricultural investment and intensification.

About 2 % of households interviewed reported that they grow tea (mean landholding = 0.05 ha). In contrast, 87% of the households reported that they grow coffee. At the household level, over 55 % of the changes (increase or decrease) in the size or number of coffee growers interviewed were attributed to proximate (physical drivers, conversions from forests and crop fields to coffee, conversion of coffee to other croplands) while 18% to changes market drivers, and 26% to external demographic and policy drivers (Table 8). According to local informants, *Eucalyptus* plantations grew mainly during the last 10 years; and 57 % of respondents reported that they have an average of 0.1 ha of *Eucalyptus*, an equivalent of 350 individuals planted per household over the last 10 years. Overall, about 90% of all households surveyed indicated that they had one or more of the three types of plantations (tea, coffee, or *Eucalyptus*) on their land.

Focus group discussions from the 10 villages reported 16 proximate and underlying drivers of deforestation that were not mutually exclusive categories (Table

8). The most reported drivers in Yeki were agricultural expansion (100%, all households interviewed), population growth (100%), formal resettlement (85.7%), coffee expansion (85.7%), and villagization (85.7%). Agricultural expansion (100%); land-tenure changes (100%); charcoal and fuel-wood harvesting (100%); population growth, investment/plantations, formal resettlement (each 75%) were the most reported drivers in Decha region (Table 9). Grazing, climate change, conflict and ineffective conservation policies that did not fully involve local communities were also drivers reported by local people.

4. Discussion

Landscape changes in southwest Ethiopia, a region that supports high biodiversity and ecosystem services (Wiersum 2010; Getachew 2013) have been rapid during the last four decades with the expansion of agricultural areas including coffee farms, tea and *Eucalyptus* plantations, and small-scale cultivated lands. These deforestation patterns detected by the remote-sensing findings were generally congruent with the more elaborated information generated from local people who reported rapid socio-ecological dynamics as a result of complex proximate and underlying drivers. Deforestation rates showed significant spatial and temporal variability mainly due to broader socioeconomic and policy changes over time that interacted with varying socio-cultural and land-use practices. I found strong observed differences between the two districts in terms of forest loss rates, in the patterns of human-forest interactions that influenced deforestation rates, and in the informant reported deforestation drivers. A salient socio-cultural difference between the two districts emerged in the contrasting relationships between population density and forest loss rates, with forests actually better conserved in the highly populated areas where traditional forest-based livelihoods are dominant. In both districts, deforestation patterns were also correlated with biophysical features such as elevational and slope gradients, and socio-economic features including roads and settlement patterns.

4.1 Regional variations in deforestation rates and patterns

Our results show that landscape changes in Decha and Yeki districts varied in the extent and timing of maximum deforestation rates and associated drivers. The highest deforestation rate in Yeki district occurred between 1973 and 1987 which overlapped with land-tenure changes (1974) and major resettlement scheme following the 1984 Ethiopian famine. Resettlement significantly increased the rates of deforestation in Yeki as a result of high demographic pressure from resettlement, investment and competition for land resources. This underscores the need for careful planning on future resettlement schemes to minimize impacts of resettlement on forests, and on ecosystem functions and services in the region.

Additionally, deforestation was relatively lower in Decha due to better forest protection from indigenous forest-based livelihoods and recent Participatory Forest Management schemes. Participatory forest management and conservation practices in 2000s (Winberg 2010) contributed to the recent deceleration in deforestation rates of

Decha whereas in Yeki where participatory conservation programs are not active, forest rates were higher. This entails that the involvement of local communities in conservation of forest biodiversity can be effective if we promote the benefits forests provide to local people (. Participatory forest conservation has been widely and effectively used in Africa and is viewed as an effective tool in sustaining forests (Lakuma 2000) although Polansky (2003) explained that such programs did not effectively address deforestation and rural poverty. Yemiru *et al*. (2010) also found that forest income under participatory forest management programs reduced poverty and become safety nets during income crises of rural households in the Bale Highlands of south Ethiopia.

Although national policies that influence deforestation rates could generally be the same, local demographic and socio-cultural conditions influencing the land-cover dynamics can vary. The two districts varied in terms of demographic, socio-cultural and livelihood practices. Most people in Yeki depend on cultivated lands and managed coffee farms with some forest-based traditional livelihoods. But, Decha is dominated by traditional livelihoods such as forest apiculture, and the collection of spices and wild coffee. This high forest dependency (forest-based livelihoods) (see Byron & Michael 1999) might generally have contributed to rather relatively non-destructive interactions between forests and people in the region.

The variable impact of population growth on forest cover between the two districts shows the lack of consistent relationships between population density and deforestation patterns (Meyer & Turner 1992). Our results showed that forests have been maintained in some areas regardless of population growth due to traditional forest-based livelihoods. Forests and people co-occurred strongly in Decha, whereas in Yeki, where there are more people, fewer forests remained which was the pattern over time what we might expect nowadays where forest loss rates have been higher in areas where more people lived. This implies that in Decha, people are relatively actively conserving forests likely because of the dominance of forest-based livelihoods there partly through increasing intensification of the existing farmland that reduced further forest conversion.

Hence, traditional forest-based livelihoods maintained forest cover in Decha which questions the neo-Malthusian views about the feedback loops between population growth and environmental degradation (Perrings 2000; Scherr 2000) or deforestation. Our findings underpin that deforestation in the region is primarily a political and socio-economic outcome (see Adger *et al*. 2001) than the result of local-scale population pressure or poverty-driven environmental degradation contrary to the neo-Malthusian views that describe antagonist people-forest relationships (Ehrlich & Holdren.1971). Teferi *et al*. (2012) found that population growth in Northern Ethiopia led to intensified cultivation rather than conversion of non-agricultural land into cultivated land. This supports the neo-Boserupian perspectives about the interactions between human population and forest cover which states that population growth can result in positive changes on forest cover due to positive effects of agricultural intensification that reduce deforestation pressure (Leach & Fairhead 2000). But my findings showed that neither the neo-Malthusian nor the neo-Boserupian arguments can be adequate to explain the interactions between population growth and forest cover in southwest Ethiopia but a rather complex interactions among many drivers including population growth determined forest cover dynamics.

Therefore, we should not over-emphasize the old narratives about the negative impact of population growth on forest cover without critically examining the ecological and socio-cultural processes that affect land-use dynamics. Forest protection programs should rather target the underlying policy and socio-economic drivers while promoting mutual people-forest interactions locally. Additionally, sustainable forest management cannot be achieved without increasing access to forests or without involving local people in conservation (Fairhead & Leach 1996; Scherr 2000; Scherr *et al*. 2002).

4.2 Landscape change drivers and socio-ecological feedbacks in southwest Ethiopia

Changes in property rights and land-tenure, institutional dynamics, resettlement, and population growth occurred in agrarian dominated livelihoods of southwest Ethiopia over the last 40 years (Woube 2005; Stellmacher 2007; Rahmato 2009). Chronologically, the four most locally recognized and non-mutually exclusive drivers of deforestation in the region were land-tenure changes, formal resettlement, population growth and agricultural expansion.

Land-tenure changes in the region resulted in tenure insecurity and conflict with customary forest property rights in the past which might have aggravated competition for forest lands. These tenure changes perhaps exacerbated deforestation rates by initially providing usufruct rights to farmers and by further weakening the traditional forest ownership and conservation practices, as observed in some parts of Africa and Latin America (McCann 1997; Tole 2004; Peres & Schneider 2012). Place and Otsuka (2000) also found that high reduction in tree cover and expansion of agricultural land in parts of Malawi which experienced greater changes in traditional tenure systems.

Although some resettlement schemes could have low ecological impacts if they are well-planned, many others could perturb the human-environment interactions that have been in a state of dynamic equilibrium (1) by weakening existing traditional ownership, management and conservation practices, or (2) by increasing rivalry for land resources that led to unsustainable land-use (Woube 2005). Areas with more resettlement in Yeki were more deforested than those with less resettlement in Decha, and this likely reflects the effects of resettlement on high demographic pressure, associated with road infrastructure, and villagization. The negative effects of resettlement on woody vegetation cover in southwest Ethiopia was also observed by Elliott *et al*. (2006) in Zimbabwe where resettlement generally decreased woody vegetation cover.

Like land-tenure changes, resettlement could also cause conflict and environmental degradation (Woube 2005) aggravated by rivalry for land resources.

For example, conflict (2001/2 in Yeki) (Vaughan 2003), and competition for resources between different appropriators (settlers, investors and indigenous people) could have exacerbated forest degradation like some areas in Ghibe Valley and other areas in Ethiopia (Wood 1993; Reid *et al*. 2000). Some argue that land rents can increase with more settlers coming to an area, forcing native people to sell their land and to clear more forests (Peres & Schneider 2012) which was also observed in Yeki district.

While formal settlers might have contributed to deforestation through agricultural expansion, some temporary contract workers in state and individual coffee farms illegally settle after their contract is over, and also caused deforestation through fuel-wood and charcoal harvesting or by clearing forests for small-scale agriculture (Yeshitila 2008; TCPE 2010; Getachew 2013).

Most of the focus groups and households recalled and perceived landscape changes as the result of local responses induced by broader changes in political economy that has been coupled with demographic and socio-cultural changes over time. Local people emphasized the negative effects population growth had on forest cover, more commonly in Yeki than in Decha. The major driver commonly reported in both districts was agricultural expansion which may have resulted with other underlying drivers including population growth and agricultural policy changes. People in Yeki district described reduced forest cover as an outcome of coffee agroforest expansion, resettlement and population growth which was also detected by the satellite data analysis; whereas in Decha land-tenure changes, charcoal and fuel wood selling were also reported important.

The perception of local people on land-use changes was a cumulative experience that resulted from day-to-day interactions with their farms for production, and with their forests for ecosystem services (Getachew 2013). These interactions have been considerably influenced by the effects of regional and national drivers that affect local land-use decisions. Thus, we argue that proximate drivers are not driving land-use changes alone, but are strongly shaped by the larger-scale changes in the national and regional drivers during the last 40 years of land-use history in the region.

4.3 Effects of topography and roads on deforestation patterns

Socioeconomic and demographic drivers interacted with topography and elevation that consistently influenced deforestation patterns. Many forest fragments in the study region occurred at higher elevations from 1500 to 2000 m, where 75% of the total forest cover in the landscape was found, and that mostly occurred in hill-slopes often unsuitable for cultivation. If forest loss spreads to higher elevations where higher species endemism is found (see Hall *et al*. 2009), it will have detrimental effect to the already threatened biodiversity (Birdlife International 2012). Forest cover declines with increase in development of a region (Mather 1992; Grossman & Krueger 1995; Jha & Bawa 2005) and with expansion of infrastructure including roads and settlement. Roads are permanent landscape injuries (Freitas *et al.* 2010) that facilitate deforestation, fragmentation, and biodiversity loss by providing access to human disturbance, logging, over-exploitation, and markets (Laurance *et al*. 2002). They can also increase population pressure and the spread of exotic species (Trombulak & Frissell 2000) where we observed invasive species more commonly around roads in southwestern Ethiopia. The construction and expansion of roads in the region during the 1980s was correlated with high deforestation rates and fragmentation during the same period. Relative forest cover in the study landscape increased away from major roads since the abovementioned effects of roads on forest cover decrease away from roads. With the expansion of more roads in the region, deforestation will affect smaller forest remnants found at lower elevations and even those larger remnants occurring at higher elevations.

Deforestation patterns along elevational and slope gradients also varied between the two districts. Elevation has more significant effect on deforestation patterns in Yeki than in Decha. Most of the remnant fragments in Yeki district were pushed further to higher elevations that are scarcely populated with indigenous people who depend on livestock production, non-timber forest products and small-scale cultivation. This implies that low elevation forests with gentle slopes are more susceptible for deforestation and landscape modification since they are suitable for development and agriculture. In contrast, forest fragments in Decha were scattered at mid to higher elevations and did not concentrate at specific elevation ranges probably because many forest patches were not completely destroyed by human activity in this district.

4.4 Consequences of deforestation and land-use changes in southwest Ethiopia

The impacts of human activities during the last 40 years in the region have resulted in massive deforestation and fragmentation where ~70% of the forest vegetation in southwest Ethiopia is considered highly disturbed (EPA 2003). The substantial forest loss in the region is also linked to high fragmentation, a typical pattern in tropical deforestation (Laurance 1999). Most of the forest fragments in the region are increasingly disturbed for the production of coffee and other crops. Even if the loss of these forests can be reduced with continuing deforestation and fragmentation, the structure of these forests within the remnants will change with a decline in tree canopy cover below the minimum threshold cover (10% high canopy trees) that can support forest biodiversity (FAO 2008). While deforestation and forest fragmentation are significant at large spatial scales (Morris 2010), selective logging and grazing are important human disturbances, in terms of conservation, at small spatial scales.

In the past, people in the region perhaps interacted with forests at a level where both co-existed without substantial forest loss or without clear boundary between forests and managed landscapes. Forests in human-dominated landscapes, including those in southwest Ethiopia, have long been used by humans in diverse ways including agroforestry, hunting and gathering, non-timber forest products, and small-scale agriculture (Pfund *et al*. 2011). However, remnant patches have been recently subjected to enormous pressure from logging, extraction of lianas, disturbance, grazing, fire, and roads that increased forest loss and fragmentation in the region. We are not only losing these forest fragments but also the associated biodiversity that is already threatened, and ecosystem services that support the livelihoods of most communities who intensely depend on these forests (Gole 2003; Senbeta & Denich 2006; Weirsum 2010; Getachew 2013).

These drivers had synergistic and complex interactions resulting in cultural transformations and socio-economic changes in the region. In addition to direct forest loss, such changes have brought perturbations to traditional livelihoods and forest management practices including the *Guddo* and *Kobbo* forest conservation systems (Getachew 2013).

The rapid land-use changes and deforestation in southwest Ethiopia caused a substantial loss of diverse Afromontane forest remnants that support high biodiversity and ecosystem services (Senbeta & Denich 2006; Getachew 2013). Unlike Afromontane forests of the Bale Mountains in south Ethiopia, which remained relatively stable between 1973 and 2008 (Kidane *et al*. 2012), forest cover in southwest Ethiopia notably decreased. Deforestation trends in our study was consistent with other estimates for natural high forests of Ethiopia from 1973 to 1990 (Reusing 2000), central Rift Valley woodland vegetation (1973–2006) (Garedew *et al*. 2009), and dry Afromontane vegetation in other regions of Ethiopia (Tekle & Hedlund 2000; Zeleke & Hurni 2001). Generally, deforestation rates in the study region are much higher than annual deforestation rates in humid-tropical forests of Africa (0.43%) (Achard 2002). Ethiopia is one of the 29 countries which lost > 90% of its original forest cover (MEA 2005), and with current trends, it will soon become one of the 25 countries without forest cover (MEA 2005). This risks causing ‘a down-ward spiral’ of poverty and land degradation that resulted from the loss of forests, biodiversity and ecosystem services (MEA 2005).

In addition to forest cover losses, land-cover changes that were not necessarily detected based on satellite data such as forest disturbance or the conversion from one land-use type to another, and agricultural intensification are also significant to conservation (Foley *et al*. 2005). Certain land-use trajectories such as the conversion of forests to traditional smallholder coffee agroforests can buffer some of the effects of deforestation and forest degradation (Perfecto *et al*. 1996; Getachew 2013), though others including the recent agricultural intensification or large-scale agricultural investment can aggravate deforestation (Morton *et al*. 2008).

Promotion of cereal-based production following Agricultural Development-led Industrialization Policy after 1990s provided extension and credit programs that increased intensive farming practices and farmland expansion (MoARD 2010; Gebreselassie 2006). On top of the expansion of state farms, liberalization policies after 1990s encouraged small and medium-scale agricultural investment that contributed to deforestation in the region.

Although local people respond to increased deforestation by maintaining coffee agroforestry and exotic species plantations in some areas, they are also substituting indigenous forests with production forests and agroforests that shift the composition of native species (Getachew 2013). Many forest fragments have already been converted in to coffee, tea and eucalyptus plantations in both regions and more forest fragments are still being leased to investors for tea and coffee plantations.

Additionally, expansions of small-scale *Eucalyptus* plantations became significant drivers of forest loss. In some places, people reported that *Eucalyptus* expansion occurred in areas where the abundance of native trees and forests declined. Recently, over 2455 hectares of land have been leased for investors working on coffee and spices in Yeki district (TCPE, 2010); mostly forest land (~10,000 ha) in surrounding Godarie district have been recently leased for tea plantations (MoARD 2012). Large-scale investments on coffee and tea plantations of 17,100 ha were established (TCPE 2010) with a rapid expansion of tea (2,580 ha) and *Eucalyptus* (1,300 ha) plantations after 1980s (SUPAK-s 2010). Recently, the national government of Ethiopia leased at least 435,287 ha of land for large-scale in various regions (Ministry of Agriculture of Ethiopia, MoARD 2010) for monoculture production. Farmers prefer *Eucalyptus* and other fast-growing exotics for fuel wood, shade-coffee, house construction and timber sales (Getachew 2013). These are socio-ecological feedbacks to the loss of forests and forest resources in the region.

Other than agricultural expansion, local drivers such as logging, firewood and charcoal production have been significant drivers of deforestation and overexploitation of woody species. About 89% and 85% of total households in Yeki and Decha use firewood for domestic fuel (CSA 2008). Fuel-wood/charcoal production continues to be a significant driver of deforestation since more (1) woody biomass will continue to be consumed due to inefficient energy use within the villages, (2) fuel-wood demand and sales occurs with growing populations in expanding adjacent towns, and (3) fuel-wood/charcoal is transported and sold to neighboring regions and major cities as road access, markets and fuel demand grow.

The expansion of towns increased the demand for domestic energy fuel-wood and charcoal selling. Villagization programs in some areas of Yeki district increased pressure on forest resources and were observed to intensify land-use around the villages. Growing market demand, change in people's attitude towards selling firewood and economic problems of marginalized minorities increased dependence of many households on fuel-wood and charcoal selling (Zewdie Jotte 2005). Finally, we should also be concerned about other threats to the indigenous Afromontane forests in the region including climate change (Davis *et al*. 2012) and forest fires (Wesche *et al*. 2000). Our priority should not only be conserving forests and biodiversity but also the livelihood contribution of these forests equitably.

Conclusion

Overall, the study region in southwest Ethiopia has lost more than half of its remaining forests over the last 40 years mainly due to underlying demographic and policy factors that triggered land-insecurity and that influenced socio-economic decisions locally. Deforestation rates varied spatially and temporally since the drivers of forest loss varied between the two districts, and across historical periods. Deforestation rates in regions where demographic pressure from resettlement and investment occurred were two-times faster than rates in areas where indigenous people who mainly rely on forest-based livelihoods were dominant. Spatial variation in deforestation rates were due to demographic and cultural differences that influenced the interactions between people and forests through their land-use practices. Temporally, forest loss rates over the 40-year period appear to reflect the impacts of key policy changes, mainly land-tenure, resettlement and forest conservation programs.

Although settlers are not necessarily environmentally destructive, improper resettlement schemes that do not integrate local environmental conditions with socio-economic and cultural conditions of both settlers and indigenous people would detriment the sustainability of settled landscapes. Future resettlement schemes in such regions should therefore effectively integrate ecological conditions with economic and socio-cultural goals. Recent forest conservation programs such as Participatory Forest Management programs and designation of National Forest Priority Areas, and UNESCO's biosphere reserves can play vital role in reducing deforestation and forest degradation in the region.

Efforts to prevent deforestation and to plan for sustainable land management in such regions should integrate biophysical and socio-economic conditions of both settlers and indigenous people in the landscape. More deforestation and degradation continued in areas partly where traditional forest management regimes have been disrupted and where local participation in conservation has been low. These forests can be protected by intervening on the (significant) underlying market and policy drivers that affect local deforestation patterns, by restoring customary forest ownership and management regimes, and by increasing local participation in conservation. In order to reduce the ongoing forest loss and coffee intensification and conversion, we suggest the promotion of forest-based ecosystem services that directly benefit local people (e.g. wild/semi-wild coffee, spices and honey), and promote payment for environmental services (e.g. biodiversity/bird friendly coffee, forest coffee), and the use of Reducing Emissions from Deforestation and Forest Degradation (REDD+).

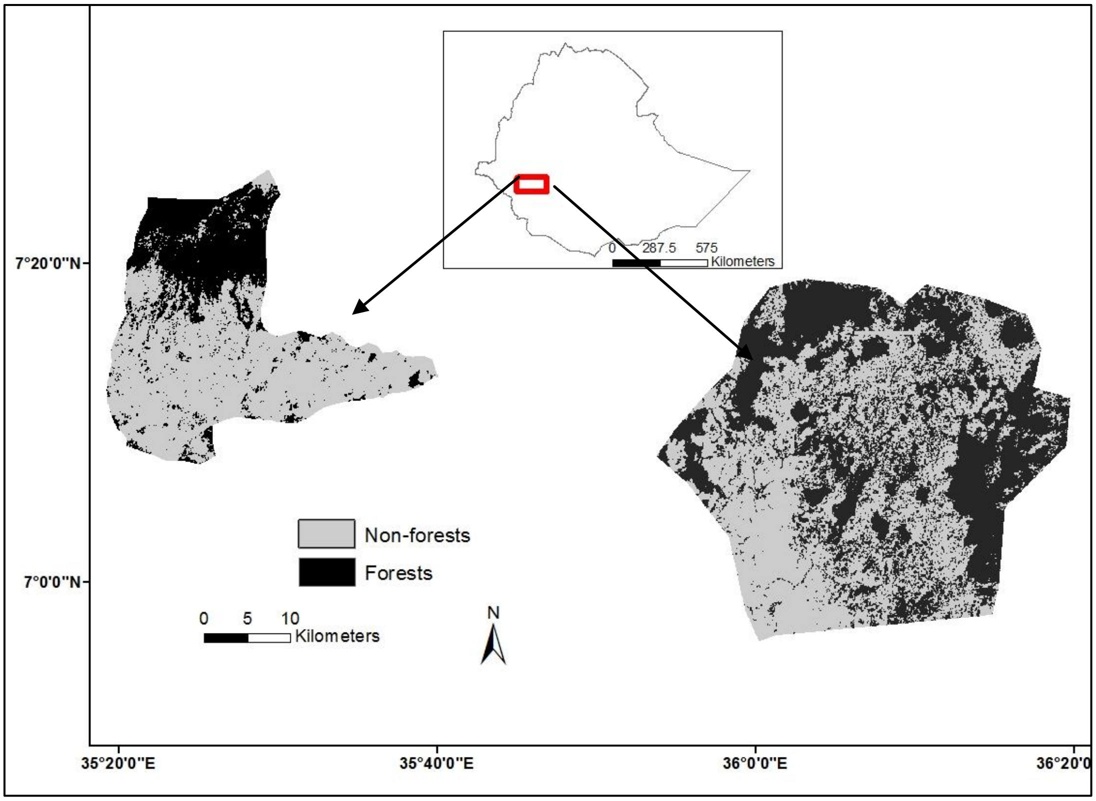

Figure 1. Map of the study area includes Yeki (left) and Decha (right) districts from 2010 LANDSAT images

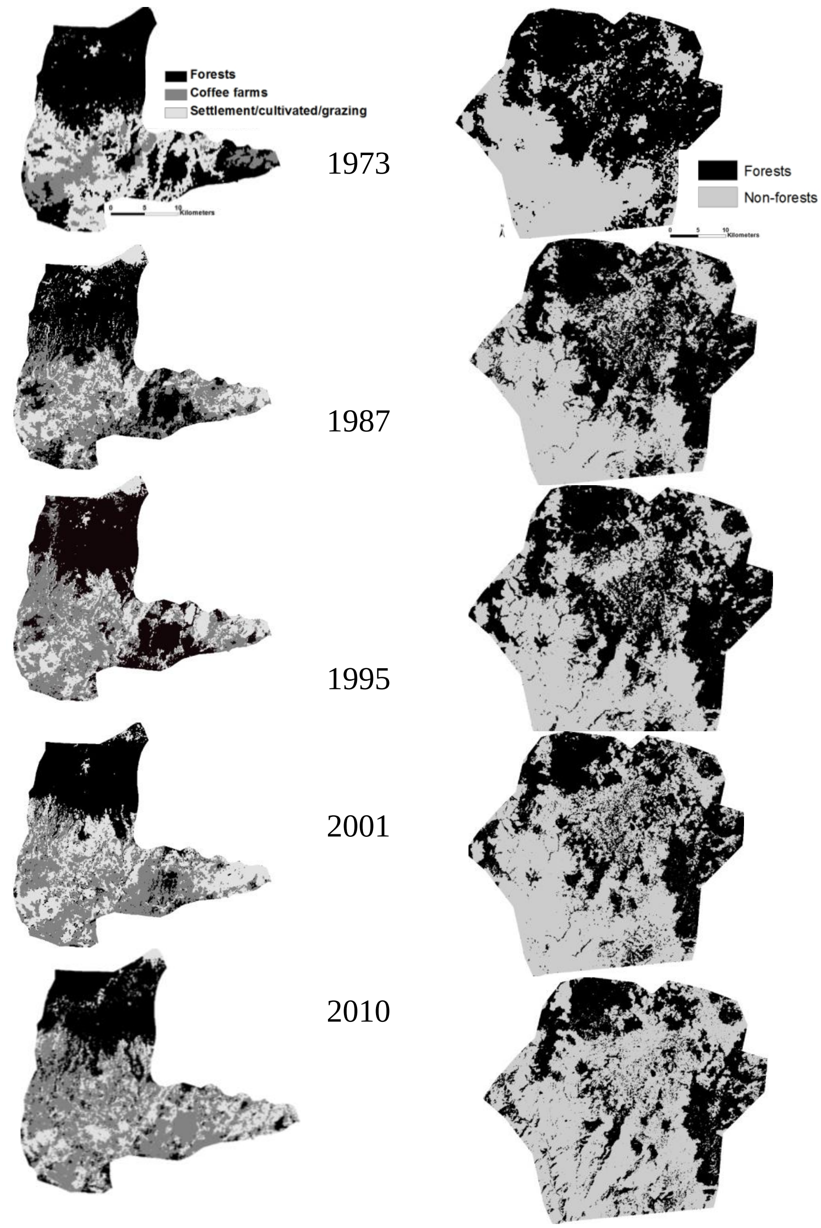

Figure 2. Forest cover change detection maps of Yeki district (left column) and Decha region (right column) from 1973 to 2010.

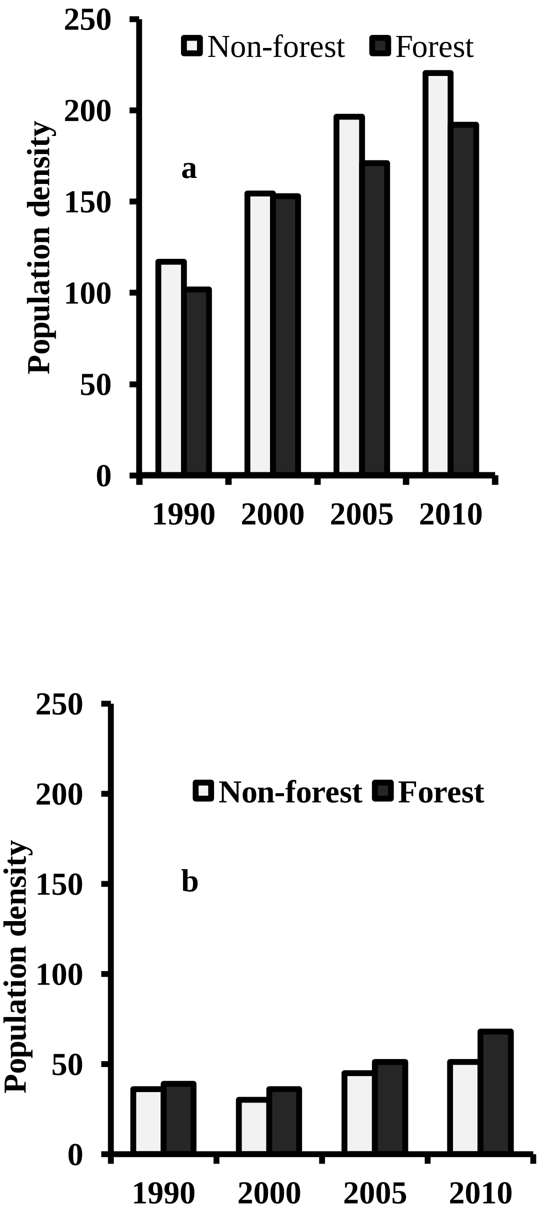

Figure 3. Population density of Yeki (a) and Decha (b) of forested and non-forested areas from 1990 to 2010.

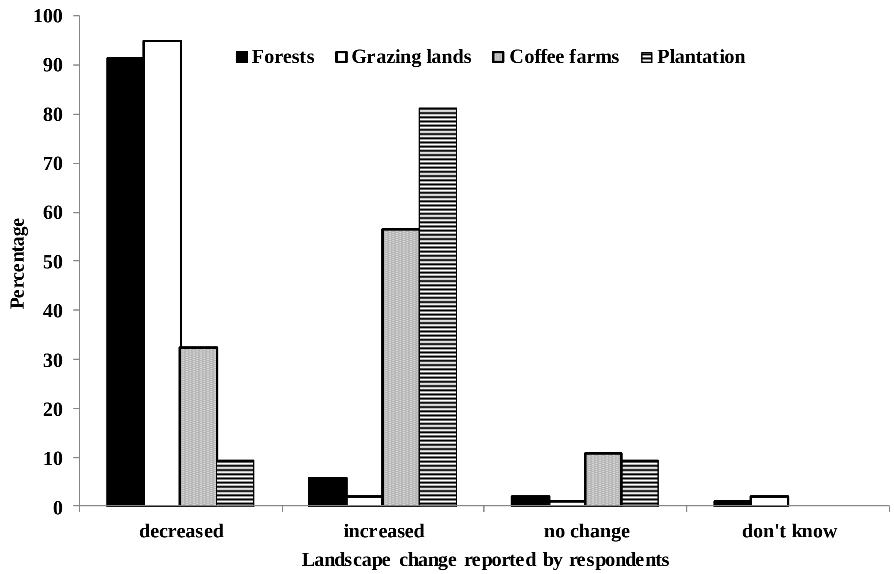

Figure4. Changes in major land-use units based on interviews about local perceptions (plantation refers mainly to *Eucalyptus*).

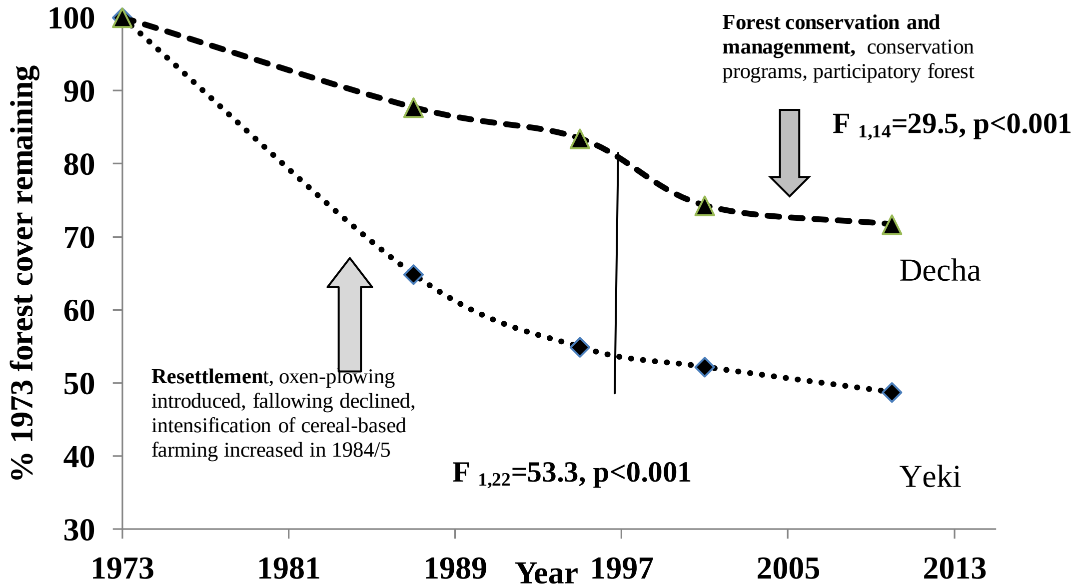

Figure 5. Deforestation trends in two Yeki and Decha districts in the study area based on interpolated slopes between observed dates. BACI analysis shows temporal trends are consistent with the hypotheses that resettlement in Yeki (1984/5) and forest protection (2005) in Decha influenced forest loss rate relative to the district that did not experience each policy.

Table 1. Socio-ecological dynamics of the region (1973 - 2010) based on local information and literature survey

Year	Trends and events	Source
1970s	Major land redistribution (1974), majority of households given entitlements to cultivated lands	Rahmato 2009
1980s	Large-scale resettlement (1984/5), increase in oxen plowing, decrease in fallowing, missionaries and introduction of exotic species and fruits, large state farms (1987), coffee, tea and Eucalyptus plantations (1980-1989)	Woube 2005 TCPE 2010
1990s	Promotion of cereal based production, extension and credit programs, agricultural investment policy, Ethiopian Forestry Action Plan (1994)	MoARD 2010
2000s	Market-based agricultural investment, large-scale agricultural expansion, Participatory Forest Management, designation of National Forest Priority Areas (NFPA), UNESCO Biosphere Reserve	Ministry of Agriculture 2010

Table 2. Spatial characteristics of satellite images used for land-cover classification and change detection (all data were WGS 84), CC= Cloud Cover, s.m.= spatial resolution in meters)

Image ID	Area	CC	Date	Band	s.m.	Sensor
P183R055	Yeki area	0	2/2/73	3,2,1	60	MSS
P182R055	Decha area	0	2/2/73	3,2,1	60	MSS
P170R055	Yeki , Decha	0	22/1/87	5,4,3	30	TM
LT5170055	Yeki, Decha	5	17/3/95	5,4,3	30	TM
LE7170055	Yeki, Decha	0	5/2/01	5,4,3	30	TM
LE7170055	Yeki, Decha	6	3/1/10	5,4,3	30	ETM+

Table 3. Fragmentation indices used in this study

Indices	Description
Forest area	Total forest area in hectares
Number of patches	Number of isolated patches in the landscape
Largest patch index	% of forest area occupied by the largest patch
Patch cohesion	Measure of the physical connectedness of forest patches
Mean patch size	Average area of patches
Total core area	Sum of the total surface of all areas of a particular land-use class (ha)

Table 4. Landscape and forest cover changes in the overall study region, and Yeki and Decha regions (1973-2010), 1973 image was used as reference data

LULC (ha)	Year				
1. Overall	1973	1987	1995	2001	2010
Forests	136640	100178	75164	64675	61176
Coffee farms/ agroforests	19208	51425	67145	51524	53871
Grazing	8493	10118	5770	10662	6429
Roads/cultivated/settlement	22478	28334	39663	61030	63521
Others	4969	1733	5125	3753	4025
% forests in the landscape	71.3	52.3	39.4	33.8	32
Annual rate forests loss (ha)		2604	3126	1748	389
1973 forest cover remaining (%)		73.3	55	47.3	44.5
Annual rate of deforestation (ha)		186	391	291	43
Annual % forest loss *(P)*		2.2	3.5	2.5	0.6
2. LULC in Yeki district					
Forests (ha)	40981	26579	22504	21392	19973
Cultivated/settlement (ha)	11012	13399	19621	19387	18531
Coffee farms/agroforests (ha)	9769	21784	19638	20984	23259
% 1973 forest remaining		64.9	54.9	52.2	48.7
Annual forest loss (ha)		1029	509	185	158
Annual % forest loss (*P*)		5.4	1.2	0.9	0.8
3. LULC in Decha					
Forests (ha)	76491	67079	63817	56809	54834
Non-forests (ha)	62668	72080	75342	82350	84325
% 1973 forest remaining		87.7	83.4	74.3	71.7
Annual forest loss (ha)		672	408	1168	219
Annual % forest loss (*P*)		1.6	0.4	1.9	0.4
Accuracy assessment (%)	78.5	83.3	74.2	83	80

Table 5. Forest fragmentation patterns from 1973 to 2010. Largest patch index is the proportion of forest cover contained within the largest patch.

Over all Indices	1973	1987	1995	2001	2010
Total forest area (ha)	136640	100178	75164	64675	61176
Number of patches (N)	446	1895	3299	3335	2807
Largest patch index	40	22	6	11	7
Mean patch size (ha)	301	52	34	19	22
Yeki Patch indices					
Total forest area (ha)	40473	26580	25986	21392	19863
Number of patches (N)	142	882	967	2467	1422
Largest patch index	36.5	30.1	28.7	28.4	26
Mean patch size (ha)	285	30.1	26.9	8.7	16.4
Total core area (ha)	18813	4834	10079	11184	6099
Decha indices					
Total forest area (ha)	76491	67080	64808	50131	54834

Over all Indices	1973	1987	1995	2001	2010
Number of patches (N)	125	856	1632	5864	2815
Largest patch index	51.3	41.9	28.5	10.6	12.3
Mean patch size (ha)	612	78	92	27	19
Total core area (ha)	34058	17250	9728	7319	13393

Table 6. Change in forest covers between 1973 and 2010 in Yeki and Decha districts across elevational gradients

Elevation range	Forest % area Yeki	% 1973 remaining	Forest % area Decha	% 1973 remaining
500-1000	0.1	45	6.4	43
1001-1500	62.8	52	25.1	83
1500-2000	15.5	467	50.8	73
2001-2593	21.6	42	17.7	50
Overall	100	48.3	100	71.3

Table 7. Relative dominance of forests and cultivated lands with varying distance from roads

Dominance (%) in the total landscape	Buffer distance from roads			Overall
	1 km	3 km	5 km	
Forests	17.7	27.5	30	32.5
Cultivated/settlements/grazing	51.6	43	45.5	33.4
Coffee farms	30.7	29.5	24.5	28.5

Table 8. Reported major drivers for changes in coffee farms at the household level with their increasing (I) and decreasing (D) effects on the area of coffee farms owned by the surveyed households.

Drivers for changes in coffee farms	Effect	Percentage
Proximate physical drivers		
Conversion from forests	I	30
Conversion from crop fields	I	18
Conversion to other crops	D	4
Expansion to fruit trees	D	4
Economic drivers		
Decreased productivity	D	3
Economic incentives	I	4

Sold to other farmers	D	3
Purchased more coffee land	I	2
More production needs	I	4
Underlying drivers		
Population growth	D	22
Villagization and settlement	D	4
Land redistribution policy	D	1
Protected forest designation	I	1

Table 9. Percentage distribution of deforestation drivers based on the percentage of focus group participants in 11 villages in each district.

Drivers	% reported Yeki	% reported Decha
Grazing	14.3	25
Climate change	28.6	0
Conflict	42.9	0
Land redistribution	42.9	25
Illegal resettlement	42.9	25
Infrastructure	71.4	25
Logging	71.4	25
Villagization	85.7	0
Agro-forest expansion	85.7	25
Charcoal/fuel-wood	57.1	100
Investment/plantations	64.3	75
Formal resettlement	85.7	25
Land-tenure change	71.4	100
Population growth	100	75
Agricultural expansion	100	100

CHAPTER TWO

Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia

by

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Abstract

Land-use changes are major global threats to both biodiversity and ecosystem services. Some of the last remaining forest fragments in Ethiopia, and the world's only habitats that retain diverse wild Arabica coffee populations, have experienced rapid recent conversion to coffee farms, plantations and agricultural fields. We examined patterns of remnant woody plant diversity in the remaining forests, and assessed the potential and limitations of coffee agroforests to maintain this diversity. I explored (1) the effects of edge, disturbance and fragment size on woody species diversity, size class distribution, and regeneration in remnant forests and (2) patterns of woody biodiversity in nearby smallholder and state-owned shade-coffee farms. We recorded a total of 155 native woody species including rare/threatened species of *Baphia, Cordia, Manilkara, Prunus,* and *Pouteria*. Of these species, 56 (36.2%) and 18 (12%) were restricted to forest fragments and coffee farms, respectively. Smallholder and state-owned coffee farms maintained 59% and 26% of the 155 recorded native woody species compared to the 137 species (88%) found in forest fragments. Within remnant forests, woody biodiversity was higher in fragments that were large or that contained harvestable resources (*Coffea arabica, Piper capense* and *Aframomum corrorima*); and was lower with increased fragment edge, disturbance intensity, and elevation. Native woody species regeneration in state-owned farms was lower than in smallholder farms, which in turn was lower than forest fragments. Our findings indicate that coffee farms could support a substantial portion, though not all, of the woody biodiversity of disappearing forest in this region. Persistence of forest woody diversity and associated ecosystem services depends strongly on the scale and type of shade coffee cultivation pursued.

1. Introduction

As tropical deforestation and fragmentation continue, production landscapes will necessarily play important roles in biodiversity conservation (Bhagwat et al. 2008; Gardner et al. 2009). More than 90% of tropical biodiversity is found in human-modified landscapes, outside protected areas (Chazdon et al. 2009). In particular, agricultural landscapes such as shade coffee agroforestry systems (Moguel and Toledo 1999; Mendez et al. 2007), and home gardens and plantations (Hylander & Nemomissa 2008, 2009) can serve as biodiversity refugia. However, the amount and composition of biodiversity retained in agroecosystems depends strongly on type of agriculture, and management practices (Harvey et al. 2008). Conservation must thus consider carefully the extent and limitations of biodiversity maintenance in production landscapes with particular land-use trajectories.

A review by Baghwat et al. (2008) based on 36 studies that compared agroforestry systems with nearby forests showed that conservation potential of different agroforests varied widely with the taxa in question and the type of agroforest. While tea and oil-palm plantations conserve little native biodiversity, traditional coffee agroforests have potential to do better since it incorporates shade trees in order to retain ecosystem services such as soil fertility, wood and non-wood products. Coffee agroforestry systems can potentially (1) protect biodiversity by providing heterogeneous and critical habitats, (2) buffer against overexploitation of forest biodiversity, and (3) serve as corridors and permeable matrices that connect meta-communities in natural landscapes (Perfecto et al. 1996). Coffee landscapes may have greater conservation potential in hyper-fragmented landscapes with long histories of human use and disturbance since much of the original forest vegetation is lost and modified. While under-studied, coffee landscapes in hyper-fragmented Eastern Afromontane ecosystems of Africa may offer critical conservation opportunities given the ongoing loss of already diminished natural habitats and expansion of production landscapes.

Only 10% remains of the original vegetation in the Eastern Afromontane biodiversity hotspot with 75% endemism in vascular plants, 40% of it found in Ethiopia (White 1981; Burgess et al. 2005; Birdlife International 2012). Within Ethiopia, the large majority of moist Afromontane vegetation and biodiversity occurs in remnant forests in the southwest of the country. Although biophysical and anthropogenic conditions vary, humid Afromontane forests in Ethiopia maintain diverse emergent angiosperms in the overstory; shrubs, herbs, and ferns in the understory; and lianas, epiphytes, and lycopods (Friis et al. 1992). Beyond their high diversity and floristic endemism, these fragments are the only global natural habitats for genetically diverse wild populations of *Arabica* coffee. Finally, most local people depend on these forests for ecosystem services and goods such as coffee, spices, forest honey, fiber, and fodder (Senbeta & Denich 2006).

Ethiopian Afromontane forests are highly fragmented and have been converted to agricultural. The effect of this ongoing loss of woody species is especially serious since they are both crucial habitats for most other organisms and important providers of ecosystem services. Effects of fragmentation and disturbance on the distribution and diversity of woody species in the region is inadequately studied. However, we know that remnant forests in southwest Ethiopia are hyper-fragmented and depauperate (Burgess et al. 2005). Over 50% of the forests present in the early 1970s have been lost due to conversion to working landscapes (Getachew 2013). With only a small and declining fraction of remnant forests left, we urgently need to understand the potential for and limitations of coffee agroforestry systems to maintain native woody diversity and associated ecosystem services.

Arabica coffee is the second most traded global commodity after petroleum and the backbone of the Ethiopian economy. Besides being the birthplace of coffee, Ethiopia is the fifth largest global producer of Arabica coffee (Tepi Coffee Plantation

Enterprise, or TCPE 2010). In Ethiopia and the study region, coffee is produced under native tree canopies in wild (5%), semi-wild (10%) and cultivated systems (85%) (Petit 2007). Smallholder coffee production systems (c. 700,000 ha and 90% of total production in the region), practiced by over 15 million smallholder farmers (Petit 2007), are more prevalent than large-scale, state-run coffee production (c. 21,000 ha, 5% of total production) (FAO, 2000). Smallholder farms range from 0.5 to 3 ha and are found in homegardens, forest margins, and semi-cultivated forests (Getachew 2013).

The biodiversity conservation potential of agroforests depends strongly on management intensity (Jose 2012). Management in Ethiopia's smallholder coffee farms involves both cultivated and semi-cultivated production, with shade tree selection based on both thinning the original understory vegetation and frequent planting of woody species desirable for shade and other purposes (Senbeta & Denich, 2006). Although growth and management of shade coffee trees in smallholder farms vary from one farmer to another, farmers frequently cut or coppice these trees for various purposes including beehive construction, fuel wood, furniture and timber. Conversely, in Ethiopia's state-owned farms, trees established for coffee shade are not necessarily used or removed for other purposes since they are protected by the state enterprise (Eshete, pers. obs.). Besides native shade trees, >10 exotic coffee-shade species are being introduced in both types of coffee farms (Getachew 2013).

Although there has been considerable work on biodiversity in coffee agroforestry in many regions, there has been relatively little examination of the ability of coffee agroforests in southwest Ethiopia to conserve biodiversity. Previous studies focus on agronomic aspects of coffee production (Labouisse et al. 2008), or on diversity and floristic composition of natural coffee forests (Schmitt et al. 2010). However, to our knowledge, there are no comparative ecological studies that measure and compare the diversity and distribution of native woody species on the two prevalent types of managed coffee farms and in adjacent forested landscapes. We studied both state-owned and smallholder coffee farms adjacent to natural forest-fragments to examine the relative roles of each type of coffee farm in maintaining native woody species diversity, floristic structure and regeneration status. I explored the effects of both fragmentation (patch size, edge effect and matrix quality) and anthropogenic disturbance on diversity, size structure and regeneration of woody species in remnant forests and the two distinct types of coffee farm that continue to expand in southwest Ethiopia.

2. Methods

2.1 Study area

To explore species distribution and diversity patterns among coffee farms and forest-fragments, we studied (1) 18 natural forest patches (2) three large government coffee farms and (3) 39 smallholder coffee farms in 2010 and 2011. We sampled areas from within these three land-cover types of comparable biogeographic history and biophysical conditions in two districts of southwest Ethiopia (1) Yeki (618 km^2 area) in the Sheka zone (7.2^o N, 35.3^o E) and (2) Bonga region (2764 km^2 area) in the

Kaffa Zone (36.1^{o} E, 7.1^{o}N) (Figure 1). Rainfall in the region is uni-modal with annual precipitation of >1600 mm and a mean monthly temperature that ranges from 18^{o}C to 23^{o}C (National Meteorological Services Agency, 2008). The two study regions were selected based on the presence of a mosaic of coffee and forest fragments and contrasting land-use changes, with Yeki having higher deforestation rates than Bonga region.

In this region, **forest fragments** are predominantly Afromontane with lowland transitional rainforest vegetation composed of both deciduous and evergreen woody species, lianas and other life forms (Friis et al. 2010). Although hyper-fragmented and under high anthropogenic threats such as conversion to coffee and tea plantations and other cultivated landscapes, these forests maintain diverse flora and fauna.

State-owned coffee farms were established between 1975 and 1988 from various landlord- managed and private coffee farms, nationalized after the 1974 revolution, and some recently converted adjacent forests (TCPE, 2010). The three state coffee farms in this study represent the second-largest government plantation area in Ethiopia (2482 hectares) and also cultivate fruits, spices, and some honey (TCPE, 2010). Although the majority of shade trees on government farms remained protected at least since early 1980s except if lost by fire or wind fall (TCPE 2010), people have been replacing native trees with many native and introduced legumes and shade trees. Management in these farms includes use of machinery (tractors), manual labor for weeding, some use of herbicides and fertilizers, clearing of understory shrubs, and harvesting of coffee and other tree fruits.

Smallholder farms are heterogeneous in terms of land-use and management history, ranging from old farms to more recently converted forest-fragments. These farms are actively managed by individual farmers who remove weeds, tend, transplant, coppice, harvest and replace shade trees for various purposes. The majority of small farms are more recent and less intensified with minimum understory shrub and liana clearing, lower per hectare coffee density than state-owned farms. Fewer than 10% of small farms have below 10% shade cover or more intensified (i.e., less shade tree cover and more coffee density per hectare) and are usually found around homesteads (Getachew 2013).

2.2 Data Collection

To select forest fragments of varying sizes, we made a reconnaissance survey, taking GPS coordinates and mapping different forest remnants and adjacent government and smallholder coffee farms using ArcMap Version 9.3. To quantify woody biodiversity, we sampled 115 400-m^2 plots from 18 forest-fragments of varying size (with a total of 29,794 ha) using transects that run from forest edge to core at 250 m intervals. For larger fragments of >10 ha, we sampled on transects along forest edges (at 300 m from forest fringes) and in forest cores. We also sampled 39 400-m^2 plots, each owned by different smallholder farms distributed across different elevations and adjacencies to forest fragments and state-owned farms. A total of 40 400-m^2 plots were established in the 3 large state-owned farms (2200 ha), with more plots in larger farms, using systematic random sampling to capture variation in elevation, and management histories (newly established, old farms).

In each 400 m^2-plot in all the three land-use types, we measured woody species composition and abundance, canopy cover, and height and DBH for all trees and shrubs > 10 cm diameter. We classified each woody species into four functional groups (trees, small trees with height <15 m, shrubs and lianas). I used one randomly-located 25 m^2-plot nested within each larger plot to census seedlings (< 2 cm DBH) and saplings (2-10 cm DBH) of woody species. DBH for larger individuals (>10 cm) and height were measured using a diameter tape and LTI Laser, respectively. We measured altitude and geographic coordinates for each plot using a Garmin e-Trex H Portable Navigator, slope using a clinometer (Suunto), and canopy cover using convex densiometers. We recorded matrix quality of the major habitat next to each forest fragment on a categorical scale from lowest to highest matrix quality as follows: (1) settlement and/or roads (2) annual crop fields only (3) crop fields and coffee farms (4) coffee farms only and (5) mixed coffee farms and remnant forests. Evidence of disturbance within each 400-m^2 plot and each entire forest fragment was recorded as low, intermediate and high, based on equally weighted observations of the following variables: grazing intensity (high/low/medium), counts of logged tree stumps, and presence or absence of trails. In each forest plot, the abundances of harvestable resources (wild coffee and spices) were recorded.

2.3 Data analyses

Since sample size varied across forest patches, I used both individual and species-based rarefaction using EstimateS 8.2.0 (Colwell et al. 2012) and R-vegan (Oksanen, 2011) to estimate species richness in each fragment. We measured

Shannon diversity (H') and relative abundance (evenness J') of species using the Shannon index, compared floristic similarity among samples using Jaccard's index (J), and calculated beta-diversity (β) among forest-fragments based Sørensen dissimilarity index (Magurran 1988) in R-Vegan. In order to examine the effect of isolation on species dissimilarity between fragments, we correlated β of each pair of fragments with the pair-wise distance between the fragments. In order to explore the effects of environmental (slope and elevation gradients, patch size) and anthropogenic factors (disturbance, matrix quality, edge effects, frequency of harvestable resources) on species diversity in the forest-fragments, we constructed a multivariate linear model with forward stepwise regression in R-vegan (Oksanen 2011). For this analysis we defined edge forests as <300 m from forest patch boundaries and cores as >300 m from this boundaries.

I used one-way ANOVA and Tukey's post-hoc tests to compare species richness, evenness, functional group composition, DBH, height, canopy cover and stem density (individuals ha^{-1}) across land-cover types and across disturbance levels within the forest fragments; and to compare species richness between fragments with and without harvestable resources T-tests and chi-squares were used to examine differences in DBH (cm), height (m), basal area (m^2ha^{-1}), and canopy cover (m^2ha^{-1}) between the edge and core samples in larger fragments (n=15). To estimate woody species importance in each land-use type, importance value index (IVI) was also calculated following Curtis and McIntosh (1951). Pearson's coefficient was used to correlate species richness with stem density and canopy cover in coffee farms.

Finally, we examined floristic nestedness across forest fragments to ask whether progressive declines in species richness involved consistent losses of particular species. To measure nestedness, I used a metric based on paired overlap and decreasing fill (NODF) that corrects for matrix fill and matrix dimensions and that is less sensitive to matrix size and shape, and matrix temperature (NT) (Almeida-Neto et al. 2008). I analyzed matrices of 137 species X 18 forest-fragments (115 plots total).

3. Results

3.1 Overall species diversity

Across all 195 400-m^2 plots in all three land-use types, we recorded 155 native woody species belonging to 74 families, dominated by Moraceae (9.5%), Rubiaceae (8.7%), Euphorbiaceae (8.2%) and Fabaceae (5.2%). Most of these species were trees (59.4%) and shrubs (32.9 %) with 8.4% liana species (Figure 2). Evergreen species comprised 66%, with the remaining 34% deciduous. Of the 155 species, 88% (137 spp) occurred in forest-fragments of which large-scale and smallholder coffee farms contained 26% (40 spp) and 56 % (91 spp), respectively. An additional 18 native woody species, 12% of total native flora, were found in the shade coffee farms but not in the forest-fragments. Species diversity within woody plant functional groups also differed among the three land-use types ($F_{2,266}$=15.9, p<0.001). Smallholder farms had fewer tree, small tree, shrub and liana species than natural forests (χ^2_8=36.9, p<0.001) but more of each type than state-owned farms (p=0.017)(Figure

2). Beta-diversity from forests to state-owned and to smallholder farms was 0.63 and 0.33 respectively, while it was 0.51 between the two types of coffee farms.

3.2 Forest fragments

Species rarefaction curves for each fragment (Table 1) illustrated large variation in richness among fragments (from 9 to 72 spp). The divergence in species diversity from one fragment to another, expressed as β, increased significantly with increase in pairwise physical distance between patches ($t = 45.1$, $df = 152$, $p<0.001$, $\beta_{mean}=0.69$).

Patch size, presence of harvestable resources in fragments (wild coffee and spices), disturbance intensity and elevational range were all associated with species richness of forest fragments ($F_{8,8}=8.9$, $p=0.004$) (Table 2). About 50 % of the patches sustained wild populations of *Arabica* coffee and spices, which were associated with higher richness ($F_{1,16}=13.7$, $p=0.002$).

Species assemblages in smaller fragments were significantly nested within those of larger, more species-rich fragments ($z = -33.3$, $p<0.01$). Moreover, the rank of fragments based on patch size was a strong predictor of their rank based on nestedness order ($r^2=0.61$, $p=0.01$). With declining patch size, lianas, understory shrubs and valuable timber species were the first to disappear.

Woody species richness ($t=117.7$, $df=126$, $p=0.005$) and evenness ($t=116.8$, $df=126$, $p=0.005$) within forest fragments varied significantly between forest edges and cores, with both richness and evenness increasing away from the edge. On the other hand, seedling and sapling density of woody species in the cores were higher than cores ($t = -3.95$, $df = 126$, $p < 0.001$).

Edge effects and disturbance along edge-core gradients did not affect DBH, height or basal area of woody species in fragments ($t = 1.5$, $df = 56$, $p = 0.15$). Richness of non-harvestable species increased with increasing abundance of harvestable resources such as forest coffee and spices ($F_{1,14} = 16.5$, $p = 0.001$). Forest edges were dominated by pioneer and light-demanding species such as *Lannea welwitschii, Croton macrostachyus, Macaranga capensis, Polyscias fulva* and *Albizia* spp. The interiors of fragments were dominated by understory shade-tolerant shrubs, forest-specific and emergent genera of *Diospyros*, *Olea*, *Pouteria* and *Trilepsium*.

Both mean tree DBH ($F_{1,16} = 33$, $p < 0.001$) and mean tree height ($F_{1,16} = 25.8$, $p < 0.001$) declined with increasing intensity of human use in forest-fragments (Table 3). Density of woody individuals across fragments also decreased significantly with increasing disturbance ($F_{1,113} = 23.1$, $p < 0.001$). Finally, canopy cover was significantly lower in highly disturbed fragments than in less disturbed ones ($HSD_t = -7.67$, $p = 0.027$) but did not vary between intermediate and highly disturbance sites ($p = 0.13$).

3.3 Diversity and structure in the coffee landscapes

Individual-based and sample-based rarefied richness (Table 4) differed significantly among land-use types (individual-based $F_{2,190} = 212.4$, $p < 0.001$; sample based $F_{2,190} = 186.9$, $p < 0.001$) (Figure 3). Mean woody species density per 400 m^2 in smallholder and state coffee farms was 7 and 4 respectively, while it was 14 species in forest-fragments. State-owned farms had significantly lower woody species richness than forests (HSD_t=-9.6, p<0.001) or smallholder farms (HSD_t=-3.2, p=0.02). Diversity (H') in natural forests was greater than in smallholder and state-owned farms ($F_{2,190}$ =220.9, p<0.001).

Similarly, evenness (J') declined from natural forests to state-owned farms (Table 4). No single species made up more than 4% of the total composition in the fragments, while mean dominance by a single species was 20% and 9% dominant in smallholder and state-owned farms, respectively. The five most dominant species in state-owned and smallholder accounted for 49.5% and 31% of the total individuals respectively, compared to 18.9% in the forest-fragments.

The three land-use types shared 30 species in common, while 56 species were found exclusively in forests, and 4 and 11 species in large-scale and smallholder respectively. The remaining 64 species occurred in at least two of the three land-use types. The two types of coffee farms shared 83% of all tree species and 50% of the most abundant species in common (Table 5). Almost all lianas, understory shrubs, and many other woody species were restricted to natural forests.

Woody species differed in height (χ^2=52.6, df=12, p<0.001) and DBH distribution **(**χ^2=80.7, df=8, p<0.001) across land-use types (Table 4). The proportions of juveniles (0-10 cm) and mid-adult (20-50cm) trees were higher in forests than in smallholder and state-owned farms (Figure 4a). However, state-owned maintained a higher proportion of large adults (DBH>1 m) than forest-fragments (χ^2=28.1, df =8, p<0.001) or smallholder farms (χ^2=6.6, df=4, p=0.04). Woody species in smallholder farms had higher seedling (DBH<=5 cm) abundance than did state-owned farms (χ^2=90.8, df=16, p<0.001). However, natural forests had higher seedling (χ^2=18, df=12, p=0.01) and sapling abundance (DBH=5-10 cm) (χ^2=495.9, df=152, p<0.001) than smallholder farms (Figure 4b).

Per-hectare density of mature woody individuals in smallholder farms (207) was greater than on state-owned farms (109), but lower than in forest-fragments (265) (land-use $F_{2,192}$=66.5, p<0.001). Smallholder farms had significantly higher stem density (HSD_t=177.4, df=77, p<0.001) than state-owned farms (Figure 4b). Smallholder farms had higher canopy cover (mean=72%) than state-owned farms (mean=63%) (HSD_t=8.7, df=77, p=0.005) but had similar canopy cover to forest fragments (forest mean=84%) (p<0.08). Finally, species richness at the plot scale was significantly correlated with both stem density (Pearson correlation coefficient =0.87, p<0.001) and canopy cover (Pearson's correlation coefficient =0.21, p=0.054) across the two farm types.

4. Discussion

We found that in addition to the loss of many old growth populations of tree species and megafauna (Birdlife International 2012) reported previously, our study forests have lower diversity and more threatened taxa than other, better-protected forests in southwest Ethiopia **(**Gole 2003**)**. While coffee agroforestry protected significant fractions of forest woody diversity, we found that conversion of forests to traditional coffee agroforests resulted in a loss of at least 34% of forest-based woody species, with an additional 37% loss if intensified to large-scale coffee plantations. Although coffee farms capture only subsets of remnant forest diversity, they maintain important components of woody biodiversity compared to, for example, tea and palm-oil plantations. Over 60% of endemic and IUCN-threatened species found in the region also occurred in coffee farms (Table 6). Finally, differences between smallholder and state-run farms underscore the importance of specific management approaches for maintaining the conservation value of shade-coffee systems (Harvey et al. 2008).

Forest fragments thus provide important biodiversity not maintained on coffee farms and could also be necessary to maintain the tree diversity of working landscapes over longer time scales. Our findings indicate that tree species, epiphytes (Gove et al. 2008; Hylander & Nemomissa 2008, 2009) and consequently many birds and primates can be maintained in coffee landscapes, but that other life forms such as lianas, small trees, herbs, shrubs and associated wild biodiversity are not well conserved. Forest fragments have the most woody plant regeneration with relatively even size class distribution. In contrast, regeneration on coffee farms is lower, especially on state-owned farms, raising the question of whether there are important source-sink relationships between forest-fragments and coffee farms, and therefore whether the populations of native woody species in agroforests are self-sustaining without forest-fragments nearby in the landscape. One direct piece of evidence for such source-sink relationships is the observation that forests are actively used by smallholders as sources for seedlings and saplings of woody species to be planted in smallholder farms. Slightly more than a third (25) of the tree species found on smallholder farms are regenerating, showing some ability to self-sustain diversity compared to the fewer than 20 woody species regenerating in the large, state-owned coffee farms. Smallholder farms therefore have somewhat greater conservation potential than a similar area of coffee plantations as currently managed by the state.

Although many of the forest fragments we surveyed are depauperate in relation to less fragmented forests in some Afromontane regions in the region (Gole 2003), our results show that high woody species diversity is still maintained. Ecosystem service dependence could enhance maintenance of diversity; our finding that forest patches containing wild coffee and spices tend to be more diverse is possibly due to protection, provided by users of these services, from widespread logging and disturbance (pers. obs.). Here, the presence of coffee plantations may support forest fragment conservation in another way: although wild coffee may have incentivized people to protect fragments from outright destruction over coarse time and spatial scales, intensive wild coffee management in forest-fragments would reduce density, regeneration and diversity of tree species (Senbeta & Denich 2006). Coffee plantations will thus reduce pressure on these wild coffee forests.

4.1 Floristic similarity and nestedness in forest fragments

The presence of nested patterns of species occurrences that we found in forests and the vulnerability of particular types of species, large-trees, and species that are rare and valuable timber, both underscore that it is especially important that more species-rich fragments (larger patches, lower elevation, with more understory species, and less disturbed) be protected. Some of the more vulnerable species also include those with particular economic uses, such as *Antiaris toxocaria, Cordia africana, Manilkara butugi, Morus mesozygia, Ocotea kenyensis, Pouteria adolfi-friedericii, Prunus africana*, and *Trilepsium madagascarense*. Accordingly, there is ecosystem service value associated with protecting the most species-rich remnants.

4.2 Species diversity in coffee landscapes

While elevational gradients, disturbance and fragmentation affected species diversity in natural forests, tree selection and management of the shade tree canopy strongly influenced diversity in coffee farms. Compared to state-owned farms, smallholder farms support higher woody species diversity that likely resulted from (1) varying choices of shade-trees by individual farmers that maintained overall heterogeneity in these landscapes, and (2) lower intensification that allow woody species recruitment unlike in state-owned farms, where biodiversity decreased with intensification (agrochemical use, weed and shade tree management, use of exotic shade trees, homogenization of farm plots). We found increased species diversity with increased shade tree density in coffee farms similar to diverse polyculture shade coffee farms in central America (Lopez-Gomez et al. 2007; Mendez et al. 2007).

Forests and smallholder farms, and the two types of coffee farms had more species in common than do forests and state farms. High similarity in floristic structure and composition between state-owned and smallholder farms occurred due to selection of a similar pool of native species (Table 5), which are not random assemblages but rather include subsets of forest species that are desirable for optimum shade coffee production. Farmers traditionally prefer trees that (1) grow high enough to allow optimum light radiation for the understory coffee, (2) provide a shade and create conducive microclimate (3) fix nitrogen and provide quality litter as mulch (3) do not produce fruits which interfere with coffee bean harvesting and (4) are multipurpose for goods and services including bee forage, beehive hanging sites, timber, fuel wood and construction (Getachew 2013). Smallholder farms are species diverse since they are usually low-input systems. They provide landscape diversity and heterogeneity that can further increase matrix quality for the forest fragments (Perfecto & Vandermeer 2008; Gardner et al. 2009).

In addition to planned biodiversity for shade coffee, associated biodiversity such as ferns, epiphytes, insects, birds and primates are supported in these farms (Gove et al. 2008) although likely at lower levels than the forest fragments. Higher woody biodiversity was maintained in individually managed small-farms compared to large state farms or collectively managed cooperatives in central America (Mendez et al. 2010). Generally, woody species richness in state-owned and smallholder farms in this study is comparable to traditional polyculture and rustic coffee systems of Latin America respectively (Miguel & Toledo, 1999; Philpott et al. 2008). Tree density in our study coffee systems is also comparable to or higher than the density of some rustic and traditional agroforestry systems in Latin America (Philpott et al. 2008). Canopy covers of the large-scale and smallholder farms in our study were equivalent to respective traditional polyculture and rustic coffee landscapes in Latin America (Miguel & Toledo 1999).

4.3 Prospects and challenges for conservation in coffee landscapes

Since 1970s over 50% of the forest-fragments in southwestern Ethiopia have been converted to working landscapes (Getachew 2013). Out of these converted forests, about 25 % became traditional coffee farms, and 30% and 15% were converted to cultivated fields and tea and eucalyptus plantations, respectively (Getachew 2013). Given current land-use trends, forest fragments will continue to decline and disappear in the foreseeable future. Consequently, smallholder coffee farms will have an increasingly significant role as biodiversity repositories and ecosystem services sources. Our results corroborate that primarily smallholder and then state-owned farms have great conservation potential besides reducing overexploitation of forest species for fuel wood, charcoal and construction; buffering the effects of disturbance and fragmentation; and connecting forest habitats, populations and communities, sources and sinks among meta-communities in these fragmented landscapes, especially for trees and to a lesser extent for herbs, shrubs, epiphytes and lianas.

We found coffee agroforests, in the original habitat of the crop, to have significant potential for biodiversity conservation. However, homogenization of coffee production standards, cooperativizing small growers, introduced species and population pressure are ongoing biodiversity challenges in the coffee landscapes (Getachew 2013). Growing demands for more land and coffee yield could increase transitions from shaded to unshaded, and from wild and semi-wild to garden coffee and plantations. Introduction of exotic shade and non-shade species, and subsequent biotic homogenization has already increased during the last 30 years (Getachew 2013). Extension programs in the region are promoting fast-growing exotic tree species such as *Grevillea robusta*, *Spathodea campanulata*, *Eucalyptus* spp., and *Sesbania sesban* (Tolera et al. 2008, Getachew 2013) as coffee shade and wind breaks. The increasing farmer preference and growth of fast-growing and introduced *Eucalyptus* plantations for economic reasons is replacing native agroforestry trees (Getachew 2013). Current trends toward coffee intensification by reducing shade tree density and diversity threaten biodiversity on-farm and in natural forests as reported by some studies (Perfecto et al. 1996; Harvey et al. 2008; Tscharntke et al. 2011).

The emerging practices of intensive cereal and spice production following recent market incentives will also threaten the traditional coffee production systems. Promotion of the traditional production systems through coffee certification programs that promote ecological friendly coffee, and other incentives such as payment for ecosystem services, could help to substantially reduce the rate of woody biodiversity loss in the region (Rappole et al. 2003; Garcia et al. 2010; Aerts et al. 2011).

Conclusion

Finally, although the coffee farms may become vital refugia for some species, many other species may not be maintained in these farms if the forest habitats are further disturbed, destroyed, or converted to coffee farms. Hence, remaining forest-fragments need to be protected for conserving the species restricted to the forests as well as for the values the remnant fragments provide to local livelihoods. This implies that conservation in working landscapes and forest-fragments needs to be integrated to sustain biodiversity and ecosystem services for meeting livelihood, cultural and conservation needs.

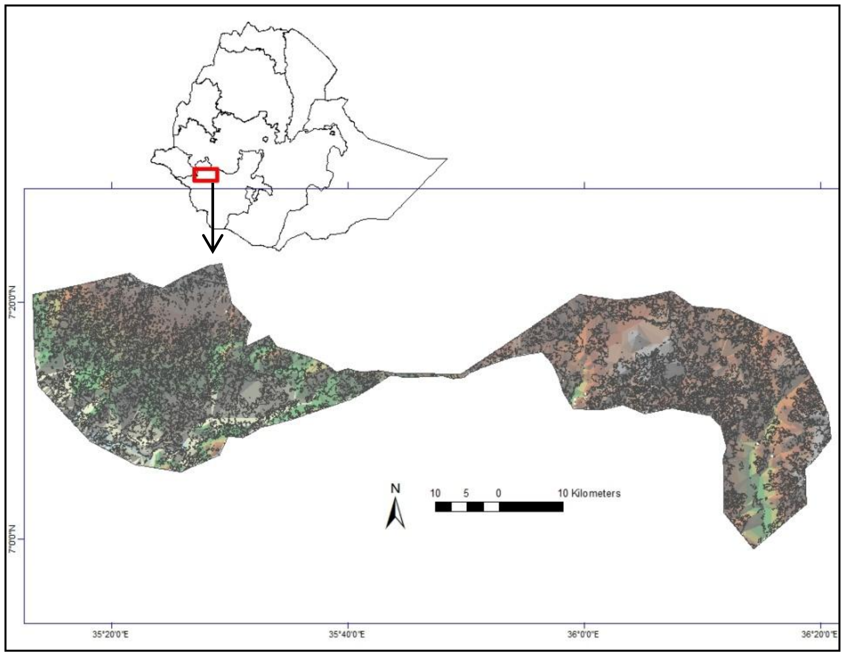

Figure 1. Map of the study sites in Yeki (left) and Decha (right) districts in southwestern Ethiopia

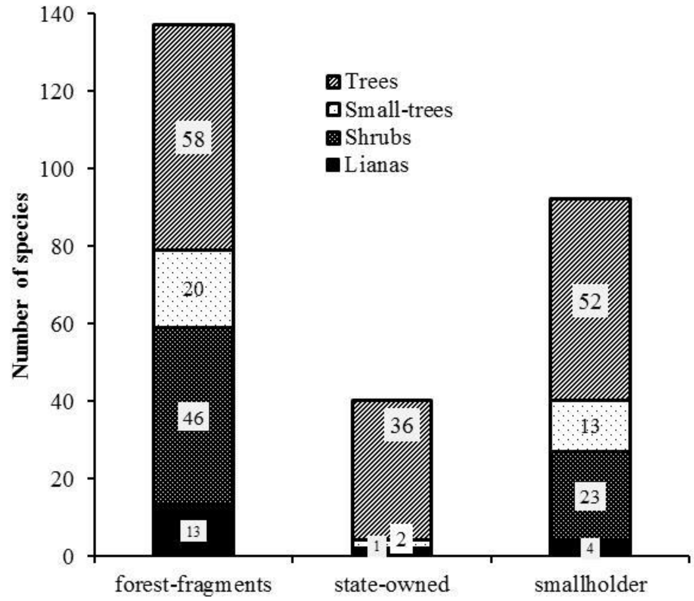

Figure 2. Plant distribution by growth habit across the three land-use types studied. Values on the bars indicate the percentage of each habit type relative to the total number of species found in each land-use, with small trees referring to species that reach a maximum height of 15 m.

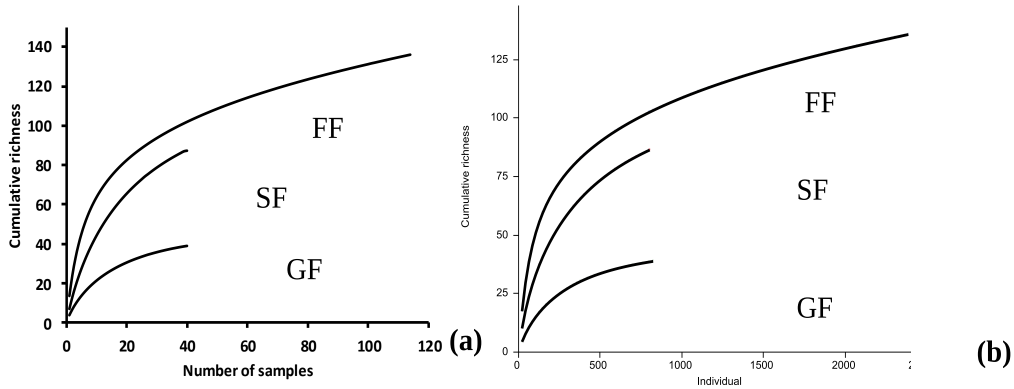

Figure 3. Sample-based (a) and individual-based (b) rarefaction curves for the three land-use types (FF= forest-fragments, GF=state-owned (government) farms, SF=smallholder farms).

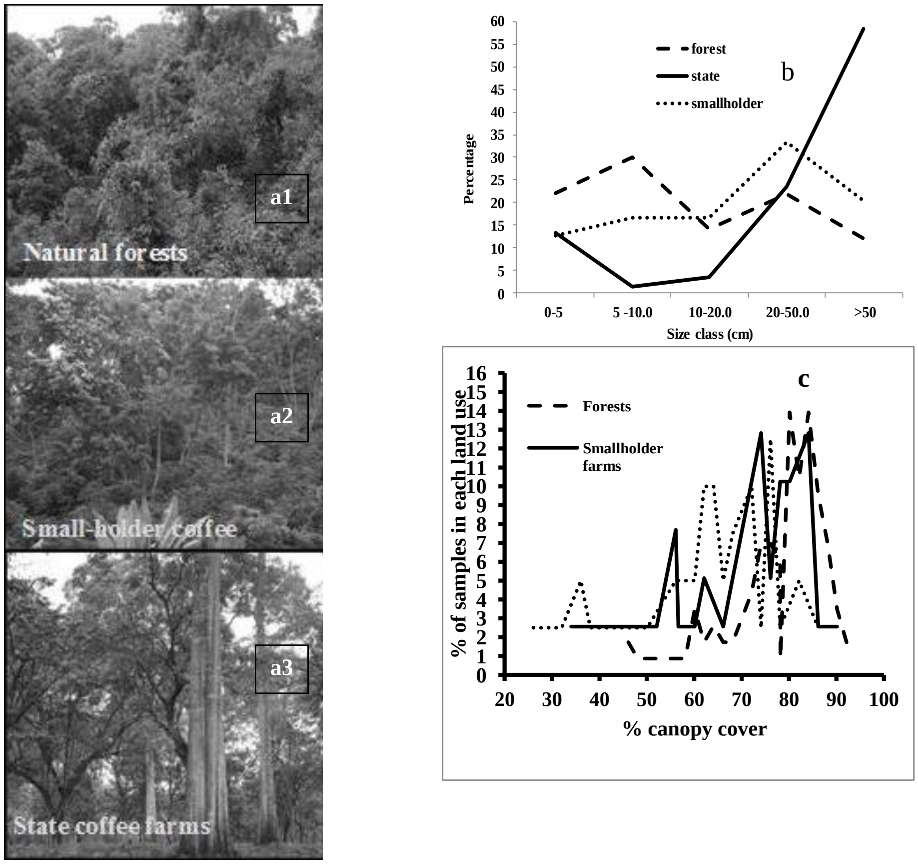

Figure 4 (a) Vegetation structure of the three land-use types: Plate (a1) forest fragment with and woody species of lower size classes, (a2) smallholder coffee farm dominated by mid-size classes of shade trees, and (a3) state-owned dominated by large-size shade trees; (b) size class distribution, and (c) canopy cover distribution across the three land-use types.

Table 1. Site characteristics (mean values), richness and diversity of study forest fragments; estimated richness is based on individual-based rarefaction using Coleman curves (Elev=mean elevation, PS=patch size, D=disturbance index, MQ=matrix quality, , HS=harvestable resources, S= richness, H'= diversity, J'=evenness).

Sites	Elev. (m)	Slope (°)	PS (ha)	D	MQ	HR	Observed S	Rarefied S	H'	J'
Arat60	1976	18	15908	1	6	25	72	84	3.9	0.89
Chira	1926	23	75	2	2	8	53	61	2.8	0.98
KomBechi	1179	2	9	3	3	0	9	11	2.9	0.85
Daget	1558	34	931	2	5	0	21	24	3.3	0.9
Dope	1194	5	45	2	4	0	15	17	3.1	0.9
Gupta	1346	16	340	2	1	0	16	17	2.6	0.95
Sherakeja	1857	30	2568	1	2	9	46	60	3.4	0.9
Kichib	2006	20	781	2	1	20	50	65	3.7	0.91
Komy	1104	10	315	3	3	2	33	57	3.1	0.82
Kuta	1946	28	703	2	1	4	30	38	3.0	0.89
Merki	1655	18	26	2	5	0	27	53	2.7	0.79
Rimich	2225	11	5854	1	5	2	36	66	3.2	0.87
Shosha	1263	10	33	3	4	0	31	53	2.8	0.83
Shumechi	2072	6	377	2	6	0	27	55	3.2	0.87
Ufa	1908	28	506	1	6	29	25	89	3.4	0.85
Yeyebito	2024	20	1323	2	2	3	56	48	3.5	0.93

Table 2. Stepwise regression of environmental variables in forest fragments to determine the most significant predictors of rarefied richness, AIC=Akaike's information criterion. Overall $F_{8, 8}$=8.9; adjusted R2=0.80, p=0.004)

Parameter	AIC	Estimate	SE	t value	Pr(>|t|)
Patch size	55.6	7.0	1.5	4.8	0.002
Harvestable resources	45.9	0.3	0.1	3.1	0.018
Altitude range	44.6	0.1	0.1	2.9	0.024
Matrix quality	41.7	-1.3	0.5	-2.4	0.048
Disturbance	40.8	4.5	2.0	2.2	0.059
Slope range	40.0	0.0	0.0	2.1	0.073
Altitude	35.7	0	0	-0.4	0.7
Slope	37.1	0.2	0.1	1.6	0.16

Table 3. DBH and height across disturbance intensities and between edges (<300 m from forest edge) and cores in the forest fragments, with different superscript letters denoting significantly different values

Disturbance	Mean DBH (SD)	Mean height (SD)	Mean canopy (%)

Low	39.6(14.8)^{a}	20.7(6.9)^{a}	80.3^{a}
Medium	39.8(14.8)^{a}	22.1(6.9)^{a}	78.9^{a}
High	48.7(31.5)^{a}	23.1(8.1)^{a}	72.6^{a}
Edge	39.7^{a}	18.5^{a}	79^{a}
Core	33.8^{b}	19^{a}	89^{b}

Table 4. Diversity indices of the three land-use types; DBH and height distribution of woody plant species by growth form (S=richness), with different superscript letters denoting significantly different values.

	Forests	Smallholder	State-owned
Observed S	137	91	40
Sample-based S	101.2^{a}	87.9^{b}	38.8^{c}
Individual-base S	103.2^{a}	86.3^{b}	38.8^{c}
H'	4.1^{a}	3.5^{b}	2.8^{c}
J'	0.85^{a}	0.87^{b}	0.84^{a}
Mean DBH (cm)	36.3^{a}	42.9^{b}	70.2^{c}
Mean height (m)	21.6^{a}	19.5^{a}	29.5^{b}
Basal area (m^2 ha^{-1})	54.6^{a}	54.5^{a}	57.1^{b}
Mean % canopy	84^{a}	74^{a}	63^{b}
Mature density ha^{-1}	265^{a}	207^{b}	109^{c}
Juvenile density ha^{-1}	258^{a}	113^{a}	58^{b}

Table 5. The 12 most abundant species found in each of the three land-use types.

Rank	*Forests*	IVI	*Small farms*	IVI	*State-owned*	IVI
1	*Olea welwitschii*	25.3	*Millettia ferruginea*	37.0	*Cordia africana*	46.7
2	*Vepris danielli*	20.8	*Albizia schimperiana*	31.1	*Albizia schimperiana*	20.0
3	*Chonanthus mildbrandei*	18.5	*Cordia africana*	23.5	*Pouteria altissima*	17.8
4	*Syzigium guneense*	17.8	*Croton macrostachyus*	22.7	*Milicia excelsa*	15.6
5	*Phoenix reclinata*	17.0	*Phoenix reclinata*	16.8	*Albizia gradibracteata*	13.3
6	*Trilepsium madagascarense*	16.7	*Mimusops kummel*	16.0	*Antiaris toxicaria*	11.2
7	*Dracaena afromontana*	16.3	*Baphia abyssinica*	16.0	*Trichilia dregeana*	6.7

Rank	Forests	IVI	Small farms	IVI	State-owned	IVI
8	*Millettia ferruginea*	15.9	*Diospyros abyssinica*	11.8	*Millettia ferruginea*	6.7
9	*Oxyanthus speciosus*	15.1	*Albizia gradibracteata*	10.9	*Trilepsium madagascarense*	5.6
10	*Bersama abyssinica*	14.9	*Pouteria altissima*	10.1	*Diospyros abyssinica*	5.6
11	*Mimusops kummel*	14.8	*Albizia gummifera*	10.1	*Lannea welwitschii*	5.6
12	*Maytenus gracilipes*	13.9	*Celtis africana*	9.2	*Celtis africana*	5.6

Table 6. Endemic and IUCN red-listed plant species found in the study region (IUCN, 2012; Vivero et al, 2005), LC= Least concern; NT= Near threatened; VU= Vulnerable, EN= Endangered, NE= Near Endemic; species with * marks indicate their presence in coffee farms.

Species	Endemic	Threatened
Alstonia boonei		LC
Baphia abyssinica	NE	VU
Bothriocline schimperi	Yes	LC
*Erythrina brucei**	Yes	LC
Euphorbia dumalis	Yes	LC
*Lippea adoensis**	Yes	LC
*Milicia excelsa**		NT
Millettia ferruginea *	Yes	LC
Ocotea kenyensis		VU
Pittosporum abyssinicum *	Yes	
*Pouteria altissima**		LC
*Prunus africana**		VU
Rinorea friisii	Yes	EN
*Solanecio gigas**	Yes	
Tiliacora troupinii	Yes	

Species	Endemic	Threatened
*Vepris dainellii**	Yes	LC

CHAPTER THREE

Ecosystem services and livelihoods in changing Ethiopian coffee landscapes

by

Getachew Tadesse Eshete

Abstract

As natural ecosystems are diminished by land-use changes, people will rely more on working landscapes such as coffee agroforests for ecosystem services. To understand the relative roles of remnant forests and working landscapes in ecosystem service delivery, local ecosystem service assessment in the context of land-use changes on such landscapes is fundamental. Using socioeconomic surveys and fieldwork in southwest-Ethiopian agroecosystems, I assessed the impacts of land-use changes on the provisioning ability of forest fragments and the potential and limitations of coffee agroforests to provide complementary ecosystem services. I convened ten focus group discussions and performed 105 household surveys from 6 major socio-cultural groups (indigenous groups and recent settlers) across ten villages. I found that most cultural, regulating and supporting services were provided by natural forests and were more vulnerable to deforestation than provisioning services partially provided by coffee agroforests. Although coffee agroforests managed by diverse small-scale farmers provided important ecosystem services, intensification and homogenization of coffee agroforests are diminishing their capacity to provide these services.

Ecosystem service use and awareness was very high locally, although it varied with indigenous knowledge, degree of forest dependency, gender, cultural background and market and non-market values of these services. While recently settled farmers valued more marketable provisioning ecosystem services, indigenous people appreciated cultural and regulating services more than settlers did. We need to consider both provisioning and socio-cultural ecosystem services to be integrated with the conservation of biodiversity in the region to prevent further forest loss or to reduce intensification of traditional coffee agroforests. This indicates the need to examine the livelihood and conservation implications of biodiversity and ecosystem services through promoting local ecosystem benefits using environmental incentive programs and market opportunities.

1. Introduction

1.1 Forest ecosystem services

Ecosystem services are products of ecosystem functions and processes through which biodiversity and human life are sustained (Costanza et al 1997, Daily 1997). These include provisioning, supporting, regulating, and cultural services (Millennium Assessment, MA, 2005) that are directly available as products derived from within forests, or through indirect support of working landscapes. Working landscapes are agricultural areas that are actively used and managed by people to meet economic, ecological and social needs (Morse 2010). The direct services provided by forests include timber and non-timber forest products (NTFPs, see Ruiz-Pérez *et al*. 2004) including building materials, bioenergy, grazing, food supplements, and traditional medicines; socio-cultural benefits such as ecotourism and human health; clean air and water; carbon sequestration; and biodiversity conservation (Foley *et al.* 2007). Indirect ecosystem services include pollination and biocontrol of agricultural pests (Power 2010), sources of propagules for shade and agroforestry trees, nutrient cycling and regulation of disease, drought/flooding, and climate (de Groot *et al.* 2002; MA 2005; Jose 2009).

1.2 Land-use changes and the prospects for ecosystem services on working landscapes

Human activities such as logging, deforestation and land-use changes are diminishing ecosystem services globally (Foley *et al.* 2007).The most direct driver for changes in ecosystem services over the last 50 years is land-use changes (Tengberg *et al.* 2005). Some ecosystem services are affected by land-use changes more than others (Metzger *et al*.2006). The loss of forest ecosystem services following land-use changes may have variable impact on local people as a function of their degree of dependence on such goods and services. This dependence is dictated by socio-economic and cultural backgrounds. It order to prioritize conservation of forest ecosystem services, it is essential to identify specific ecosystem services that disappear first as well as socio-economic groups (such as native minorities, women, and the landless) that become more vulnerable following forest degradation and conversion into working landscapes. Studies addressing ecosystem service vulnerability due to land-use pressures are critical for the assessment and planning of ecosystem services (Vihervaara *et al.* 2010).

Apart from actual agricultural production in working landscapes, there has been little examination on the ability of working landscapes to provide other ecosystem services formerly provided by natural ecosystems. We need to address important questions about how well working landscapes can support human well-being, either instead of or in addition to more pristine habitats. When forest ecosystem services decrease following deforestation, people will inevitably rely more on goods and services in working landscapes (e.g. coffee agroforests, home-gardens, and plantations) by managing these landscapes to deliver more goods and services. However, the role of working landscapes for providing ecosystem services has been underappreciated (Power 2010) despite growing interest in their capacity to support biodiversity beyond food production (Calvet-Mir *et al.* 2012). Agroecosystem services can (1) reduce the pressure and overexploitation of forest resources, (2) serve as additional sources for growing demand for goods and services, and (3) promote sustainable agro-ecosystem productivity (Porter *et al.*, 2009). People can increase agroecosystem services through management (Power *et al.* 2010) by increasing native species diversity; and through substitution and supplementation of lost forest services with new ecosystem service providers in their managed lands (Swift *et al.*, 2004).

For understanding the potential of working landscapes to deliver different types of ecosystem services, I studied coffee landscapes in southwest Ethiopia that sustain rich biodiversity. These landscapes maintain the last remaining natural forests of the nation and are the origin and the only global wild habitat for *Arabica* coffee (Meyer 1965). However, deforestation and agricultural intensification are ongoing threats to the region's biodiversity, ecosystem services and traditional livelihoods. Given continuing deforestation, I hypothesize that some forest-based ecosystem services can be maintained in traditional shade coffee agroforests if they are not greatly intensified (i.e. reduced shade tree cover and diversity, and use of high yielding coffee cultivars that do not require more shade trees, agrochemical inputs) or if they are not converted into tea and oil-palm plantations or annual croplands (Getachew 2013).

Here I studied (1) major locally valued ecosystem services in the rapidly changing landscapes of southwest Ethiopia, (2) the effects of land-use changes on availability of forest goods and other ecosystem services, and (3) the potential for working landscapes, mainly traditional coffee agroforests to sustain ecosystem services delivery.

1.3 Local valuation of ecosystem services

Previous ecosystem service assessments have used economic indicators based on economic and ecological studies at regional and global scales (Martin-Lopez *et al.* 2012). As a result, empirical data on local awareness about the importance of ecosystem services are limited (Sodhi *et al.* 2010), and the role of ecosystem services at local scales from socio-cultural perspectives has been little studied (Chan *et al*. 2012). Larger-scale market-based valuation for ecosystem services such as watershed protection and climate regulation may promote the values and conservation of ecosystems with further opportunities for local communities (Kroeger & Casey 2007; Deal *et al.* 2012). However, many ecosystem services including cultural, supporting and regulating services do not have market values locally and globally, indicating that market-based conservation measures are not adequate.

Values for ecosystem services are the products of perceptions, culture and worldviews on nature (MA 2005). As intimate users of ecosystem services for their survival, local people value ecosystem services not only based on their direct consumptive or market value but also other non-market values including cultural, heritage, aesthetic and spiritual values (MA 2005). Local perspectives are thus needed to accurately assess ecosystem services relevant to local people, and to understand factors determining social preferences and trade-offs associated with land-use changes and conservation decision-making (MA 2005; Martin-Lopez *et al.* 2012). Incorporating local perceptions and valuation of ecosystem services can also increase local awareness and participation, and the legitimacy of the assessment for effective management and promotion of ecosystem services (MA 2005; Liu *et al.* 2010). Understanding the local values and perceptions about ecosystem services helps design approaches for their successful management (Cerdan *et al.* 2012) and sustainable use at local and regional levels, compared to reliance on values derived from international ecosystem market actors including carbon credit programs and biodiversity conservation incentives. Here I explore the socioeconomic and biophysical factors affecting local valuation of provisioning and cultural ecosystem services by local inhabitants in southwest Ethiopian agroecosystems.

Since people have been in southwest Ethiopia probably longer than anywhere on Earth, they rely especially on the ecosystems in the region for a range of ecosystem services. It is critical for us to think about the livelihood and cultural implications of losing forest-based goods and services, and about what of these can come instead from coffee agroecosystems. Therefore, I studied both direct consumptive services and the socio-cultural services of forests and agroforests based on local values and preferences. Here, preference refers to ranking of one use-value before or above another because of the notion of betterness by the informant (Brown 1984). Locally, the valuation and preferences for ecosystem services can vary by gender, socio-economic status, and indigeneity (indigenous vs. settlers) (Lewan & Soderqvist 2002; Martin-Lopez *et al.* 2012).

In order to assess ecosystem services from multiple end-users and perspectives, I carried out focus group discussions and household interviews with various socio-cultural groups in southwest Ethiopia. Using the focus group discussions and household interviews, I sampled both indigenous households who depend more on traditional forest-based livelihoods, and settlers who came from other regions of Ethiopia and who depend more on cereal cultivation. I anticipated indigenous people to value forest-based ecosystem services more than settlers.

2. Methods

2.1 Study area

My study area included two regions over 1900 km^2 with varying degrees forest and agroforest covers -Yeki district (604 km^2) and Decha/Gimbo districts (1390 km^2) (Figure1). The Yeki district is found at 7.2^o N, 35.3^{o}E latitude and longitude respectively with an area of and population density of 236 persons km^{-2}. As compared to Decha/Gimbo region, Yeki district has more large-scale plantations and more settlers, who reconstruct the landscape they remember with more intensive agricultural practices. Settlers came mainly after the 1980s; and Majanger, Kafficho, and Shakicho are indigenous to Yeki. The Manjos are indigenous inhabitants of both districts who in the past used to move from place to place in search of arable land and forest products for their livelihood. The Menit are also indigenous to the region who came from adjacent districts and represented minorities in Yeki. The land-cover composition of Yeki district includes perennial agriculture (42.4%), annual agriculture (34.3%), and forests (22.5%) (Tepi Coffee Plantation Enterprise, TCPE 2010). Land holding sizes range from 0.5 ha to 5.5 ha, with mean size of 1.3 ha of cropland, 0.6 ha coffee, 0.3 ha spices, 0.4 ha grazing and 0.3 ha plantations (Pers. comm. Yeki Agricultural Department 2010).

Decha district and its surrounds is found between 6^{o}15″ and 8^{o}8″ N and 35^{o}30″ and 36^o 46″ E latitudes and longitudes. The population with a density of 77 people km^{-2} is 92.6% rural with more (87%) indigenous people (Kaffichos and minority

Manjos), fewer settlers and more wild coffee forests (1.8 ha per household farms) (FAO, 2010) than in Yeki (42% settlers). Over 76.2% Decha farmers rely on mixed crop and livestock production followed by 14.7% crop production and 9.1% pastoralists. Cultivated and cultivable lands comprise 23 % and 25% respectively, with grazing (6%), bush and shrubs (32 %) and others including forests (15%) (FAO, 2010; Central Statistical Agency of Ethiopia 2010).

2.2. Sampling villages and focus groups

In 2009-10, I carried out ten focus group discussions (FGD) in 10 villages distributed across both districts. The selection of villages for focus group data was based on our attempt to sample different levels of proximity to forests and varying degrees of forest cover around those villages. Each focus group was composed of 10-15 key informants with varying gender, age group, socio-cultural/economic backgrounds (settlers and 5 indigenous groups). Both men and women were interviewed together in the households although the list of the respondents included more men than women partly because women were less involved in activities associated with the use of forests and partly due to low participation of women for cultural reasons. Focus group discussions addressed (1) identification of locally valuable ecosystem services and their main land-use sources, (2) ranking of major land-use units (including forests and agroforests) based on ecosystem services provisioning, (3) comparing use and diversity of ecosystem services among socio-cultural groups, and (4) examining the impact of land-use changes on ecosystem services and on socio-economic groups that are more affected by ecosystem services loss. Here we considered ecosystem services as all forest-based provisioning goods; or cultural, regulating, and supporting services available in forests and working landscapes that are collected, sold, and used directly or indirectly by people in the region. Focus group discussions were used to prioritize local importance of ecosystem services using direct matrix ranking as well as reviewing the ecosystem disservices associated with native vegetation.

I interviewed 105 randomly selected households from the six major socio-cultural groups between 2009 and 2011 using semi-structured questionnaires (Table 1). I sampled both indigenous people and settlers who came from other parts of the country. This interview data generated the identity of forest-based ecosystem service providing species, purpose of collection, quantity collected in locally known units in a year, land-cover type where it was collected (mainly forest fragments, coffee agroforests), season of collection, distance travelled to collect, coping strategies to mitigate declining resource or income due to these changes, and the price of the ecosystem services per a locally known unit if it was sold by household.

I assessed the value of forest-based ecosystem services by documenting the direct provisioning services and their monetary values based on the household interviews (what people reported as annual income gained from their sales). Local valuation refers to the exchange value of products sold in local and regional markets, as well as direct utilitarian values (consumptive and cultural) by households in this study. I did not include livestock or managed cultivated crops in our valuation except shade coffee and spices which were forest-based under wild, semi-cultivated and cultivated production systems. I also documented different coping strategies used by local communities as a result of ecosystem service losses following deforestation.

2.3. Field and Market Surveys

Local valuation was assessed based on semi-structured interviews about the direct consumptive value and amount of ecosystem services sold in the year 2010 in each household, cultural value, market surveys. I did not estimate the economic value of forests and working landscapes in their role to regulate climate, water, and maintenance of soil fertility, and biodiversity conservation as refugia and nursery.

The market survey involved documenting goods and services supplied in six local markets and their prices per locally known units. Field surveys included field walks (guided by local field assistants) and observations on ecosystem service users in the forests and agroforests and recorded various ecosystem services used by people that were directly observed in the field and supplemented with the information from the local field assistants in addition to those reported by focus group and household informants. The 114- 400 m^2 plots in forests and 39-400 m^2 plots in small-scale agroforests used for ecological studies were also used for ecosystem service quantification in the field. In each plot, I recorded the abundance (number and density of providers per hectare), of harvestable resources (wild and semi-wild coffee, spices, construction lianas, honeybee hives), and other ecosystem service providing species and habitats during my ecological surveys.

2.4 Data analysis

I entered the socioeconomic (households and village) survey data into a spreadsheet and coded using qualitative and quantitative categories for analysis. I estimated the percentage contribution (amount and price) of each ecosystem service to household income and use. In order to compare the economic values of major ecosystem services, I used F-tests and t-tests. I used correlation and regression analysis to examine the relationships between different village and household characteristics and use of ecosystem services. I used ANOVA using Tukey's HSD comparisons to test the effect of land-use type on wood density distribution of woody species. I compared the relative abundance of tangible ecosystem services and their providers found in the forests and small-scale coffee agroforests using t-tests. I calculated ecosystem service diversity within land-use types using Shannon's index (H). I used chi-square tests to examine the effects of socio-cultural group and land-use type on ecosystem service use and valuation. Direct matrix ordinal ranking was averaged to analyze the relative importance of various ecosystem services by different focus groups in the landscape. Based on unit price for each good marketed, I calculated mean price of each ecosystem services in Ethiopian Birr (ETB) of the year 2010 and later converted to USD. The average forest-based income from the sale of ecosystem services by households from each land-use type was calculated in terms of income ha^{-1} of corresponding land-use.

3. Results

3.1 Ecosystem services in forests and coffee agroforests

I found forest-based ecosystem services (both marketed and directly consumed provisioning services); and non-market (cultural, regulating, supporting) services. Some ecosystem services such as pollination, biological pest control, biodiversity conservation and carbon sequestration services were not reported by local people.

A range of provisioning services provided supplementary and major incomes for households in the study region which, according to estimates from local informants, was between 30% and 75% of household cash income. The results show that the mean (±SD) income from sales of all forest-based services per households I studied during the year 2010/11 survey was \$827 ± \$84.4.

Ecosystem service contribution to household consumption and sale varied among source land-use types (χ^2_{25} =104.6, $p<0.001$). Forest fragments had high ecosystem service richness (85%, N=44, H'=3.0) followed by traditional coffee farms (N=27, H'=1.9) which sustain 61% of those found in the forests (Table 3). Most of the fuel (74%), lianas (90%), and wild fruits and vegetables (65%) were collected from the forest fragments. Forests (50.8%) and smallholder coffee agroforests of <3 ha (39%)

were the major sources coffee, honey and spices that represented the major marketable ecosystem services in the region(Figs. 2 & 3).

Forests were reported by 40 % of the focus group participants as sources for clean air and water; regulation of disease, climate and drought; and erosion control. Forest fragments were recognized for their cultural and ritual services (*Guddos*), or for their heritage values in traditional honey production (*Kobbos*) whose ownership used to be inherited down from generation to generation. Although these forests were recognized as the major providers of cultural services, some sacred grazing lands in the highlands; and big trees (e.g. *Ficus vasta*) in many settlement areas were also used for ritual purposes besides their role as shaded places for meetings, arbitration and mourning ceremonies.

Coffee farms, on the other hand, sustained about 40% of marketable, 67% of provisioning and < 50% of cultural and regulating services found in forest fragments. Coffee farms were also the major sources for some forest-based goods such as semi-wild and garden coffee (91%), medicinal plants (55%), mushroom (50%), and oils and condiments (80%) (Figure3). Both coffee farms and forests were sources for 46% and 49% of the honey produced in 2010; and they did not vary in the per hectare density of traditional beehives they support ($F_{1,10} = 0.36$, $p = 0.56$).

About 75% of Decha households depended on forests for forest-based ecosystem services compared to only 32% of the Yeki households who relied on forests ($\chi^2_4=37.2$, $p<0.001$). Forest-based ecosystem services such as lianas, forest spices, wild and semi-wild coffee, medicinal plants, wild meat, and wild fruits that were collected from forests were used more by Decha households than Yeki household (χ^2_{19}=51.3, p<0.001).

3.2 Local valuation of ecosystem services

About 96% of the households recognized the value of forests and the provisioning of one or more forest-based ecosystem services. People named more distinct categories within provisioning and regulating services than cultural and supporting ones (Table 2). Of all ecosystem services recognized by local communities, 62% and 20% were provisioning (i.e., honey, coffee, wild food, bioenergy, construction materials, fiber, spices, medicine) and regulating (shade, soil fertility, climate/soil/disease regulation) services, respectively, with 10% cultural and 8% supporting services. Forty percent of the focus groups and 30% of households appreciated forests for their intangible services: controlling disease, climate regulation, cultural values, and maintaining good physical well-being. On average, 45% of the participants within a focus group reported practicing honey production with 86.6% produced traditionally (with 92% of the hives were constructed by and hung in native trees where the honey bees mostly forage) and the remaining 13.4% produced from transitional and modern hives that made up 8% of the total number of hives.

People valued forests for their tangible and intangible forest-based ecosystem services. For instance, people from one of the focus groups I discussed with described that "Forest is life; without it there is no life and we cannot improve our livelihoods. When the sun is very intense, we and our livestock go to the shade. Forests are equally important as our children and families; the values we obtain from forests are beyond what we get from cultivation and the benefit from forests is greater and more sustainable than those obtained from expanding our farms. In the court, we witness against our brothers and children who cut trees in forests. Those *Cordia* trees our forefathers used to burn or make simple tools from are now becoming more rare and expensive, and we can sell one *Cordia* tree for up to 100 'dollars'. Our wildlife from forests (buffalo, lion, leopard, wild pig, colobus and bushbucks) could bring us significant income through ecotourism" (*Rimich* focus group, pers. comm.; October 15, 2010).

Generally, the perceived value of ecosystem services increased with increase in their relative contribution to household income and consumption. However, local valuation of ecosystem services also varied with (1) socio-cultural and gender groups, (2) direct market and non-market contribution, and (3) emerging markets and scarcity of ecosystem service providers overtime.

Socio-cultural composition - The reported values for ecosystem services varied among socio-cultural groups (χ^2_{94}=121, p=0.04), with indigenous people dependent on a wider range of forest-based ecosystem services (85%) than settlers (15%). Indigenous people used and recognized more ecosystem services (fish, honey lianas, material culture, hunting, and medicinal plants) than settlers, who valued a small set of marketable ecosystem services (coffee, construction materials and spices) from coffee agro-forests (Table 5). For instance, mean annual honey sales in 2010 were higher in indigenous households ($172.5) than settlers ($105.7) (Figure 5). 28% of indigenous households used wild meat compared to only 7.6% settlers ($F_{5, 15}$=3.6, p=0.05). The number of marketable goods used by settlers decreased with more recent time of settlement ($F_{1,21}$=13.2, p=0.002). Households with small land holdings or who described themselves as poor (Manjos and Menit) depended more on selling fuel wood, charcoal, lianas and honey which were largely forest-based services (Table 5) ($F_{1,269}$ = 3.95, p= 0.05). The major sources of forest-based ecosystem services for indigenous people were forests (50 % of total) whereas that of settlers were working landscapes (75%), mainly from coffee agroforests (65.8%) (χ^2=13.6, p<0.001) (Figure 4).

Household gender - Men and women in households traveled significantly different distances to collect ecosystem goods (t = -1.29, p = 0.03) used distinct categories of goods and services (χ^2= 6.7, DF= 1, p=0.01) (Figure 6). More women than men sold wild vegetables, fuel wood, charcoal and fruits in local markets (χ^2=2.4, df=2, p<0.001) Usually, men went very far to the forest for honey production, collecting lianas or hunting, but women travelled to forest margins and coffee farms to collect mostly wild vegetables, fodder and firewood. Accordingly, women gave more value to wild vegetables and domestic fuel, while men valued forest honey, lianas, hunting and construction materials. This pattern for children by gender varied along with their parents (Figure 6).

Direct market and non-market value - The mean direct market income from sale of provisioning services from all land-use types was \$570 ha $^{-1}$yr $^{-1}$(Figs. 7 & 8). Over 50% of all reported goods and services were marketable and the majority of market sales (93.7%) was from coffee, honey and spices (Figure 8). Coffee and honey that can be coproduced and have relatively higher market prices, were universally valued across all villages (100%, 82%) and households (81%, 56%) (Figs.7 & 8). Others with low market or exchange values such as wild meat, mushroom, fishing, medicinal plants, cultural services and soil conservation were still appreciated by a few villages (Table 4). Market values were not always correlated with people's rankings (r^2=0.58, df=9, p=0.06) which indicated that non-marketed ecosystem services such as cultural and regulating services were also valued by local communities. Fodder (rank=4.9, universality= 90%), water clarification and erosion control (rank= 5.6, universality=80%) were ranked low, but used by people in most villages (Table 4).

Market availability and rarity overtime - Market availability and values for some forest products changed significantly over the years (e.g. according to local informants, the price for a kilo honey has tripled since the 1980s). Use-values for some ecosystem services increased with increase in rarity of the service providing species over time; about 80% informants reported that values for lianas and fodder increased because they became rare due to deforestation and overharvesting. People also reported growing value for soil fertility services as farming practices become increasingly intensive, unlike in the past when soil fertility was not an issue due to swidden systems and fallowing that used to regenerate soil nutrients.

3.3 Land-use changes and prospects for ecosystem services on working landscapes

Most people reported that land-use changes and deforestation resulted in loss of cultural and ritual resources; increased the time needed to collect forest-based ecosystem services; reduced income; and decreased ecosystem service providers (Figure 10). Focus groups reported that many ecosystem services became less available due to deforestation. Honey, lianas, wild animals, soil/water/drought regulation, and cultural services were reported to be disappeared first following deforestation. Generally people reported that cultural and regulating services were more affected than provisioning services since many forest-based provisioning services (67%) could be substituted in working landscapes. They also recognized that socio-economic groups who strongly depend on forest-based ecosystem services (indigenous Manjo and Majanger peoples, women, landless) were more vulnerable to the loss of forest-based ecosystem services following deforestation. According to informants, land-cover changes over the last 30 years made goods less accessible in both Yeki and Decha by increasing the mean distance (mean hour ±SE) to collect by 1.9 ± 1.5 hours more ($F_{1, 19} = 4.1$, $p<0.001$). Due to the loss of forests, average time (hours ± SE) needed to collect a good from coffee farms and cultivated fields was (0.7±0.16) and (0.7±0.4) respectively, compared to forests (1.4±0.7). Among some ecosystem services, lianas (3.3±0.4), and fuel (3.5 ± 0.6) took longer compared to timber (0.7±0.4), coffee and spices (0.9±0.2) and honey (1±1) which could be substituted in coffee landscapes. People were able to hunt easily in 1980s, while recently they had to travel several hours to days (4 ± 3) for a successful hunting (pers. comm.).

Landscape changes also decreased the average number of beehives a household owned by 15 ($t=-3.37$, $p = 0.005$) compared to the period before mid-1980s. However, average time to collect honey did not increase significantly since trees in coffee farms and cultivated fields were used to support traditional beehives. People reported that land-use changes decreased the amount of forest honey that was produced before the mid-80s by one-third. This loss was attributed to (1) the loss of native bee forage species and beehive-supporting trees, (2) the increasing use of exotic and invasive plant species and agrochemicals that are toxic to honey bees, and (3) increased fire frequency that decreased honeybee populations. Following land-use changes, fallowing (*Guya*) decreased with loss of some shrubs (*Vernonia* spp.) that had been important bee forage known for medicinal honey production in addition to decrease in fodder and shrub cover that used to increase soil organic matter input to the soil.

Ecosystem service availability and use varied from place to place partly as a function of land-use changes. The average time needed by a household member to collect a particular ecosystem service in relatively forested Decha landscape (2.8 ±1.6

hrs.) was shorter than in the more deforested Yeki district (4.2 ±3.7 hrs.) ($p = 0.05$). More households in Yeki depended on coffee farms for semi-wild and garden coffee, honey, charcoal/fuel than in Decha who used more forest ecosystem services such as wild coffee, lianas, spices and vegetables (χ^2_4=36.4, $p<0.001$) (Figure 9). Mean (± SE) income from ecosystem service sales in Decha ($823 ± 62) was relatively higher than in Yeki ($604 ± 33).

Land-use changes and deforestation were blamed for decreased income from sales of lianas, tools, fuel, honey and hunting. People also reported that land-use changes aggravated erosion and decreased the quality and volume of perennial springs with declining soil fertility and increased soil acidity in some villages. As part of coping strategies of diminishing forest goods, households reported a shift from use of forest products to imported plastics and modern inputs; and a shift from selling fuel, hunting and fishing to coffee, crop and livestock production.

Traditional coffee farmers reported that they encouraged or planted a set of multipurpose tree species to satisfy their diverse ecosystem service needs such as coffee-shade, fodder, beehive support, bee forage, timber, fuel wood, soil fertility, and microclimate regulation. Some of the highly ranked multi-purpose trees included species of *Milletia, Albizia, Cordia, Ficus, Erythrina, Schefflera*, *Milicia* and *Mimusops*. Farmers traditionally preferred trees that (1) grow high enough to allow optimum light radiation by providing shade and create conducive microclimate for the understory coffee, (2) fix nitrogen and provide quality litter as mulch, (3) produce edible fruits which do not interfere with coffee bean harvesting, and (4) are multipurpose for other services including bee forage, beehive hanging sites, timber, fuel wood and construction materials.

4. Discussion

4.1 Ecosystem services in forests and coffee agroforests

Southwest Ethiopian coffee agroecosystems maintain unique and diverse biodiversity and a range of ecosystem services on which millions of subsistence farmers belonging to diverse socio-cultural groups highly depend. Most of these services were provided by forest remnants, the last remaining ecological supermarkets for the majority of forest-based provisioning and regulating services. As most of these forests are commonly found on the hill-slopes susceptible to erosion, they have indispensable roles in regulating erosion, landslides and flooding (Getachew 2013). Regionally, in addition to being hotspots of biodiversity that is also highly endangered (Birdlife International 2012), the remnant forests are water sources that regulate the critical watersheds for the surrounding regions and for the White Nile sub-basin.

Next to forests, smallholder agroforests provided many of the four ecosystem service categories identified by MA (2005). These include timber and non-timber forest products, soil enrichment, erosion control, carbon sequestration, biodiversity conservation (including regeneration and nursery services), and the regulation of soil, water and drought . Many of these ecosystem services from agroforests as a form of multifunctional working landscapes have also been reported elsewhere (Jose 2009; Idol *et al.* 2011). Although diverse coffee landscapes provide many of the forest-based ecosystem services in the region, many cultural (e.g. *Kobbos* and *Guddos*), regulating (water, soil, climate) and supporting services (conservation of shrubs and small trees, lianas, slow-growing trees, megafauna) that used to be provided by forest fragments could not be substituted in coffee landscapes (Getachew 2013).

Most of the forest-based provisioning and some of the regulating services were substituted in coffee agroforests compared to grazing lands, annual croplands, or monocultures (tea, *Eucalyptus*, oil-palm). This was because traditional coffee agroforests in the region are multifunctional working landscapes that have been established from the original forest vegetation through minimal management (understory clearings), or by active management and eventual diversification of shade tree species. The traditional small-scale coffee agroforests maintained high plant species and functional group diversity than large-scale coffee farms or monoculture plantations (Getachew 2013). This implies that ecosystem services in coffee agroecosytems can be enhanced through management shade tree species functional group richness (Getachew 2013) similar to the effects of management in enhancing ecosystem services from agricultural landscapes (Power 2010). Empirical studies show that high species and functional group richness is often linked to high ecosystem functioning and services (Hooper *et al.* 2005; Balvanera et al. 2006; Diaz & Cabido 2009).

Most of the ecosystem services I found in these coffee landscapes were provided by the diverse shade tree species, other functional groups, and the associated biodiversity that have been selected and maintained by coffee farmers for their diverse needs. Integration of such diverse trees in the form of ecoagriculture for various ecosystem services including drought and climate regulation (Sherr & McNeely 2007) has been reported elsewhere and in drier parts of Ethiopia and other east African countries (Kristjanson *et al.* 2012). This implies that on-farm diversification and management of ecosystem service providers can enhance the services provided to and from agricultural landscapes (Jose 2009; Power 2010) besides their role in buffering overexploitation of forest ecosystem service providers.

Human-forest and agroforest interactions in southwest Ethiopia primarily for ecosystem services might have contributed to the conservation of forest fragments and to the maintenance of diverse native species in coffee agroforests until recently. Local farmers have multiple and varied ecosystem service needs that are provided by various shade-trees and associated biodiversity in their coffee farms. Although farmers used to maintain high shade tree diversity for multiple needs, these landscapes are facing rapid deforestation and agricultural intensification (Getachew 2013).

However, the recent intensification of coffee agroforests (reduced shade tree richness and stem density, increased exotic shade trees) in the region is decreasing the capacity of coffee landscapes to provide ecosystem services (Getachew 2013).

Agricultural intensification is considered as a major driver of ecosystem service degradation globally (Foley *et al.* 2005). The intensification of coffee agro-forests and other agricultural systems in the region have been driven by population growth, agricultural policies, socio-cultural transformation, and market drivers (Getachew 2013). The level of intensification of these coffee farms depended on the availability of land to coffee growers, the scale of production, and the location of the farm in the landscape. Intensification increased with conversion of forest coffee and semi-forest coffee into garden coffee (more intensification occurred in coffee gardens around homesteads), and into large-scale farms (Getachew 2013). Generally, our discussion with the focus groups and field observations signified that the prospects for ecosystem services in coffee landscapes depends on the intensity of management that often varied with the livelihood strategies, production practices, and the needs of coffee growers.

4.2 Local and regional valuation of ecosystem services

As a function of the contribution of ecosystem services to livelihoods in the region, I found high awareness of and values placed upon forest-based ecosystem services, similar to high local values and awareness of indigenous people in the protected areas of southeast Asian countries (Sodhi *et al.* 2010). I found assessment of ecosystem services by local people to be more holistic and diverse than strictly ecological or economic assessments. Hence local valuation of ecosystem services is important in the promotion and conservation of biodiversity and livelihoods if local assessments are incorporated with regional assessments and planning of ecosystem services (de Groot 2007).

People highly ranked the cultural ecosystem services from forests, which implies that people's valuation was not based on direct consumptive or market values alone but also based on other non-exchange use values. Prioritizing socio-cultural ecosystem services (e.g. the *Guddo* systems,, aesthetic and ecotourism values) that are provided by the total biodiversity can reduce the overexploitation of or neglecting of specific biodiversity components in the region. On the other hand, low-rated ecosystem services such as fodder and medicinal plants were used almost universally by communities. This suggests the "diamond-water paradox" in people’s ratings (diamond has high value since it is scarce but is rarely used compared to the less valued water which is not scarce but widely used, Farley 2012) and ecosystem service valuation (Farber et al. 2002) where high use-value goods essential to human well-being such as water had low exchange values compared to wild meat. This implies the need to also conserve ecosystem services that are rated low but used widely .

My results showed that promoting the market values of various forest-based ecosystem services could increase their household use and contribution as well as their conservation (see Ruiz-Pérez, M. *et al*. 2004) if they are not overexploited. However, not all locally valuable ecosystem services were exchanged in local and regional markets, and many could not be easily quantified (Costanza *et al.* 1997). Some such as fodder and medicinal plants had high value in use but not in exchange.

Additionally, focusing only on few marketable ecosystem services will neglect important socio-cultural services that may be excessively damaged during extraction of marketed goods. The risks of focusing on forest valuation using monetary measures including carbon credit programs have been observed elsewhere as cases of forest commodification and green grabbing, i.e., the appropriation of land and resources for environmental ends by marginalizing local stewards (Fairhead *et al.* 2012; Muradian & Raval 2012). I noticed similar risks in our study region where attention is being given only to high value NTFPs such as wild coffee and spices while ignoring non-marketed biodiversity and other ecosystem services (cultural services, water purification, erosion control or drought regulation). Therefore, we need to value and conserve these forest remnants beyond their NTFPs or other than specific biodiversity components so that we can sustain multiple functions and services in these agroecosystems.

The interactions between people and forests, and hence local assessment of forest-based ecosystem services, can vary spatiotemporally (Rantala & Lyimo 2011). Local use-values about forest-based ecosystem services varied with the experience and socio-cultural background of individual users and their interaction with ecosystem service providers. Although most people valued provisioning services, indigenous people in southwest Ethiopia valued cultural services more than settlers, who valued more marketable services. This implies that deforestation is affecting cultural and other forest-based ecosystem services and that this in turn affects indigenous people more than settlers. Men and women also varied in the ways they interacted with forests and agroforests and accordingly valued ecosystem services differently. Hence, they will be affected differently by the loss of forest fragments, with men possibly needing to travel more to continue forest-based activities, or to substitute new activities for lost forest-based livelihood options.

People can value and conserve forests if they sustainably use and manage them. In the past, people might have conserved forests and trees for their provisioning and socio-cultural services such as traditional apiculture forest plots (*Kobbos*), ritual forests (*Guddos*), and sacred trees for ritual ceremonies (*Adbar*). The role of traditional religious beliefs and religious leaders in forest conservation has also been observed in other parts of Africa such as Zimbabwe (Byers et al. 2001) and Mozambique (Virtanen 2002). Globally, the positive roles of sacred groves in the conservation of biodiversity and forests globally has been reported by Bhagwat & Rutte (2006).Recently, however, the use of these forest ecosystem services have been diminished in southwest Ethiopia because of deforestation and cultural transformation, and due to lack of ownership and of local access to the use of forests following land-tenure changes (Getachew 2013).

Since our analysis was based on 2010 annual surveys despite inter-annual variations in the contribution and assessment of ecosystem services , long-term studies on ecosystem services assessment would better capture the spatio-temporal dynamics of ecosystem service flows and changes associated with land-use dynamics in the region. Local people also reported that values for ecosystem services were dynamic spatiotemporally. Since some such as lianas and fodder were dwindling, their demand is rising as they are being exhausted. Others such as honey and spices are increasingly more appreciated since their market prices are rising. Soil fertility services were valued more than ever since soil productivity is decreasing following intensification although this was not a problem in the past when people used slash-and-burn agriculture and fallowing. Creating local awareness about little appreciated but vital services such as pollination, dispersal, biodiversity and carbon sequestration services would also promote local involvement in sustainable use of biodiversity and ecosystem services.

Finally, ecosystem service values depend on the scale at which they are generated (Hein *et al.* 2006), with carbon sequestration, biodiversity conservation or flood protection benefits mostly being generated outside the landscape (Scherr & McNeely 2008) while most of the provisioning services are generated at local scales. Demands for other ecosystem services such as aesthetic, ecotourism, and supporting services can increase with population growth and economic development (see Guo & Li 2010). Promoting the local awareness on the importance and values of ecosystem services can contribute to the conservation and restoration of ecosystem functions and services in the region.

In southwest Ethiopia, small-scale farmers largely shaped and influenced their production landscapes to deliver more ecosystem services. Management, shifts to working landscapes and other coping strategies can partially mitigate ecosystem service losses following deforestation. Many farmers started planting multipurpose species (wild vegetables, fodder, honey, shade, soil fertility and microclimate regulation services) around their homesteads and coffee farms to substitute for ecosystem service declines by deforestation and overexploitation of forest tree species. Ecosystem service availability in coffee landscapes depends on management and the degree of intensification that varies with (1) knowledge, skills and background of coffee growers, (2) proximity to forests since establishment of native shade trees in these farms depends on propagule dispersal from source populations and from various ecosystem service providing species. More intensification occurred around homesteads and recently established large-scale coffee farms.

The benefit from managing forests more sustainably often exceeds the value associated with the conversion of forests through farming and other uses (MA 2005). Balmford *et al.* (2002) reported an 18% greater total economic value (TEV) in sustainable forestry than small-scale farming in Cameroon (~$2570 compared with ~ $2110 ha-1) which implies a negative TEV by conversion of forests to plantations. MELCA (2006) estimated the annual value of a traditionally managed Sheka forest in southwest Ethiopia to be $1260 ha^{-1} while the maximum cost of converting those forests into perennial crop plantation, in terms of carbon release was $1240 ha^{-1}. Wild coffee in southwest Ethiopia is a major global resource although its current production is low compared to its potential (15% of the yield per hectare obtained in plantations and garden coffee). The estimated value of genetic diversity of wild coffee for breeding programs alone is about 1.5 billion USD (Urich 2005; Hein & Gatzweiler 2006).

4.3 Land-use changes and prospects for ecosystem services on working landscapes

Ecosystem services, in many regions have been threatened by changes in land-use, socio-economic and policy environments (Foley *et al*. 2005; Pfund *et al.* 2011). With the loss of more than 50% forests over the last 40 years in southwest Ethiopia (Getachew 2013), the associated ecosystem services have been either lost or degraded which was confirmed by local communities during our surveys. Local people recognized the loss of tangible and non-tangible ecosystem services as a result of land-use changes over time because they are directly affected by income losses, or by the decrease in availability of ecosystem service providing species or habitats. Current trends of converting forests and wetlands into tea and oil-palm plantations, and into crop production will not only reduce biodiversity but also the actual and potential economic benefits from ecosystem services, as reported in other parts of Africa (Pfund *et al.* 2011). Land-use changes particularly affected cultural and regulating services more severely than provisioning services.

Some land-use conversions such as forests to traditional agroforests had less impact on ecosystem services than others such as converting forests to annual crop fields or tea and oil-palm plantations. Traditional coffee agroforests provided better ecosystem services than monoculture perhaps due to varying management and landscape heterogeneity. However, current trends of intensification and homogenization of coffee production systems in the region (Getachew 2013) will decrease the potential of these diverse systems in delivering ecosystem services. This dynamic illustrates the potentials and challenges of traditional coffee agroforestry in ecosystem service provisioning, and the need to develop incentives for the ecosystem services provided in working landscapes in order to reduce their intensification or to prevent their conversion into low-ecosystem service production landscapes such as tea and oil-palm plantations, and annual croplands.

Due to their high reliance on ecosystem services, people in southwest Ethiopia, especially indigenous minorities, the poor, disabled, and landless, were more vulnerable to ecosystem service degradation. Deforestation has been encroaching indigenous people in the region to inaccessible territories of low ecosystem service productivity, and compelling them to change their life strategies to cope with such changes. Households (indigenous minorities, women, and the landless) who depended more on forest products, hunting, and the sale of fuel wood were more vulnerable to loss of forests than households whose main income was selling coffee and related products in highly managed coffee agroforests. In addition to loss of ecosystem services, we should also be concerned about the loss of traditional knowledge and practices related to the use and local management of ecosystem services. The use of some forest-based ecosystem services (traditional honey production, fishing, spices) was reported to decline for households that lack traditional knowledge or practice either by cultural transformation or by diluting effects of resettlement.

People in less-forested landscapes such as Yeki relied more on ecosystem services from working landscapes than people living with more forest cover such as Decha (Getachew 2013). With the loss of more forest cover in Yeki, it is likely that ecosystem services that are mainly available in forests will no longer be used which indicates that further forest loss will affect some ecosystem services such as lianas, wild meat, wild coffee and spices, water purification, erosion control, and cultural services than others such as honey, semi-wild coffee, fodder and fuel. There is some potential for shifting practices to accommodate the loss of forest-based ecosystem services, but those mostly found in the forest remnants (construction lianas, wild meat, and ritual services) could not substituted for by the coffee farms. Ecosystem service provisioning in production landscapes such as coffee agroforests depends strongly on presence of adjacent forest fragments that act as sources for propagule dispersal and ecosystem service flows.

Given the current land-use trajectory, most of the ecosystem services will be degraded and lost in the foreseeable future. People will largely depend on working landscapes particularly the diverse traditional coffee agroforests for various ecosystem services (e.g. soil fertility, climate regulation, shade, fodder, honey production, timber, fuel wood/charcoal). Still, cultural and regulating services could not be fully substituted in coffee agroforests and cultivated landscapes are hence are more vulnerable to land-use changes than provisioning services.

Both forests and coffee farms are needed – we cannot lose all the forests to coffee without losing important components of ecosystem services including sources for coffee shade tree diversity and for the coffee itself. I also cannot lose low-intensity and semi-wild coffee from these landscapes without losing considerable ecosystem services, since coffee is now a large part of these landscapes and forests are increasingly scarce. Supporting forest ecosystem services have been shown to be important to coffee productions in other regions; e.g. coffee yields increased by 20% due to adjacent forest-based pollinators in Costa Rica (Ricketts *et al.* 2004) which may be true for many crops in this region but further studies are necessary. Sustainable management of forests and traditional coffee farms has the potential to benefit millions of farmers.

Finally, conserving cultural values and diversity depends on conserving forest diversity, and conserving the forests depends on conserving cultural diversity and values in these landscapes. It is important to include different socio-cultural groups, and men and women, in the planning and management of ecosystem services and biodiversity, since they value different sets of ecosystem services that are most relevant to them and such practices be replicated to other coffee growing regions including nearly 20 million coffee growers in Ethiopia. Additionally, socio-economic groups (e.g. minority indigenous people and the landless) who are largely dependent on forest-based ecosystem services but often blamed for deforestation, should also be involved. These forests and species diverse coffee agroforests could be protected if the benefits from both are enhanced by environmental incentive programs including adding more market values using certification programs such as labeling bird-friendly, shade, or forest coffee in central America (Perfecto *et al.* 2005; Gove *et al.* 2008); and reducing emissions from deforestation and degradation (REDD+), and by promoting ecotourism (Rice 2008; Jose 2009).

Conclusion

Coffee agroecosystems in southwest Ethiopia maintain unique biodiversity and a range of ecosystem services that support subsistence farmers and local communities in the region. Indigenous people interacted with a different set of ecosystem services than settlers and men and women also interacted differently with forest-based ecosystem services. The interaction between forests and indigenous people and men will be affected the loss of forests more than settlers and women. Although the majority of forest-based ecosystem services can be maintained in traditionally diverse small-scale coffee agroforests, most of the cultural and regulating services cannot be supported by the coffee landscapes. While it is important to promote markets for the diverse ecosystem services, attention should be given to those most affected by land-use changes particularly the cultural, supporting and regulating services. I conclude that the forest-coffee mosaics in the region could continue providing ecosystem services if (1) forest conversion and coffee intensification are reduced, and (2) if cultural diversity is maintained and traditional and local institutions are strengthened. Local people may substitute for the loss of forest-based ecosystem services following deforestation, but the extent to which they adapt and substitute those losses in coffee farms depends on the socio-cultural background of people, and policy and demographic drivers that affect agricultural intensification. Promoting ecosystem benefits to local people by increasing market and other incentives could help reduce the ongoing challenges of deforestation and intensification and help alleviate poverty in the region. Therefore, integration of environmental incentive programs with the promotion of local ecosystem benefits through market mechanisms will critically determine the ability of these coffee landscapes to be vital biodiversity refugia while sustaining livelihoods.

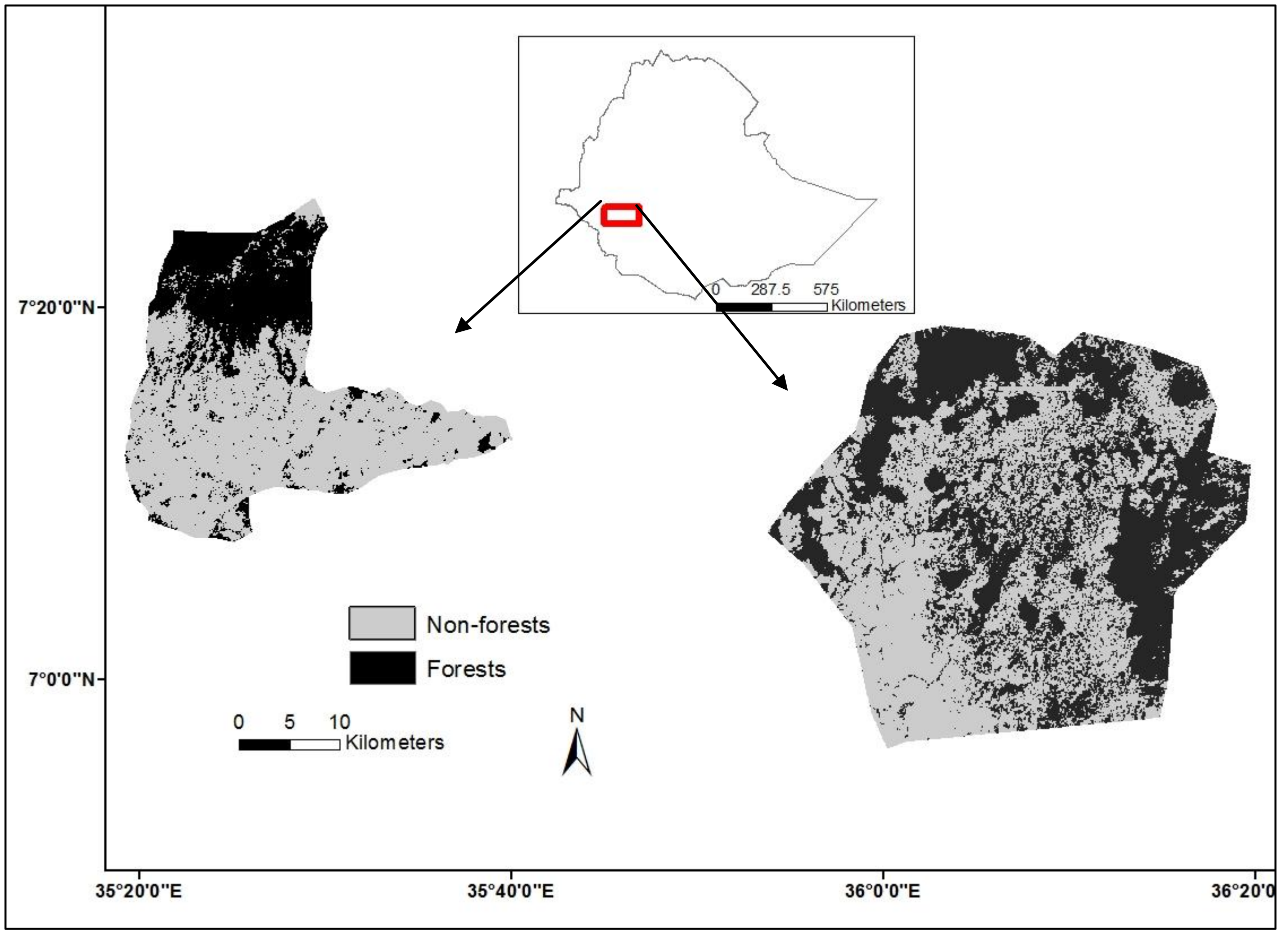

Figure 1. Map of the study area in Yeki (left) and Decha (right) districts with non-forested areas (grey shaded) and forested areas (dark shaded).

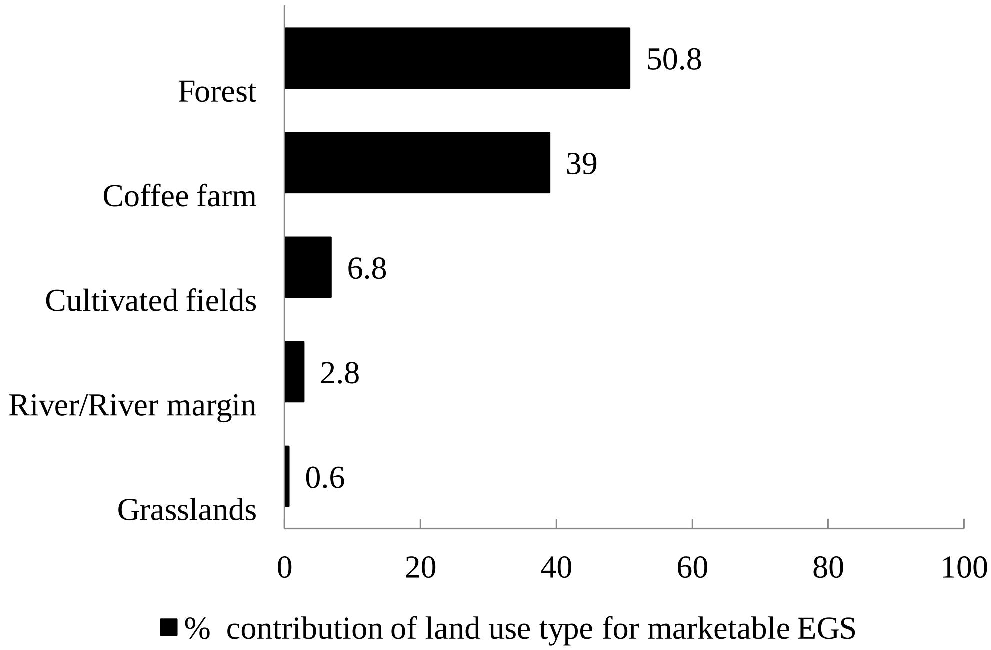

Figure 2. Potential of land-use types based on their contribution in marketable ecosystem services

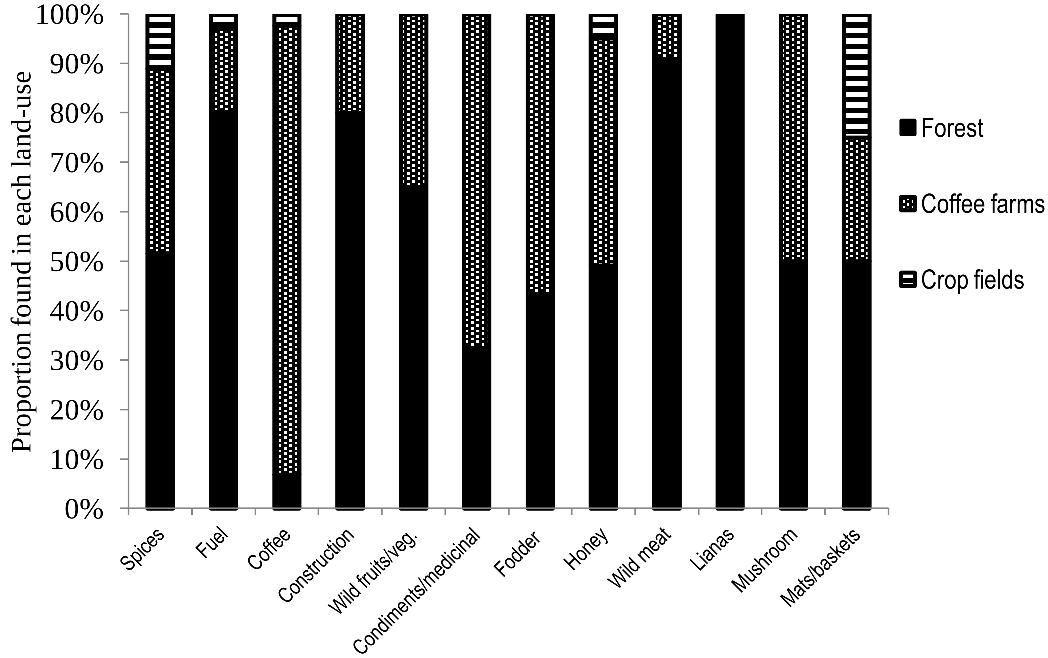

Figure 3. Percentage distribution of major ecosystem services in major land-use types

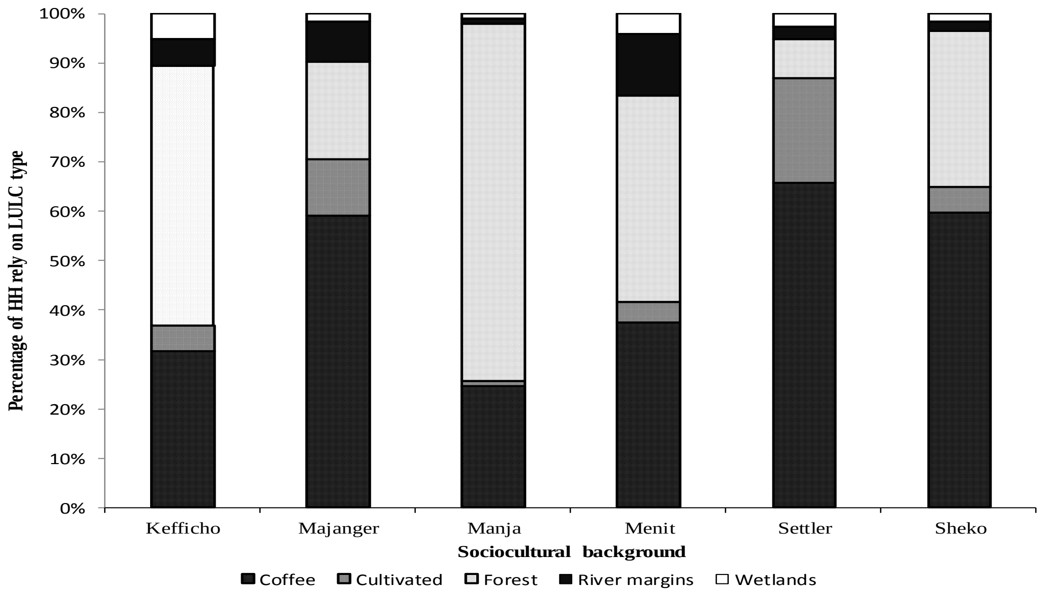

Figure 4. Percentage of households belonging to different socio-cultural groups who depended on ecosystem services from different land-use types

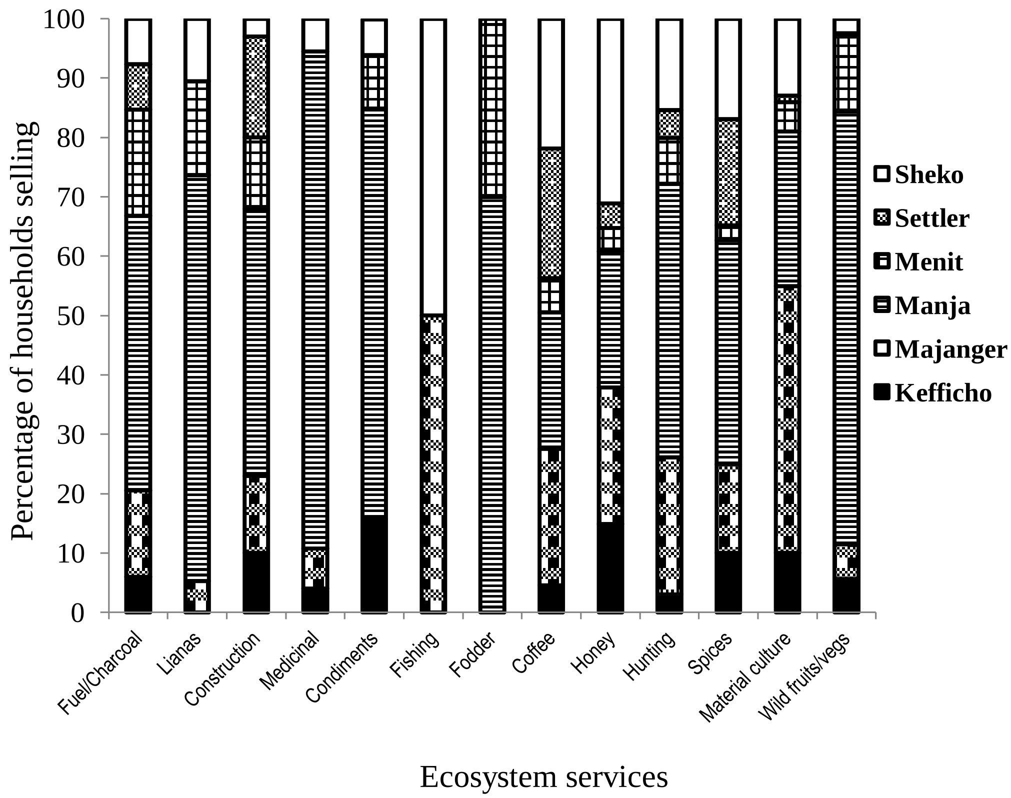

Figure 5. Proportion of households who sold ecosystem services in 2010 by socio-cultural groups

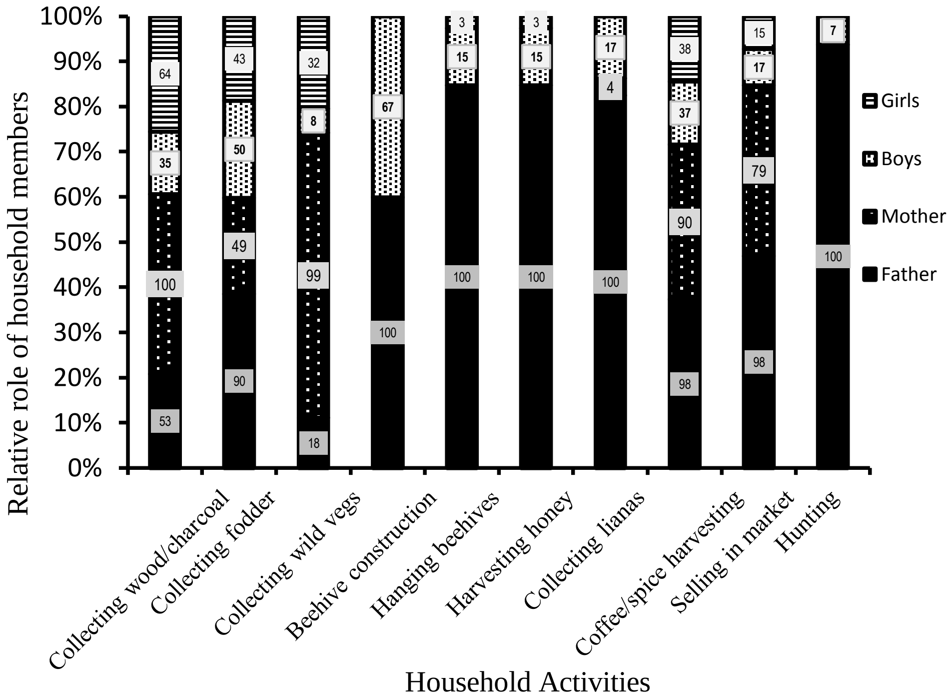

Figure 6. Relative roles of household members in collection and marketing of ecosystem services

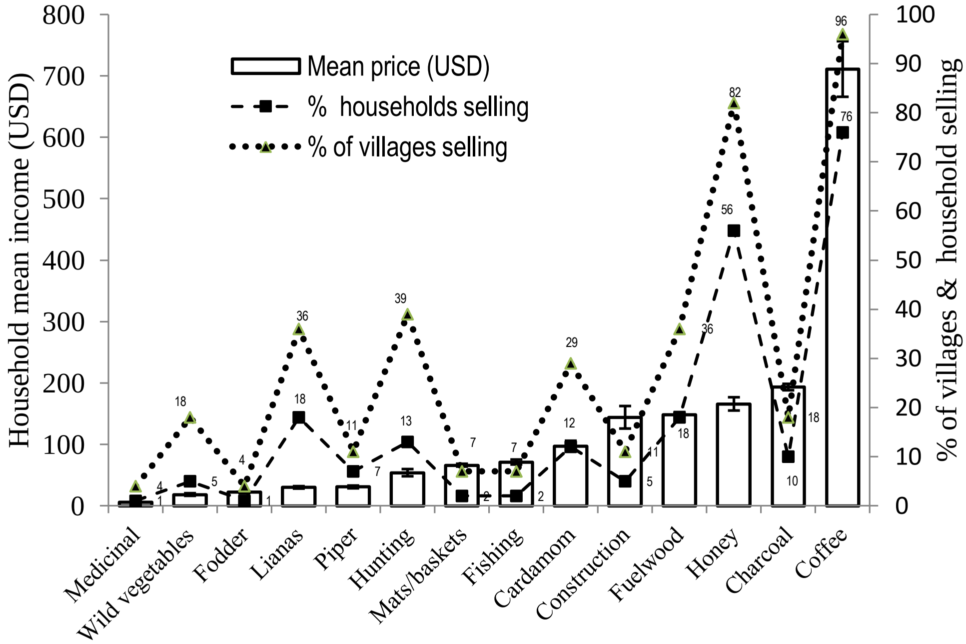

Figure 7. Mean annual household sales of ecosystem services in 2010, village and household frequencies denote % of villages and households reported for sold goods

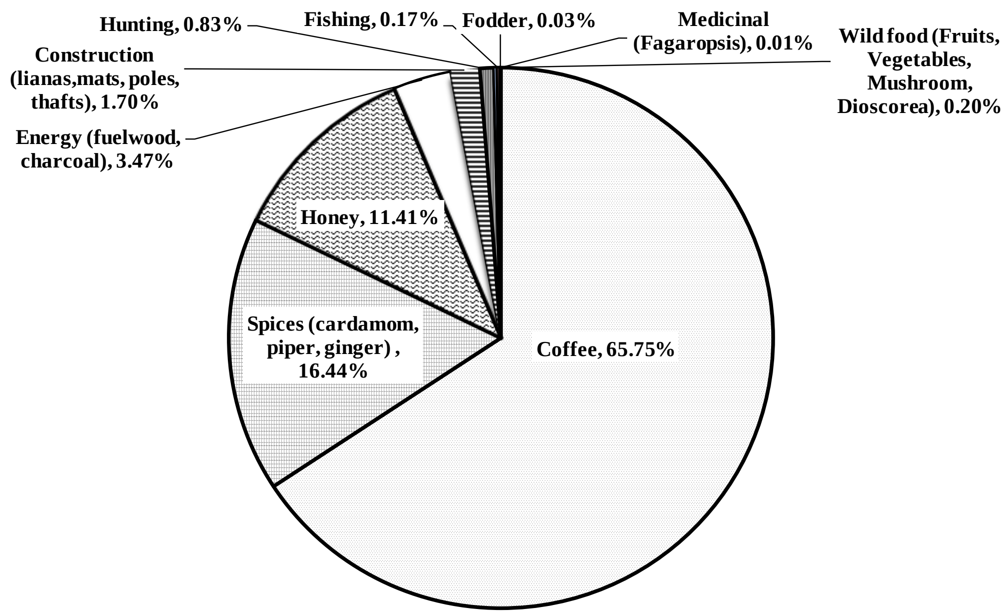

Figure 8. Contribution of major ES by total direct market value (average per household) in the year 2010

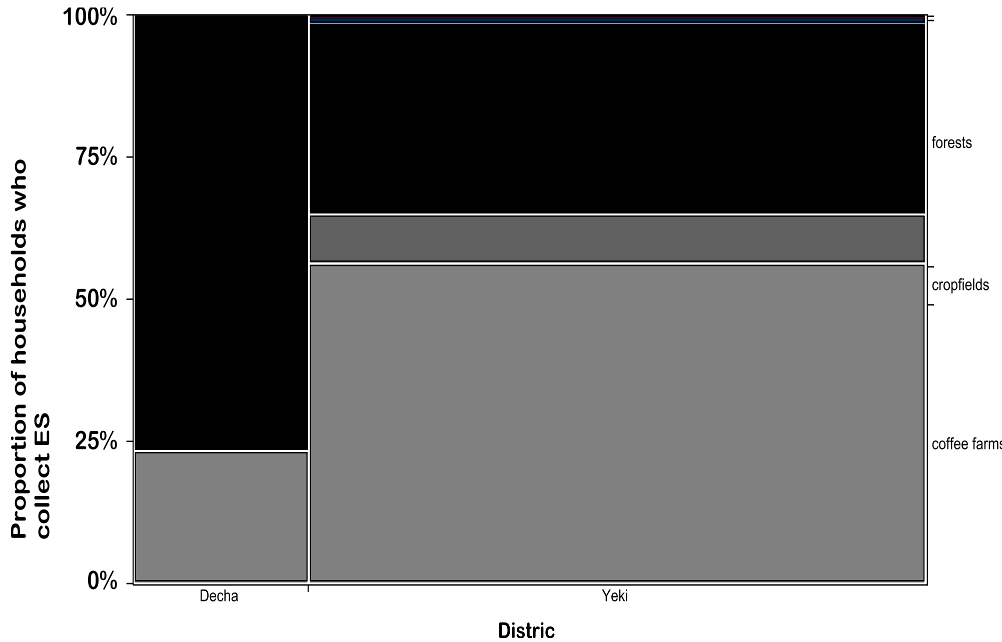

Figure 9. Percentage of households in two regions of varied forest cover who depended on coffee farms and forests

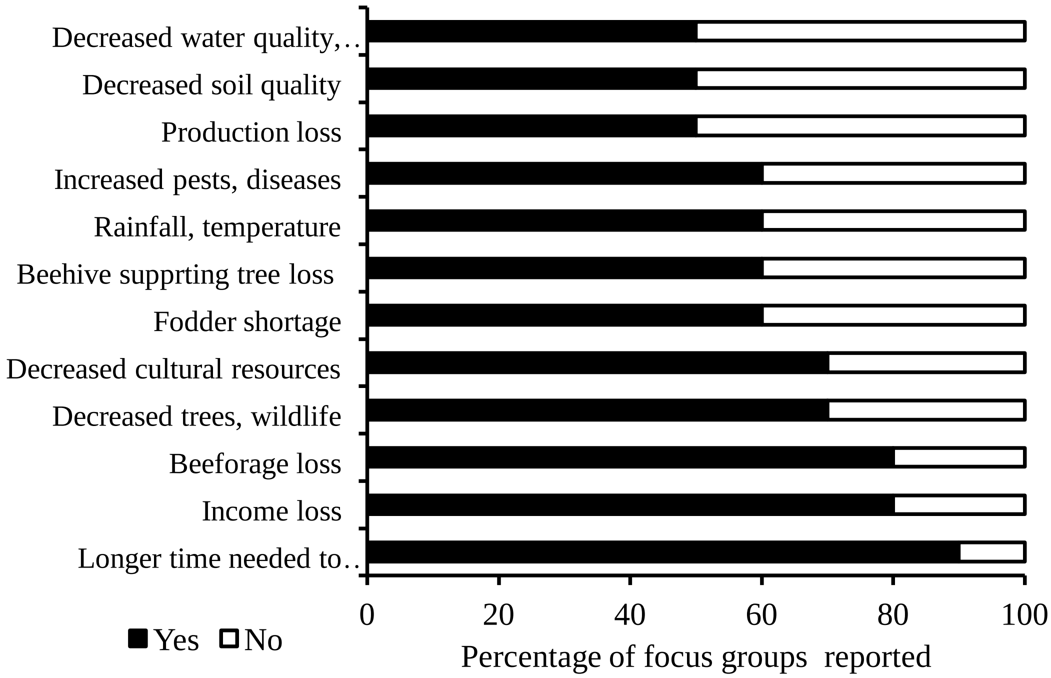

Figure 10. Perceptions of informants on the effect of LUC on ecosystem services

Table 1. Socioeconomic composition/characteristics of focus group participants

Village	Household survey			Focus group discussion				
	Gender composition F	M	Mean Age	Dominant sociocultural group	N	Age range	Forest cover	Major economic activity in decreasing order of importance
A.Berhan	12.5	87.5	43	Settlers	8	25-65	Low	Cultivated, coffee, honey
Awarada	14.3	85.7	41	Kafficho	8	23-63	High	Cultivated, coffee, spices
Baha	7.1	92.9	45	Kafficho	9	20-62	Medium	Cultivated, coffee, spices
Bechi	15.4	84.7	44	Mixed	14	28-70	Medium	Coffee, cultivated, honey
Beko	7.7	92.3	45	Settlers	14	22-67	Low	Coffee, cultivated, honey
Chingawa	7.1	92.9	42	Shakicho	13	27-68	High	Honey, livestock, cultivated
Ermo	9.1	90.9	44	Kafficho	10	24-65	Medium	Cultivated, coffee, spices
Fide	10	90	39	Mixed	9	26-67	Low	Cultivated, coffee, fishing/hunting
Rimich	10	90	40	Shakicho	12	28-30	High	Coffee, honey, cultivated
Shay	8.3	91.7	54	Mixed	14	35-37	Low	Coffee, cultivated, honey

Table 2. Major goods and services reported by local communities (% frequency) in this study

ES categories (MA, 2005)	Local values frequency (%)
Provisioning: wild food (fruits, vegetables, meat, mushroom), fiber, honey, spices, medicinal, fodder, construction (lianas, tools, material culture), energy (biomass, fuel wood, charcoal)	62
Cultural: *Kobbos*, *Guddos* (cultural forests), *Adbars*, ecotourism, recreation	10
Supporting: nutrient cycling, foliage/trees, capture leached nutrients, N-fixation, shade coffee	8
Regulation: of (micro)climate, watershed, disease, invasive species, pests, landslide/erosion, flood; drought mitigation	20

Table 3. Ecosystem services (ES) diversity indices of reported goods and services from 6 different landscapes

Indices	Forests	Coffee farms	Home-gardens	Arable fields	Grassland	Wetlands & others
ES richness	44	27	5	8	4	7
Frequency (%)	51.0	37.6	2.6	5.5	1.0	2.4
Shannon (H')	3.0	1.9	1.5	1.7	1.4	1.6
Evenness (J')	0.5	0.3	0.9	0.8	1.0	0.9

Table 4. Ordinal ranking by studied villages (V), 0 refers rank not given, 1= highest, 10 = lowest.

Ecosystem services	V 1	V 2	V 3	V 4	V 5	V 7	V 8	V 9	V10	Mean Rank	Universality (%)
Construction	2	3	1	2	1	1	3	2	2	1.9	100
Fodder	3	7	4	0	2	6	6	6	5	4.9	90
Honey production	1	5	2	4	4	4	0	3	4	3.4	90
Water/soil conservation	7	2	5	5	5	0	0	7	8	5.7	80
Coffee shade/production	0	4	3	3	0	2	5	1	1	2.7	80
Fuel wood	3	0	0	0	3	3	4	0	3	3.2	60
Medicinal	6	6	0	0	0	0	7	5	0	6.0	50
Climate regulation	0	1	0	1	0	5	0	8	0	3.8	50
Hunting	0	0	6	6	0	0	1	0	6	4.9	50
Wild food	4	0	0	0	0	0	1	0	0	2.5	30
Cultural/Ritual services	5	0	0	0	0	0	0	4	0	4.5	30

Table 5. Livelihood ordinal ranking by households, mean income per household from selling goods, and average time needed to collect ES.

Background	Mean family size	Mean land size (ha) ±SD	Livelihood rankings						Mean Income $ ±SE	Mean time (hr) ±SD
			crop	livestock	coffee	Spices	honey	fuel		
Kafficho	7	2.3^{ab}±0.7	1	4	2	2	4	6	363^{ab}±182	2.1^{ab}±0.77
Majangir	6.1	2.8^{ab}±1.2	1	6	2	2	2	5	431^{ab}±64	1.6^{ab}±0.27
Manjo	7	1.7^{b}±0.9	2	5	3	4	5	1	198^{b}±50	1.3^{b}±0.21
Menit	6	1.5^{b}±0.8	1	5	2	2	6	2	161^{a}±102	2.8^{a}±0.43
Settlers	5.8	2.2^{a}±1.5	1	3	2	3	3	6	471^{a}±78	1.2^{b}±0.32

Shakicho	7.4	2.7[a]±1.0	1	5	2	4	2	6	323[ab]±64	1.0[b]±0.27

Appendix.1. Questionnaire: Ecosystem goods and services (EGS) and local livelihoods under changing land-use (LULC) in southwest Ethiopia

PART I: FOCUS GROUP DISCUSSIONS (FGD)

I. General Information

Group______________________________ Date_________________

Name of Participant	village	Sex	Age	Religion	Educ.	Occupation	Represented from

II. Description of Land Cover Changes & Ecosystem Services

1. How do you define ecosystem goods & services?

____

____

____

2. What kinds of ecosystem goods & services are found in your community?

EGS type	Local Importance	Found mainly in Availability	Ownership Access	

3. Botanical description of the tree or species (to be completed by the investigator & FGD)

Local name	Species name	Family	EGS obtained

4. Plant parts used for the EGS (to be completed by the investigator)

EGS[1]	Flower	Seed/fruit	leaf	Branch	Root	Bark	Sap	Whole plant
Food								
Fodder								
Soil/water conservation								
Medicinal								
Construction								
Bee forage								
Beehive hanging								
Pollination								
Rituals/cultural								
Others								

5. Ranking of the 10 most important ecosystem goods or services

Informant	Ecosystem goods or service	Rank Score	Reason for Ranking	Found in	Abundance

III. Seasonality & Availability

6. At which season (s) does the community use most of the ecosystem goods & services?

____

7. Are the most important goods & services or their providers locally abundant? (refer 4 above)

[1] honey, pollination services, coffee, spices, fodder, food, fiber, disservices (pests, diseases), construction materials, medicinal plants, nitrogen fixation and soil conservation

IV. Changes in LULC & EGS, Drivers & Effects

8. What major changes in the land use land cover (forests, grazing fields) have been observed?
   a. Dergue (1967 E.C/1974 G.C)
   b. EPRDF (1983 E.C/1991 G.C)

   Now (2000s)

9. What major changes did you observe?

Change	Yes/No	Cause	Effect
Land cover			
Land use			
Land tenure			
Deforestation			
Settlement patterns			
Biodiversity			
Others (specify)			

10. If there is biodiversity change, what did you observe?

a. Species becoming rare

b. Species becoming abundant

c. Other (specify)

11. What do you think are the drivers for the observed land cover changes & deforestation?

	Proximate	Underlying	Endogenous	Exogenous
Population growth				
Poverty				
Climate change				
Policy				
Migration				
Conflict				
Market				
Institutions				
Others				

12. What do you think are the consequences of LULC changes on EGS?

Effect	Yes/No	Particular EGS affected	Socioeconomic groups affected
Loss of income			
Loss of food production			
Loss in livestock feed			
Loss in bee forage			
Loss in trees for hanging beehives			
Loss of soil/ nutrients			
Water quality & amount			
EGS availability (distance to collect)			
Change in amount & Seasonality of RF			
Climate change			

Biodiversity loss			
Loss in pollination services			
Change in disservices- pests & diseases			
Loss of cultural & ritual resources			
Others (specify)			

V. Vulnerable Socioeconomic Groups & EGS

13. Who do you think is more dependent on ecosystem goods & services in your community?

____

____

14. Which members of the community (women, children, landless, poor) do you think are most affected by such changes?

____

Why do you think these groups are more affected?

____

Which EGS providing species are the most affected?

____

VI. Management and Coping Strategies

15. Do you manage ecosystem goods & services?

____

Could you mention the major coping strategies your community use to overcome problems associated with loss of forests, native trees & associated ecosystem goods & services?

____

____

16. List of community conservation practices that protect ecosystem goods & services

____

17. Cultural map of the village (showing resources, ecosystem goods & services, land use/cover units, forests, villages, farms, pasture, wastelands) (*Separate sheet needed*).

____

PART II. HOUSEHOLD SURVEYS

I. GENERAL INFORMATION

1. Name______________________________Age______Sex____Education_
2. Village___________________________P.A. ____________________________
3. Family size_______________________Total land ____________________
4. How long have you lived in the area? ______________________________
5. Land use/cover type owned ____
6. Livestock owned:

Livestock	Number
Ox	
Cow	
Sheep and goats	
Equines	
Beehives	
Others	

7. Ranking of your major sources of income /livelihood

Major livelihood	1st	2nd	3rd	Remark
Crop cultivation				
Livestock production				
Coffee				
Spice				
Honey				

Charcoal				
Fuel wood				
Others				

8a. Land use/cover types you own & providing ecosystem goods & services

Major land cover types	**Size**	**Major EGS types obtained**
Home gardens /Agroforests		
Natural forests		
Coffee farms		
Crop/cultivated fields		
Plantations		
Grazing lands		
Others		

8b. If you 3 hectares of the following land cover types, which of these do you think you get the most values from?

Land use type	Rank	Reason
Natural forest		
State coffee		
Small-scale coffee		
Cropland		
Grazing land		
Homegarden/plantation		

II. Land use land cover and ecosystem goods and services

8. What are the most important EGS providing species

EGS	Species
Fodder	
Construction	
Honey	

EGS	Species
Spices	
Coffee shade	
Wild meat/edible plants	
Medicine	
Charcoal/Fuel wood	
Climbers	
Soil conservation	
Others	

9. What **services or disservices** are particularly associated with forests around you?

Disservices	Availability
Disease	
Pests- monkeys	
Pests- birds	
Pests- insects	
Others	

10.2 Seasonal availability of Ecosystem goods and Services

Month	September-October	Nov_Dec	Jan-Feb	March-April	May-June	July-August
Honey						
Kororrima						
Piper						

III. CONSUMPTION AND MARKETING OF EGS

10. **Consumption and marketing** of ecosystem goods and services collected

EGS type	amount consumed yr^{-1}	Amount sold yr^{-1}	price/sack or bartered	Major LULC collected	Time needed to collect/hrs.
Wild food/meat					
Fodder					
Construction					
Honey					
Spices					
Coffee					
Medicine					
Charcoal					
Fuel wood					
Climbers					
Luya					
Acho					
others					

***Who in the community sells: *Luya*? *Acho*? Charcoal? Fuel wood? Climbers?

11. Which **household member** collects the goods and/or sells ecosystem services

Activities	Father	Mother	Boys	Girls
Collecting wood/charcoal				
Collecting fodder				
Collecting wild food				
Beehive construction				
Hanging beehives				
Harvesting honey				
Collecting climbers				
Coffee/spice harvesting				
Selling in the market				

Hunting				
Others				

IV. CHANGES IN LULC AND ECOSYSTEM SERVICES

12. What major changes have you observed during the last 35 years?

Changes in	1970s/Dergue	Major reason[2]
Forest size		
Grazing land		
Cultivated land		
Agroforests		
Plantations		
Fallowing		
Livestock productivity		
Invasive species		
Others/specify		

13. What major biodiversity or **SPECIES** changes do you observe? [3]

LULC owned	Increased	Decreased/lost	Unchanged	Causes
Home gardens				
Cultivated fields				
Forests				
Grazing				
Others				

14. What are the major changes in EGS for the last 35 years?

EGS type	**D/I/NC[4]**	**Major Causes**	**Major Effects**
Wild Food			

[2] Population growth, poverty, market, fragmentation, selective logging, land cover conversions could be mentioned (to be coded by the investigator)

[3] Separate sheet is needed to record the species information

[4] D= decreased; I= increased and NC= no change

EGS type	D/I/NC[4]	Major Causes	Major Effects
Fodder			
Construction			
Honey/hives			
Spices			
Coffee			
Wild meat			
Medicine			
Charcoal			
Fuel wood			
Climbers			
Others			

15. What have been the values of ecosystem goods & services lost due to habitat fragmentation & deforestation? Are the most valuable goods & services becoming rare or abundant?

____

____

16. If there are losses in EGS, what livelihood changes have you done to overcome or compensate for these losses?

Lost EGS in forests	Coping strategies	Substitutability in HG/AG/PL[5]
Wild Food		
Fodder		
Construction		
Honey		
Spices		
Coffee		

[5] HG= Homegardens, AG= agroforests, PL= plantations

Wild meat		
Medicine		
Charcoal		
Fuel wood		
Climbers		
INCOME		
Others/specify		

17. Do you select species around settlements for wood, shade, beehive hanging, farm utensils, market values and any other services?[6]

Species	Most Desirable trait

Further questions

20a. Ranking of timber/wood for various purposes

Purpose	Rank										
	1	2	3	4	5	6	7	8	9	10	Species
House construction											
Beehive construction											
Farm tools											
Furniture											
Poles											
Termite resistance											
Others, specify											

20b. Local use categories of woods

Use category	Use	DBH range	Species	Silvocultural properties	Area mostly available

[6] Species with their desirable traits to understand human filtered traits will be collected here

21. Would you think of all the materials your house is built from and tell the species used for construction?

House part	Construction material	Species	Source	Durability (years)

21. Ranking climbers based on use and availability

Climbers	**Rank**										**Remark**
	1	2	3	4	5	6	7	8	9	10	
Landolphia											
Hippocratea											
Paulinnia											
Clematis hirusta											
Cissampelos											
Cissus petiolata											
Oncinotis tenuiloba											
Tiliacora caffra											
Landolphia owrensis											
Cissampelos pariera											
Eugenia bukombensis											
Sericostachys scadens											
Erythrocca trichogyne											

18. Ranking trees suitable for coffee shade

Species	Rank	Reason

Appendix 2. Woody species (and associated life forms of ecosystem service values) found in the study region with their corresponding Importance Value Index in the forests and coffee farms (FF= Forest fragments, GF= State-owned farms, SF= Smallholder farms)

Species name	Family	FF	GF	SF
Acanthus eminens	Acanthaceae	0.1	0	0
Aframomum korrorima	Zingibraceae	0.9	0	0
Alangium chinense	Alangiaceae	0	0	0.8
Albizia grandibracteata	Fabaceae	0.4	5.8	2.6
Albizia gummifera	Fabaceae	0.5	0	2.4
Albizia schimperiana	Fabaceae	0.6	8.7	7.4
Alchornea laxiflora	Euphorbiaceae	0.3	0	0.2
Allophyllus abyssinicus	Anacardiaceae	2	0	0.8
Allophyllus sapindifolius	Anacardiaceae	0.3	0	0
Alstonia boonei	Apocynaceae	0	0.5	0.4
Anthocleista schweinfurthii	Gentianaceae	0	0	0
Antiaris toxicaria	Moraceae	0.2	4.9	0.6
Apodytes dimidiata	Iacinaceae	0.5	0	0.4
Argomullera macrophylla	Euphorbiaceae	0.1	0	0.2
Artabotrys monteiroae	Annonaceae	0.4	0	0
Arundo donax	Poaceae	0	0	0
Asparagus africanus	Asparagaceae	0	0	0
Baphia abyssinica	Fabaceae	1.9	0.5	3.8
Basella alba	Basellaceae	0	0	0
Bersama abyssinica	Melianthaceae	2.9	0	1
Bixa orellana	Bixaceae	0	0	0
Blighia unijgata	Sapindaceae	0	0	0.2
Breonadia salicina	Rubiaceae	0	0	0
Bridelia micrantha	Euphorbiaceae	0	0	0.2
Brucea antidysenterica	Simaroubaceae	0.2	0	0.6
Caesalpina sp.	Fabaceae	0.1	0	0
Canthium oligocarpum	Rubiaceae	2.1	0	1
Capparis tomentosa	Capparidaceae	0	0	0.2
Cassipourea malosana	Rhizophoraceae	0	0	0.4
Ceiba pentandra	Malvaceae	0	0.5	0
Celtis africana	Ulmaceae	0.9	2.4	2.2
Celtis gomphophylla	Ulmaceae	0	0.5	0.4
Celtis phillipensis	Ulmaceae	0	1.5	0.2

Species name	Family	FF	GF	SF
Celtis zinkeri	Ulmaceae	0	1	0.4
Chasmanthera dependns	Menispermaceae	0	0	0
Chionanthus mildebraedii	Oleaceae	3.5	0	0
Clausenia anisata	Rutaceae	1.3	0	1.6
Clematis longicauda	Ranunculaceae	0	0	0
Clerodendrum myricoids	Lamiaceae	0	0	0
Coffea arabica	Rubiaceae	1.8	0	0.8
Combertum molle	Combretaceae	0	0	0.6
Conyza pyrrhopapa	Asteraceae	0	0	0
Cordia africana	Boraginaceae	1	20.4	5.6
Croton macrostachyus	Euphorbiaceae	2	1.5	5.4
Croton sylvaticus	Euphorbiaceae	0	0	0.2
Cyathea manniana	Cyatheaceae	0.7	0	0
Deinbollia kilimandscharica	Sapindaceae	1.3	1	1
Diospyros abyssinica	Ebenaceae	0.9	2.4	2.8
Dombeya torrida	Sterculiaceae	0.4	0	0.6
Dracaena afromontanum	Dracaenaceae	3.1	0	0.6
Dracaena fragrans	Dracaenaceae	1.5	0	0.6
Dracaena steudneri	Dracaenaceae	0.1	0	0
Ehretia abyssinica	Boraginaceae	0.5	0	1.2
Ekbergia capensis	Meliaceae	0.5	0	0.6
Elaeodendron buchannani	Celesteraceae	1.2	1.9	1.6
Embelia schimperi	Myrsinaceae	0.2	0	0.2
Erythrina brucei	Fabaceae	0	0	0
Eugenia bukobensis	Myrtaceae	0	0	0
Euphorbia abyssinica	Euphorbiaceae	0.2	0	0
Euphorbia candelabrum	Euphorbiaceae	0.3	0	0
Euphorbia pulcherima	Euphorbiaceae	0	0	0
Fagaropsis angolensis	Rutaceae	0.6	1.5	0
Fagaropsis angolensis	Rutaceae	0	0	0
Ficus exasperata	Moraceae	0.4	1.9	1.4
Ficus lutea	Moraceae	0	1.5	0
Ficus mucuso	Moraceae	0	0	0
Ficus ovata	Moraceae	0.3	0.5	0
Ficus palmata	Moraceae	0	0	0
Ficus sur	Moraceae	1.3	1	1.4
Ficus sycamorus	Moraceae	0.5	1	0.4

Species name	Family	FF	GF	SF
Ficus thonningi	Moraceae	0	0	0
Ficus thonningi	Moraceae	0.1	0.5	0
Ficus vallis-chaudae	Moraceae	0.1	0	0
Ficus vasta	Moraceae	0	0	0.4
Flacourtia indica	Flacourtiaceae	0.1	0	0
Galineiria saxifraga	Rubiaceae	2.1	0	1
Garcinia buchannani	Clusiaceae	0	0	0
Gomphia sp.	Ochnaceae	0	0	0
Gouania longispicata	Rhamnaceae	0	0	0
Greviella robusta	Proteaceae	0	0.5	0
Grewia mollis	Tiliaceae	0.1	0	0
Grewia trichocarpa	Tiliaceae	0	0	0.2
Hallea robrostipulata	Rubiaceae	0	0	0
Harungana madagascarense	Rubiaceae	0	0	0
Hilleria latifolia	Phytolacaceae	0	0	0
Hippocratea africana	Celesteraceae	0.1	0	0.2
Hippocratea goetzei	Celesteraceae	0.2	0	0
Ilex mitis	Aquifoliaceae	2.2	0	0.4
Jasminum abyssinicum	Moraceae	0.4	0	0
Justicia schimperiana	Moraceae	0.2	0	0
Landolphia buchananii	Moraceae	1.3	0.5	0.4
Landolphia buchananii	Apocynaceae	0	0	0
Landolphia owariensis	Moraceae	0.3	0	0.2
Lannea welwitschii	Moraceae	0.9	2.4	1.6
Lannea welwitschii	Anacardiaceae	0	0	0
Lecaniodiscus fraxinifolius	Sapindaceae	0	0	0
Lepidotrichillia volkensii	Meliaceae	1.3	0	0.6
Lobelia gibberoa	Lobeliaceae	0	0	0.4
Lonchocarpus laxiflorus	Fabaceae	0	0	0
Macaranga capensis	Euphorbiaceae	1.5	0	1.4
Maesa lanceolata	Myrsinaceae	1.2	0	1
Mallotus oppositifolius	Euphorbiaceae	0	0	0
Manilkara butugi	Sapotaceae	1.6	1	2
Maranthacloa leuacantha	Maranthaceae	0	0	0
Margaritaria discoidea	Myrtaceae	0.1	0	0
Maytenus gracilipes	Celesteraceae	2.1	0	1.2
Maytenus gracilipes	Celesteraceae	0.1	0	0.2

Species name	Family	FF	GF	SF
Milicia excelsa	Moraceae	0.3	6.8	0.8
Milletia ferruginea	Fabaceae	3	2.9	8.8
Mimusops kummel	Sapotaceae	2.2	1.9	3.8
Mimusops laurifolia	Sapotaceae	0	0	0.2
Morus mesozygia	Moraceae	0	1.9	0.8
Ocotea kenyensis	Lauraceae	1.7	0	0
Olea welwitschii	Oleaceae	4.8	0	0
Oncoba routledgi	Flacourtiaceae	0	0	0.2
Oxynathus speciosus	Rubiaceae	2.7	0	0.2
Passiflora edulis	Passifloraceae	0.1	0	0
Paullinia pinnata	Sapindaceae	0.2	0	0
Pentas schimperiana	Rubiaceae	0	0	0
Phoenix reclinata	Arecaceae	3.2	1.5	4
Phyllanthes sepialis	Euphorbiaceae	0.3	0	0.2
Physalis peruviana	Solanaceae	0.1	0	0.2
Piper capense	Piperaceae	1.6	0	0.2
Pittosporum virdiflorum	Pittosporaceae	0.8	0	1
Polyscias fulva	Araliaceae	0.9	0	1.4
Pouteria adolfi-friedericci	Sapotaceae	1.3	1.5	2
Pouteria alnifolia	Sapotaceae	0	0	0.4
Pouteria altissima	Sapotaceae	1.1	7.8	2.4
Premna schimperi	Lamiaceae	0.1	0	0.6
Prunus africana	Rosaceae	0.5	0	0.2
Rhamnus prinoides	Rhamnaceae	0.1	0	0
Ricinus communis	Euphorbiaceae	0	0	0.2
Rinorea ilicifolia	Violaceae	0	0	0
Ritchea albersii	Capparidaceae	0.4	1	0.2
Rothmania urcelliformis	Rubiaceae	2	0	0.2
Rubus rosifolius	Rosaceae	0.1	0	0
Rytigina neclecta	Rubiaceae	0.8	0	0.2
Sapium ellipticum	Euphorbiaceae	1	1.9	0.8
Schefflera abyssinica	Apiaceae	1.1	0	0.6
Schefflera volkensii	Apiaceae	0.2	0	0
Senecio gigas	Asteraceae	0	0	0.4
Syzigium guineese	Myrtaceae	3.4	0	0.8
Teclea nobilis	Rutaceae	0.9	0	0
Tilacora troupini	Menispermaceae	0.9	0	0

Species name	Family	FF	GF	SF
Tinospora caffra	Urticaceae	0	0	0
Trema orientalis	Ulmaceae	0	1	0.2
Trichillia dregeana	Meliaceae	0.1	2.9	0.6
Trichillia purreara	Meliaceae	0.1	0	0
Trilepsium madagascarense	Moraceae	3.2	2.4	0.8
Turrea holstii	Meliaceae	0.4	0	0.2
Vepris danielli	Rutaceae	4	0	0.6
Vernonia amygdalina	Asteraceae	0.2	0	1
Vernonia auriculifera	Asteraceae	0	0	1
Vernonia exasperata	Asteraceae	0	0	0.4
Zanha golugensis	Sapindaceae	0	0.5	0

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