2016

Missing the Trees for the Forest: The Socioecological Significance of Dispersed Farmland Trees in Northern Ethiopia

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May 16, 2016

A thesis submitted to the faculty of the Environmental Studies Program in partial fulfillment of the graduation requirements for the Degree of Bachelor of Arts with honors in Environmental Studies.

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ABSTRACT

Scattered trees are prominent features in the agricultural landscape of the Ethiopian highlands. The dry Afromontane forests of the Amhara Region in northern Ethiopia have faced centuries of deforestation - the FAO estimates only 3% of the region is forested today. The remaining landscape has been largely converted into agricultural and grazing lands, with the exception of some limited government-protected lands, as well as thousands of small forest fragments left around Orthodox Churches (“church forests”). But while a growing body of scholarship has highlighted the ecological and cultural importance of church forests and other natural forest fragments, the roles of scattered remnant trees left in actively cultivated agricultural systems remains understudied. The ecological and socio-cultural benefits of scattered trees is widely acknowledged in some human-modified landscapes, including in the context of agroforestry where such trees provide important ecosystem services such as carbon sequestration, erosion control, water quality enhancement, biodiversity conservation, pollination, and topsoil enrichment, as well as numerous economic benefits including food, fodder, and fuel. This study examines the measured and perceived temporal change in scattered tree abundance in non-agroforestry systems, through Geographic Information Systems (GIS) analyses and social survey data collection in croplands in the Amhara Region. Findings from GIS analyses indicate a surprising increase in scattered tree abundance since the 1960s and ground-truthing indicates that remnant tree scattered tree species are very diverse. In social surveys, farmers also report a perceived increase in tree numbers on cropland in recent decades – with social survey responses emphasizing the considerable economic importance and perceived ecosystem services of tree species as justification for why scattered trees are retained even when they interfere with crops. The study results highlight the importance of scattered trees on farmland and suggest policy interventions for single tree-scale conservation and scattered tree restoration across northern Ethiopia.

ACKNOWLEDGMENTS

I would like to sincerely thank my thesis advisor, Assistant Professor of Environmental Studies Travis W. Reynolds for all his valuable guidance, persistent enthusiasm, and constant mentorship throughout this project. I would like to thank my reader, GIS and Quantitative Analysis Specialist and Research Scientist in Environmental Studies Manny Gimond, for helping me implement spatial analyses and answering my unrelenting questions. I would also like to thank Manny for being such a warm and welcoming presence in Diamond and allowing me to live in the GIS lab. Thank you also to my third reader Bruce Rueger for his time and insightful suggestions. I can’t thank Hannah Peters ’19 enough for all of the incredibly hard work she put into helping me with all of the Google Earth work. This project would not have been possible without Dr. Alemayehu Wassie who has provided constant support for the past three years and the Clare Boothe Luce Assistant Professor of Biology Cat Collins for the incredible mentorship throughout this project. I would also like to thank Gezahegn Ayinie for helping me implement the social surveys and for being a good friend. Janice Liang, a huge thanks goes out to you for making all of the trips to Ethiopia a blast and putting up with me for months on end. Thank you also to Tizezew Shimekach Sisay, Sam Lovell, and all of the REU students: Ralph Olacio, Chloe Geffken, Annika Min, Wilford Briggs, Klaus DeBoer, Tracy Gatumu, Dawn Brown, Yenesew, Walelign Alemu, Kilash Kifili, and Zeneb Awoke. This project would not have been possible without you. Finally, a huge heartfelt thank you to all of the respondents who so willingly took my survey and welcomed me into their homes. I will never forget those wonderful moments.

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Introduction

The problem of land degradation is severe across Ethiopia with extreme poverty and rapidly growing populations adding to the intense strains on Ethiopia's natural resource base (Desta, 2000). Forested and tree-scattered landscapes represent the last refuge of biodiversity and ecosystem function in Ethiopia. For decades Ethiopia has been seen by the developed world as a country of famine, prevalent hunger, food shortages, and an enduring dependency on foreign aid, with the 1984-85 famine cementing this image (Horne, 2011). While the state of famine is not a constant, Ethiopia remains one of the poorest countries in the world, currently experiencing high levels of acute and chronic food insecurity especially among rural households and small-scale farmers (United States Agency for International Development (USAID), 2015). Faced with food price spikes, recurring drought, and food insecurity, Ethiopia is currently the largest recipient of food aid in the world (WFP, 2013).

Agriculture is the foundation of Ethiopia's economy accounting for half of gross domestic product and 90% of exports (USAID, 2015). More than 85% of the population resides on rural lands and is involved in an agricultural based profession (Haileselasie, 2011). The Ethiopian government has put a large emphasis on agricultural development as a means to alleviate food insecurity while improving Ethiopia's economy (Abbink, 2011). Much of this agricultural development is in the form of large-scale commercial operations by foreign investors usually growing cash crops for export, such as sugarcane, cotton, and rice (Abbink, 2011; Horne, 2011). In the context of fighting food insecurity, improving human health, and alleviating poverty, the Ethiopian government has considered sustainable land management and environmental policies in general as secondary priorities. Large-scale agricultural development can threaten adjacent ecosystems and human populations but its potential for economic growth and food security generally triumphs (Rahmato, 2011).

Expansion of agricultural land is one of the principal causes of biodiversity loss, land degradation and deforestation in tropical countries (Phalan et al., 2013). In Africa, most of the deforestation is caused by agricultural expansion, largely by smallholder farmers

(Garrity, 2011). This is especially true in Ethiopia in which both large- and small-scale agricultural development are the main drivers of land degradation, deforestation, and loss of biodiversity due to clear cutting for the expansion of agriculture (Dessie and Kleman, 2007; Taddese, 2001). Forest cover across the country has declined from about 40% in the 1900s to around 4% today, largely due to agricultural development (Teketay et al., 2010).[1]

In the agricultural context, land degradation is exhibited in the form of soil fertility loss initiated by numerous factors including deforestation, soil erosion, severe soil moisture stress, and poor and continuous cultivation designs (Yebo, 2015; Desta, 2000). Soil fertility loss, which is the result in loss of soil depth and organic matter, leads to a vicious cycle of ecological degradation, poverty, and food insecurity (Desta, 2000). The Ethiopian government uses fertilizer as a blanket recommendation for soil fertility loss, which is often not a successful strategy due to differing agro-climates, soil conditions and socio-economic status of farmers across the country (Yebo, 2015). Innovative agricultural techniques at the local level will be a vital part of solving the growing problem of environmental degradation, soil fertility loss, and food security in Ethiopia.

Agroforestry, defined as the intentional incorporation of trees or shrubs into crop and animal farming systems (Sanchez, 1995), provides a potential solution to combat soil fertility loss and environmental degradation while also improving the profitability and sustainability of small-scale agricultural systems (Jose, 2009). Agroforestry integrates the most environmentally appealing aspects of forestry and agriculture into the same system in which the interactions between the two components are highlighted in order to enhance sustainability (Steppler and Nair, 1987). By design, agroforestry is considered to create more diverse, profitable, and biologically productive agricultural systems than monocultures or forestry systems (FAO, 2013). As the benefits of agroforestry are currently being identified (Sanchez, 1995; Nair, 1998; Jose, 2009, Nair, 2011; Garrity, 2011), its potential has not been fully realized due to a lack of agroforestry development and integration into land use planning and policy formation (FAO, 2013).

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1 These estimates are still heavily disputed today, with others suggesting the forest cover to have been reduced to anywhere from 8% (Parry, 2003) to less than 3% (Bishaw, 2001). Reusing (1998) indicated a deforestation rate of 163,600ha/yr between 1986 and 1990, and the FAO (2007) indicated a 0.93 percent deforestation rate between 1990 and 2000 with an increase to 1.04 percent from 2000 to 2005. These reports combined yield 2,114,000 of forest cover loss from 1990 to 2005 (Teketay et al., 2010).

The fundamentals of agroforestry have been investigated by many institutions and researchers throughout the world (Sanchez, 1995; Nair, 1998; Jose, 2009, Nair, 2011; Garrity, 2011; and see Chapter 3 for a recent comprehensive review), however the role that scattered trees play in the agricultural landscape of Norther Ethiopia is understudied. The purpose of this chapter is to outline the history of land degradation in the Amhara Region and how scattered tree cover change is incorporated into this history.

Background: Land Cover Changes in Ethiopia

Over the past century, Ethiopia has experienced substantial deforestation due to conversion of forested landscapes to agricultural, grazing, and urban land uses, as well as woodcutting for fuel and construction purposes (Bongers & Tennigkeit, 2010; Haileselasie, 2011). Forest clearing continues today (Springsguth, 2013). This section reviews the history of deforestation in Ethiopia, the causes and consequences of deforestation, and the institutions that govern Ethiopia's forests.

Deforestation in Ethiopia

Ethiopia was once rich in natural forests. Several authors have indicated that 40% of the country was historically covered by forests as recently as the early 1900s and has declined to around 4% in only a century (Bongers & Tennigkeit, 2010; Dessie & Christiansson, 2008; Bishaw, 2001; Yirdaw, 1996). These estimates are still heavily disputed, with other authors suggesting that forest cover has been reduced anywhere from 11% (Mekonnen et al., 2016) to 8% (Parry, 2003) to less than 3% (Bishaw, 2001). The EFAP (1994) suggests that in the 1950s about 16% of Ethiopia's area was covered by forest, which then rapidly declined to 3.6% in the early 1980s and 2.7% by 1989. Reusing (1998) indicated a deforestation rate of 163,600 ha/yr between 1986 and 1990, and the FAO (2007) indicated a 0.93 percent deforestation rate between 1990 and 2000. From 1990 to 2010 an estimated 2.65% of the forest cover was deforested in which forest cover decreased from 15.11 million ha in 1990 to 12.2 million ha in 2010 (FAO, 2010; Teketay et al., 2010). Other estimates more recently have indicated an increase of forest cover of about 1.04 percent from 2000 to 2005 (FAO, 2007). Even though estimates of

deforestation vary heavily, it is evident that deforestation has been a sustained environmental problem in Ethiopia.

Despite the dramatic loss of forest over the last century, some studies insist that deforestation in Ethiopia is not just a recent problem and dates back far before the last hundred years. Using historical accounts, Bishaw (2001) suggests that deforestation has been occurring over the last 3000 years, with reports from the seventeenth century describing a lack of forested land due to tree cutting for fuel and construction wood (Pankhurst, 1995). Archived photographs and historical documents indicate that forest resources in Ethiopia were already scarce by the nineteenth century (Nyssen et al., 2015; Meire et al., 2013; Boerma, 2006; Pankhurst, 1995).

Even though the issue of deforestation is not a new problem it has been amplified by rapid population growth (Bishaw, 2001). Ethiopia is the second-most populated country in Sub-Saharan Africa with a population of 96.5 million and a population growth rate of 2.5% in 2014 and 2.92% prior to 2000 (World Bank, 2015; Bekele, 2001). Growing populations have put pressure on Ethiopia's natural resource base as demand has grown for agricultural development coupled with the need for settlement expansion and fuel wood (Assefa & Bork, 2014; Dessie & Kleman, 2007). More than 85% of Ethiopia's population resides on rural lands and practices small-scale cropping, making agriculture the foundation of Ethiopia's rural economy (Haileselasie, 2011). Meanwhile at the national level, agriculture accounts for half of gross domestic product (GDP) and as much as 90% of annual exports (USAID, 2015). Agriculture is therefore not only key to rural livelihoods, but also to the economic welfare of the nation. Although, continuous cropping and agricultural expansion are the main drivers of land degradation, deforestation, and biodiversity loss in the country, short-term increases in agricultural production may be at the cost of long term sustainability of the natural resource base (Dessie & Kleman, 2007; Taddese, 2001; Bekele, 2001; Pankhurst, 1995).

Meanwhile the Ethiopian government has come to view large-scale commercial agricultural development as a pathway to improve food security and human health while alleviating poverty (Abbink, 2011). Because of this, some of the remaining forests in Ethiopia are also under pressure by large-scale agricultural development (Bekele, 2001). Conversion of forested landscapes to agricultural systems not only has direct implications

on biodiversity loss, carbon storage, and other ecosystem services, but deforestation also contributes to soil degradation, which limits agricultural production and further contributes to food insecurity and poverty (Assefa & Bork, 2014; Teketay, 1992; Mekonen, 1998).

Today, deforestation in Ethiopia is very different depending on the region. The remaining natural forested areas are located primarily in the south and southwestern regions (Bishaw, 2001). These forests are still being cleared due to the presence of large tracts of forested land (Bishaw, 2001). In northern Ethiopian, however, excluding plantation forests, few natural forests remain (Wassie et al., 2010). The biggest problem today for the northern forests is forest degradation, with livestock grazing and agriculture expansion putting pressure on forest edges (Wassie et al., 2010; Wubet et al., 2003).

Causes and Consequences of Deforestation in Northern Ethiopia

Estimates of past forest cover suggest that the northern Ethiopian Highlands were once covered by a co-dominant *Juniperus* and *Olea* forest, both of which are seen in today's remnant natural forests (Logan 1946; Teketay, 1992; Wassie et al., 2010). Since then, the dry Afromontane forests of Northern Ethiopia have faced vast exploitation and centuries of deforestation, driven by the conversion of forestland to agricultural land and the need for fuel and grazing land (Wassie et al., 2006). Almost all of the forests in the Northern Highlands have been converted into agricultural lands, grazing lands, or scrublands with the exception of small fragments left either in the most inaccessible areas or around Orthodox churches as "church forests" (Wassie, 2002; Wassie et al, 2006; Wassie, 2007; Wassie et al, 2010; Wassie et al, 2009; Cardelús et al, 2013; Reynolds et al., 2015). Today it is estimated that only 2% of forest cover remains in this region, most of which persists around these Orthodox churches (Wassie, 2002; Wassie, 2007; Wassie et al., 2009).

The Ethiopian Orthodox Tewahedo Church is one of the oldest Christian churches in Africa and has a long history of protecting and preserving trees (Wassie, 2013). As many as eight thousand or more of these church forests have been protected for centuries by church leaders and community members and serve as hubs of forest conservation (Wassie, 2003; Fig 1.1). According to recent studies as many as 170 native trees and

shrubs can be found in the church forests, which also harbor wildlife otherwise absent from the landscape (Gili, 2014; Wassie, 2007). The church forests also supply numerous ecosystem and economic benefits including providing habitats for native bee and other pollinating insect populations, which are essential for agricultural crops and ecosystem functions. The church forests also serve as the last seed banks for native trees in the region since they consist of most of the only intact remnant Afromontane forests in the region (Gili, 2014). The church forests contribute to the restoration of the degraded landscape, biodiversity conservation, and provide many ecosystem, economic and social benefits. However, today the church forests are declining in area and density due to increased population pressure and demand from local communities for agriculture, tree harvesting for fuel wood, and livestock grazing (Wassie et al., 2010; Wassie,et al. 2009, Ceccon et al., 2008).

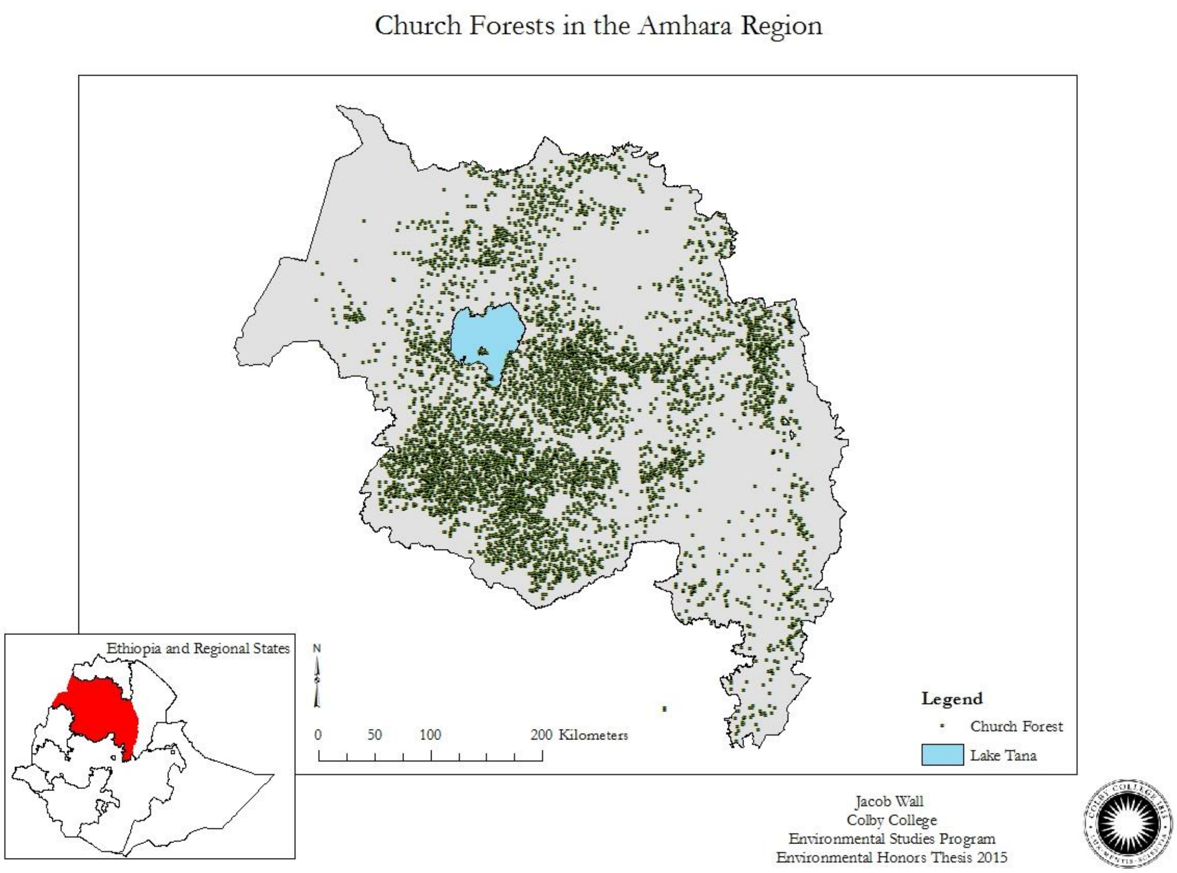


Figure 1.1. Distribution of Church Forest in the Amhara Region

The main concern of forests fragments in the Ethiopian Northern Highlands is forest degradation caused by a number of different factors. The original fragmentation of these forests makes it more difficult for indigenous plants in the forests to sustain populations due to a decline in regeneration status, which also increases the threat to biodiversity (Cardelús et al., 2013). Fragmentation also causes forest species to become more isolated, which leads to demographic constraints such as less access to animal vectors including pollinators and seed dispersers (Wassie, 2007). As fragmentation occurs, the forest edges increase relative to forested area, in which detrimental physical and biotic impacts are increased, such as greater light intensity, elevated wind turbulence, elevated temperature variability, lower soil moisture, and reduced humidity (Murcia, 1995; Debinksi & Holt, 2000). Directly cutting trees for construction and firewood in the forests further promotes forest degradation by affecting the forest structure, leading to decreased levels of biodiversity, and creating gaps in the canopy, which negatively influences soil moisture and water resources of the forested environments (Debinksi & Holt, 2000). Furthermore, the role of repeated livestock grazing for extended periods of time has a negative impact on tree regeneration (Wassie et al., 2009). Continuous grazing causes irreversible damage through soil compaction, erosion exacerbation, loss of air pockets, seed and sapling trampling and feeding, all of which add to the declining regeneration status of these forests (Wassie, 2009, Cardelús et al., 2013).

Institutions Governing Forests in Ethiopia

Over the last century, Ethiopia has witnessed many political transitions and an ever changing economic and social environment (Assefa and Bork, 2014; Pankhurst, 1995). Deforestation and land degradation has been credited to the dynamic nature of Ethiopian politics, which has yielded a complex history of land rights and land ownership (Dessie and Christiansson, 2008; Boerma, 2006). During political transitions large tracts of forested land was cut and degraded largely due to the uncertainty of land tenure security (Dessie and Christiansson, 2008). This next section focuses on the institutions governing forests in Ethiopia and the historical framework that influenced these institutions.

Forest policy in Ethiopia has historically not been a top priority, largely due to a lack of strong environmental institutions and resources for oversight and enforcement (Cleaver & Schreiber, 1994; Abbink, 2011). Because of this, forests have been treated essentially as open access resources, leading to their extensive deforestation throughout the country (Lemenih, 2010). Under the leadership of Haile Selassie during the mid-20th century, a 'modernization' movement swept through Ethiopia's government in an attempt to follow in the footsteps of western industrialized countries (Ayana et al., 2013). This movement emphasized large-scale commercial farming and industry, which consequently pushed forest development and conservation to the background (Ayana et al., 2013). In the mid-1970s the Marxist Derg regime induced land reform by extinguishing all property rights including all privately owned forests (Ayana et al., 2013). During this period, the Derg created an equal per capita redistribution of all farmland across rural Ethiopia in an attempt to encourage agricultural development to address food security, as well as address environmental problems such as deforestation (Hoben, 1995). This was observed through production forestry of exotic fast growing trees, such as pine and eucalyptus (Lemenih, 2010; Devereux & Guenther, 2009). However, repeated redistributions of land weakened the security of land ownership, which ended up causing land degradation due to a lack of motivation for environmentally beneficial land management practices (Hoben, 1995; Cohen and Isaksson, 1988).

The Derg lost power in 1991 to Meles Zenawi and the Tigray People's Liberation Front (TPLF), which became the present-day Ethiopian People's Revolutionary Democratic Front (EPRDF). The Derg system of state-owned land remained largely intact following the change in power (Devereux & Guenther, 2009). Prime Minister Meles Zenawi similarly pushed for commercial farming as a means to address food insecurity (Devereux, 2000). This included encouraging domestic and international investors to lease large tracts of land to boost agricultural production and exports, while ultimately serving to improve the economy (Gebreselassie, 2006). As a result, large-scale agricultural development continued to expand through the 1990s – during which time national forest policy also shifted to include many more specific laws that addressed forest degradation from small- and large-scale agriculture alike (Lemenih, 2010). However, the environmental and social impacts of large-scale agricultural development,

such as deforestation and threats to indigenous communities and wildlife species, were often overlooked as the issues of food insecurity and poverty remained at the forefront of Ethiopian politics (Rahmato, 2011).

Many national, regional, and local institutions and actors play a role in the management of Northern Ethiopia's natural resource base. At the national level, the Ethiopian Environmental Protection Authority (EPA), which was established in 1994, creates policy, laws, and forms strategies involved with monitoring and regulating the Ethiopian Environment (EPA, n.d). The EPA focuses on promoting economic development initiatives that use environmental resources in a sustainable manner (EPA, n.d.). The Ethiopian Ministry of Agriculture and Rural Development (MoARD) is another national institution responsible for implementing development strategies focused around natural resource conservation, food security and rural development (zur Heide, 2012; Awulachew et al., 2009).

The EPA established the Ethiopia's National Conservation Strategy (NCS) in 1997, which is a framework policy that looks to provide guidelines for effective management and conservation regarding Ethiopia's natural resources with an emphasis on human settlements impacts (Awulachew et al., 2009). The policy attempts to enable local participation and empowerment concerning natural resource management. In 1994, a forest law was enacted by the EPA to contribute to forest development and protection of ecosystem services while introducing the principle of benefit sharing with local communities (Lemenih, 2010). This law was followed up in 2007 with Ethiopia's first comprehensive forest policy, "The Forest Management, Development, and Utilization Policy" (FDRE, 2007). This policy, created by the EPA, attempts to promote forest conservation and development, strengthen forest product markets, administer and manage state forests, and prevent deforestation (FDRE, 2007). The main objective of Ethiopia's Forest Management, Development, and Utilization Policy is to meet the forest demands of society while increasing forest resources through applicable management (FDRE, 2007). The policy established two types of forest ownership, including state forests and private forests, in which the government specified that state owned forests would be protected for sustainable development, conservation, and utilization. However, as the name implies, this policy was very much a resource development policy rather than a

resource preservation policy (Rahmato, 2011; FDRE, 2007), and thus did little to protect indigenous forests and scattered trees in Ethiopia.

Regionally, the Bureau of Agricultural (BoA) supports efforts to curb natural resource degradation in the Amhara Region, by monitoring the agricultural, animal farming, forestry, and fisheries sectors as well as providing assistance to rural smallholders. This is realized through oversight over various projects related to forest rehabilitation, agroforestry, sustainable land management, and erosion control (zur Heide, 2012). The BoA also promotes conservation of forest resources through awareness creation and capacity building (Mekonnen et al., 2016). Sustainable use in the Amhara Region is also promoted by the Boreau of Environmental Protection, Land Administration and Use (BoEPLAU). The BoEPLAU is described as a regional equivalent of the EPA, and has established regional environmental regulations that encourage sustainable use of forest and other natural resources, which tend to mimic those established at the national level by the EPA (Awulachew et al., 2009).

Within the Amhara Region, multiple woredas, which are regional districts, and kebeles, which are regional wards, exist as more local governing bodies. In the Amhara Region there are 105 Woredas and 3429 Kebeles. Woredas and kebeles implement regional policies as well as are important advocates for sustainable land management at the local level. The MoARD, working with the EPA and the BoEPLAU created the Community-based integrated natural resources management project in 2010, as part of an 8 year project to restore ecosystem services at the watershed level as well as prevent future watershed land degradation through promoting community-based forest management (International Fund for Agriculture (IFAD), 2009).

Forest governance in Ethiopia is also controlled by informal institutions. Unwritten norms, values, and belief systems within local communities create informal institutions and provide structures for land management within a certain group (North, 1991). Church forests are managed predominantly by priests and other religious leaders, who protect the forests for religious and spiritual reasons. These religious leaders advocate for and enforce forest conservation (Wassie, 2002). These church leaders also have influence beyond the churches and in some circumstances have been able to reforest past agricultural lands surrounding the church forest (Wassie, 2002).

Table 1.1. National, regional, and local institutions and relevant policies that govern forests and scattered trees in the Amhara Region

Level	Institution	Description	**Policies**
National	Environmental Protection Authority (EPA)	Creates policy and forms strategies involved with monitoring and regulating the environment. Focuses on promoting economic development initiatives using natural resources sustainably[1]	National Conservation Strategy (1997).[2] The Forest Management, Development, and Utilization Policy (2007).[5]
	Ministry of Agriculture and Rural Development (MoARD)	Implements development strategies focused around natural resource conservation, food security and rural development.[2,3]	Community-based integrated natural resources management project (2010).[6]
Regional	Bureau of Agriculture (BoA)	Supports efforts to curb natural resource degradation through monitoring agricultural, animal farming, forestry, and fisheries sectors.[3]	Community-based integrated natural resources management project (2010).[6]
	Bureau of Environmental Protection, Land Administration and Use (BoEPLAU)	Regional equivalent of the EPA, establishing environmental regulations that encourage sustainable use of forests and other natural resources.[2]	Community-based integrated natural resources management project (2010).[6]
Local	Religious Leaders	Religious leaders protect the church forests for religious and spiritual reasons advocate for and enforce forest conservation.[4]	Community-based conservation projects.[4]
	Kebele and Woreda Administrations	Implement regional policies and are important advocates for sustainable land management at the local level.[3]	

[1]EPA, n.d; [2]Awulachew et al., 2009; [3]zur Heide, 2012; [4]Wassie, 2002; Wassie et al, 2006; Wassie, 2007; Wassie et al, 2010; Wassie et al, 2009; Cardelús et al, 2013; Reynolds et al., 2015; [5] Rahmato, 2001; FDRE, 2007; [6]IFAD, 2009

Thesis Overview

A growing body of scholarship has highlighted the ecological and cultural importance of church forests and other natural forest fragments in Northern Ethiopia (Cardelús et al., 2013; Wassie et al., 2010; Wassie et al. 2009, Ceccon et al., 2008). However, a literature gap remains regarding the landscape surrounding these forest fragments. These non-forested agricultural landscapes in Northern Ethiopia harbor trees, which persist as remnants of the forests that once engulfed the highlands. This study reports preliminary findings on the spatial, ecological, social, and cultural characteristics of the scattered trees persisting in these non-forested agricultural landscapes in hopes of

adding to this gap in the literature. More specifically, this thesis seeks to answer these three questions:

1. How have scattered tree abundances changed over time in the agricultural landscape of the Amhara Region of Northern Ethiopia?
2. What is the perceived scattered tree abundance change and why have the abundances changed over time?
3. What is the ecological, social, and cultural significance of these scattered trees that has allowed them to persist despite widespread deforestation?

Each of the three subsequent chapters answers one of these questions. The chapters are structured in the following manner. Chapter 2 uses exclusively Global Information Systems (GIS) analyses to present the change in scattered tree abundances over time, as well as identify the shortcomings of using national forest cover estimates to adequately measure tree cover. Chapter 3 uses social survey data to identify how community members have perceived scattered tree cover to change over time. This chapter ends with identifying possible drivers of scattered tree cover change over time and the implications of those drivers. In order to understand the specific reasons scattered trees persist today, chapter 4 consists of a literature review on the benefits of trees in agricultural contexts. This final chapter then uses social survey data to illustrate the perceived ecological and socio-cultural benefits of scattered trees in the agricultural landscapes of Northern Ethiopia.

CHAPTER 2: MISSING THE TREES FOR THE FOREST – NATIONAL FOREST COVER ESTIMATES UNDERSTATE TREE COVER CHANGE OVER TIME

Introduction

The definition of a forest is ambiguous worldwide and is still widely disputed today. The FAO (2001) describes a forest to consist of land with a tree crown cover of more than 10% over an area of more than 0.5 ha with trees above 5 m at maturity. The UNFCCC (2006) agrees with this definition, describing a forest to consist of a minimal land area of 0.5 – 1 ha with a tree crown cover of 10 – 30% and a tree height of 2 – 5 m. Hansen et al. (2013), however, uses a tree cover cut-off of 25%. Published in *Science*, Hansen et al. (2013) data sets are strongly regarded as an accurate high-resolution indication of global forest cover. Differences in forest definitions have implications for how we measure forest loss and gain, especially in developing countries, where much of the forest cover and change estimates are completed remotely, and the definition of a forest is further tested by the introduction of exotic tree species.

Regardless of which forest definition is used to estimate forest cover in the Amhara Region of Ethiopia, non-forested landscapes that contain trees are largely ignored. Today, scattered trees persist in the agriculture and pasture landscapes as remnants of the past wooded habitat. These scattered trees are indigenous to the Amhara Region and serve as reminders of where the forest once was and what they looked like in the distant past. Since scattered remnant tree landscapes make up less than 10% of tree cover on any given piece of land, however, there has been little to no literature documenting their extent nor how their abundances have changed over time.

This chapter uses Geographic Information Systems (GIS) analysis and remote sensing to explore the degree to which forest cover estimates have understated tree cover by not including these scattered trees. Also, this chapter analyzes how scattered tree abundances have changed over time and compares these trends to the well documented changes in landscape-scale forest cover.

Background: Tree Cover in the Amhara Region of Northern Ethiopia

Like much of the Northern Highlands, the Amhara Region has faced centuries of Afromontane deforestation and largely consists of agricultural and pasture land today (Mekonnen et al., 2016). Loss of forest cover in the region has caused a high rate of soil erosion, loss of soil fertility, and water resource degradation (Mekonnen et al., 2016). Mekonnen et al., 2016 used a 20% tree cover cutoff and estimated that 12,884 km^2 of the Amhara Region is forested, making up 8.2 % of the total land area. Hansen et al. (2013) estimates that in 2014 only 1% of the Amhara Region was forested, using a tree cover cut-off of 25%. Using an FAO definition of a forest, which is 10% tree cover, the Amahara Region was roughly 21.5% forested in 2014 (Fig. 2.1). Forest estimates, like that of Hansen et al. (2013), Mekonnen et al. (2016), and the FAO, have inconsistencies between each other due to different forest classification methods, as well as problems in estimating forest cover in general.

The challenge of estimating forest cover in developing countries has been exacerbated by an increase in exotic tree plantations, which can potentially have an impact on forest cover estimations. The FAO (1993) defines forest plantations as forest stands established "artificially by afforestation on land where forests previously did not grow, or forest stands established artificially by reforestation on land that had supported forests within the previous 50 years that involves the replacement of previous trees and new and essentially different trees."

In the Amhara Region, forest estimates have also been used to describe forest cover change over time. Using 1960s aerial imagery, Clemons and Heisler (2015) estimate that as much as 60.64% of remaining native forest cover in the Lake Tana watershed of the Amhara Region has been lost since the 1960s and at least 34.31% of native riparian forest cover has been lost from the 1960s to 2014. They suggest that these declines in riparian and native forest cover can be attributed to an increase in human pressures as population size in the region has grown, creating an intensification of agricultural activities (Clemons and Heisler, 2015).

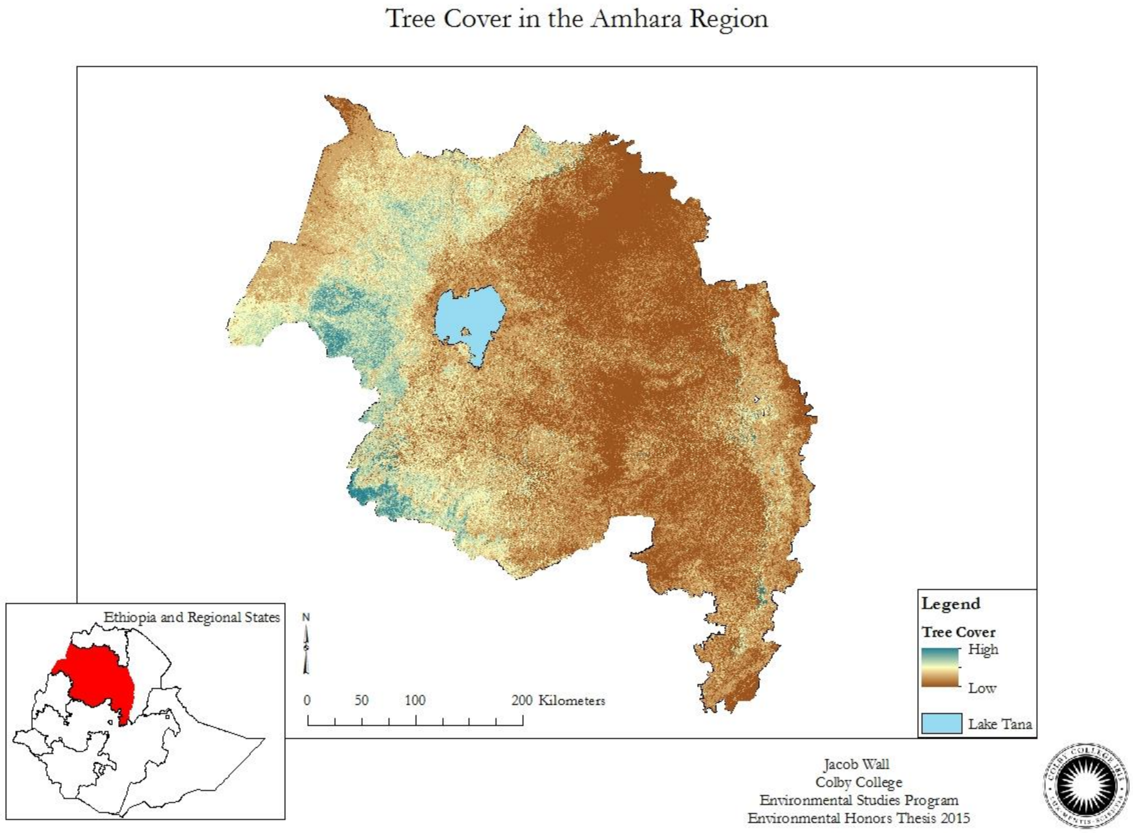


Figure 2.1. Forest Cover of the Amhara Peoples National Regional State (Hansen et al., 2015).

Hansen et al. (2013) also characterized global forest change over time. Their analysis estimated forest cover change from 2000 through 2014 using a time-series analysis of Landsat images (Hansen et al., 2013). Their outputs are very coarse, however, when looking at more local forest cover estimates. Their output consisted of estimates of percent tree cover per grid cell as can be seen in Figure 2.1 (Hansen et al., 2013). Using a Hansen et al. (2013) cutoff of what a forest is, they found that in the Amhara Region there was an increase of 4264 ha of forested area from 2001 to 2014 and a loss of 1463 ha, with a total net gain of 2801 ha of forest. Using the FAO definition of a forest (10% tree cover), the Amahara Region experienced a loss of 7385 ha of forested land from 2001 to 2014 with a gain of 4264 ha, resulting in a net loss of 3121 ha of forest (Hansen et al., year). Depending on the definition forest cover in the Amhara Region, tree cover can be described as either increasing or decreasing.

Moreover, neither of the forest estimates account for non-forested landscapes that contain trees such as agroforestry systems nor scattered remnant trees persisting in

agricultural systems (Mekonnen et al., 2016). In other parts of the world, scattered tree cover has been documented over time. Intensive agricultural development is associated with scattered tree loss worldwide and multiple studies have identified the loss of scattered trees in these systems (Gibbons et al., 2008). Scattered trees have been described to be declining in remnant-wooded habitats in Europe (Pulido et al., 2001), North America (Lathrop et al., 1991), Australia (Maroon, 2005), Central America (Harvey and Haber, 1998), and South America (Barchuk and del Pilar Díaz, 1999). Gibbons et al. (2008), analyzed scattered tree cover loss in agricultural landscapes in Spain, the United States, Australia and Costa Rica and predicted that the mature trees in the landscape would be lost within the next 90-180 years under the current management systems. They also indicate that the even with implementing improved management immediately, which would increase the recruitment of the trees, the number of mature trees in the landscape will decline before they are able to increase (Gibbons et al., 2008).

This chapter analyzes how scattered tree abundances have changed over time in the Amhara Region agricultural landscape, and considers if current methods of national forest cover estimation are able to recognize these change.

Methods

Geographic Information Systems (GIS) analyses were used to depict the change of scattered tree abundance and extent over time. All of these methods were implemented across 14 study sites in four study regions in the Amhara People's National Regional State of the Ethiopian Northern Highlands including, Banja Shekudad Woreda, Dera Woreda, Farta Woreda, and Bahir Dar Zuriya Woreda.

The data from this study were collected over the course of a 4 week period during July and August of 2015 and over a 2 week period in January of 2016. The data collection in the summer of 2015 was completed as part of a Research Experience for Undergraduates (REU) in Ethiopia with Colby College and funded by the National Science Foundation (NSF). Data collection in January of 2016 was completed with a small team comprised of Colby College students and Ethiopian students and guides. The January, 2016 research trip was funded by Colby College as well as the U.S. National Science Foundation grant SMA-1359367.

Study Sites

All of the study sites included in this report are in the Amhara National Regional State, which lies in northwestern part of Ethiopia (Fig. 2.2). The Amhara Region is situated between 8° 45' –13° 45' N latitude and 35° 15' - 40° 20' E longitude and covers about 157,127 km^2. The Amhara Region is one of the nine ethnic divisions of Ethiopia and is the homeland of the Amhara people. It has common boundaries with four other national regional states including Oromiya to the south, Afar to the east, Tigray to the north, and Benishangul-Gumuz to the West, and it shares a boundary with the country Sudan to the west. The Amhara Region has a population of 17.22 million, which represents about 18% of Ethiopia's total population. Of this population about 87.3% lives in rural areas and the remaining 12.7% live in urban areas (CSA, 2007).

The region is divided into eleven administrative zones, 105 woredas, and 3429 kebeles (local government). GIS data were collected in four of these woredas, found in two of the administrative zones including, South Gondar Administrative Zone (SGAZ) and the Awi Administrative Zone (AAZ). The four woredas include Banja Shekudad Woreda, Dera Woreda, Farta Woreda, and Bahir Dar Zuriya Woreda (Fig. 2.2). These study sites were selected because of the presence of remnant indigenous trees in the agricultural landscape as well as familiarity with and accessibility of the locations.

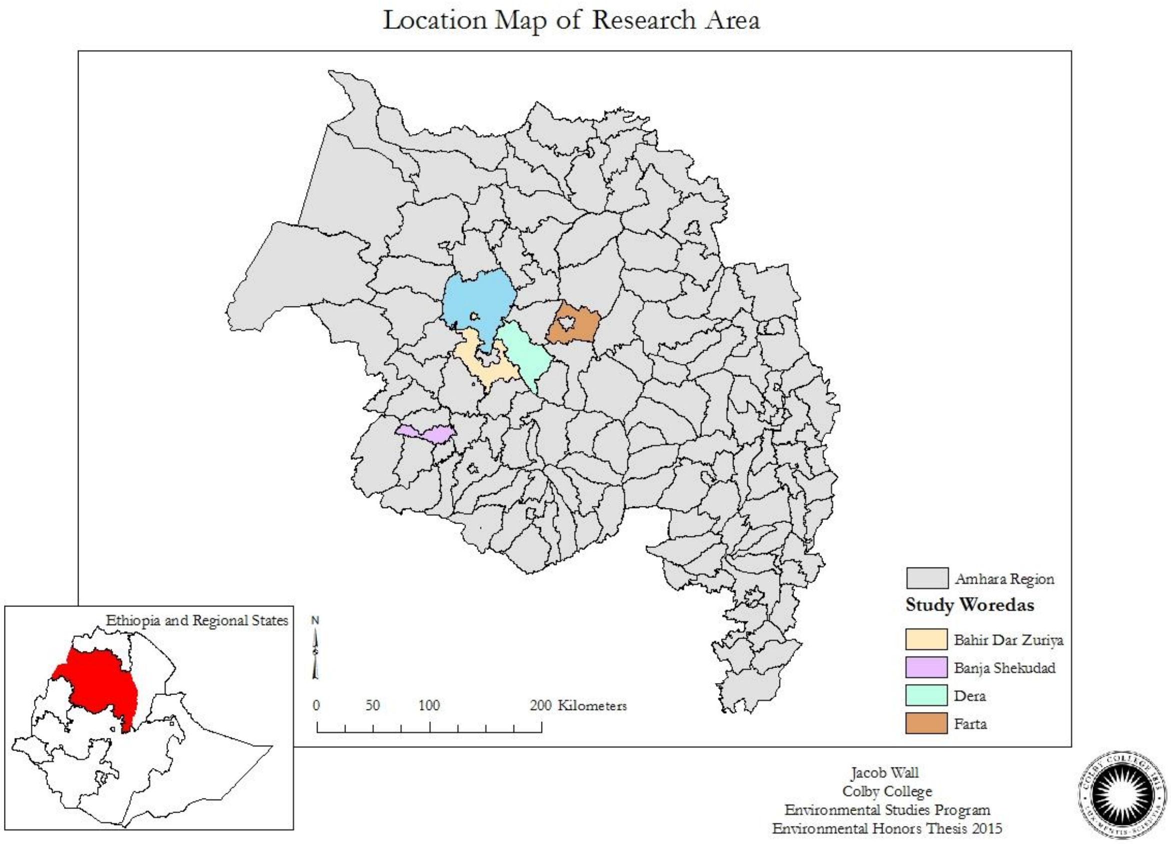


Figure 2.2. Location map depicting the four woredas in which ecological and social survey data was collected (Bahir Dar Zuriya, Banja Shekudad, Dera, and Farta Woredas).

Banja Shekudad Woreda

Banja Shekudad Woreda is located in the Agew Awi zone of the central part of the Amhara Region between (Fig. 2.3). Banja Shekudad Woreda has an area of 508 km^2 and a population of 111,975 with a density of 220 km^{-2} (CSA, 2007). The woreda is dependent on mixed agriculture and pastoralism as a principal sources of livelihood. The forest cover of the woreda is depicted in Figure 2.3.

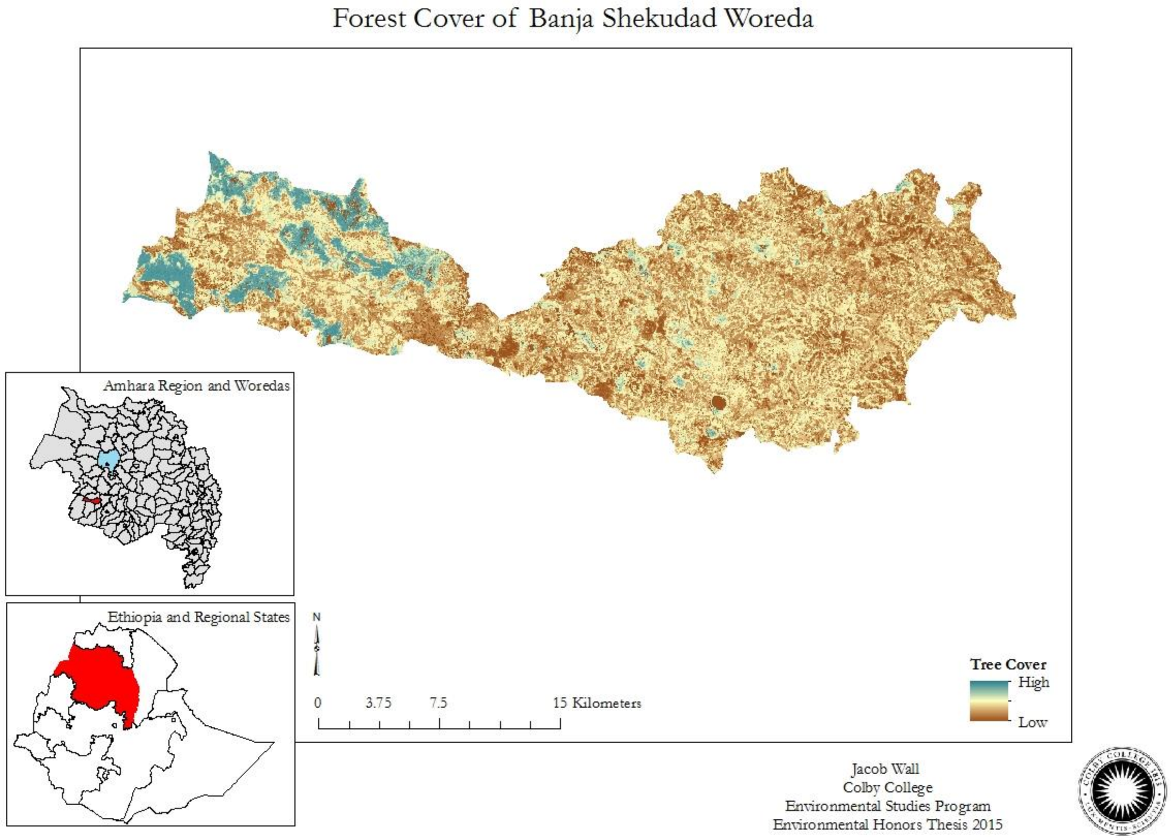


Figure 2.3. Forest cover of Banja Shekudad Woreda depicted as low to high tree cover. (Data from Hansen et al., 2013).

Dera Woreda

Dera Woreda is located in the South Gondar Zone in the central part of the Amhara Region between 12º 92’ – 13º 12’ N latitude and 34º 40’ – 35º 80’ E longitude. Dera Woreda is bordered by Lake Tana to the west and the Abbay River to the south. The woreda has an area of 1,525 km^2 and a population of 248,464 with a density of 187 persons km^{-2} (CSA, 2007). Topographically the Dera Woreda consists of a gently undulating terrain with a plateau at the upper limit and a plain in the lower limit with a range of altitude from 1798 to 2118 m above sea level. The average annual rainfall and temperature is 1250 mm and 19º C respectively (Gashaw et al., 2014).

Of the total area of Dera Woreda, 46% is arable or cultivable land, 6% is pastureland, 1% is forested or shrub land, 25% is covered with water, and the remaining 25.9% is considered degraded or miscellaneous (ESIA, 2006). The population of Dera Woreda depends on rain-fed subsistence agriculture of both crops and livestock as

principal livelihood sources (Gashaw et al., 2014). The most common crops consist of teff, maize, and sorghum (Gashaw et al., 2014). The forest cover of Dera Woreda is shown in Figure 2.4. The green circles of forested land are church forest as well as eucalyptus plantations.

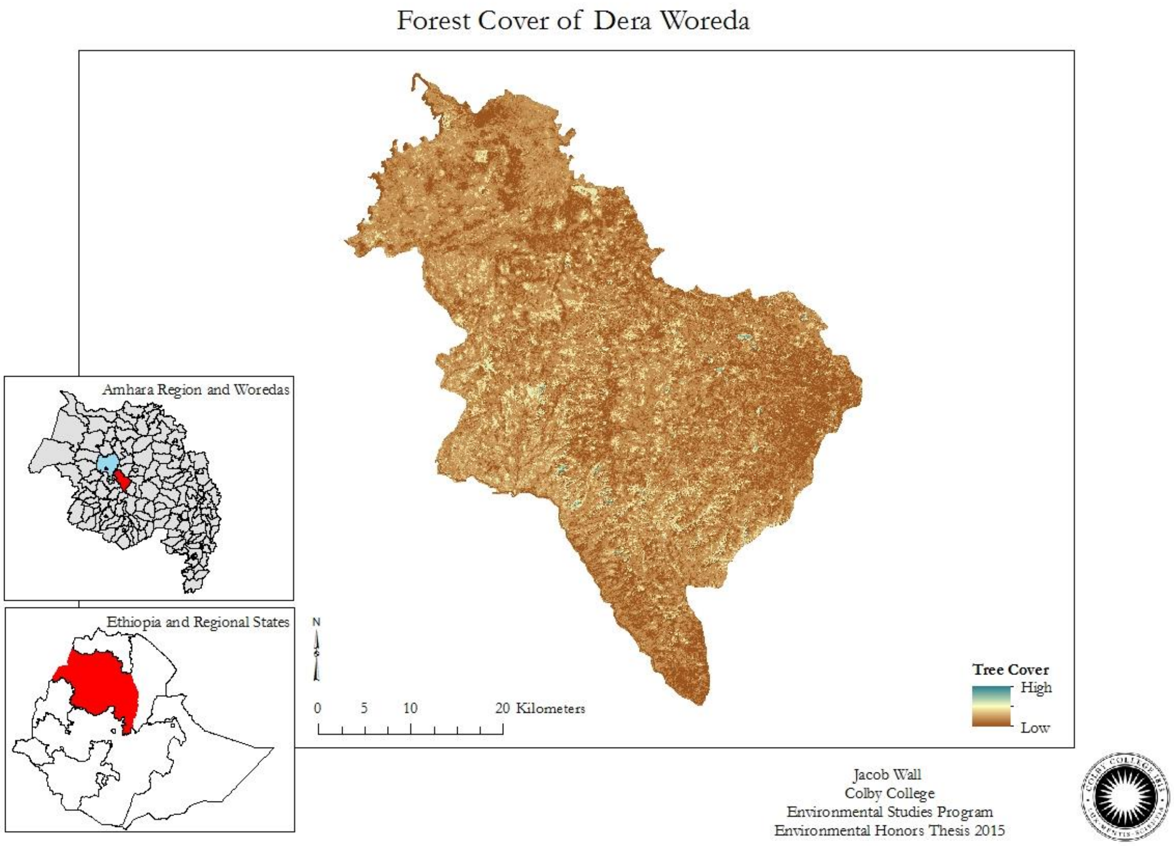


Figure 2.4. Forest cover of Dera Woreda depicted as low to high tree cover. (Data from Hansen et al., 2013).

Farta Woreda

Farta Woreda is located in the South Gondar Zone in the central part of the Amhara Region between 11º32' – 12º03'N latitude and 37º31' – 38º43'E longitude. Farta Woreda surrounds the town of Debre Tabor and has an area of 1,099.25 km^2 and a population of 232,181 km^2 with a density of 211 persons km^{-2} (CSA, 2007). The topography of Farta Woreda is 74% flat to gentle slopes (<7 degrees), while steeply sloping lands (>25 degrees) account for 26% of the land area (MaARD, 2000). Average annual minimum, maximum and mean temperatures are 9.7º, 22.0º, and 15.5º, respectively. Annual rainfall ranges from 1097 to 1954 mm with a long-term mean of

1448 mm (Yitbarek, 2012). The woreda is dependent on mixed agriculture and pastoralism as a principal sources of livelihood. Farta woreda is characterized as food insecure (Alemtsehay et al., 2006). The forest cover of Farta Woreda is visualized in Figure 2.5. The smaller forest fragments are church forests and eucalyptus plantations, while the larger forested area on the western border of the woreda is a government protected forest called Alem Sega Forest.

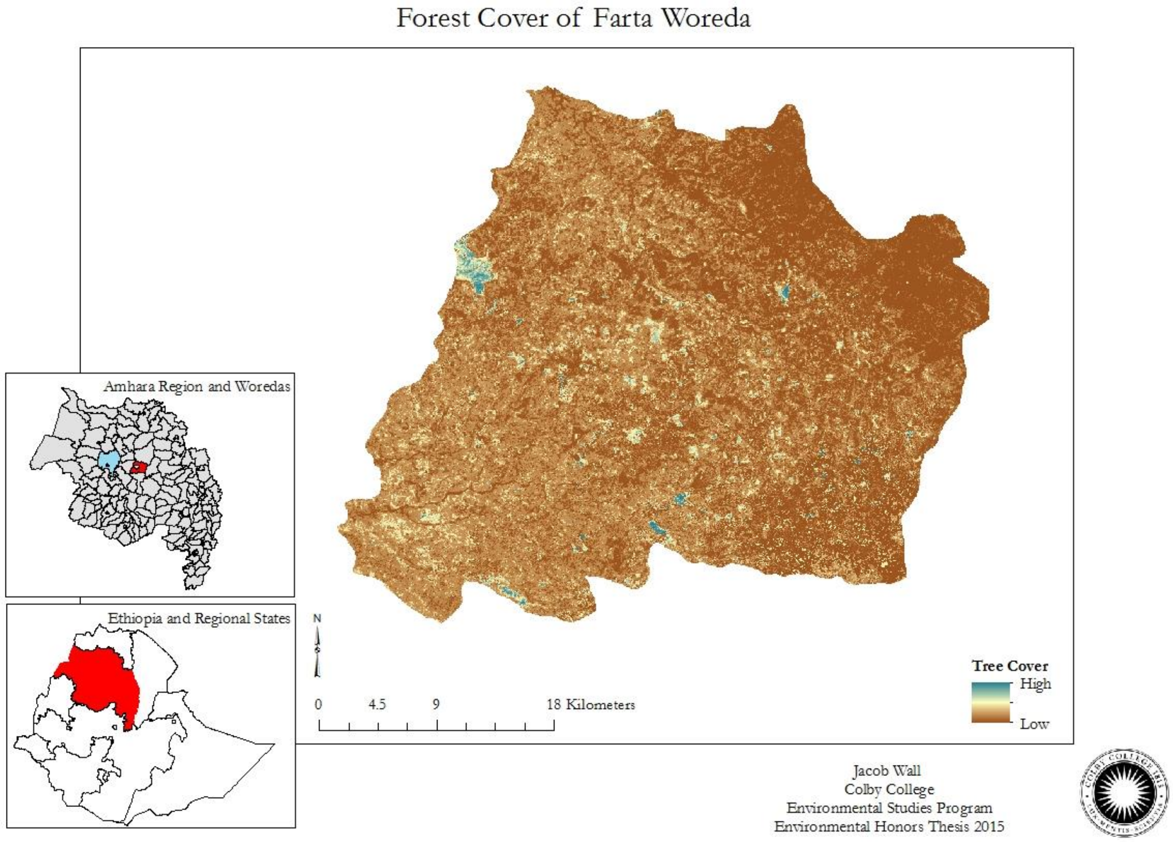


Figure 2.5. Forest cover of Farta Woreda depicted as low to high tree cover. (Data from Hansen et al., 2013).

Bahir Dar Zuriya Woreda

Bahir Dar Zuriya Woreda is situated in the central part of the Amhara Region in the west Gojam zone located between 11º19' - 11º52'N latitude and 37º05' -- 37º 39' E longitudes. Bahir Dar Zuriya borders Bahir Dar, which is the capital city of the Amhara Region. The woreda has an area of 1,443 km^2 and a population of 198,284 with a density of 137 persons km^{-2} (CSA, 2007). Topographically the Bahir Dar Zuriya Woreda consists

of a gently undulating terrain with a range of altitude from 1750 to 2300 m (Mulugeta and Admassu, 2014).

Of the total area of the Bahir Dar Zuria Woreda, agricultural crops constitute 46.4%, 21.5% is grazing land, 7.3% is forests cover, 5.1% is bush land, 0.5% is wetland, 3.6% is hillsides, and miscellaneous consists of 15.6% of the total area (DOoA, 2010). Most of the population of the woreda depends on agriculture as their principal source of livelihood, which consists mostly of subsistence-level mixed farming of rain-fed crops as well as livestock production. The most common crops are teff, maize, millet, bean, pea, and oil crops (Mulugeta and Admassu, 2014). The forest cover of Bahir Dar Zuria Woreda is shown in Figure 2.6.

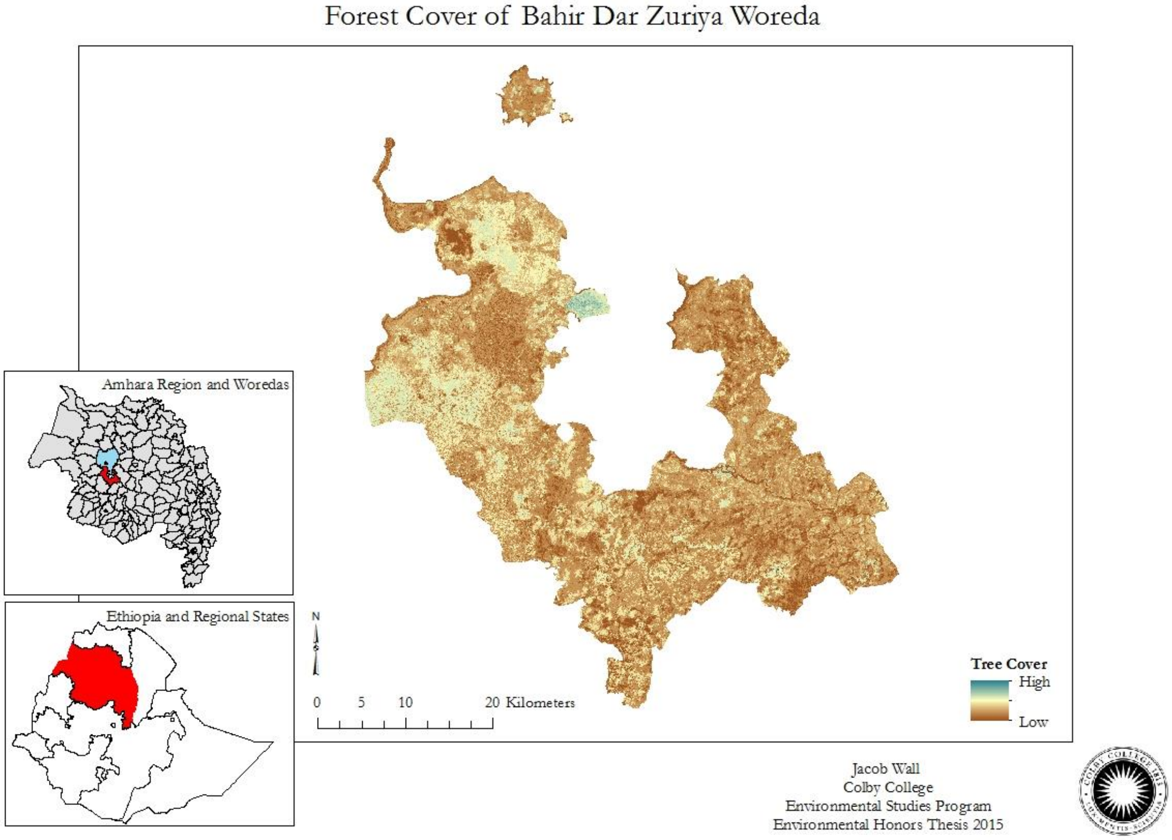


Figure 2.6. Forest cover of Bahir Dar Zuriya Woreda depicted as low to high tree cover. (Data from Hansen et al., 2013).

All four woredas are geographically similar, and also fairly similar demographically, with a slightly larger urban population in Banja Shekudad. Demographic and geographic characteristics of the four woredas are shown in Table 2.1.

Table 2.1. Characteristics of the four woredas in which the study took place.

	Banja Shekudad	Dera	Farta	Bahir Dar Zuriya
Area (square km)	508	1,525	1,099	1,443
Population	111,975	248,464	232,181	198,284
Population Density (pp/km^2)	220	187	211	137
Sex	50% Male 50% Female	51% Male 49% Female	51% Male 49% Female	51% Male 49% Female
Urban	20%	7%	3%	4%
Religion	99% Orthodox	98% Orthodox	99% Orthodox	99% Orthodox

Farmer Survey Study Sites

Fourteen individual study sites were selected within the four woredas for GIS analyses (Figure 2.7). These individual study sites consist of the agricultural and pasture land surrounding a church forest. These study sites were visited to implement the farmer survey, which is a survey method described further in in chapter 3 section 2.2.1. The spatial characteristics of each of the study sites is tabulated in Table 2.2.

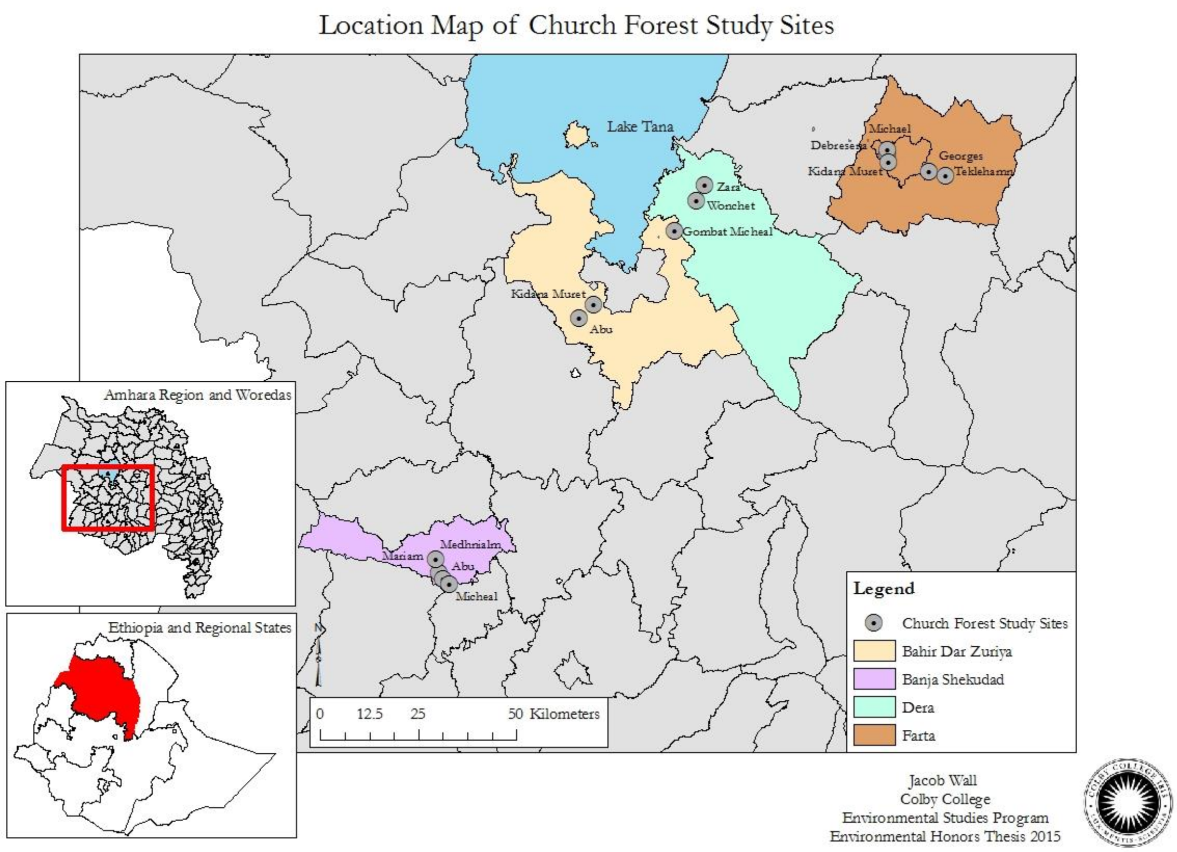


Fig 2.7. Church forest study sites for the farmer survey and GIS analysis

Table 2.2. Summary of forest characteristics among the 14 studied church forests

Woreda	Church Forest	Area (ha)	Perimeter (m)	Elevation (m)
Farta	Teklehamn	16.21	2239.6	2770
	Georges	5.60	971.1	2663
	Michael	5.34	1256.2	2671
	Debresena	17.45	2191.6	2664
	Kidana Muret	4.08	1025.5	2614
Dera	Zara	10.80	1270.2	1923
	Wonchet	8.68	1191.3	1952
Bahir Dar Zuriya	Gombat Michael	5.84	925.6	1919
	Kidana Muret	2.62	620.2	1958
	Abu	5.59	919.6	1973
Banja Shekudad	Medhnialm	1.92	516.7	2573
	Mariam	6.66	998.2	2496
	Abu	2.04	546.8	2523
	Michael	1.94	517.5	2506

GIS Methods

I used four different GIS methods including GPS pinpointing, 1960s aerial photography processing, tree and settlement counts, and Landsat Satellite NDVI processing to analyze how scattered tree abundance and extent has changed over time. All three methods were completed for the 14 church forest study sites at which the farmer surveys took place (Fig. 1.9).

GPS Pinpointing

GPS pinpointing was used to assess the diversity, abundance, and spatial configuration of scattered indigenous trees in the agriculture and pasture land. GPS pinpointing coincided with the farmer survey method and was conducted surrounding church forests in Banja Woreda, Dera Woreda, Farta Woreda, and Bahir Dar Woreda (Fig 2.7). The church forests were chosen at random with the exception of Debresena and Gombat Michael, at which other survey methods took place. For the farmer survey, respondents were chosen by chance as we circumnavigated the church forest. For each respondent at least one of the remnant scattered trees that was on their land was marked as a global positioning systems (GPS) waypoint using a Garmin Oregon 550t GPS (Fig. 2.8). For each tree the local name (vernacular name) was identified, a picture was taken, and the corresponding survey number was recorded so that the tree could be linked to the

survey responses during the analysis. Woody species including trees and shrubs were considered in this study. Reference materials (Mulugeta and Admassu, 2014; Enyew et al., 2013) and expertise from university professors in the region were used to identify the scientific name of each tree species. For some surveys multiple trees were recorded, however most of the respondent's scattered trees were not usually pinpointed due to time and location constraints. While walking from one respondent to the other, scattered trees that were in the walking path were also recorded even if no corresponding survey was completed.

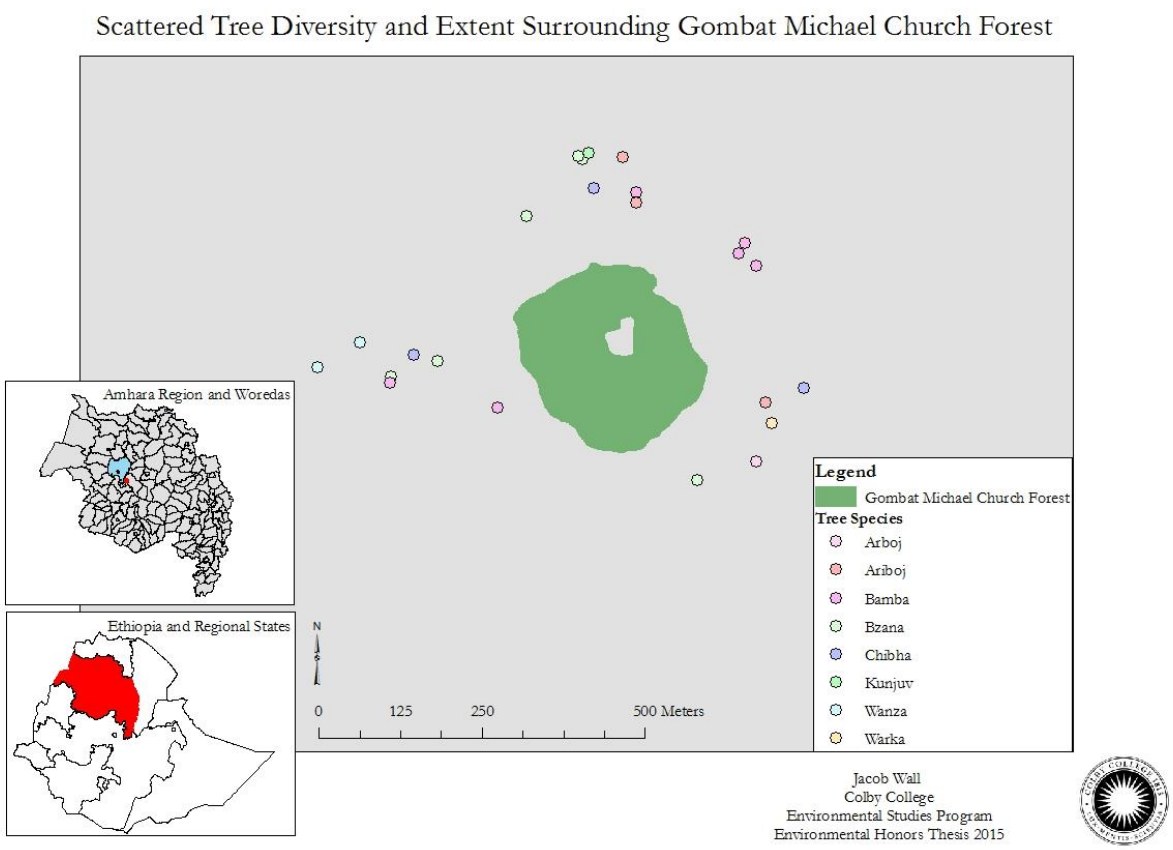
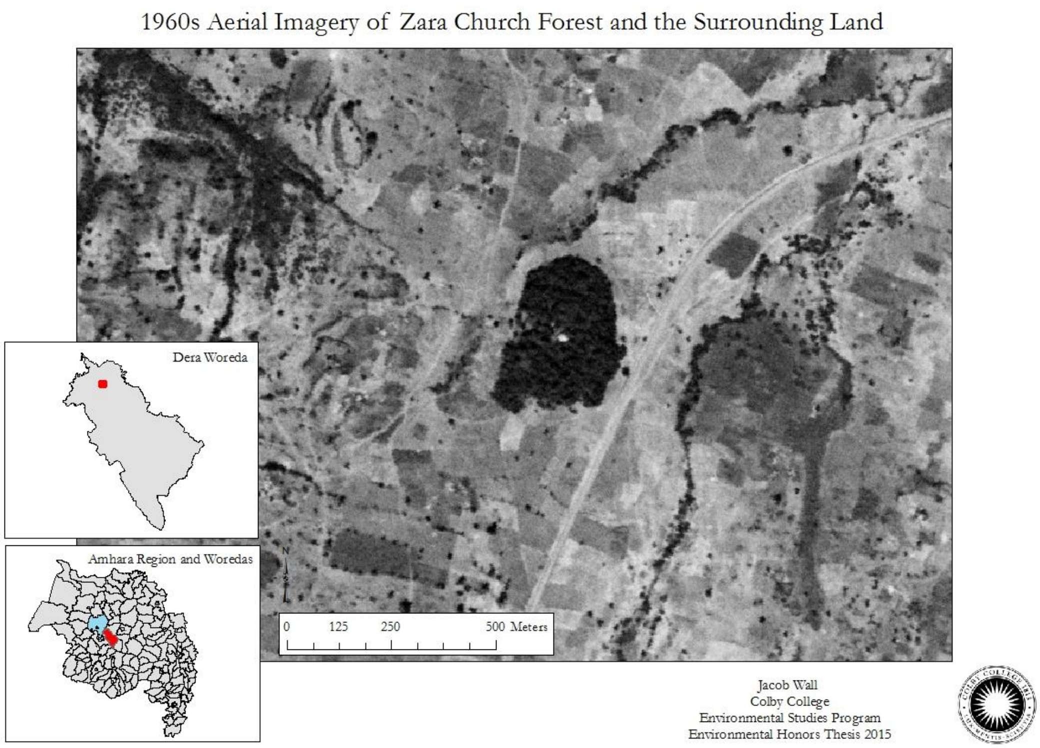


Figure 2.8. Example of GPS waypoints of different tree species (local names) surrounding Gombat Michael Church Forest, which is seen as the green circle.

1960s Aerial Photography Processing

Aerial imagery and satellite imagery from the 1960s to present day was used in order to measure tree cover change over time. Declassified aerial photography taken in 1965 and 1967 by U.S. spy planes of the Ethiopian landscape happen to cover the four woredas included in this study (Banja Woreda, Dera Woreda, Farta Woreda, and Bahir

Dar Woreda). This imagery was downloaded from the U.S. Geologic Service (USGS) EarthExplorer database in the form of digitized strips of film (USGS, 2015). The aerial imagery was georeferenced into the WGS 84/Pseudo Mercator coordinate reference system using QGIS Desktop 2.12.1 (QGIS, 2015). The images were georeferenced using reference points from the Google Satellite plugin (Google Satellite, 2015). The aerial images were warped into the WGS84/UTM zone 37N reference system and opened in ESRI ArcMap 10.3.1 for analysis (ESRI, 2014). Some of the 1960s aerial images were processed by Maravilla Clemens and Alex Heisler as part of their senior capstone research at Colby College. Other scenes were processed by NSF-REU students during the summer of 2015 and during the spring of 2016 and by myself during the 2015-2016 school year. Figure 2.9 shows an example of the 1965, which is an aerial photo of Gombat Micheal church forest in 1965 and how the landscape looks today using Google Earth imagery.



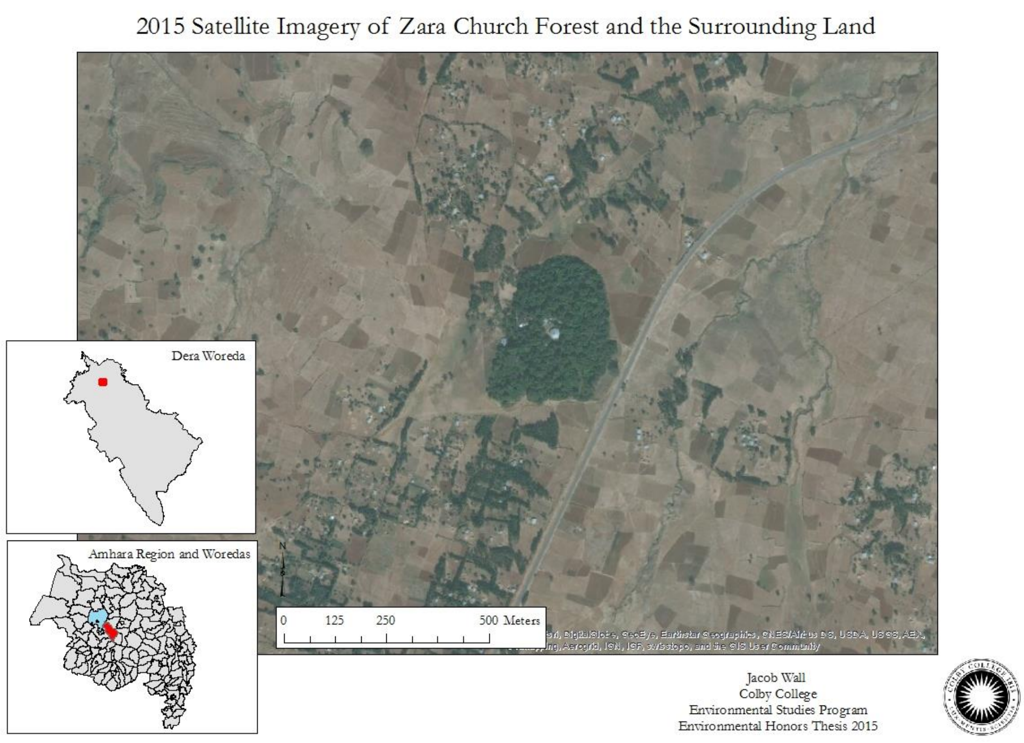


Figure 2.9. Example of 1960s aerial imagery and 2015 satellite imagery. Zara church forest and the surrounding agricultural landscape with scattered remnant trees in 1965 and 2015 (USGS, 2015; Google Earth, 2015).

Tree Counts and Crop Tracings

The scattered trees GPS pinpoints were uploaded to Google Earth as .kml files. Google Earth was then used to trace the cropland surrounding the church forest in which these studied remnant scattered trees persist in. In order to encompass more of the cropland, a 400 meter buffer surrounding the church forests was created in ArcMap. This buffer was exported to Google Earth and all of the remaining crop plots within the buffer were traced (Chapter 3, Fig. 2.10). Individual crop plots can be distinguished in Google Earth based on the difference in colors between different crop species, as well as, barriers and or fences defining the crop areas.

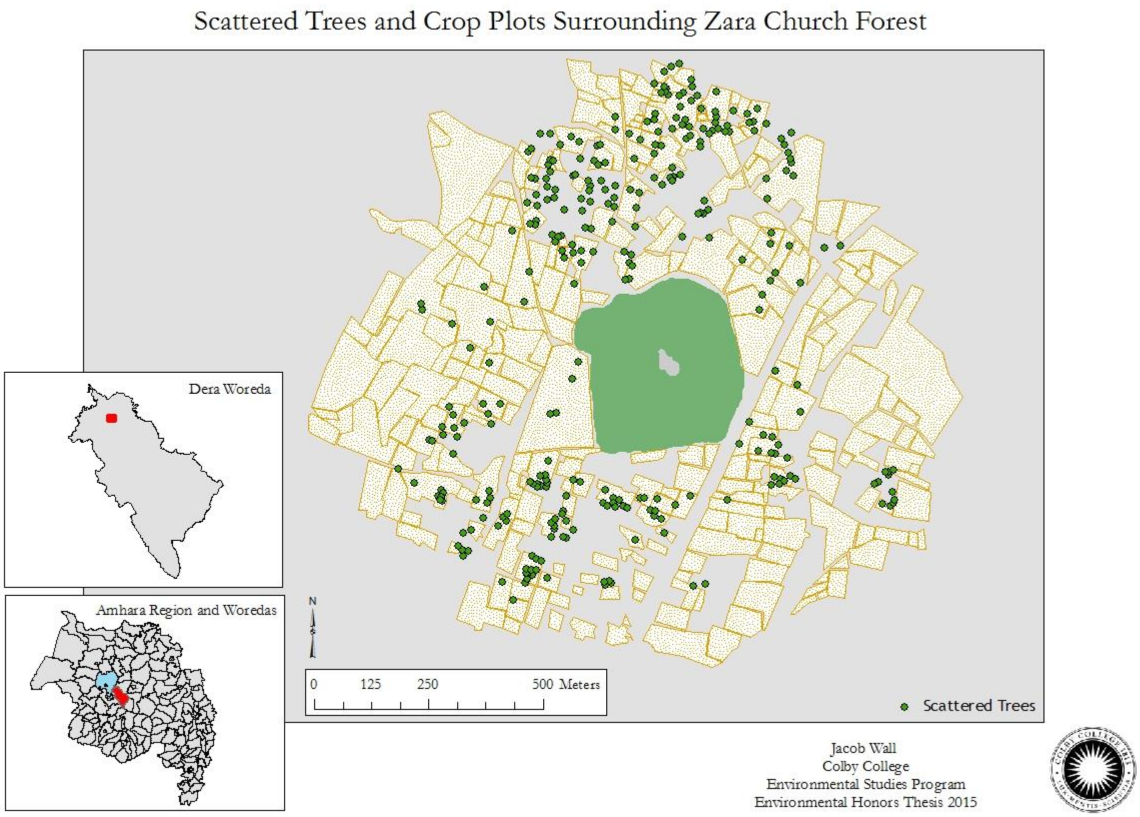


Figure 2.10. Polygons depicting the crop plots and points indicating scattered remnant trees in the land surrounding Zara Church Forest. This represents Zara study site and the crop plots and scattered trees are within a 400 meter buffer surrounding Zara Church Forest.

The scattered trees within the traced agricultural plots that had not been accounted for by GPS pinpointing, were marked using Google Earth's "Add Placemark" feature (Fig. 2.10). The pinpointed trees were used as a groundtruthed guide to determine what

trees looked like from satellite imagery. From this, the number of trees in the agricultural landscape and the spatial distribution of these trees could be calculated. The Google Earth imagery for all of the study sites ranged from 2014 to 2015. Following this, the georeferenced 1960s aerial images were uploaded to Google Earth Pro as rasters. Using the same technique, the crops surrounding each church forest within the 400 meter buffer were traced in Google Earth Pro and the individual scattered trees were marked. The crop polygons were then used to analyze how crop plot areas have changed over time since the 1960s and the individual tree counts were used to analyze how the number of scattered trees has changed over time within the plots. The change in size of agriculture plots was analyzed in R Studio and the change in tree counts was analyzed in ArcMap 10.3.1.

Landsat Satellite Imagery and NDVI Processing

Land cover analyses were performed using geospatial data from the USGS Landsat program. The Landsat program, sponsored by the National Aeronautics and Space Administration (NASA) since the early 1970s, provides freely available 30 meter by 30-meter resolution satellite imagery of the earth's surface (USGS, 2015). There is a large literature base demonstrating the use of satellite imagery to analyze temporal land cover change (Lunetta, 2006; De Mûelenaere et al., 2012; Mas, 1999). This study uses similar methods to analyze land cover change over time. The Landsat imagery was downloaded from USGS to create vegetation maps of the agricultural landscapes that scattered trees persist in. The Landsat scenes used in the analysis from the dry season are from February. Landsat data were taken from four different 10 year increments including: 1985, 1995, 2005, and 2015.

The Landsat scenes were processed using R Studio to calculate the Normalized Difference Vegetation Index (NDVI). NDVI is an index of plant “greenness”, or green biomass of a landscape, and is one of the most commonly used vegetation indices (Huete et al., 2002). NDVI is used to understand the extent and density of vegetation of a region. Photosynthetic vegetation reflects poorly in the visible part of the spectrum but strongly in the near-infrared (NIR) part of the spectrum. This unique characteristic allows researchers to quantify the amount of plant biomass using remote sensing imagery. NDVI combines the energy absorbed by chlorophyll in the red sector of the electromagnetic

spectrum (RED) with NIR. NDVI is computed by the calculating the difference between RED and NIR bands and normalizing this difference using the following equation:

$$NDVI = (NIR-RED) / ((NIR) + RED)$$

The NDVI value can range from -1 to 1 with values closer to 1 indicating high green vegetation content.

Once all of the NDVI scenes were processed for each time period the scenes were clipped to the extent of each study site crop area in all four of the woredas. Figure 2.11 is an example of how NDVI is used to illustrate the land cover of a study site. The NDVI data across the four different time periods was analyzed for each of the study sites. Descriptive statistics including the median and mean NDVI pixel values were calculated at each of the study sites for each of the time periods using R Sudio.

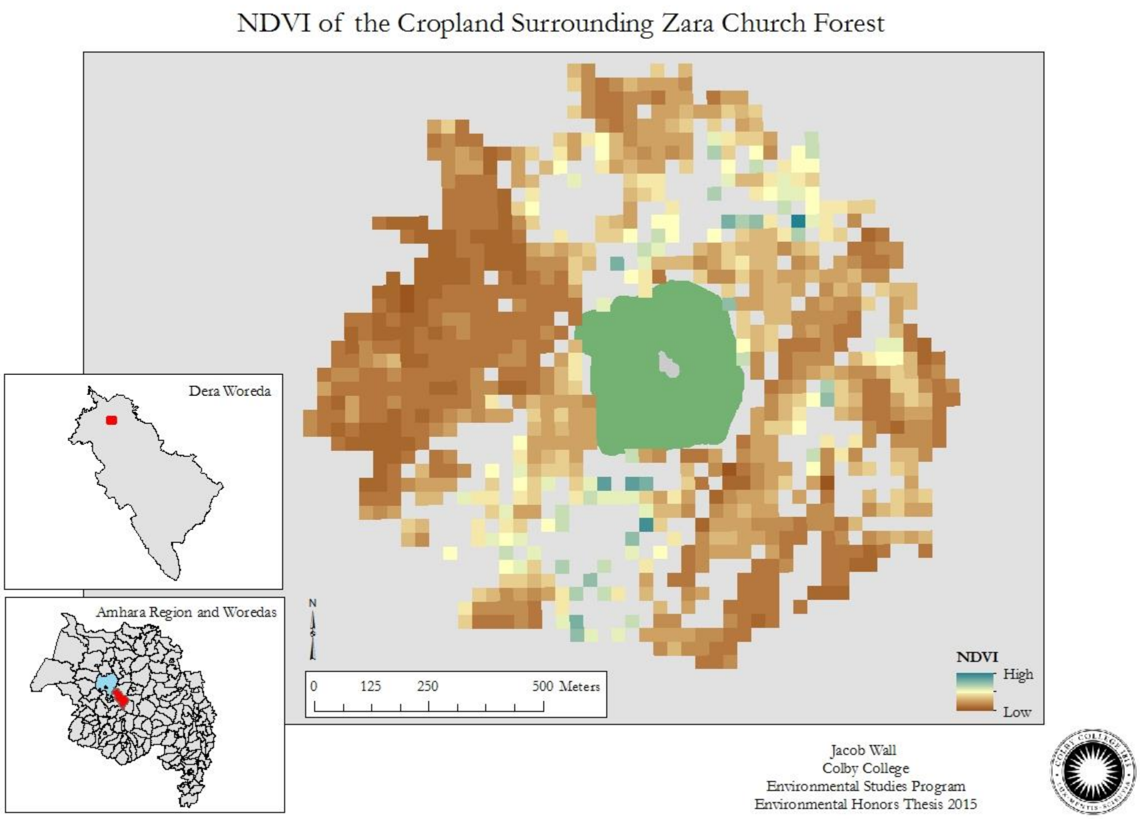


Figure 2.11. NDVI of the cropland surrounding Gombat Michael church forest in which the studied remnant scattered trees persist for 2015.

Results

How Scattered Tree Landscapes Are Defined

Hansen et al. (2013) characterized global forest extent and change over time from 2000 through 2014 using a time-series analysis of Landsat images. They defined trees as vegetation taller than 5m and their output consisted of estimates of percent tree cover per grid cell (Hansen et al., 2013). Hansen et al. (2014) forest cover estimates have a resolution of 30m by 30m and for each of these pixels they indicate the tree cover percent ranging from 0 to 100%. The pixel represents the average forest cover for the 30m by 30m area. The median Hansen et al. (2013) pixel value of each of the study sites and study regions is shown in Table 2.3 and the distribution of pixel values across the scattered tree agricultural systems of the study sites is illustrated in Figure 2.12.

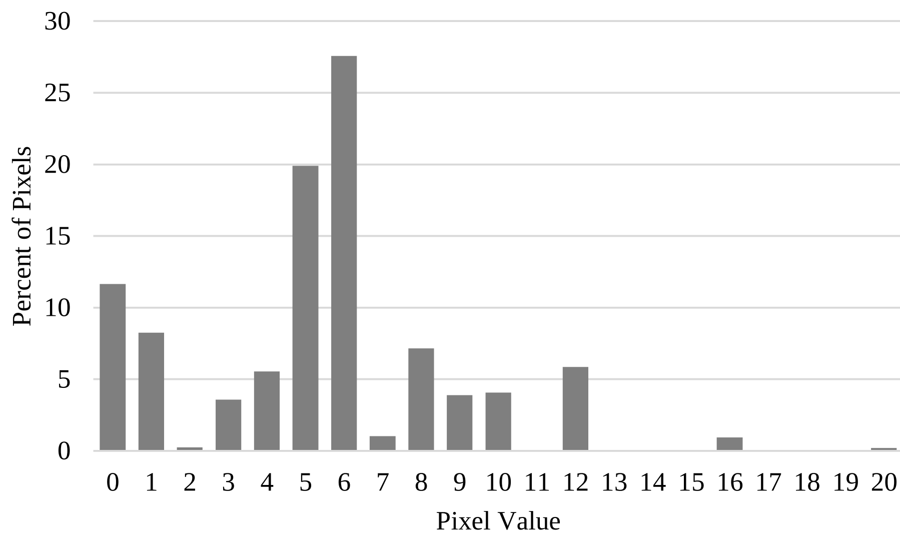


Figure 2.12. Aggregated distribution of Hansen et al. (2013) pixel values for all of the study sites, described by percent (%) of all pixels in the study region.

Aggregating the entire study region, the median Hansen pixel value is 6, corresponding to a 6% tree cover within that pixel (Table 2.3). As Figure 2.12 shows, most of the pixel values for the region are below 10, indicating that most of the study area has less than 10% tree cover. Looking at the median pixel value based on study region, Bahir Dar and Banja Woredas have a median Hansen pixel value of 7, while Dera and Farta Woredas have a median Hansen pixel value of 6 and 5 respectively.

The number of scattered trees and the tree density (number of trees per hectare) are also tabulated in Table 2.3. The study sites in Dera Woreda had the highest tree density (3.324 trees per hectare), followed by Bahir Dar (2.405 trees per ha), Banja (1.268 trees per ha), and Farta (1.267 trees per ha) Woredas. The median Hansen value does not seem to correlate with tree density, with the exception of the Kidana Muret study site in Bahir Dar Woreda, which has both the highest median Hansen pixel value of 9 and the highest scattered tree density at 4.929 trees per ha. However, some of these patterns could be due to differing abundances of exotic tree species within the plots. The study sites were purposefully traced in Google Earth to exclude exotic plantation tree species (mostly *Eucalyptus spp.* in the study area), however the coarse nature of the Hansen et al (2013) data set could have led to these plantations impacting the median Hansen tree cover value.

Table 2.3. The median Hansen et al. (2013) pixel value, the number of trees (tree count), the area (ha), and the tree density (trees per ha) for each of the study sites and study regions.

Study Site	**Median Hansen Tree Cover Value**	**Tree Count**	**Study Site Area (ha)**	**Tree Density (tree per ha)**
Bahir Dar	**7**	**561**	**233.31307**	**2.405**
Abu	5	162	110.9184	1.461
Gombat Michael	6	163	74.51834	2.187
Kidana Muret	9	236	47.87633	4.929
Banja	**7**	**279**	**220.06154**	**1.268**
Abu	8	30	42.46322	0.7065
Mariam	5	37	40.03147	0.9243
Medhnialm	8	64	41.55067	1.54
Michael	8	148	96.01618	1.541
Dera	**6**	**550**	**165.46988**	**3.324**
Wonchet	6	244	88.36061	2.761
Zara	6	306	77.10927	3.968
Farta	**5**	**528**	**416.77877**	**1.267**
Debresena	5	130	89.41512	1.454
Georges	5	85	69.56012	1.222
Kidana Muret	5	90	67.7625	1.328
Mariam	5	117	112.7654	1.038
Michael	5	106	77.27563	1.372
Total	**6**	**1918**	**1035.62326**	**1.852**

Even with the potential error associated with the Hansen data set, none of the study regions would as a whole be classified as a forest under the FAO definition, which is at least 10% forest cover, and certainly not under Hansen et al.'s criterion of 25%. Looking at the pixel value distribution (Fig. 2.12) only 11.14% of the study region has pixel values above 10 (10% tree cover), and therefore only about a tenth of the study region would be considered a forest under the FAO definition. However, to be defined as a forest under the FAO, the area with 10% tree cover must be over 0.5 ha. Each pixel is 900 m^2, which is 0.09 of a hectare. Since the pixel values that are over 10% are not usually adjacent to other pixel values of over 10%, none of the study area is considered to be a forest under the FAO or Hansen's cut off.

These forest cutoffs therefore miss a significant number of trees – in this case 1,918 trees in roughly a 10 km^2 region – which leads to the unmonitored change in abundance of these scattered trees. The institutions monitoring tree abundance variation only focus on trees that are defined as a forest and these trees go unmonitored. Ethiopia's Amhara Region consists of mostly cropland, with some estimates suggesting that certain parts of the Amhara Region have roughly 62% (Ali et al., 2011) to 66.12% (Tesfaye et al., 2014) to 70% (Tegene, 2002) cropland. The Amhara Region is 15.471 million ha, and using a conservative estimate of 60% cropland cover, there would be roughly 9.282 million ha of cropland in the Amhara Region. Using the calculated 1.852 trees per ha of cropland and the estimated cropland in the Amhara Region, this suggests as many as 17 million trees could be persisting unaccounted for in the Amhara Region's cropland.

Scattered Tree Cover Change over Time (1960s to Present)

The declassified aerial photography taken by U.S. spy planes in 1965 and 1967 revealed what the landscape looked like with very fine resolution during that time. For each of the 14 studied church forests the number of trees apparent in the 1960s imagery was counted and compared to the number of trees persisting in the study sites today and is tabulated in Table 2.4. Certain study sites including Medhnialm and Michael in the Banja Shekudad Woreda, Gombat Michael and Kidana Muret in the Bahir Dar Zuriya Woreda, and Debresena in Farta Woreda had unusable 1960s imagery to do clouds and darkness and therefore are not listed in Table 2.4. The aggregated counts indicate an

increase of scattered trees from the 1960s to 2015, with an aggregated increase of 191 trees.

Table 2.4. Tree counts for the study sites in the 1960s and 2015.

Study Site	1960s Tree Count	2015 Tree Count	Change over Time
Banja Shekudad	**38**	**279**	**+29**
Abu	26	30	+4
Mariam	12	37	+25
Dera	**385**	**550**	**+165**
Wonchet	193	244	+51
Zara	192	306	+114
Farta	**401**	**528**	**-3**
Georges	93	85	-8
Kidana Muret	17	90	+73
Mariam	230	117	-113
Michael	61	106	+45
Total	**824**	**1918**	**+191**

NDVI as a Proxy for Scattered Tree Cover

Normalized Difference Vegetation Index (NDVI) is one of the most commonly used vegetation indices to display the density of vegetation in a region (Huete et al., 2002). For this study NDVI was calculated using Landsat satellite imagery, which has a resolution of 30 meters by 30 meters (USGS, 2015). NDVI analyses using Landsat imagery typically map the amount and distribution of vegetation cover for large-scale ecosystems due to the coarse nature of the data set (Huete et al., 2002). Despite the coarse nature of Landsat imagery, differing levels of vegetation within one 30 by 30 meter Landsat pixel will show up as different NDVI values. Therefore, scattered trees, which persist in the agricultural landscape should influence NDVI values even if there are as few as one scattered tree per 30 by 30 meter pixel.

To investigate if this claim is in fact true Gombat Michael study site was used as a case study. Figure 2.13 illustrates the scattered trees found in the study site in 2015 and the NDVI of the cropland also taken from 2015. The pixels, which overlap with scattered trees, were separated from the pixels that do not have scattered trees and the NDVI values between the two groups of pixel values was compared (Figure 2.14). A Welch two-sample t-test indicates that the NDVI pixels with scattered trees present are significantly

higher than the NDVI pixels without scattered trees (t = -8.7276, df = 175.432, p-value = 1.979e-15). This suggests that NDVI can be used to describe relative scattered tree cover in agricultural settings as well as demonstrate how relative scattered tree cover has changed over time. The next section analyzes how NDVI has changed over time across the 14 study sites as a way to describe how scattered tree abundance has changed over time.

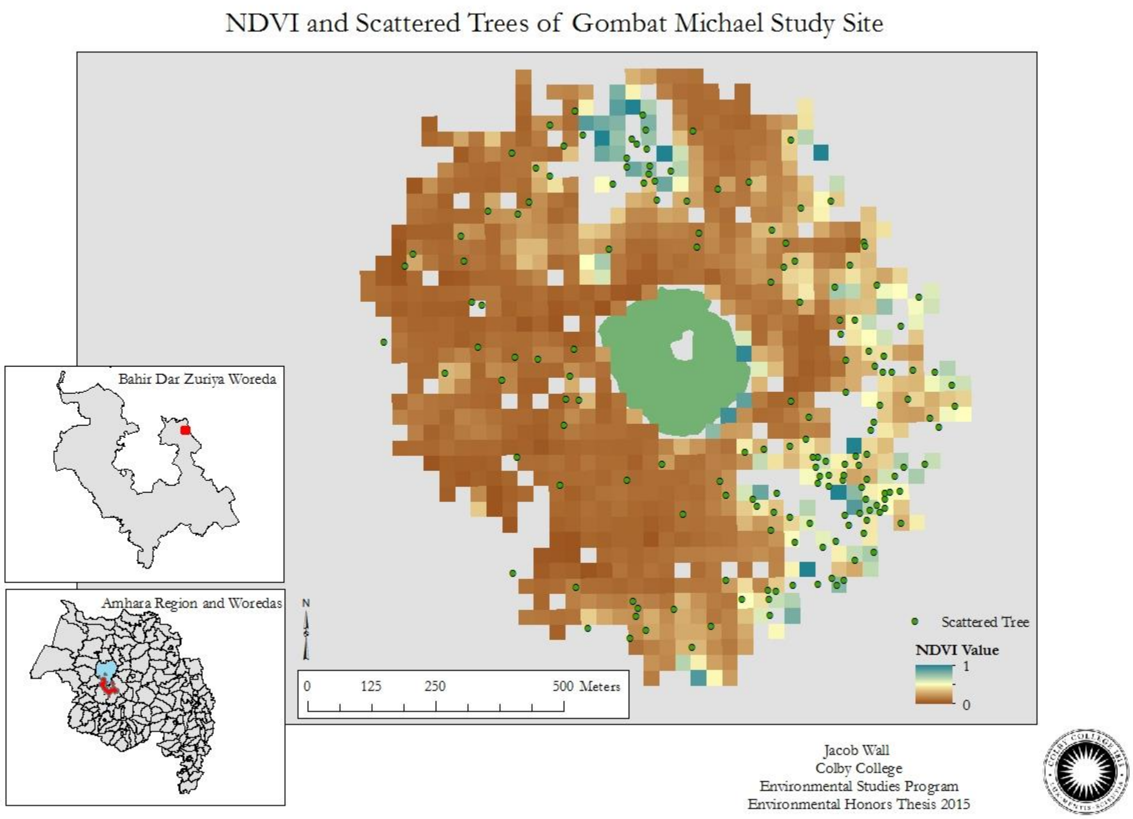


Figure 2.13. NDVI (2015) and scattered trees for Gombat Michael Study Site.

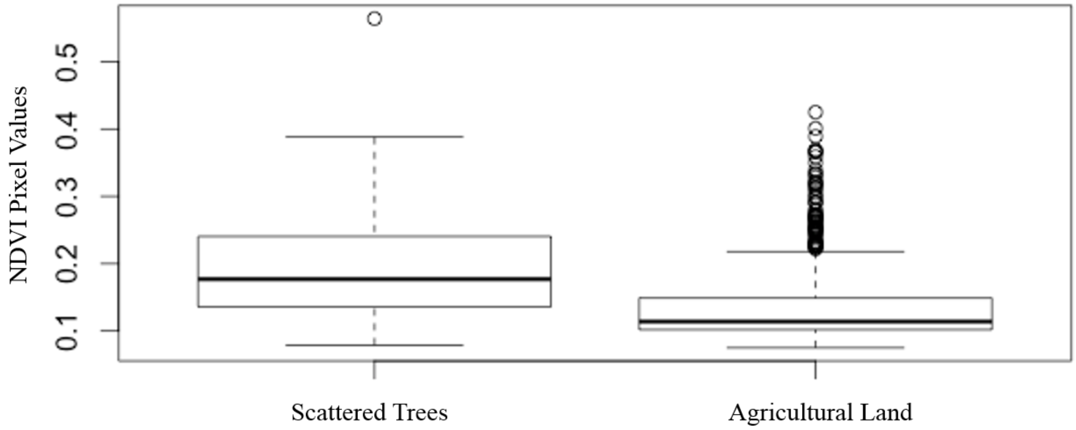


Figure 2.14. NDVI pixel values for scattered trees and agricultural land. Boxplot illustrating the difference between NDVI values of the pixels, which have scattered trees and the pixels that just are agricultural land for the Gombat Michael Church Forest study site.

NDVI Change Over Time (1985 to Present)

NDVI raster's were calculated for the 14 study sites across four time periods (1985, 1995, 2005, 2015) spanning a total of 40 years. Each study site consists of the cropland within a 400-meter buffer surrounding the selected church forest and since each of the forests is a different size and has a different perimeter length, the number of pixels representing each study area differs across sites. The study sites ranged from having 489 to 1276 number of 30- by 30-meter NDVI pixels within the study site (Table 2.4). The median values of the NDVI pixels for each study site are tabulated in Table 2.5.

Table 2.5. Median NDVI values and number of NDVI pixels for the 14 study sites. The pixel counts for each of the woredas (Bahir Dar, Banja, Dera, and Farta) are the sums of the pixel counts for each of the study sites in the woreda. The "Mean Value" is the mean of the medians for each of the columns. Study sites with a decreasing NDVI trend have an asterisk next to their name, while all the other study sites showed a general increasing trend

Study Site	Pixel Count	1985	1995	2005	2015	Mean Value
Bahir Dar*	**2634**	**0.1697**	**0.1543**	**0.1580**	**0.1530**	**0.1588**
Abu*	1232	0.1540	0.1460	0.1480	0.1390	0.1468
Gombat Michael*	845	0.1780	0.1470	0.1440	0.1170	0.1465
Kidana Muret	557	0.1770	0.1700	0.1820	0.2030	0.1830
Banja	**2607**	**0.2330**	**0.2413**	**0.2590**	**0.3258**	**0.2648**
Abu	532	0.2520	0.2500	0.2820	0.3660	0.2875
Mariam	471	0.2230	0.2410	0.2670	0.3140	0.2613
Medhnialm	489	0.2290	0.2360	0.2360	0.3130	0.2535
Michael	1115	0.2280	0.2380	0.2510	0.3100	0.2568
Dera*	**1941**	**0.1705**	**0.1575**	**0.1695**	**0.1530**	**0.1626**
Wonchet*	1017	0.1680	0.1640	0.1800	0.1570	0.1673
Zara*	924	0.1730	0.1510	0.1590	0.1490	0.1580
Farta	**4625**	**0.1658**	**0.1678**	**0.1856**	**0.1871**	**0.1766**
Debresena	1050	0.1760	0.1760	0.1700	0.1900	0.1780
Georges	802	0.1530	0.1500	0.1650	0.1670	0.1588
Kidana Muret	1276	0.1640	0.1670	0.1840	0.1840	0.1748
Mariam	789	0.1640	0.1750	0.2090	0.1820	0.1825
Michael	708	0.1720	0.1710	0.2000	0.2125	0.1889
Sum and Mean Values	**23614**	**0.1865**	**0.1844**	**0.1984**	**0.2145**	**0.1960**

Aggregating the medians of the NDVI data across all of the study sites it appears that NDVI has slightly increased over time (Coef = 0.001, $R^2 = 0.046$) (Fig. 2.15). The range of median NDVI values also has increased over time from 0.1530 to 0.2520 in 1985 to 0.1170 to 0.3660 in 2015, indicating that the NDVI pixel values have become more spread. Looking at the aggregated data may be misleading since the woreda-scale analyses tell a different story.

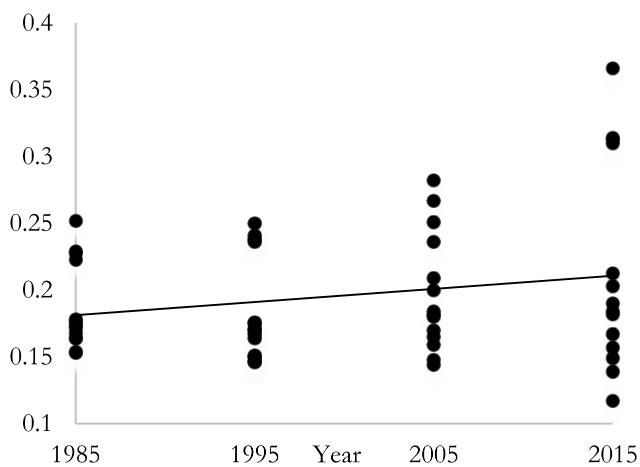


Figure 2.15. Median NDVI Pixel Values. Change of median NDVI pixel values for all 14 study sites over time (1985 to 2015)

Figure 2.16 separates the median NDVI pixels for each year by woreda. The Banja Shekudad woreda study sites have the highest starting median NDVI values of the four woredas (Fig. 2.16). The median NDVI values for the Banja Shekudad woreda study sites increase every year (coef = 0.00296) as described by the multiple linear regression (Table 2.6) (t = 5.64, P = 0.000). The increase in NDVI of 0.00296 each year is very small but statistically significant. However Banja Shekudad has consistently higher median NDVI values than the other four woredas throughout the four time periods and its high NDVI values likely skewed the overall NDVI trend for the entire study region.

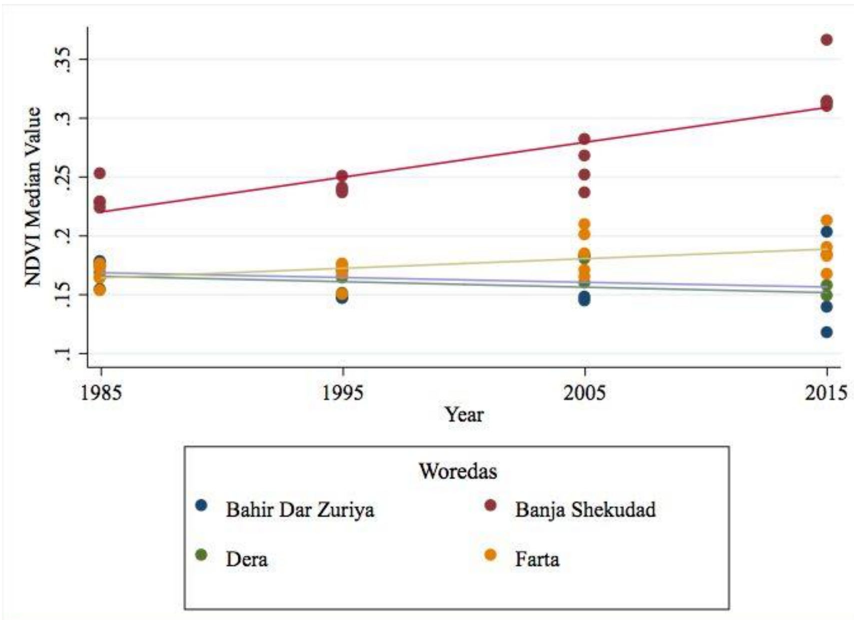


Figure 2.16. Median NDVI change over time by woreda (Bahir Dar Zuriya, Banja Shekudad, Dera, Farta).

Farta Woreda's NDVI values increases over time as well (t = 2.91, P = 0.009), however by a much smaller amount (coef = 0.000817) when compared with Banja Shekudad (coef = 0.00296). The Farta woreda study sites have very similar NDVI pixel values as Dera woreda and Bahir Dar Zuriya in 1985 and 1995, however in 2005 and 2015 Farta's NDVI pixel values are higher, indicating a more recent increase.

The Bahir Dar Zuriya and Dera woreda study sites show a slight decrease in NDVI pixel value over time (Table. 2.6). Therefore the NDVI pixel values stayed relatively constant for these two woredas. Of the individual study sites, only Gombat Michael and Abu of Bahir Dar Zuriya Woreda, and Wonchet and Zara of Dera Woreda

showed a decrease in NDVI over time (Table 2.6). All the other study sites showed an increase in NDVI.

Table 2.6 Multiple linear regression output for the change in NDVI values over time.

Median Value	Coef	Standard Error	t	P>|t|
Year	0.0009804	0.0006072	1.61	0.112
Bahir Dar Zuriya	-0.0004633	0.0006216	-0.75	0.473
Banja Shekudad	0.00296	0.0005246	5.64	0.000
Dera	-0.000405	0.0003271	-1.24	0.262
Farta	0.000817	0.0002803	2.91	0.009
Cons	-1.764759	1.21441	-1.45	0.152

Assuming that NDVI can be used as a proxy to describe scattered tree abundance over time, the study sites in Banja Shekudad woreda appear to have experienced an increase in scattered tree abundance since the 1980s. Farta Woreda experienced an increase in NDVI in 2005 and 2015 and therefore scattered tree abundance appears to have only increased over these two time frames. The NDVI analysis of the study sites in Dera and Bahir Dar Woredas indicate that scattered tree abundances stayed relatively static over the 30-year timeframe.

The NDVI analysis overtime was also broken down into two different government periods. In 1991 the governmental shifted from the Derg Regime to the Ethiopian People's Revolutionary Democratic Front (EPRDF). The EPRDF had very different forest policies compared to the Derg Regime (Chapter 1) which could be an influence on the number of scattered trees. Figure 2.17 illustrates the difference between the mean NDVI pixel vales before and after the EPRDF regime took power. The pixel values are aggregated across all of the study sites and depict an increase and wider range from pre- to post-EPRDF (t = 1.5423, p-value = 0.1305).

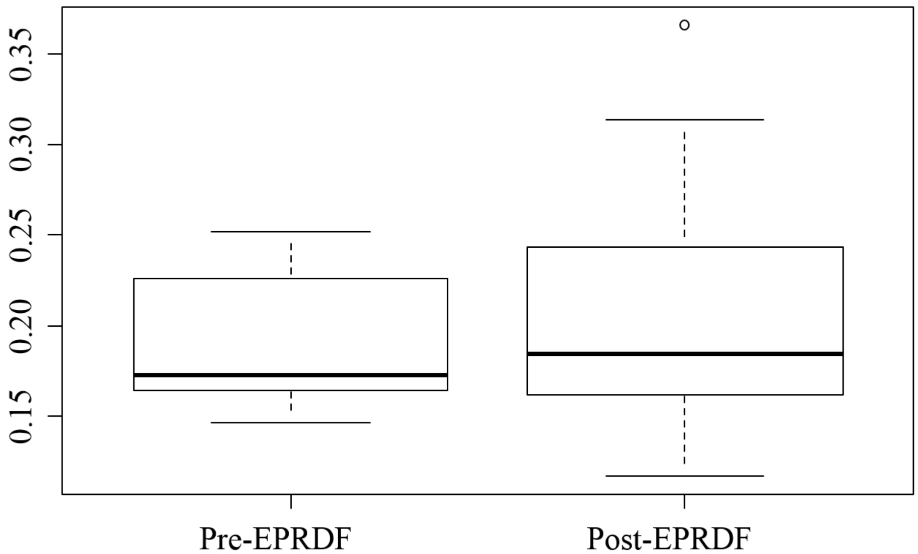


Figure 2.17.. Box plot indicating the difference in means of NDVI pixel values before the EPRDF regime and the NDVI pixel values after the EPRDF (t = 1.5423, df = 42.146, p-value = 0.1305).

Study Limitations

In this study, NDVI is represented as 30 meter by 30 meter pixels with values ranging from -1 to 1. Values closer to 1 indicate high green vegetation content and lower values indicate less vegetation density and cover. Since the data set is relatively coarse, using NDVI to measure change of single-tree cover, which typically deviates on the meter scale, could be problematic especially in such small study regions. This section defines some of the errors associated with a NDVI-based analysis of scattered tree cover change over time.

Google Earth Errors

At each of the 14 study sites, Google Earth was used to trace individual crop plots in which the studied remnant scattered trees persist. In every study site, eucalyptus plots were excluded because eucalyptus is an introduced non-native plantation species and does not fit the criteria of a scattered remnant tree. Also, eucalyptus would significantly skew the NDVI change over time values since eucalyptus has been planted relatively recently in most of the study areas. Eucalyptus tends to be planted surrounding or adjacent to cropland. The smallest amount of error both in terms of human tracing error

and Google Earth position error could yield a study site that accidently includes a eucalyptus plot.

Google Earth's positional accuracy is not fixed and varies over time due to Google Earth constantly replacing and updating images with better resolution (Mohammed et al., 2013). A study by Mohammed et al (2013) indicates that Google Earth's horizontal accuracy in Khartoum, Sudan is about 1.8 meters. In many of the study sites, crop tracings are within 1.8 meters of eucalyptus plots, and if the study sites have a similar horizontal accuracy it is likely that eucalyptus has been included in the NDVI analysis.

The amount of eucalyptus varies across all of the study sites today, and likely varied across the study sites in the past. In 2015, the study sites in the Banja Shekudad woreda had a significantly higher amount of eucalyptus within the study sites surrounding the cropland compared to the other woredas. Most of the agricultural land in Banja Shekudad woreda has eucalyptus surrounding as depicted in Figure 2.18. The other woredas have eucalyptus present, however, it does not surround the agricultural plots like that of Banja Shekudad. With a 1.8 meter horizontal accuracy, the traced crop plots for the study sites in Banja Shekudad woreda could have easily picked up the surrounding eucalyptus when calculating the NDVI. This error could have potentially caused the significantly higher NDVI values for the Banja Shekudad study sites compared to the other 3 woreda study sites.

Figure 2.18. An example study site for each of the woredas including: Gombat Michael in Bahir Dar Zuriya Woreda, Abu in Banja Shekudad Woreda, Zara in Dera Woreda, and Debresena in Farta Woreda. The image is depicting the difference in the amount of eucalyptus across the four study sties, with Banja Shekudad woreda having eucalyptus surrounding most of the agricultural plots (Google Earth, 2015).

Errors of NDVI Analysis

Because NDVI is a measure of vegetation cover and density, climatic changes and variations in the type of vegetation impact NDVI values. Climatic changes can include annual rainfall differences, drought, and seasonality changes, all of which impact the vegetation cover and density. For example, Ethiopia experienced a severe drought from 1983 to 1985, in which a disastrous famine ensued (Bewket & Conway, 2007). The drought in the early 1980s could have impacted the NDVI values from 1985, and could explain why they are lower for some regions. Additionally, the vegetation cover itself can impact the NDVI values. The study areas over the 30 year study period could have had different crops. Different crops have differing amounts of chlorophyll and leafy vegetation extent, which also may impact NDVI values.

Discussion

Analyses used to describe land cover change over time in the Amhara Region of Ethiopia are based on relatively coarse land cover data sets such as Hansen et al. (2013). These coarse analyses, which are based on vegetation cover alone fail to differentiate between indigenous forest loss and plantation forest gains. These two forest types are qualitatively and quantitatively very different in terms of ecological importance and ecosystem services flows. Depending on the definition of a forest used, the Amhara Region could have experienced forest loss or forest gain from 2000 to 2014, with stricter definitions indicating an increase in forest area (Hansen et al., 2013) and less strict definitions (FAO) describing a loss in forest area. The stricter definition indicates an increase due to more tree plantations of exotic species.

The recent studies looking at tree cover change over time with more strict definitions of forests capture only relatively dense forest, which not only has the potential of being skewed by exotic plantation species, but also of underestimating loss of native woody plant density and biodiversity on landscapes characterized by dispersed trees. Scattered remnant trees are ecologically and economically important, however, the literature does not emphasis this. As of 2015 the cropland of the selected study sites has about 2 scattered trees per hectare, which suggests that millions of these trees potentially persist in the farmland of the Amhara Region. Yet these scattered trees in the cropland are not counted in tree cover change metrics because they make up less than 10% tree cover.

Since the 1960s the Amhara Region has experienced a continuing decline in native forest cover. However, since the 1960s, single tree scale analyses indicate a net gain of scattered tree abundances over the last half a century. NDVI analyses also point to an increase in scattered tree abundances. From 1985 to 2015, NDVI pixel value for the entire study region on average has increased at 10 year increments (1985, 1995, 2005, 2015). Banja Shekudad and Farta Woredas both saw a significant increasing trend in NDVI pixel values, while the other two study regions, Bahir Dar Zuriya and Dera Woredas witnessed an insignificant decline/no change in NDVI pixel values. The analysis indicated that the NDVI pixel values increased noticeably more in 2005 and 2015 compared to the change in 1985 and 1995. The NDVI values also increased from

the pre- to post-EPRDF time period (1991), suggesting that a change in government regime could have influence scattered tree cover. Under the EPRDF national forest policy shifted to include more specific laws and further addressed forest degradation. The Ethiopian Environmental Protection Authority (EPA) and the Ethiopian Ministry of Agriculture and Rural Development were established under the EPRDF (zur Heide, 2012; Awulachew et al., 2009). Both of these programs focused on conservation projects and emphasized reducing human impact on the forests and could have led to an increase in scattered tree numbers in the agricultural landscape (zur Heide, 2012; Awulachew et al., 2009).

Conclusions

This chapter - though a preliminary analysis - is the first study of scattered tree cover change over time in the Amhara Region of Ethiopia. Forest cover and forest cover change estimates miss dispersed trees in the agricultural landscapes due to forest definitions (FAO and Hansen et al., 2013) ranging from 10% to 30% tree cover. In the Amhara Region of Ethiopia, where land has been cultivated for thousands of years, many of the only remaining trees persist as scattered remnant trees in the cropland. Based on estimates, close to 20 million of these trees could be persisting in the Amhara Region agricultural landscape. Therefore, forest statistics in Ethiopia, which use relatively coarse land cover data and only capture relatively dense forest greatly underestimate native woody plant density and biodiversity on land characterized by scattered – but still ecologically and economically important – remnant trees.

Over time, certain study sites have witnessed decreases in scattered tree cover while others have seen an increase, with a net increase in scattered trees across the entire study region. More geospatial research is needed to confirm this trend in scattered tree cover. Through this research another potential source of forest statistics error in Ethiopia forest estimates was identified, however, not quantified. Forest estimates fail to differentiation between indigenous forests and plantation forests, though the two forest types are qualitatively and quantitatively very different in terms of ecological importance and ecosystem flows. Further research is needed to identify how this error plays a role in estimating Ethiopia's forest cover and deforestation statistics.

CHAPTER 3: THE SOCIAL SIGNIFICANCE OF SCATTERED REMNANT TREES IN NORTHERN ETHIOPIA

Introduction

A growing body of scholarship has highlighted the ecological and cultural importance of church forests and other natural forest fragments in the Amhara Region. The roles of scattered remnant trees left in actively cultivated agricultural systems remain understudied, with the exception of a more general literature addressing the specific benefits of tree species to the regional ecosystem and to the rural smallholders whose land the trees occupy (Tolera et al., 2008; Negash, 2007; Alebachew, 2003). There is a gap in the literature surrounding how scattered tree cover has changed over time in the physical landscape, as well as how the scattered trees are perceived to have changed over time from the perspective of farmers.

This chapter considers how scattered trees have changed over time through the lens of rural smallholders that live with the trees. Using social survey data this chapter identifies how community members have perceived scattered tree cover to change over time as well as identifies possible drivers of scattered tree cover change over time and the implications of those drivers.

Methods

I use two primary methods to investigate scattered tree cover change in the Ethiopian Northern Highlands. Survey data analyses provided information on how scattered trees are perceived to have changed in the agricultural landscape. GIS analyses indicated possible explanations for a change in scattered tree abundance over time. The data survey and GIS data was collected over the course of a 4 week period during July and August of 2015 and over a 2 week period in January of 2016 as described in the methods section of Chapter 2.

Study Sites

Like in Chapter 2, all of the study sites included in this chapter are located in the Amhara National Regional State, within the following four woredas: Banja Shekudad Woreda, Dera Woreda, Farta Woreda, and Bahir Dar Zuriya Woreda (Fig 2.2). All of

these methods were implemented across 14 study sites in the four study woredas, as well as 6 church forests in Farta and Bahir Dar Zuriya Woredas.

Church Forests Study Sites

During the summer of 2015, household surveys and farmer focus groups were conducted at six different church forests in the Amhara Region, including Debresena, Woji, Abalibanose, Alember, Robit Bata, and Gombat Michael (Fig. 3.1). Ecological data including soil sampling and seedling measurements was taken at four of the church forests including Debresena, Woji, Abalibanose, Robit Bata, and Gombat Michael.

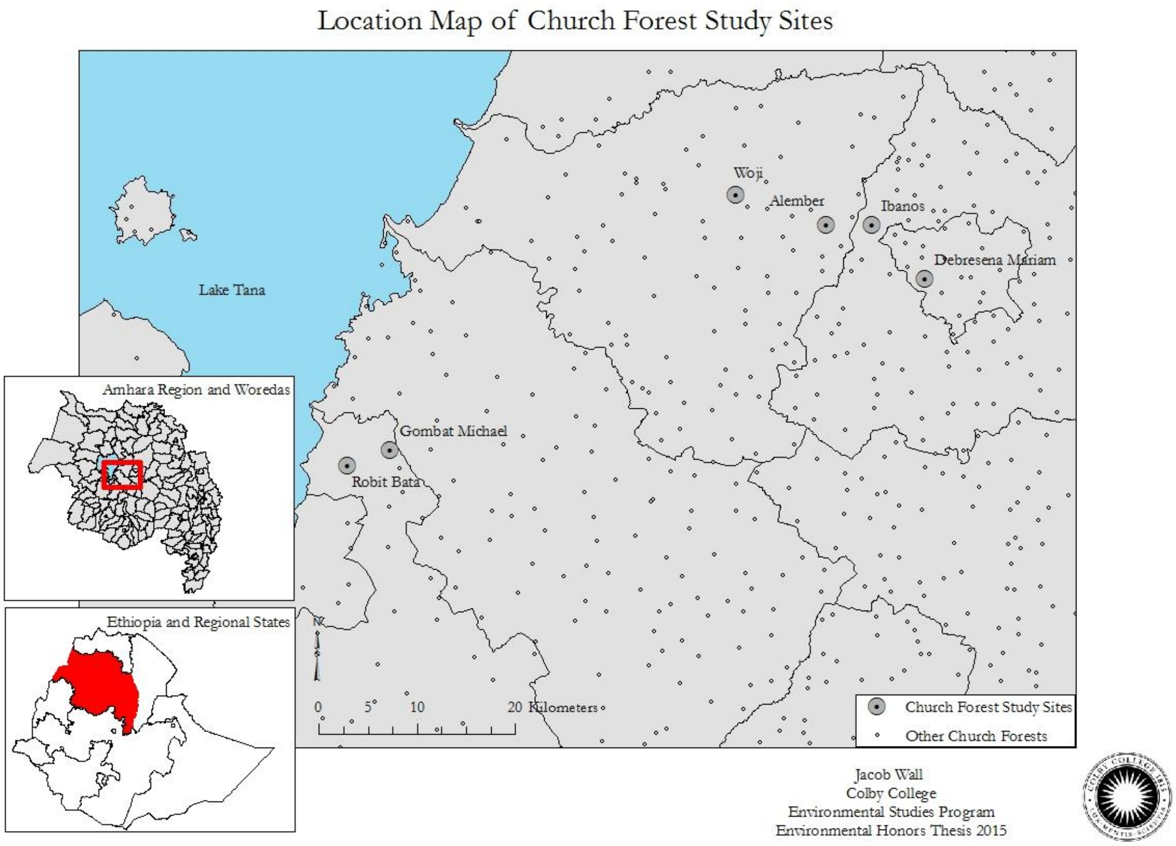


Figure 3.1. The 6 church forest study sites including: Debresena, Woji, Abalibanose, Alember, Robit Bata, and Gombat Michael

The six church forests spanned a wide range of area, perimeter, and elevation (Table 3.1). They varied in areas from 5.82 to 26.04 ha and perimeters of 1.00 to 2.66 km. The forests were located at altitudes ranging from 1,863 to 2,664 m. All of the church forests were surrounded by deforested, agricultural and grazing land. The forests

have been continuously disturbed with livestock and people entering and leaving the forests constantly, as well as a number of students live within the church forests in permanent buildings in some of the forests.

Table 3.1. Summary of forest characteristics among the six studied church forests

	Debresena	Woji	Abalibanose	Alember	Robit Bata	Gombat Michael
Forest Area (Hectares)	12.17	26.04	9.06	16.21	6.80	5.82
Forest Perimeter (km)	1.41	2.66	1.43	1.91	1.14	1.00
Elevation (m)	2,664	2,005	2,379	2,151	1,863	1,918

Survey Methods

I used three social survey methods to analyze the socio-cultural significance of scattered remnant trees in the agricultural landscape. These three methods include farmer surveys, household surveys, and farmer focus groups.

Farmer Survey

Farmer surveys were conducted across 14 study sites in Banja, Dera, Farta and Bahir Dar Woredas in August of 2015 and January of 2016 to further understand the socio-ecological significance of scattered trees in agricultural systems. These are the same 14 study sites that were studied in Chapter 2. The survey collected demographic information of the respondents, all of whom have scattered trees in their agricultural crops or pasture land (Table 3.2.) and information on the trees in the farmers' fields. Respondents included farmers but also students, day laborers, government employees, merchants, herders, and religious service members. The surveyors were hired professionals from Ethiopia and the data was collected over the course of 9 days, 3 days at each of the woredas. In Banja Woreda the surveys were completed in August of 2015 and in Dera, and Farta Woredas, and Bahir Dar Woredas the surveys were completed in January of 2016.

Table 3.2. Summary of farmer survey data for each study site, including the date, sample size, and respondents' demographics (sex, age, primary occupation, income, number of livestock, area of owned land, and number of scattered trees in their agricultural fields).

	Banja Woreda	**Dera Woreda**	**Farta Woreda**	**Bahir Dar Woreda**
Survey Date	August, 2015	January, 2016	January, 2016	January, 2016
Sample Size	50	50	50	25
Church	48% Michael 18% Mariam 18% Medhnia 16% Abu	56% Wonchet Michael 44% Zara Michael	20% Kidana Muret 20% Debresena 18% Michael 14% Mariam 8% Georges	48% Kidana Muret 24% Abu 28% Gombat Michael
Sex	48% Male 52% Female	58% Male 42% Female	56% Male 44% Female	48% Male 52% Female
Median Age Range	30-39	40-49	40-49	30-39
Head of Household	60%	94%	82%	80%
Average Number in Household	5.1	5.5	5.4	6.0
Occupation	54% Farmers 18% Students 10% Day Laborers	96% Farmers 2% Government Employment 2% Student	90% Farmers 4% Day Laborers 2% Religious Service	92% Farmers 4% Merchant 4% Herder
Median Annual Income (Birr)	--	1,000 – 2,500	1,000 – 2,500	1,000 – 2,500
Average Number of Livestock	--	5.2	5.6	5.5
Average Area of Land Owned (Timad)	--	4.2	3.0	3.1
Average Number of Scattered Trees in Field	--	5.8	5.2	6.0

The surveys were conducted surrounding 2 to 5 different church forests in each woreda. Two of the church forests (Debresena and Gombat Michael) were also study sites for the other social survey methods. The other church forests around which surveys were conducted were chosen at random (Chapter 2, Fig. 2.7 and Table 2.2). Respondents were chosen by chance as the church forest was circumnavigated, walking in the agriculture and pasture land. Respondents usually were farming in their crop land, watching their livestock in their pasture land, or close to their homes when they were surveyed.

The farmer survey instrument was field tested at Banja Shekudad Woreda in August of 2015, and asked questions about how the number of remnant scattered trees has changed over time in crop and pastureland, the reasons for the indicated change, the kinds of services and benefits that the trees provide, as well as the negative impacts of the

trees in the cropland. The species of each tree found in the agricultural land was also noted (see GPS pinpointing method in Chapter 2, section 2.3.1). The survey tool was updated for use in Dera, Farta, and Bahir Dar Zuriya Woredas in January, 2016 with the addition of demographic and household questions including annual household income, land and livestock ownership, whether any of the livestock were sick, and the exact number of scattered trees in their agriculture land or pastureland.

The farmer survey method was paired with the GPS pinpointing method. Each farmer was picked due to the presence of scattered trees in their land as the church forest was circumnavigated. The tree species identified with the GPS pinpointing were correlated to the survey of the respondent who owns that tree so further future analyses could be performed. The survey data were analyzed using Microsoft Office Excel and the open-source statistical software package R version 3.2.2 (2015).

Household Survey

Household surveys were conducted surrounding 6 different church forests in the South Gondar Administration Zone of the Amhara National Regional State in Northern Ethiopia to further understand how different church forest communities interact with their church forests, as well as investigate how the forest and surrounding landscapes have changed over time. The six church forests included in the study were Debresena, Woji, Abalibanose, Alember, Robit Bata, and Gombat Michael (Fig. 3.1). The surveys were administered by Ethiopian University student parters all in the Amharic language. The surveys were conducted over the course of four weeks in July and August of 2015 and a total of 138 respondents were interviewed across the 6 church forest communities. For the study, a household is defined as a group of people who manage a common landholding and live under one central decision-maker.

The survey collected demographic information of the respondents and the role that the respondent plays in the church (Table. 3.3). The survey also asks income related questions about how much land they use for certain activities and the income gained from each activity. The respondents were asked general questions about their church forest characteristics and the benefits that are gained from the forest. The survey also asked the respondents to describe the specific uses of different tree species found within the church

forest and which species the respondent thought should be planted within the forest. These responses were paired with the farmer surveys to analyze the uses of individual species of seed trees found in the agriculture and pasture land. Five different risk assessment questions were also asked to analyze how the respondents react to risk.

Table 3.3. Summary of household survey data including the sample size, sex, average age, primary occupation, average income, average number of livestock, and average area of land owned among the six different church forest communities (Debresena, Woji, Abalibanos, Alember, Robit Bata, and Gombat Michael).

	Debresena	**Woji**	**Abalibanos**	**Alember**	**Robit Bata**	**Gombat Michael**
Sample Size	29	25	12	19	24	29
Sex	70% Male 30% Female	68% Male 32% Female	67% Male 33% Female	74% Male 26% Female	88% Male 12% Female	74% Male 26% Female
Median Age	40-49	40-49	40-49	40-49	40-49	40-49
Average Number in Household	6.7	5.6	4.8	5.3	5.2	5.4
Head of Household	92%	96%	92%	95%	96%	96%
Occupation	59.1% Farmer 27.3% Farmer and Herder 4.5% Religious Service 4.5% Day Laborer 4.5% Merchant	54.2% Farmer 33.3% Farmer and Herder 8.3% Merchant 4.2% Religious Service	40% Farmer 60% Farmer and Herder	47.1% Farmer 41.2% Farmer and Herder 5.9% Merchant 5.9% Day Laborer	57.1% Farmer 33.3% Farmer and Herder 9.5% Merchant	46.2% Farmer 42.3% Farmer and Herder 3.8% Herder 3.8% Merchant 3.8% Government
Education Level	41.7% Adult school 25% Elementary School 21% None 12.5% Other	24% Adult School 24% Elementary School 24% None 8% Other	16.7% Adult School 16.7% Elementary School 66.7% None	26.3% Adult School 26.3% Elementary School 36.8% None 10.6% Other	33.3% Adult School 41.7% Elementary School 25% None	6.9% Adult School 3.4% Elementary School 62.1% None 24.1% Religious School
Median Income (Birr)	10,000 to 20,000	10,000 to 20,000	5,000 to 10,000	10,000 to 20,000	10,000 to 20,000	5,000 to 10,000
Average Number of Livestock	5.3	6.5	5.8	NA	6.5	8.8

For the purpose of this study, four questions related to scattered indigenous trees in the respondent's fields were asked. These questions inquired about how respondents perceived the total number of seed trees to change over time. If they thought the number of trees was decreasing the respondents were asked for the reasons for this change

Farmer Focus Group

Farmer focus groups were conducted surrounding 6 church forest communities including: Debresena, Woji, Abalibanose, Alember, Robit Bata, and Gombat Michael. Three focus groups were conducted at each forest, one with priests, one with women, and the third with farmers of the church community. Each focus group followed a pre-planned protocol for questions and participatory activities. Certain questions remained consistent across protocols but also certain questions differed. The nature of a focus group is very fluid, and as such, the enumerators were able to ask other questions between the pre-determined questions. The enumerators consisted of Ethiopian university students; all of the focus groups were done in Amharic.

Since this study focuses on the trees within the farmers' fields, only the farmer's focus group responses were used for the report. On average, 6 farmers participated in each of the focus groups. The farmers were asked to discuss a range of questions including a few introductory questions such as, "tell me about being a farmer in this community," and "what are the best crops to grow? And why?" The farmers were also asked to discuss questions about the indigenous trees in their fields. These questions asked about the certain species found in the farmers' fields, why those specific species, the benefits and negative impacts of those species, and how often the trees are harvested.

In the first trial of the protocol, questions at the end of the focus group suffered and were sometimes skipped due to time constraints. This, however, became less of a problem with the next focus group sessions. As such, the last few questions at the end of the protocols at Debresena are very incomplete. The responses to the focus groups were recorded using a voice recorder as well as recorded by hand. Both the voice recording and hand recorded notes were translated to English and the responses were coded in excel and were analyzed using Microsoft Office Excel and the open-source statistical software package R version 3.2.2.

GIS Methods

Crop Tracings and Monte Carlo Simulation

GIS analyses were used in order to examine the relationship between crop plot size, human settlements, and tree abundances. As described in chapter 2, 2015 Google Earth imagery was used to trace the individual crop plots in the 400 meter buffer surrounding each church forests study site. The individual crop plots were also traced for the 1960s imagery. Both of these methods are further described in Chapter 2, Sections 2.3.2 and 2.3.3.

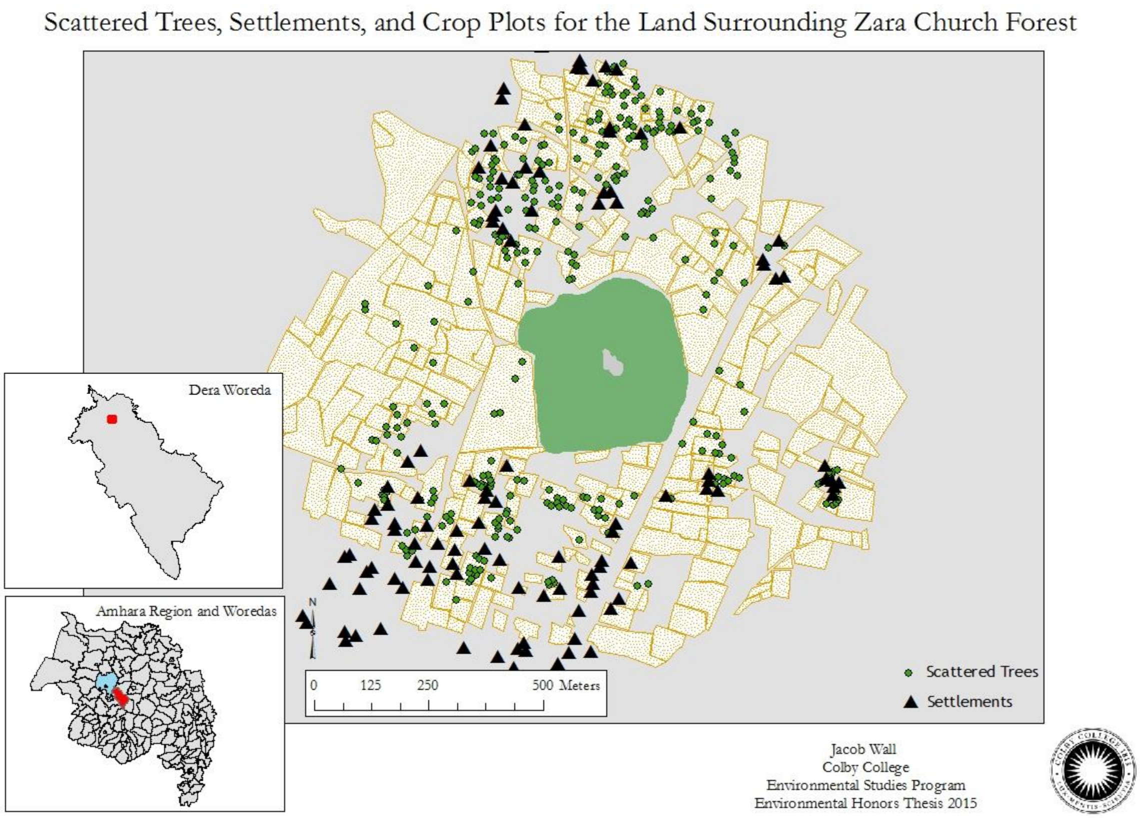


Figure 3.2. Polygons depicting the crop plots, and points indicating scattered remnant trees and settlements in the land surrounding Zara Church Forest. This represents Zara study site and the crop plots and scattered trees are within a 400 meter buffer surrounding Zara Church Forest.

Settlements within the 400 meter buffer were also recorded in Google Earth with placemarkers (Fig 3.2). Each hut or structure with a roof was indicated with one placemark. Using ArcMap, the Euclidean distance tool was used to create a raster indicating distance from the nearest settlement—this raster was used to extract the

distance from each observed tree to the nearest settlement. Using R, a Monte Carlo (MC) simulation was conducted where each tree was randomly redistributed across the study area and its distance to the nearest settlement (using the Euclidean distance raster) was recorded; this process was repeated 600 times. The MC simulation defined the null hypothesis that the location of trees were no more or less closer to settlements than expected had they been randomly distributed. The average distance to the nearest settlement was then compared to the distribution of average nearest settlement distances from the MC simulation giving us a pseudo p-value (note this is a p-value found using a MC simulation and not a typical statistical test).

Results

Perceptions of Scattered Tree Cover Change Over Time

The farmer survey and the household survey specifically asked how the abundance of scattered trees has changed over time in the agricultural cropland, as well as in the pasture land. Instead of asking about specific time periods the survey tools asked how the abundance of scattered trees changed over 4 different governmental periods since people can recall time periods better than specific dates. The governmental periods include the rule of Haile Selassie (1930 to 1974), the Derg Regime (1974 to 1991), the period when the Ethiopian People's Revolutionary Democratic Front (EPRDF) became the ruling political coalition, and over the past 5 years (Table. 3.4). The farmer focus group asked the farmers about how the abundance of scattered trees changed over the course of their life and did not discuss individual time periods.

Table 3.4. Ethiopia's governmental periods

Government	Time Period
Haile Selassie	1930 to 1974
Derg Regime	1974 to 1991
EPRDF	1991 to 2010
Last 5 Years	2010 to 2015

Figure 3.3 illustrates the respondents' perceived change in scattered tree abundance in the cropland for the four time periods across all the study sites. Most respondents agreed that scattered trees have increased in the agricultural landscape over the last five years, with 81% choosing this answer. The survey respondents also suggested that since the EPRDF came into power scattered tree abundances have increased (78% of respondents). Reports of the scattered tree abundances during Haile Selassie's rule and the Derg Regime, however, are a bit more inconsistent. For the Derg

Regime, 40% of the respondents indicated that scattered tree abundance decreased while 44% of respondents described an increase of tree numbers, with the other 14% suggesting that there was no change. During Haile Selassie's rule, 46% of the respondents believe that scattered tree abundance decreased while 40% think that scattered tree numbers increased, with another 14% indicating that there was no change. Respondents indicate that scattered tree abundance change was very similar for the pastureland and cropland, and the figures highlight the cropland exclusively (Figure. 3.3).

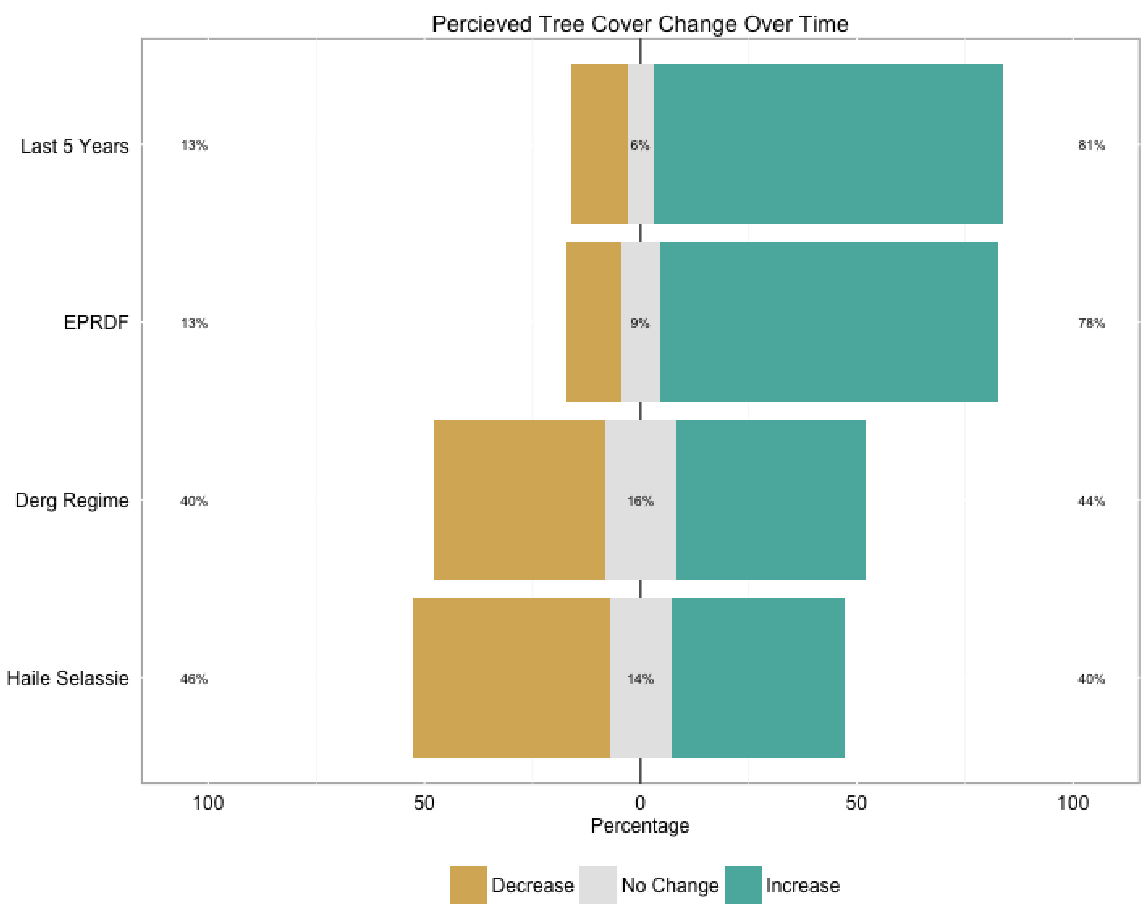


Figure 3.3. Farmer survey responses of perceived scattered tree cover change over the four time periods (during Haile Selassie's rule, under the Derg Regime, once the EPRDF came to power, and over the last 5 years) for the cropland.

Survey responses differed by study region. Figure 3.4 and Table 3.5 depicts the survey responses by region. In the Bahir Dar Woreda most of the respondents indicated that scattered tree cover decreased over the course of Haile Selassie's rule and the Derg

Regime (73% and 75% of respondents, respectively). For the other three woredas, the respondents were split over this time frame of whether or not the scattered tree cover was increasing or decreasing. All of the woredas overwhelmingly agreed that over the course of the EPRDF and over the last 5 years scattered tree cover in the cropland has been increasing.

The perceived change of scattered tree abundance for all the study sites parallels the NDVI analysis, both of which indicate a general increase in abundance over the recent time periods (EPRDF for the survey analysis and since 2005 for the NDVI analysis) and not much change during the later time periods (Derg Regime and Haile Selassie's rule for the survey analysis, and from 1985 to 1995 for the NDVI analysis).

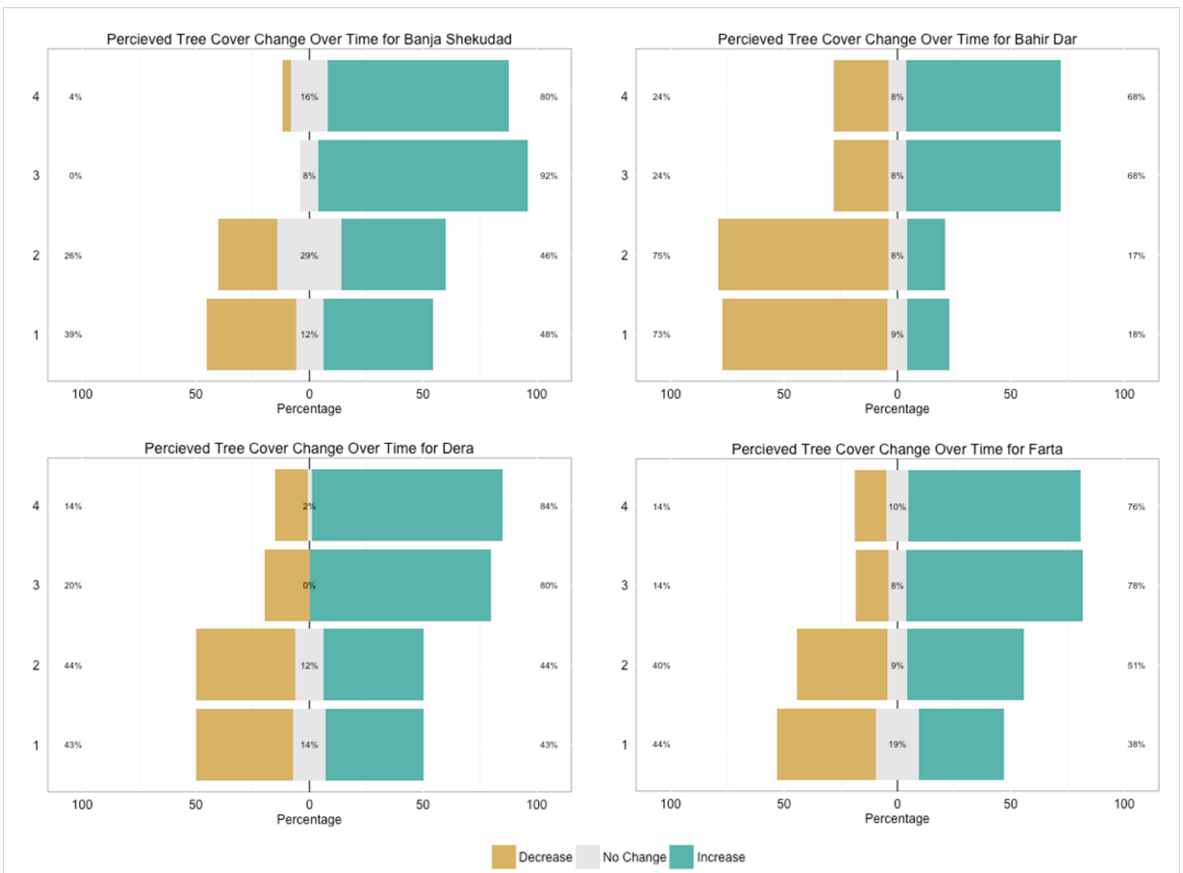


Figure 3.4. Farmer survey responses of perceived scattered tree cover change over the four time periods (1= during Haile Selassie's rule, 2= under the Derg Regime, 3= once the EPRDF came to power, and 4= over the last 5 years) for the cropland for the four study regions (Banja Shekudad, Bahir Dar, Dera, and Farta Woredas).

Table 3.5. Percent of respondents from the farmer survey responding that the number of scattered indegenous trees either increased, decreased or did not change over each time period (Last five years, during the EPRDF, during the Derg Regime, and under Haile Selassie's rule) in their cropland and pastureland.

	Bahir Dar Zuriya		**Banja Shekudad**		**Dera**		**Farta**	
Period	**Cropland**	**Pastureland**	**Cropland**	**Pastureland**	**Cropland**	**Pastureland**	**Cropland**	**Pastureland**
Last Five Years	68% Increase 24% Decrease	72% Increase 24% Decrease	58.8% Increase 35.3% No Change	65.6% Increase 28.1% No Change	84% Increase 14% Decrease	72.0% Increase 24.0% Decrease	76% Increase 14% Decrease	80.0% Increase 14.0% Decrease
EPRDF	68% Increase 24% Decrease	72% Increase 24% Decrease	79.3% Increase 20.7% No Change	67.7% Increase 29.0% No Change	80% Increase 20% Decrease	74.0% Increase 24.0% Decrease	77.6% Increase 14.3% Decrease	68.0% Increase 20.0% Decrease
Derg Regime	15.4% Increase 76.9% Decrease	15.4% Increase 76.9% Decrease	25% Increase 28.1% Decrease	34.9% Decrease 38.1% No Change	43.8% Increase 43.8% Decrease	43.8% Increase 37.5% Decrease	51.4% Increase 40% Decrease	42.9% Increase 42.9% Decrease
Haile Selassie	16.7% Increase 75% Decrease	16.7% Increase 75% Decrease	29.6% Increase 48.1% Decrease	29.8% Increase 42.1% No Change	42.9% Increase 42.9% Decrease	50% Increase 35.7% Decrease	37.5% Increase 43.8% Decrease	37.5% Increase 40.6% Decrease

Table 3.6. Percent of respondents from the Household Survey responding that the number of scattered indigenous trees either increased, decreased or did not change over each time period (Last five years, during the EPRDF, during the Derg Regime, and under Haile Selassie's rule) in their cropland and pastureland.

Period	**Cropland**	**Pastureland**
Last Five Years	58.5% Increase 28.3% No Change	42.2% Increase 29.7% No Change
EPRDF	50.0% Increase 33.3% No Change	39.7% Increase 31.7% Decrease
Derg Regime	40.5% Decrease 36.7% No Change	31.8% Increase 40.9% No Change
Haile Selassie	34.3% Decrease 40.0% No Change	33.3% Decrease 45.8% No Change

Table 3.7. Farmer Focus Group responses to the question "Have you seen the number of scattered indigenous trees increase or decrease over your lifetime?" for the 6 church forests

Church	**Response**
Debresena	Decreasing because of population growth and need for wood. There was not much of a decline during the Derg Regime but they are decreasing especially during this government (EPRDF).
Gombat Michael	The number of trees has been decreasing because they were old and fell. Previously there was a shortage of knowledge so people didn't care for the trees and cut them down but now we replace the trees when they fall and we anticipate for the number of trees to increase in the future.
Alember	The number of trees in the farmland was decreasing in the past but now they are increasing
Woji	The number of trees has been decreasing because we need space for agriculture
Robit Bata	Decreasing because some people cut them completely down to sell and others die naturally as they age
Abalibanos	No Response

Household survey results differed from the farmer survey data (Table 3.6). Of the 134 respondents that answered household survey questions about scattered trees, 103 (76.9%) indicated that they have scattered trees in their agricultural fields. Of these 103 respondents, about a third of the respondents described a decrease in number of scattered trees in the cropland during Haile Selassie's rule (34.4%) and during the Derg Regime (40.5%). The household respondents overwhelmingly answered that scattered tree abundance did not change during Haile Selassie's rule (40.0%) and during the Derg Regime (36.7%). For the EPRDF, the survey results point to an increase in scattered tree abundance in the cropland (50.0%) and for the past five years (58.5%). The perceived increase in scattered tree abundance since the EPRDF and over the last five years was much lower for the household survey compared to the farmer survey, which had an aggregate 78% for the EPRDF and 81% for the last five years (Table 3.5).

The third social survey method included six focus groups at six different church forest sites, however the focus group at Abalibanos did not ask the question about how tree abundances have changed. The responses are tabulated in Table 3.7 and included a group of farmers discussing how scattered tree abundances have changed over the course of the farmer's lives. The respondents at Debresena, Woji, and Robit Bata study sites indicated that the number of scattered trees has decreased over their lifetimes. The respondents from Gombat Michael and Alember described a decrease in number of scattered trees at the beginning of their lives but an increase more recently.

Perceived Drivers of Scattered Tree Cover Loss

For the household survey and the farmer survey, respondents were asked why scattered trees would be lost. For Farta, Dera, and Bahir Dar Zuriya Woredas, respondents were asked to pick the main driver of scattered tree loss as well as list all of the causes. For Banja Shekudad Woreda and the household surveys, respondents were only asked to list all of the drivers of scattered tree loss in the agriculture and pasture land. Respondents in Farta, Dera, and Bahir Dar Zuriya Woredas were also asked to provide all cases of scattered tree loss. The main drivers of scattered tree loss are visualized in Figure 3.5, all of the perceived causes of scattered tree loss are illustrated in Figure 3.6.

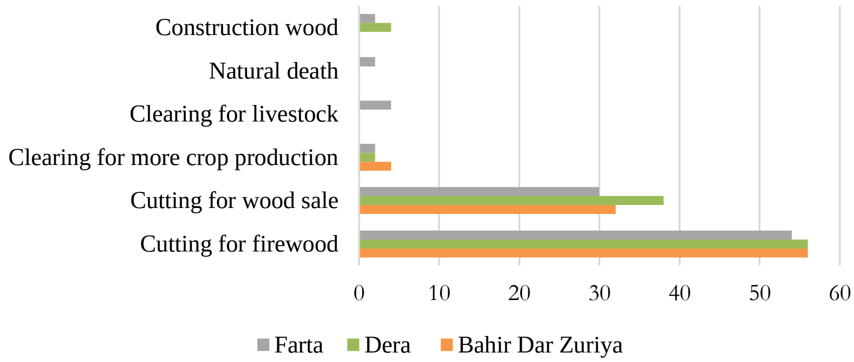


Figure 3.5. Perceived primary causes for scattered tree loss. Respondents perceived main drivers of scattered tree loss in the agriculture and pasture land for Farta, Dera, and Bahir Dar Zuriya Woredas.

Cutting scattered trees for firewood and cutting for wood sale are described as the two main drivers of scattered tree deforestation (Fig 3.5). Clearing for more crop production, clearing for livestock, natural death, and clearing for construction wood were also described to be main causes for scattered tree loss, however, on a much smaller scale.

The respondents for from the household survey also describe cutting for firewood and cutting for wood sale as the top two drivers of scattered tree loss (Fig 3.6). Clearing for more crop production, clearing for livestock, and natural death, were all described as factors that have led to scattered tree loss, however they were listed by less than half of the respondents for each site. Respondents also listed cutting for charcoal, cutting for construction wood, and cutting for food as other reasons for tree loss.

The farmer focus groups also discussed reasons for why scattered trees are lost (Table 3.7). The Debresena farmer focus group said that scattered tree numbers are declining due to population growth and a growing need for wood. The Robit Bata farmer focus group agreed and stated that people cut down the trees for wood sale. These farmers also noted that many of the trees die naturally from old age. The Gombat Michael focus group decided that trees die naturally from old age, but also indicated that historically, scattered trees were cut because there was a shortage of knowledge about the benefits of the trees and people did not care. The Gombat Michael farmers specified that now they replace the trees when they fall and they anticipate the number of scattered trees to increase in the future. At Woji, the farmers stated that scattered trees have declined in numbers due to a need for agricultural space.

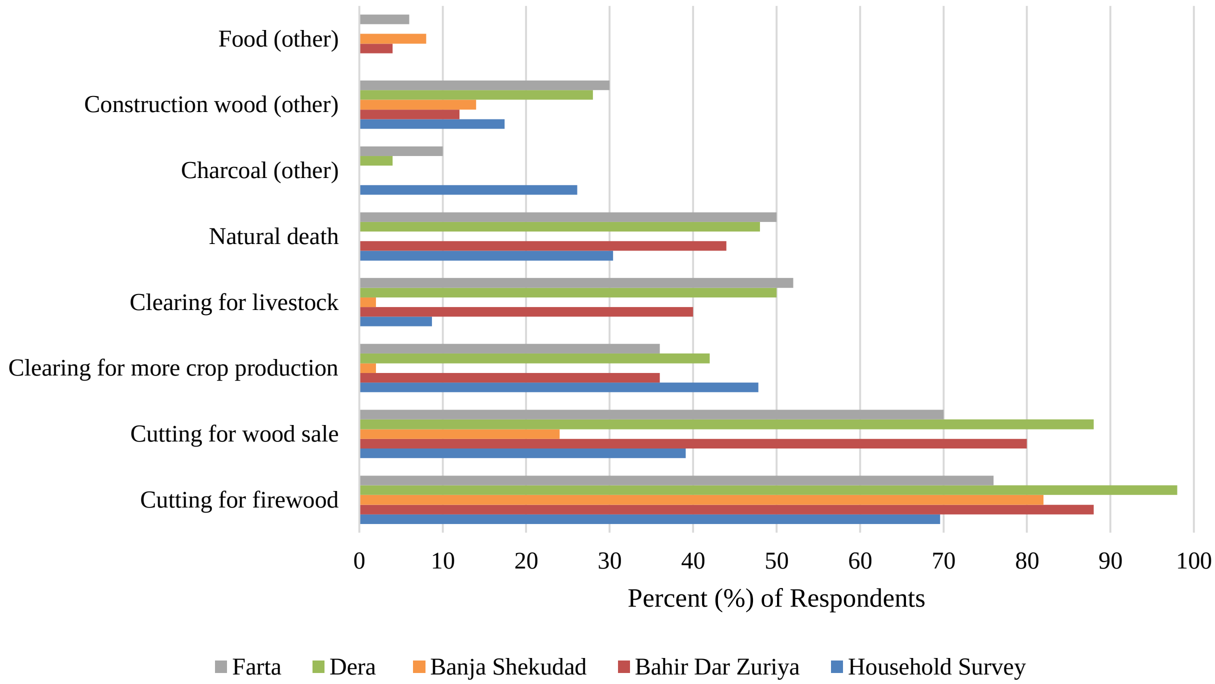


Figure 3.6. Perceived causes of scattered tree loss. Respondents perceived causes of scattered tree loss in the agriculture and pasture land for all of the study regions and for the household survey responses.

Perceived Drivers of Scattered Tree Gain

In the Farta, Dera, and Bahir Dar Zuriya woredas, respondents were asked if scattered trees have increased over time, what the drivers of this change was. (The question was put on the farmer survey tool after the household survey and Banja Shekudad was surveyed so they were excluded from this part of the study.) The format of these survey questions was exactly the same as the tree loss question and included what the respondent thought was the main driver of scattered tree cover gain as well as asked for list of all the reasons for the increase. Respondents from the three woredas indicated that the main driver of scattered tree cover gain was natural regeneration and individual farmer planting (Fig. 3.7). Some of the respondents mentioned that community planting programs were also the main driver, however to a much smaller extent. The respondents decided that natural regeneration, individual farmer planting, community planting, and government planting, all lead to more scattered trees in their field (Fig. 3.8).

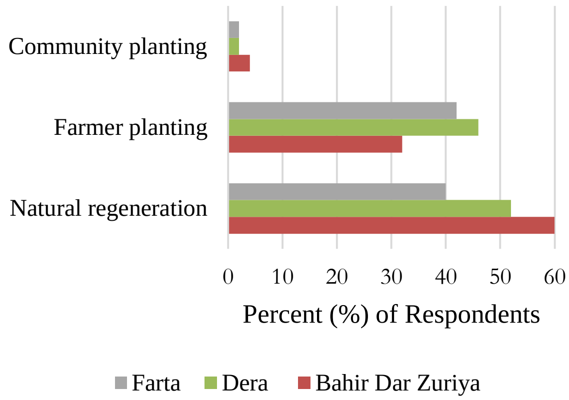


Figure 3.7 Respondents' perceived causes of scattered tree gain in the agriculture and pasture land Farta, Dera, and Bahir Dar Woredas

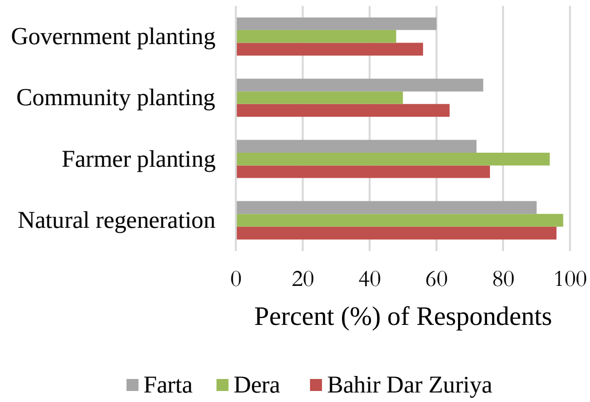


Figure 3.8 Respondents' perceived causes of scattered tree gain in the agriculture and pasture land Farta, Dera, and Bahir Dar Woredas

To further understand why scattered tree abundance have changed over time and why certain locations have more scattered trees, other factors including the influence of crop plot area, the change in plot area over time, the location and distribution of human settlements, were geospatially analyzed.

Agricultural Plots

Agricultural Plot Size

Crop plot size was compared to tree abundance and density to see if the size of the agricultural crop had any impact on the number of trees in the land. In order to test if the variation between the mean crop plot sizes differs significantly between the study sites, an ANOVA test was used. Figure 3.9 visualizes the distribution of the area data, and Table 3.8 provides descriptive statistics of the size of agricultural plots among all of the study sites. The ANOVA indicates that the agricultural plot area means are not equal ($F = 6.0967$, $p = 2.145e-11$). A Tukey post hoc test was performed to look at how each of the study sites differs from the others in order to determine specifically which means are different. Tukey post hoc tests are performed after an ANOVA test in order to pair the sites and to find which pairs are different and producing a p-value for the difference. The Abu study site in the Bahir Dar woreda was the only study site with agricultural plot sizes significantly different ($p<0.05$) from the other 12 study sites. Abu's crop plots were larger compared to every other study site. Mariam study site in the Farta Woreda was significantly different from 4 other study sites and had plots that were larger.

Michael and Abu of Banja Woreda, and Kidana Muret of Bahir Dar Woreda were statistically larger from 3 of the study sites. The agricultural plots that were significantly larger did not seem to have higher tree densities or abundances.

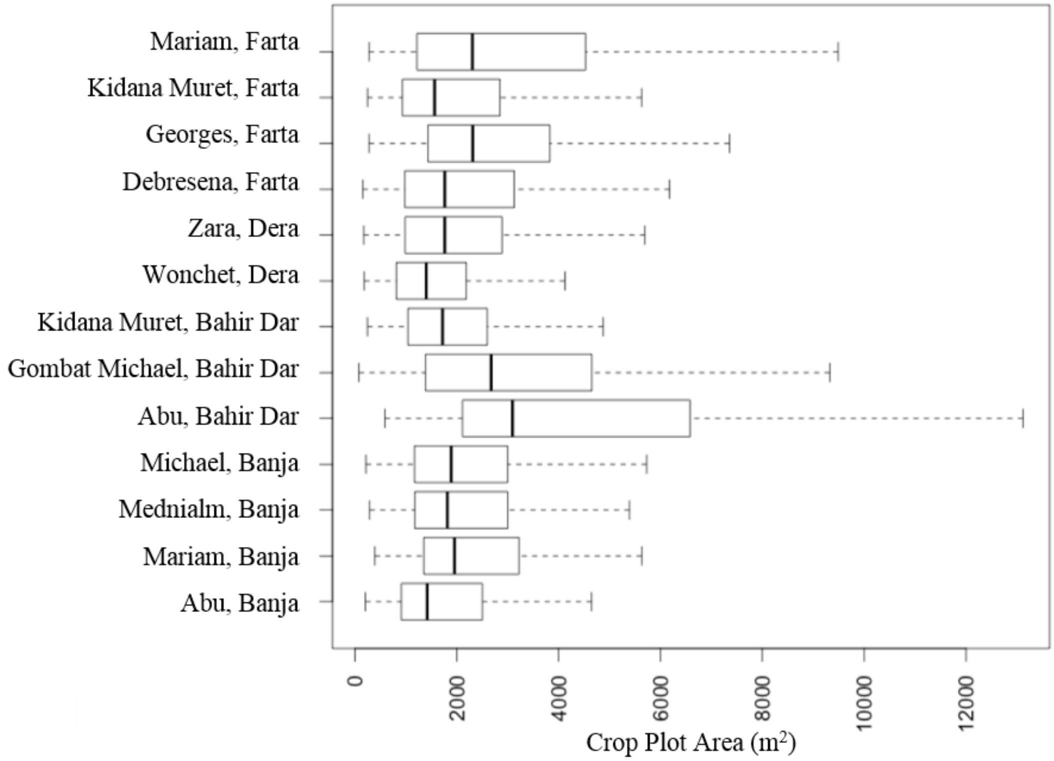


Figure 3.9. Boxplots of the crop plots area for individual study areas.

For the farmer survey tool, respondents were asked about how much land they have and the number of scattered trees that have persisting on their farmland. Figure 3.10 illustrates the statistically significant positive (0.2703) linear relationship between the amount of land a respondent owns and the number of scattered trees persisting on their land (t=1.77, p-value=0.079).

Table 3.8. Mean and median area for the agricultural plots of all the study sites.

Study Site	Mean Area (m^2)	Median Area (m^2)	Tree Density (tree per ha)
Banja Shekudad	**3070**	**1758**	**1.268**
Abu	1792	1416	0.7056
Mariam	3451	1953	0.9243
Medhnialm	2807	1813	1.540
Michael	4230	1850	1.541
Bahir Dar	**4013**	**2494**	**2.405**
Abu	6525	3092	1.461
Gombat	3450	2672	2.187
Kidana Muret	2064	1718	4.929
Dera	**2551**	**1580**	**3.324**
Wonchet	2395	1398	2.761
Zara	2706	1761	3.968
Farta	**3107**	**1972**	**1.267**
Debresena	2718	1762	1.454
Georges	3220	2311	1.222
Kidana Muret	2678	1562	1.328
Mariam	4440	2305	1.038
Michael	2477	1922	1.372

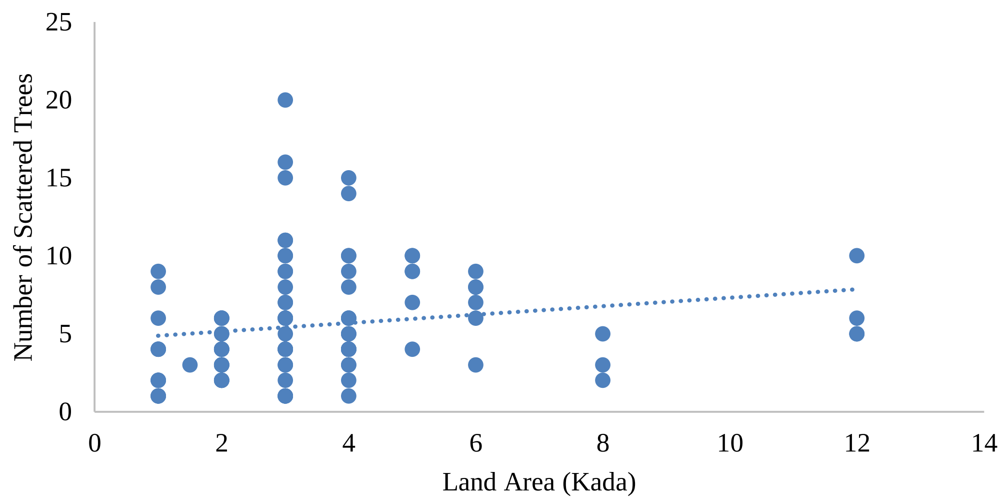


Figure 3.10. Land area and number of scattered trees on land (n=104). Responses on land area compared with number of scattered trees that respondent have (area measured in kadas, which is 0.25 of a ha). Statistically significant positive linear relationship (Coef = 0.2703, T=1.77, p-value=0.079).

Crop Plot Size Change over Time

Agricultural plot area was analyzed over time to see if a change in agricultural plot size had an influence on scattered tree numbers over time. The plots were analyzed from the 1960s using the declassified aerial imagery to 2015 using Google Earth imagery. The 1960s imagery was imported into Google Earth as a raster layer and the crop plots were traced using the tracer tool. The crop plots for 2015 were also traced in Google Earth and both were analyzed in R-Studio. Figure 3.11 illustrates the change in crop plot area from 1960 to 2015 for the Gombat Michael study site. The data for this study site suggest that crop plot area significantly decreased in size over the time frame (t = -4.1592, df = 34, p-value = 0.0002).

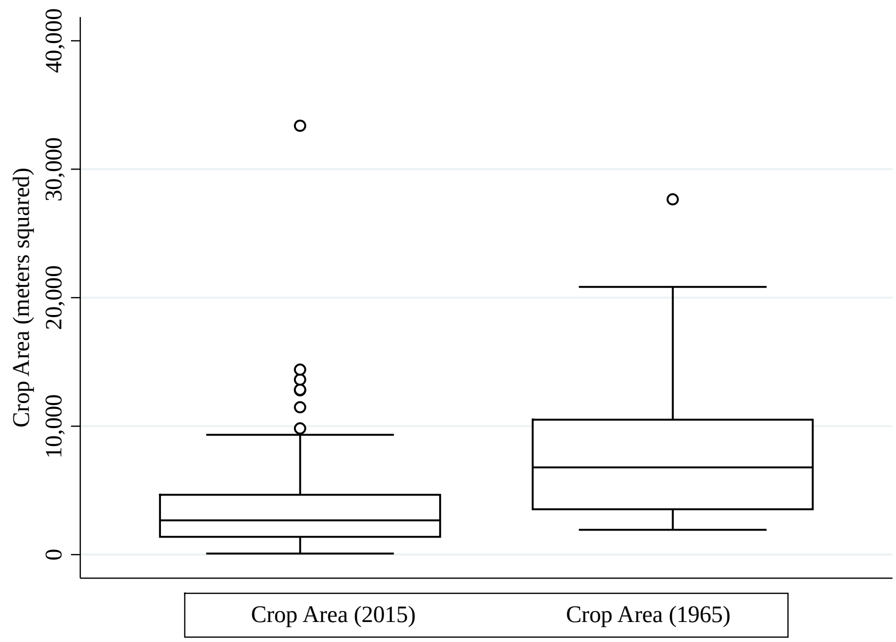


Figure 3.11. Crop plot area change from 1965 to 2015 for Gombat Michael in Bahir Dar Zuriya Woreda. Statistically significant change crop area (t=-4.1592, df=34, p-value=0.0002)

Settlement Influence on Scattered Tree Abundances

For each of the study sites, human settlements were pinpointed using Google Earth and were compared spatially to the scattered tree abundances to see if settlement location influenced scattered tree location. The average number of settlements for the study sites was 82.2, with an average settlement density of 1.032 settlements per ha. The 2015 scattered tree counts were imported into R-Studio and were randomized 600 times across each study site. For each randomization trial, the distance from the randomized tree to the settlements was calculated using a Euclidean Distance Function in ArcMap. This MC simulation was used to test if the

scattered trees are spatially closer to settlements than when randomized. The test revealed that every study site, except for Abu and Mariam in Banja Shekudad Woreda, had scattered trees clustered significantly closer to settlements than if they were randomly placed (P>0.05; Table 3.9).

Table 3.9. Number of settlements, settlement density (settlement per ha) and calculated psuedo P-value for the ANN simulation test for each of the study sites. Every study site except for Abu and Mariam in Banja Shekudad Woreda has scattered trees that are significantly (P>0.05) closer to human settlements.

Study Site	Number of settlements	Settlement Density (settlement per ha)	Pseudo P-value MC simulation
Bahir Dar	**307**	**1.315**	**<0.01**
Abu	32	0.289	<0.01
Gombat Michael	68	0.913	<0.01
Kidana Muret	207	4.323	<0.01
Banja	**281**	**1.278**	**0.1525**
Abu	101	2.379	0.235
Mariam	70	1.749	0.370
Medhnialm	49	1.179	<0.01
Michael	61	0.635	<0.01
Dera	**245**	**1.481**	**<0.01**
Wonchet	127	1.437	<0.01
Zara	118	1.530	<0.01
Farta	**337**	**0.809**	**<0.01**
Debresena	83	0.928	<0.01
Georges	32	0.460	<0.01
Kidana Muret	98	1.446	<0.01
Mariam	58	0.514	<0.01
Michael	66	0.854	<0.01
Total	**1069**	**1.032**	**0.0448**

Demographic Influences on Scattered Tree Abundances

The demographic characteristics of each respondent in the farmer survey was recorded and compared to the number of scattered trees they have on their land. Respondents were asked how much money in birr (1 Ethiopian Birr = 0.046 USD) they make annually, and this data was recorded between 5 different ranges, since people don’t typically know exactly how much they make. Annual salary did not seem to play a role in how many scattered trees the respondent had on their land (t=0.18, P=0.86, n=125). However, during the survey process many of the respondents didn’t know how much they made annually since a large population of the

respondents are subsistence farmers and sell various crops at different times, making salary calculations difficult.

To get a better estimate of how wealth plays a role in the abundance of scattered trees on respondents' land, the number of livestock that each respondent owns was used as a proxy wealth measure. Livestock numbers, which included all goats, cows, and sheep, ranged from 0 to 24 with an average of 5.4 (SD=4.4) livestock per respondent. As Figure 3.12 describes, the number of trees in a respondent's cropland and the number of livestock a respondent owns has an insignificant positive linear relationship (coef = 0.1048, t = 1.37, P=0.172).

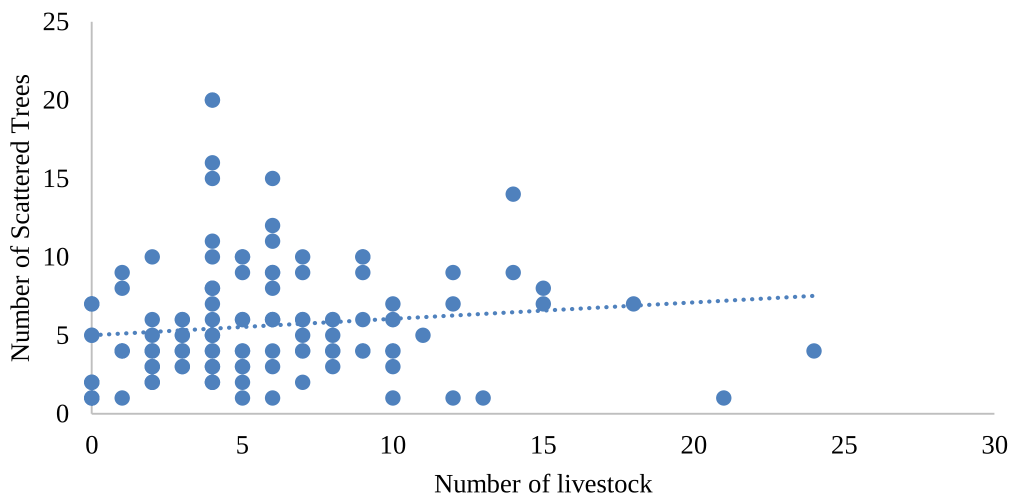


Figure 3.12. Scattered tree abundance compared to number of livestock (n=125). Responses on number of livestock owned compared with number of scattered trees that respondent have. Positive linear relationship between the number of livestock and the number of scattered trees (coef = 0.1048, t=1.37, P=0.172).

Discussion

Farmer and household survey responses to questions about past and present trends in scattered tree abundance largely parallel the NDVI and 1960s imagery trends illustrated in Chapter 2. About 40% of the respondents indicated that scattered tree cover was increasing while nearly half of the respondents suggested that scattered tree abundance was decreasing during Haile Selassie's regime (1930 to 1974). The respondents had a similar split for the Derg Regime, however slightly more respondents suggested that there was an increase in scattered tree abundances (1974 to 1991). For the EPRDF period (1991 to 2010) and for the last 5 years (2010 to 2015) about 80% of the respondents suggested that scattered tree abundance increased.

The responses seem to be largely rooted in institutional drivers tied to changing government regimes. Haile Selassie pushed for modernization of Ethiopia, hoping to follow western industrialized countries through the emphasis of large-scale commercial farming and industry development (Ayana et al., 2013). During this time period forest conservation was overlooked and development initiatives took priority, often leading to land degradation and deforestation (Ayana et al., 2013). Because of this most of the respondents indicated that scattered tree abundances were either decreasing or not changing during this time period. The Derg regime experienced land degradation and deforestation due to repeated redistribution of land, which weakened the security of land ownership and led to a lack of incentives for environmentally beneficial land management practices (Hoben, 1995; Cohen and Isaksson, 1988). During this time period most of the respondents either thought that scattered tree abundances were decreasing or not changing likely due to the change in institutional framework controlling land management.

Under the EPRDF and over the last 5 years, national forest policy shifted to include more specific laws that addressed forest degradation such as the creation of the Ethiopian Environmental Protection Authority (EPA) and the Ethiopian Ministry of Agriculture and Rural Development, both of which established programs for effective management and conservation of Ethiopia's natural resources with an emphasis on human settlement impacts (zur Heide, 2012; Awulachew et al., 2009). The changing policy dynamics could have had an impact on scattered tree abundances and led to both a perceived and concrete increase in the number of trees.

Another possible explanation for the perceived and measured increase in scattered tree abundances over time as the natural forests have been lost is the idea of shifting baselines (Gardner et al., 2009) coupled with an increase in exotic tree plantations within the local agricultural systems. In forest settings, shifting baselines is usually used to refer to the process in which ecologists must continuously readjust the baseline of which they are measuring human impacts on forests, such as continued large-scale regional deforestation and forest degradation (Gardner et al., 2009). In the context of this paper, shifting baselines refers to the change in how a respondent perceives scattered tree cover over time. As landscape-scale deforestation occurred during Haile Selassie's rule and during the Derg Regime, respondents are more likely to associate less forests with less scattered trees in the land. More recently, under the EPRDF and over the last five years as eucalyptus and other exotic tree species have been planted more

frequently, the perceived abundance of trees as a concept likely increased, which could play a role into how people think about the change in scattered tree abundances.

Other variables including crop plot size, annual income, and number of livestock were not associated with scattered tree abundances. The average size of crop plots in the study region is 3211 m^3, which is 0.3211 ha. Most of the study sites had very similar crop plot areas, however, Abu in Bahir Dar Zuriya Woreda and Mariam in Farta Woreda have significantly larger crop plots than the other study sites. Both of these study sites have very standard scattered tree densities (1.461 and 1.038 trees per ha respectively) with the average of the entire study region at 1.852. Therefore, crop plot size does not seem to impact the abundances of scattered trees. However, the change in crop plot size over time could have increased the number of scattered trees in the landscape.

Using Gombat Michael study site in the Bahir Dar Zuriya Woreda as a case study, present day crop plot areas are significantly smaller than crop areas in 1960s. Ali et al. (2011) notes that over the last 30 years not only crop size but per household acreage has declined in selected locations in the Amhara Region from about 3 ha to 2 ha. Since the 1960s as population has increased in the Amhara Region (CSA, 2007) the amount of land each household owns has declined. The size of individual crop plots also decreased, most likely to accommodate living on less land while continuing to have the same crop diversity. Because scattered trees in the agricultural landscape supply farmers with a multitude of essential benefits (see chapter 2), farmers must have made a decision to prioritize scattered tree persistence even as their agricultural land decreased in size and as the trees proportionally took up more of their land set aside for farming. The number of scattered trees a household owns has not necessarily decreased over time, however scattered tree density likely increased as the amount of agricultural acreage a household held declined. Franzel et al. (2002) supports this argument, suggesting that in agroforestry settings in Africa, there is a negative correlation between tree density and agricultural plot size. Smaller farms have also been described to have higher densities of trees as well as a higher tree canopy cover when compared to larger farms (Richard and Ræbild, 2016). Therefore, both the shrinkage of crop plot size and the reduction of total farm size likely played a role in increasing tree density of farms and consequently increasing the numbers of scattered trees in the Amhara Region farmland.

The presence of human settlements has had a similar impact to scattered tree densities as the decline in agricultural plot size. Scattered trees are statistically much more likely to be found in closer proximity to human settlements than further away in the agricultural fields. Overtime, as the population of the Amhara Region increased, more settlements were built. Households almost certainly prefer to have scattered trees closer to their settlements due to the direct benefits that the trees have, such as for fuel and construction wood, food purposes, and shade (Chapter 4). Tolera et al. (2008) agrees, indicating that in the south-central highlands of Ethiopia the highest diversity of tree species and the greatest number of scattered trees was recorded in homegardens, which are the small agricultural plots surrounding settlements. The GIS analysis in Chapter 2 indicated that scattered tree abundances have increased over time and coupled with analyses from this chapter, population in northern Ethiopia likely increased conjointly with scattered trees over time.

Conclusions

Based on this analysis, an increase in population has resulted in the improvement of farm ecosystems in the Amhara Region of Ethiopia, through the addition of more trees. However, this is not the whole story. Scattered trees are the product of centuries of deforestation and the conversion of forested landscapes to agricultural systems. Remnant scattered trees exist as reminders of the forests that once occupied the entire landscape. Since the 1960s far more trees have been lost in the Amhara Region due to deforestation than have been gained from the increase trees in agricultural landscapes associated with an increasing population. Historically, Ethiopian forests were treated largely as open access resources, leading to their overexploitation and decline. Through agricultural expansion and deforestation, these once forested landscapes fell under the realm of private ownership by individual farmers. As forests have declined, the number of scattered trees have seen increases in the agricultural landscape, largely due to the change in land management. The demand for the benefits associated with scattered trees (see Chapter 4 for an in depth analysis of tree benefits) has led to an increase in the trees themselves because of changing local incentive structure, by which alterations in land tenure security has given farmers a chance to keep trees in their land and even plant more.

Farmers that were included in the study indicated that they would plant more trees in their fields if they were given the means to do so. The Ethiopian government should support

rural stallholders in the Amhara Region with planting trees in their cropland and create further incentives to do so.

CHAPTER 4: SOCIOECOLOGICAL SIGNIFICANCE OF SCATTERED TREES

Introduction

In the northern Ethiopian Highlands, scattered trees continue to persist in the agricultural landscape even as extensive deforestation has decimated much of the forests in the region. A growing body of literature has analyzed the reasons forest fragments of the Amhara Region have persisted over time and more specifically have documented the benefits of these remaining tree stands. However, little literature attention has been paid to scattered trees surrounding these forest fragments. This study hopes to understand why trees are still persisting in these landscapes today and more specifically seeks to recognize the significance – socially, culturally, and ecologically – of these tree species.

This chapter provides a review of the literature pertaining to ecosystem services and socio-cultural benefits scattered trees provide from an agroforestry perspective and then analyzes the socioecological significance of scattered trees in the Amhara Region of Ethiopia using a combination of social science, spatial analysis, and ecological survey methods.

Background: Scattered Trees

Ecosystem Services

The services of ecological systems are critical for the functioning of the Earth's life support system (Costanza et al., 1998). Incorporating trees into agricultural systems to tap into the multifaceted benefits provided by ecosystem services is a practice that is employed all over the world. Agroforestry creates a multifunctional working landscape, generating ecosystem services, environmental benefits, and economic commodities (Jose, 2009). Large international institutions have recently started focusing on the multifunctional role of agroforestry, with recent attention by the International Assessment of Agricultural Science and Technology for Development (IAASTD, 2008), and the FAO State of Food and Agriculture Report (2007), among others. Note that there are multiple types of agroforestry found globally as well as in Ethiopia, however, for this report the specific agro-forestry practice of scattered trees on farmland is discussed.

The following ecosystem services are discussed in this chapter: topsoil fertility and soil enrichment, biodiversity conservation, carbon sequestration, erosion control, nutrient cycling, water and air quality, and pollination and seed disbursal. These ecosystem services work on

multiple different scales and provide different benefits across the local, regional, and global spatial scales (Table 4.1).

Table 4.1. Spatial scales of ecosystems services provided by agroforestry systems (Modified from Jose, 2009).

Ecosystem service	Local	Regional	Global
Topsoil Fertility and Soil Enrichment	X		
Erosion Control	X		
Pollination and Seed Disbursal	X		
Water and air quality	X	X	
Biodiversity Conservation	X	X	X
Carbon Sequestration	X	X	X

Topsoil Fertility and Soil Enrichment

Soil fertility decline is a significant issue in Ethiopia, as 85% of the population utilizes soil for their livelihoods (Yebo, 2015). Currently this population is witnessing a reduction in yield of crops due to the decline in soil fertility (Yebo, 2015). The loss in soil fertility that is seen in the depletion of certain physical and chemical properties has been intensified by continuous cultivation, deforestation, overgrazing, and soil erosion of the landscape in Ethiopia (Othieno et al., 2006; Demeke, 2003; Donahue, 1972). Soil fertility is controlled by a multitude of different factors, including those that can and cannot be altered anthropogenically.

Soil conditions on a global and regional scale are controlled by many different climate factors and parent material (Birkeland, 1984). On the local and landscape level, soil is most strongly influenced by topographical changes, microclimatic variation, soil fauna, and vegetation (Birkeland, 1984). Trees impact soil properties through many different pathways. Trees directly impact the morphology and chemical conditions of soil due to above- and below-ground litter inputs (Rhoades, 1997). The chemical and physical characteristics of leaves, roots, bark, and branches alter decomposition and nutrient availability in soil through litter breakdown (Rhoades, 1997). This process is controlled in part by soil water and the soil fauna involved in the litter breakdown process (Sanchez, 1995). Widespread root systems take soil nutrients and redistribute them beneath the tree’s canopy (Sanchez, 1995). Trees in essence represent channels through which nutrients are constantly cycled, as well as reserves of nutrients that impact the function of an ecosystem (Rhoades, 1997). Of the factors that influence soil conditions, vegetation is the most dynamic characteristic, constantly being altered by humans.

The potential for soil improvements in agricultural systems by trees due to trees ability to maintain soil fertility is one of the principle tenets of agroforestry (Palm, 1995; Schroth &

Sinclair, 2003). The idea is that trees in agroforestry systems will transfer nutrients to the intercropped plants in a similar way in which nutrients from litter is efficiently transferred to trees in natural ecosystems (Vitousek and Sanford, 1986). Emerging evidence shows that successful agroforestry systems are able to increase nutrient inputs, while enhancing internal flows of nutrients and decreasing the loss of nutrients (Sanchez et al., 1997). Nitrogen and phosphorous are two main macro-nutrients vital to agricultural systems success and in northern Ethiopia often come from fertilizer inputs (Hailu et al., 2000). In many small farms in Ethiopia, the net balance of nitrogen and phosphorous is negative, representing nutrient depletion (Sanchez, 1995). In such contexts Yadessa et al. (2009), Asfaw and Agren (2007), and Hailu et al. (2000) suggest that agroforestry practices have potential to enhance nutrient capture and retention and reverse the trends of nutrient depletion.

Leguminous trees, known for their nitrogen fixing properties, are typically planted or left within agroforestry systems. Biologically, legumes develop root nodules and fix nitrogen in symbiosis with compatible rhizobia (Graham and Vance, 2003). Fertilizer N is frequently unavailable to subsistence farmers leaving them dependent on nitrogen fixation by legumes (Asfaw and Agren, 2007). Adams et al. (2010) notes that woody legumes in the global south not only provide a good potential for nitrogen fixation but also the mechanisms for acquiring phosphorous. Phosphorous is released by enzyme activity directly related to the production of nitrogen by nitrogen fixing legumes and therefore legumes have a good potential for providing both nitrogen and phosphorous for companion crops in agroforestry systems (Houlten et al., 2008). In Ethiopia, farmers often integrate leguminous trees with crops, due to the beneficial effects of they have on soil fertility and crop yield (Ong and Huxley, 1996).

Many case studies have shown the beneficial properties of agroforestry systems on topsoil fertility and soil enrichment in Ethiopia. Asfaw and Agren (2007) describe how poor farmers in Sidama, Ethiopia, maintain soil fertility with litter from tree cultivation of *Cordia africana* and *millettia ferruginea*. Both trees managed to maintain soil fertility through increased amounts of organic matter and biological nitrogen fixation leading to improved nutrient uptake by the crops (Asfaw and Agren, 2007). Compared to other sites, the soil under these two tree species had higher concentrations of phosphorous, with almost twice as much under the *Cordia africana* trees (Asfaw and Agren, 2007).

Yadessa et al. (2009), also explored the effects of *Cordia africana* on soil quality in agricultural landscapes in western Oromia, Ethiopia. They indicated that these trees are important local nutrient reserves that influence rural agricultural landscapes (Yadessa et al., 2009). Hailu et al. (2000), focused their study on *Millettia ferruginea* impacts on soil fertility on maize crops in southern Ethiopia. They found that the level of surface soil P, organic C, exchangeable base-forming cations and cation exchange capacity were all significantly higher under the trees compared to the open field. This resulted in significantly better growth responses of the maize compared to the control (Hailu et al., 2000).

Mekonnen et al. (2009), describes how the soil within the vicinity of *H. abyssinica, S. gigas* and *C. palmensis* trees contained a substantial amount of nutrients in agroforestry systems that they studied in the Central Highlands of Ethiopia. Their conclusions corresponded with social surveys in which farmers indicated that the aforementioned trees species have potential to improve the fertility of soils and are sources of plant nutrients in the high altitude areas with limited soil fertility management options (Mekonnene et al., 2009). Teklay et al. (2006), further explored the interaction between trees in agroforestry systems and soil dynamics in Ethiopia. They found that woody legumes including *Albizia gummifera* and *milletia ferruginea* and non-legumes including *Cordia Africana* and *Croton macrostachyus* increased yield of maize by 10 to 84% compared to control plots, with higher phosphorous and potassium contents (Teklay et al., 2006).

Many studies have shown that improved soil fertility due to the integration of trees into crop farming systems has the potential of enhancing crop production (Yadessa 1998; Hailu et al., 2000; Teklay, 2005; Teklay et al., 2006; Asfaw and Agren, 2007; Mekonnen et al., 2009). Agroforestry therefore not only has the potential of conserving and improving soil quality but also holds economic incentives to do so seen through improved yields of crops.

Biodiversity Conservation

Tropical ecosystems around the world are recognized for their biodiversity. Throughout the tropics, anthropogenic factors including human settlement expansion and agricultural development threaten biological diversity (Tolera et al., 2008). Today, much of biodiversity conservation is encouraged by the desire to conserve “pristine nature” through the implementation of protected areas (Bhagwat et al., 2008). Agroforestry, however, presents a

unique opportunity to maintain species diversity in human-altered landscapes (Bhagwat et al., 2008; Schroth, 2004).

Multiple studies have indicated that agroforestry landscapes can play a key role in the maintenance of biodiversity (Harvey and Haber, 1999; Nikiema, 2005; Perfecto and Vandermeer, 2008). Many tropical agroforestry systems have high levels of woody plant diversity within the fields, in which trees have either been left from past ecosystems or are actively planted (Harvey and Haber, 1999). These tree species can also provide habitat for forest animals that use these landscapes to move from and to patches of natural vegetation (Harvey and Haber, 1999). Specifically, several studies have focused on the contribution of biodiversity within tropical silvopastoral systems (Harvey and Haber, 1999; Dagang and Nair, 2003; Pagiola et al., 2004), which is the combination of pastures and trees, as well as more traditional agroforestry systems, which is the combination of crops and trees (Perfecto and Vandermeer, 2008; Bhagwat et al., 2008; Jose, 2009; Mulugeta and Admassu, 2014).

Ethiopia's biodiversity is threatened by land conversion for agricultural purposes, which leads to fragmentation and habitat loss of natural resources (Lemenih and Teketay, 2004). Most of Ethiopia's plant biodiversity lies within the few forested regions that remain and multiple studies have indicated the alarming rate at which these areas are being lost (Reusing, 1998; FAO, 2007; Teketay et al., 2010). Despite the high rate of deforestation in Ethiopia, recent studies have also suggested that cultivated lands in provide a refuge for native woody species through the use of agroforestry (Zebene, 2003; Abebe, 2005; Yadessa et al., 2009; Asfaw and Lemenih, 2010; Mulugeta and Admassu, 2014).

Many traditional agroforestry systems are visible across the agricultural landscape of Ethiopia. In these systems, farmers intentionally preserve native tree and shrub species for numerous purposes. Tolera et al. (2008) indicated that there are more tree species on farm landscapes than in nearby natural forests in central Ethiopia. Yadessa et al., (2009) showed that agroforestry systems in the Oromia region of Ethiopia support *Cordia Africana* trees, which help conserve the biodiversity of the region by providing habitats and resources that are otherwise absent or scarce in typical agricultural settings. Mulugeta and Admassu (2014) found 59 tree species on household farms in Bahir Dar Zuriya Woreda of Amhara, Ethiopia and they concluded that there was high tree diversity at a farm level. Asfaw and Lemenih (2010) suggested that expansion of traditional agroforestry in the central Rift Valley in southern

Ethiopia could partly compensate for the high rate of deforestation in terms of maintaining woody species diversity

Carbon Sequestration

Over the last century, the concentration of carbon dioxide and other greenhouse gasses in the atmosphere has significantly increased, and these levels are set to rise further in the future (Meinshausen et al., 2009). As concentrations of carbon dioxide in the atmosphere increase, negative changes including rising temperatures, higher frequency of droughts and floods, and sea level rise will ensue. Carbon dioxide levels can be reduced through either reducing anthropogenic emissions of CO_2 or creating and or improving carbon sinks (Albrecht and Kandji, 2003). Carbon sinks would sequester carbon from the atmosphere and they include aboveground plant biomass, belowground plant biomass, soil microorganisms, organic and inorganic carbon in soils, and products derived from biomass such as timber (Nair et al., 2009).

Trees play an important role in capturing and storing atmospheric carbon dioxide (Malhi et al., 2008). Promoting agroforestry has increasingly been discussed as an option to deal with carbon dioxide-induced climate change (Makundi and Sathaye, 2004) and is recognized as a carbon sequestration strategy under the Kyoto protocol, thereby attracting attention globally (Nair and Nair, 2003; Lal, 2004). The intergovernmental panel on climate change (IPCC) concluded that by 2040 agroforestry would offer high potential of carbon sequestration in developing countries (Verchot et al., 2007). Agroforestry can sequester sizable quantities of carbon in plant biomass and wood products as well as soil carbon sequestration through root biomass and litter (Albrecht & Kandji, 2003). Agroforestry also reduces the deforestation of neighboring forests for agricultural land expansion, and thereby further reduces greenhouse gas emissions (Negash and Kanninen, 2015). Agroforestry systems have 3-4 times more biomass than traditional treeless cropping systems and in Africa they constitute the third largest carbon sink after primary forests and long term fallows (Albrecht & Kandji, 2003; Oke & Odebiyi, 2007).

Most of the deforestation in Africa is from agricultural expansion and agroforestry presents a unique opportunity to slow the conversion of forest to farmland while sequestering carbon in the trees (Garrity, 2011). Additionally, agroforestry falls under the category of reducing emission from deforestation and forest degradation, and forest conservation, sustainable

forest management and enhancement of carbon stocks (REDD+) through UNFCCC (Minang et al., 2014). In Ethiopia, agroforestry is described as a strategic option in many recent environmental policy documents including the climate resilient green economy (CRGE, 2011) and readiness preparation proposal of Ethiopia (R-PP, 2011). Negash and Kanninen (2015) modeled biomass and soil carbon sequestration of indigenous agroforestry systems in south-eastern Ethiopia. They found that the tree cohort of the agroforestry system accounted for 89-97% of the total aboveground biomass carbon stocks in all the studied systems and the soil organic carbon stocks accounted for 60-64% of the total carbon stocks in all the studied systems, indicating a strong potential for carbon sequestration through agroforestry in Ethiopia (Negash and Kanninen, 2015).

Erosion Control

Developing countries focusing on increasing agricultural production have been grappling with how to increase yields while land is shrinking due to population pressure (Gebremedhin and Swinton, 2002). Future growth in agriculture will likely take the form of increased land productivity, which is typically associated with land degradation in the form of soil erosion (Yebo, 2015; Desta, 2000). Keeping soil resources in place is a major sustainability concern, in that it ensures agricultural site productivity as well as reduces negative downstream inputs that can lead to siltation, eutrophication, and pollution of surface waters (Sanchez, 1995).

Agroforestry systems have been described to help keep soil resources in place due to trees ability to reduce soil erosion on sloped agricultural fields (Powlson et al., 2011). Trees act as a physical barrier against running surface water as well as provide sites where water can infiltrate quicker due to enhanced soil structure existing under trees compared to the adjacent agricultural landscape (Sanchez, 1995). Agroforestry systems also control erosion from wind by providing physical barriers (Sanchez, 1995). Studies in Rwanda have suggested that the integration of leguminous trees into agroforestry systems offers a promising method for soil conservation, even on slopes that are threatened by severe erosion (Roose & Ndayizigiye, 1997; König, 1992). Agroforestry systems have also been documented to be extremely effective in reducing water runoff and controlling erosion in Southwestern Nigeria agroforestry plots compared to non-agroforestry agricultural control plots (Lal, 1989).

The highlands of Ethiopia, which account for more than 43% of the country’s land area,

95% of the cultivated area, and 88% of the population, has experienced the most severe soil erosion (Gebremedhin and Swinton, 2002). In 1995, it was estimated that about 50% of the highlands were significantly eroded with more than one fourth seriously eroded, accounting for 42 metric tons/ha per year of soil loss compared to the 3-7 metric tons/ha per year of soil formation (Boja & Cassels, 1995). The issue of soil erosion in Ethiopia could be address through agroforestry. Controlling soil erosion could also promote soil fertility by reducing erosion and runoff that decreases the nitrogen and phosphorous balance in the soil while replenishing nutrients (Sanchez, 1995).

Water Quality Enhancement

Agroforestry systems are proven strategies to provide clean water (Jose, 2009; Nair, 2011). In many conventional agroforestry systems, nitrogen and phosphorous fertilizers are applied to the crops. Only half of the applied nutrients are taken up by the crops and the excess is taken away from the fields through surface runoff or leached into the subsurface water supply decreasing water quality (Cassman 1999). Agricultural surface runoff causes excess sediment, nutrient, and pesticide delivery to receiving bodies of water, which causes eutrophication and other environmental issues (Jose, 2009). The presence of trees in agricultural landscapes can reduce the velocity of runoff, which promotes sediment infiltration, deposition, and nutrient retention (Anderson et al., 2009).

Ground water has also been showed to improve due to agroforestry systems, in which trees with deep rooting systems take up excess nutrients that have been leached below the rooting zone of crops (Allen et al., 2004). Root turnover and litter fall of the trees then puts these nutrients back into the system, thereby also increasing the nutrient use efficiency of the system (van Noordwijk et al., 1996). Water quality improvement through agroforestry has received little attention in agroforestry research in the tropics (Nair, 1998) and there is no evidence on the topic from Ethiopia. In Kenya, agroforestry has been documented to protect water catchments of rural farmers, mitigate the effects of water scarcity, as well as improve water quality (Jerneck & Olsson, 2013). The same can be seen in the tropical Mountains of Rwanda, in which agroforestry efficiently managed the water quality (Roose and Ndayizigiye, 1997). Agroforestry can also reduce the risk of crop failure during droughts and prevent waterlogging when it rains (Garrity, 2011).

Pollination, Seed Dispersal, and Revegetation

Globally, important crops benefit from pollination services of nearby forests, in which the habitat provides forage and nesting space for pollinators (Klein et al., 2003; Kremen et al., 2004; Rickets, 2004). Throughout the world, 35% of crops depend on animal pollinators, and of the 115 leading global food crops, 87 are dependent on animal pollination (Klein et al., 2007). In human dominated tropical landscapes, forest remnants offer pollination services. Priess et al. (2006) emphasize that as the magnitude of forest conversion increases in tropical landscapes and the distance to forests increases, pollinator diversity and pollination services decrease. They suggest that based on simulations, ecological and economic values of pollination can be preserved in agricultural landscapes if forest patches are maintained (Priess et al., 2006).

Agroforestry practices by nature increases the overall diversity of plants and physical structures in a landscape and provides habitat for native pollinators (Hoehn et al., 2010). Pollinators have two basic habitat needs, which include, access to a diversity of plants with overlapping blooming times and habitat to nest (Vaughan & Black, 2006). The trees in agroforestry systems can supply these two basic habitat needs. In Ethiopia, agroforestry systems have been identified to provide habitat for pollinators and seed-dispersing animals by maintaining native floristic diversity within the plots (Negash et al., 2012).

Agroforestry practices have been described to have the potential to provide a stepping stone towards other, tree-based land-use systems of higher viability (Muschler & Bonnemann, 1997). Lozada et al. (2007), suggests that agroforestry habitats play a unique role as seed source and as habitat for tree recovery in tropical degraded landscapes. Mature trees scattered throughout agricultural landscapes provide a range of ecosystem services that are critical habitats for a wide assortment of biota and allow for secondary forest succession to occur in a more effective manner (Blinn et al., 2013).

Globally these trees are scattered throughout agricultural systems and have been described as keystone structures due to their high ecological importance relative to their low abundance (Manning et al., 2006). Scattered trees persist as legacies following clearing of woodlands and are maintained as part of agroforestry systems (Manning et al., 2009). Biological legacies can act as foci for tree regeneration by enriching the soils with water and nutrients as well as providing seed directly, or indirectly through seed deposited by perching birds (Elmqvist

et al., 2002). Therefore, scattered trees in agro-systems can provide cost effective sources of seed for revegetation in the future (Dorrough and Moxham, 2005).

Economic Benefits

Agroforestry systems can be viewed as multifunctional working landscapes, providing ecosystem services and environmental benefits, as well economic commodities (Jose, 2009). The Millennium Ecosystem Assessment (2005) and the International Assessment of Agricultural Science and Technology for Development (2008) have both emphasized this multifunctional role of agroforestry systems (Watson et al., 2008). Researchers have attempted to quantitatively value ecosystem services and environmental benefits associated with agroforestry systems on a single ecosystem service scale, such as analyzing agroforestry's role in conserving tropical biodiversity (Schroth, 2004), enhancing soil fertility (Schroth & Sinclair, 2003), and its global role in carbon sequestration (Montagini, 2006).

The environmental and social benefits obtained from growing trees in agricultural systems often are economically advantageous to rural households. Ecosystems services including soil enrichment, erosion control, and nutrient cycling also exhibit economic benefits seen through improved yields, which increases total economic gain from a plot of land. Agroforestry also lowers the requirement and application of fertilizer, while controlling erosion, which decreases the amount of money needed to spend on buying fertilizer and alleviating erosion. Agroforestry trees can also supply farming households with an assortment of high value timber and non-timber products that can be used for domestic use as well as for sale, which can increase cash incomes (Franzel et al., 2001; Sanchez, 1995).

People in Ethiopia use numerous products from trees, which can include food, medicine, livestock feed, and timber (Franzel et al., 2001). As deforestation has occurred throughout Ethiopia and rural smallholders have less access to forest resources, trees on farms have become extremely valuable resources (Garrity, 2004). Agroforestry has the unique potential to relieve poverty and alleviate food insecurity due to the numerous linked ecological and economic benefits.

Food Security

Agroforestry systems in general are pathways toward improved livelihoods through poverty alleviation and food security (Jose, 2009). Advances in agroforestry have many links

with improving health and nutrition of the rural poor mostly in the form of soil and water conservation resulting in higher crop yields, fruit tree cultivation, and increased cash incomes (Garrity, 2004). Soil degradation has been tied to food insecurity issues, due to decreased yields as agricultural landscapes are degraded, which is extremely apparent in subsistence communities (Garrity, 2011). Farmland in the developing world generally suffers from the continuous depletion of nutrients as farmers harvest without fertilizing adequately. Roughly one quarter of the farmland in developing countries is considered to be degraded under current farming practices (Garrity, 2004). Agroforestry has the potential to enhance nutrient retention through fertilizer trees, which can increase on farm food production (Jose, 2009).

Communities in many parts of the tropics incorporate many edible products harvested from forests into their diets, which are especially important for filling seasonal and other cyclical food gaps (Arnold et al., 2011). Also, forests provide wood fuel needed to cook food as well as the income from the sale of other products can be used to purchase food (Bishaw et al., 2013). The cultivation of trees for food, once obtained from the forest, are now being obtained by trees in agroforestry systems. The products from agroforestry trees have the potential to improve health and support livelihoods (Bishaw et al., 2013).

Indigenous fruit cultivation in agroforestry landscapes contributes to poverty reduction by generating cash for farmers and can also improve farming household's nutrition (Ndoye et al., 2004; Schreckenbert et al., 2006). In the lowlands of West Africa, bush mango or Dika Nut trees are seen in many agroforestry systems and provide good sources of vitamin C to the farmers (Leakey, 1999). A study by Jerneck and Olsson (2014) indicates that food secure farmers in Kenya are more likely to have agroforestry plots compared to the food insecure "poorest of the poor" farmers. Agroforestry engaged farmers were described as "opportunity seekers," while the poor farmers less likely to practice agroforestry were considered to be "risk evaders" (Jerneck & Olsson, 2014).

In Malawi, the trees in agroforestry maize farms fix nitrogen in their roots acting as a natural green fertilizer. These trees also reduce the risk of crop failure during droughts and prevent waterlogging when it rains. Yields of maize on the farm have been tripled since the addition of trees to the agricultural landscape, which increases food security for the rural smallholders (Garrity, 2011). A case study of *Faidherbia albida* in Ethiopia indicates that the tree species provides organic fertilizer on food crops maximizing agricultural production while

reducing the need for a fallow period on poorer soils, which helps reduce food security (Mokgolodi et al., 2011). Agroforestry provides diverse ways to secure food security for poor farmers in Ethiopia, and could be further developed to reach more households (Negash and Kanninen, 2015).

In the Amhara Region, nearly a quarter of the population is food insecure (Amhara Development Association ADA 2003) and 94% of households have insufficient land to meet their food needs (USAID, 2000). As a result rural people can no longer afford to put aside land separately for perennial crops like fruits (Fentahun & Hager, 2009). Fruit based agroforestry therefore has a real promise in alleviating poverty in the Amhara Region by contributing both consumable products and important ecological services, which will increase yields of the currently grown crops (Fentahun & Hager, 2009). Fentahun and Hager (2009) indicate that the Amhara Region agricultural landscapes currently have a lack of indigenous woody fruit bearing species diversity. They suggest that fruit bearing species in agro-landscapes are mostly conserved primarily for non-fruit utilities (Fentahun & Hager, 2009). This demonstrates that the current contribution of these tree species to food and nutritional supplementation of the households in the Amhara Region of Ethiopia are currently underexploited.

Relieving Poverty

Agricultural development is key to increasing poor people's access to income and food in rural areas of developing countries. Agroforestry has the ability to intensify and diversify land use and in turn diversify and increase rural incomes (Sanchez et al., 1997). Agroforestry trees not only enhances crop production thereby reliving poverty, but can meet the demand for many households needs including fuelwood, timber, food, medicine, livestock feed, and other non-timber forest products, which allows for rural smallholders to spend their cash incomes elsewhere (Franzel et al., 2001). The trees in agroforestry systems also provide numerous marketable products from farms that will generate alternative cash incomes for resource-poor rural households (Leakey, 1999). Therefore, agroforestry can diversify and increase rural incomes through the diversification of land use with high-value products (Duguma, 2013; Sanchez, 1995). Also, Commercial fertilizer costs two to six times more in Africa compared to Europe or Asia (Garrity, 2004). Agroforestry systems reduce the need to use fertilizer, and thereby input costs (Jose, 2009).

In Cameroon, smallholder farmers have domesticated wild fruit trees left in agricultural landscapes and increased their cash incomes by five times the amount (Garrity, 2011). In Tanzania, the *Allanblackia* tree in agroforestry systems has led to higher incomes of rural smallholders through the selling oil from the seeds of the tree (Garrity, 2011). Leakey and Simons (1997), noted that as the number, quality, and diversity of indigenous trees increases in tropical agroforestry plots, the array of NTFPs increases, which directly results in the ability of the plot to enhance the farmer's income as well as mitigate deforestation due to less of a need to exploit surrounding forests. However, without a market that incentivizes the utilization of forest products in agroforestry systems, some of these income supplementing benefits could be lost (Leakey & Izac, 1996).

Fruit based tropical agroforestry has a real promise in alleviating poverty by contributing both products and important ecological services (Fentahun & Hager, 2009). This is especially true in Ethiopia, in which wild indigenous woody perennial fruit bearing species are common in agricultural landscapes (Fentahun & Hager, 2009). Yadessa et al. (2009), also describes how rural farmers generate local household income from the sale of *Cordia Africana* products. *Faidherbia albida* in agroforestry landscapes in Ethiopia alleviates poverty by maximizing agricultural production in millet fields, increasing yield (Mokgolodi et al., 2011). In Gedeo, Ethiopia, agroforestry systems diversify the products and services allowing for the alleviation of poverty (Bishaw et al., 2013). They increase farm income through the sale of wood and other products including chat (Bishaw et al., 2013). Poverty reduction could be further met if the commercialization of under-utilized tree products is promoted more widely (Leakey, 1999).

Cultural and Social Benefits

Tropical agroforestry systems have been part of the landscape in Ethiopia throughout history and are considered to be promoters of social and economic development (Kumar & Nair, 2004). As already described, agroforestry systems supply numerous environmental, ecosystem, and economic benefits to the landscape and the farmers. Farmers around the world keep remnant trees in agricultural landscapes for many socio-cultural reasons as well, with many different factors influencing the perceived value of different tree species in agroforestry systems (Brandt et al., 2012). Remnant trees often have numerous socio-cultural benefits including, medicine, fodder for animals, and shade from the sun (Bishaw et al., 2013).

In many agricultural systems in Ethiopia, farmers preserve several native tree species to protect themselves and their animals from the sun's heat (Asfaw and Lemenih, 2010). In *Acacia albida*-based agroforestry practices in the Hararghe highlands of Eastern Ethiopia, the tree is used predominantly as a natural fertilizer to adjacent crops but additional benefits include supply of fuelwood and fodder to rural farmers (Poschen, 1986). In the Amhara Region of Ethiopia, *Millettiaa ferruginea* is seen in agroforestry systems due to its ecosystem services including topsoil fertility as well as many household uses including, for fishing rods, firewood, bee foraging, local construction materials, household utensils, shade for farmers, animal fodder, and as a source of immediate cash income (Alemu et al., 2013).

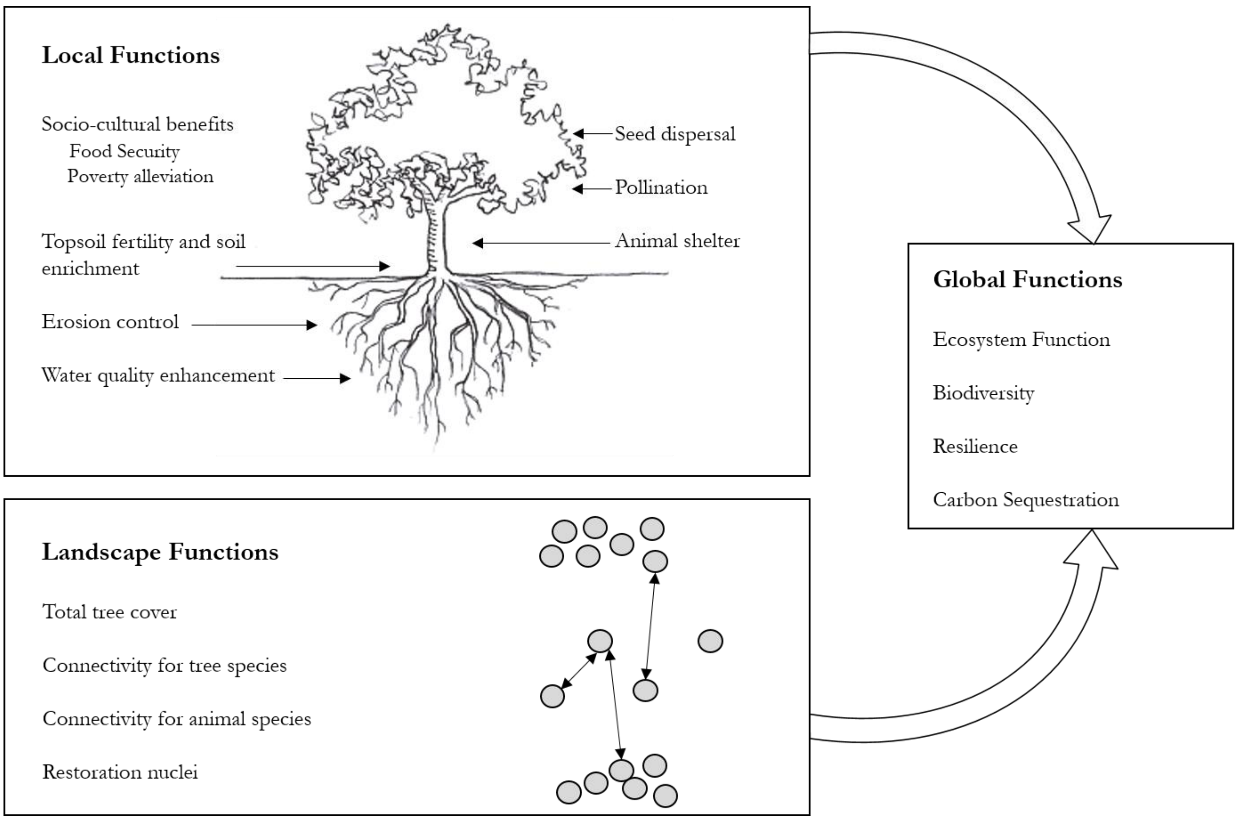


Figure 4.1. Conceptual model summarizing some key ecological and socio-cultural functions of scattered trees in the agricultural landscape in northern Ethiopia (Adapted from Manning et al., 2006).

Barriers to Agroforestry

Despite the numerous benefits associated with agroforestry, many drawbacks exist that make agroforestry difficult to implement worldwide as well as in Ethiopia. Drawbacks include but are not limited to, more complicated farm management, tying-up of land, land tenure and

long term viability, loss of tree productivity, and further pressures on trees (Kuster et al., 2012; Mbow et al., 2014).

In Ethiopia, many of the agroforestry systems contain remnant trees from the past forested landscape. The long term viability of these trees presents a limiting factor in the long-term endurance of these systems because as these trees are used for various products including fuel wood and construction wood they are lost from the system (Kursten, 2000). Another benefit of agroforestry trees includes fruit production and the associated food security and poverty alleviation benefits. However, in Ethiopia and other agroforestry systems in which remnant trees persist, many of the fruit trees in the landscape are quite old and are losing productivity, thereby limiting the benefits obtained from the trees by the farmers and reducing the incentive to keep these trees in the landscape (Assogbadjo et al., 2012).

Unsecured or ambiguous land tenure in Ethiopia results in confusion about land delineation, which could discourage agroforestry practices. Lack of long-term rights to land or a conflict of interest between the state and land users could inhibit more long-term investments in the land such as agroforestry and could lead to short term land use gains such as depletion of the timber resources (FAO, 2013). Also, since the government owns all the land, they have been leasing large parcels to foreign investors from China, India, and the Middle East as they view large-scale agricultural development as a means to alleviate food insecurity and poverty (Horne, 2011). These large-scale agricultural developments consist of large cash crop monocultures for export, which would either convert or inhibit agroforestry (Abbink, 2011; Rahmato, 2011). Other barriers to agroforestry in Ethiopia include insect pest problems associated with trees in agricultural landscapes, inadequate knowledge of the advantages of agroforestry, as well as delayed returns on investing in agroforestry due to underdeveloped markets for tree products (Rao et al., 2000).

Methods

This chapter uses two primary methods to examine the socioecological implications of scattered trees in agroforestry systems in the Northern Highlands. Survey data analyses provided information on the socio-cultural significance of the scattered trees. Geographic Information Systems (GIS) analyses were used to analyze the diversity of scattered trees. All of these methods were implemented across three study regions in the Amhara People's National Regional

State of the Ethiopian Northern Highlands including, Dera Woreda, Farta Woreda, and Bahir Dar Zuriya Woreda, as well as 6 church forests in Farta and Bahir Dar Zuriya Woredas. Refer to the methods from Chapter 2 and Chapter 3 to understand the methods used for this section.[2]

Results

Ecological Significance of Scattered Trees: Diversity of Tree Species

To look into the ecological significance of scattered trees the diversity of the tree species persisting in the agricultural landscape was analyzed. At the study sites other metrics of ecological significance of scattered trees were measured, including soil characteristics and impact on seedling growth. However, due to time constraints and resource limitations, only tree species diversity was analyzed to provide insight on ecological services provided by scattered trees.

Diversity Indices

Different measurements of diversity were used to characterize the degree of scattered tree diversity as well as compare tree species diversity across regions. Species richness was used to indicate the number of species present at each site. Species diversity indices were used to provide more information about the community composition than simply species richness. For this study the Shannon-Wiener index was used as modeled by Mulugeta and Admassu (2014) due to the similarity of the studies. This index was also picked because it is commonly used across the field (Magurran, 1988; Kent, 2011; Condit et al., 1992). The Shannon-Wiener index of diversity takes into account species richness and species evenness, which is the relative abundance of each species (Shannon and Weaver, 1949). The Shannon-Wiener index is high when the relative abundance of different species in a given sample is even and decreases as fewer species are more abundant than others. The Shannon-Wiener index is grounded on the theory that when there are many species with a similar evenness the uncertainty of predicting the next species increases (Shannon and Weaver, 1949).

[2] Methods include: From chapter 2, Study Sites, including the description of the different woredas and the church forests and one GIS method including GPS pinpointing. Methods from Chapter 3 include different social survey methods: the farmer survey, household survey, and farmer focus group.

Tree Species Diversity

Farmers have a good deal of knowledge related to the specific species of trees in their farm fields. Tree species were identified by the farmers and confirmed by Ethiopian expert partners familiar with the flora and fauna of the region. For each of the farmer surveys, the respondents listed the specific species of trees that are found on their agriculture and pasture land. Only the presence and absence of each tree species and the total number of all scattered trees was recorded without any indication of abundance of each species. Each farmer respondent was asked for the presence and absence of nine specific tree species listed in Table 4.2, and then the farmer was asked to list all of the other scattered tree species on their land.

Table 4.4 tabulates the tree species data for the entire study region with the recorded abundance indicating the number of survey respondents who signified that at least one of the specified species is present on their agriculture or pasture land. In general, a total of 63 species of trees were recorded across the study sites (Table 4.4). The respondents of the farmer survey in Dera, Farta, and Bahir Dar Woredas had an average of 5.8, 5.2, and 6.0 scattered trees on their farm and pasture land respectively. Banja Shekudad Woreda is missing this metric because the respondents of this woreda were not asked for the number of scattered trees on their land. Only two species were found in more than half of the sampled farms and include *Acacia abyssinica Hochst. ex Benth* (56.6%) and *Cordia Africana* (53.7%). *Croton macrostachyus Del.* (48.6%), *Rhamnus prinoides L'Herit.* (45.1%), and *Ficus Vasta Forssk* (23.4%) were the next most present species found in the respondents farmland.

Table 4.2 Specific species asked about for presence and absence in the farmer surveys

Local name	**Scientific name**
Woyra	*Olea europaea*
Wanza	*Cordia africana*
Zigba	*Podocarpus falcatus*
Yehabesha Tsid	*Juniperus procera*
Warka	*Ficus Vasta Forssk*
Yehabesha Girar	*Acacia abyssinica*
Kulkual	*Euphorbia abyssinica*
Koso	*Hagenia abyssinnica*
Bsana	*Croton macrostachyus*

Table 4.3. The average number of trees per farm, species richness of the scattered trees, and Shannon wiener diversity index of the scattered trees for each of the study regions

Study Site	Average Number of Trees per Farm	Species Richness	Shannon-Wiener Index
Bahir Dar	**6.0**	**32**	**2.936**
Abu	5.5	17	2.721
Gombat Michael	7.0	18	2.751
Kidana Muret	5.7	23	2.730
Banja	**--**	**20**	**2.373**
Abu	--	6	1.923
Mariam	--	3	1.033
Medhnialm	--	10	2.087
Michael	--	14	2.038
Dera	**5.8**	**32**	**2.799**
Wonchet	5.5	28	2.756
Zara	6.2	25	2.789
Farta	**5.2**	**35**	**2.860**
Debresena	5.8	16	2.595
Georges	10.25	13	2.471
Kidana Muret	3.5	12	2.301
Mariam	5.4	21	2.673
Michael	3.9	15	2.414

Table 4.4. The scientific name and local name of the tree species found in the study region and the recorded abundance of each species.

Scientific Name	Local Name	Recorded Abundance
Acacia abyssinica Hochst. ex Benth.	Yehabasha Girar	99
Cordia africana	Wanza	94
Croton macrostachyus Del.	Bsana	85
Rhamnus prinoides L'Herit.	Geshu	79
Ficus Vasta Forssk	Warka	41
Juniperus procera	Yehabesha Tsid	33
Euphorbia abyssinica	Kulkual	30
Mangifera indica L.	Mango	29
Coffea arabica L	Coffee	27
Ficus sycomorus L	Bamba	26
Olea eurpoaea	Woyra	22
Catha edulis (Vahl) Forssk. ex Endl.	Chat	21
Citrus aurantifolia (Christm.) Swingle	Lomi	20
Ficus thonningii Blume	Chibha	13
	Dumbia	11
Carica papaya L	Papaya	10
Prunus Africana	Prunus africana	10
Erythrina abyssinica Lam. ex. DC.	Koche (Red Barber)	9
Albizia schimperiana Oliv.	Sesa	9
Millitea ferruginea (Hochst.) Bak.	Birabira	8
Ensete ventricosum	Inset	8
Musa acuminata	Banana	7
Hagenia abyssinnica	Koso	7
	Chakima	6
	Kombel	5
	Meno	5
Sapium ellipticum (Krauss) Pas	Ariboj	4
	Donga	4
Syzygium guineense F.white	Dokma	3
Vernonia amygdalina Del.	Growa	3
	Kiaga	3
	Koba	3
Melia azedarach L.	Mim	3
	Shembeko	3
Podocarpus falcatus	Zigba	3
Combretum molle	Abalo	2
	Apple	2
Persea americana Mill	Avacado	2
Rhus vulgaris Meikle	Kamo	2
	Koshem	2
	Quara	2
Psidium guajava L.	Zetino	2
	Zigita	2
Carissa edulis (Forssek.) Vahl	Agam	1
	Aheto	1
	Ashkor	1
	Awfer	1
	Chimbako	1
	Chinet	1
Prunus persica (L.) Batsch	Coke	1
Mimusops kummel A. DC	Esha	1
Capparis tomentosa Lam.	Gimaro	1
	Gutam	1
	Katchina	1
	Kimim	1
	Kondo Berbery	1
Celtis africana Burm. f.	Kurat	1
Ficus sur Forssk	Shola	1
	Tenadom	1
	Tifee	1
Dodonaea anguistifolia L.f.	Tikntik	1
Otostegia integrifolia Benth	Tinigt	1
Securinega virosa (Willd.) Baill.	Wanahe	1

Socio-cultural Benefits of Scattered Trees

The farmer survey responses shed light on how farmers recognize the benefits from scattered trees in their agriculture and pasture landscape. The farmer survey tool asked each of the respondents for their perceived primary benefit of scattered trees and then proceeded to list 11 different potential benefits that the farmers either agreed with or did not. Subsequently, the survey asked respondents to list other benefits that they thought the scattered trees provide.

Figure 4.2 illustrates the respondents' perceived primary benefits from scattered trees, dividing the responses by woreda. The survey tool for Banja Shekudad Woreda did not ask for the primary benefit, so it was omitted from this part of the study. Honey was listed consistently as the primary benefit of scattered trees, followed by fuel wood and fruit. Honey, fuel wood, and fruit, are all direct benefits that farmers extract from trees and could potentially explain why farmers are first to list these as their primary benefits. Improved soil fertility, fodder, shade, and windbreaks, are all more indirect benefits and were listed as primary benefits far less.

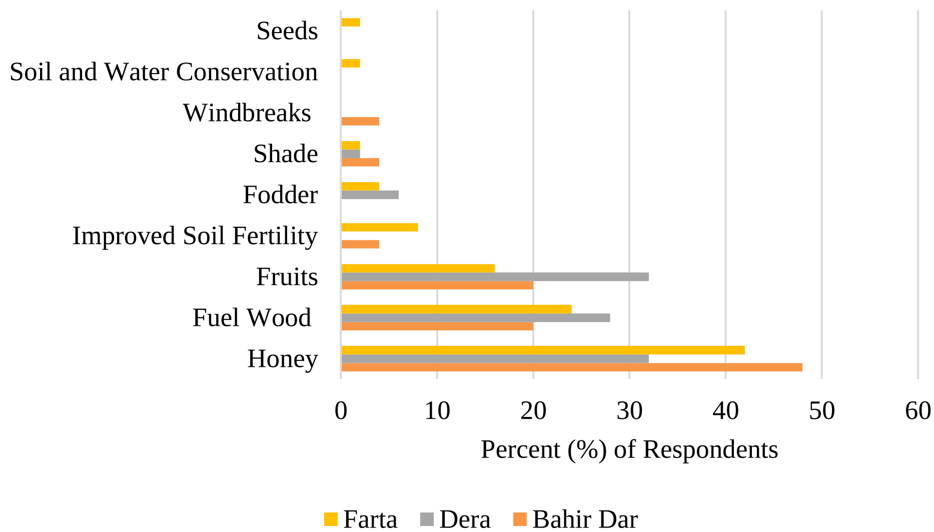


Figure 4.2. Farmers perceived primary benefits of scattered trees by site. The responses are separated by study region and include Farta (n=50), Dera (n = 50), and Bahir Dar (n=25) Woredas. Banja Shekudad Woreda was not included because the primary benefit was not asked for during survey data collection in the region. The primary benefit indicates the benefit that the farmer listed above all of the others.

The aggregated perceived benefits of scattered trees from the respondents tell a different story. Figure 4.3 illustrates the number of respondents suggesting that a certain scattered tree benefit is true for their land. For the survey, eleven benefits were listed (improved soil fertility, fuel wood, honey, shade, soil and water conservation, windbreaks, fruits, fodder, conservation of biodiversity, seeds, and medicine) and the respondents mentioned a number of other benefits (including: construction wood, charcoal, other food uses, and incense). Across all of the regions improved soil fertility (88.8%), fuel wood (84.8%), and shade (82.4%) were the most common and responses, followed by soil and water conservation (76.8%), windbreaks (76.0%), fruit (70.4%), honey (69.6%), fodder (62.4%), conservation of biodiversity (56.8%) and for seeds (52.0%), all of which over half of the respondents indicated were benefits of scattered trees on their land (Fig. 4.3). Indirect benefits such as improved soil fertility, shade, soil and water conservation, and windbreaks, were all mentioned by more respondents than when the respondents were asked to list primary benefits, which included mostly direct benefits, such as honey, fuelwood, and fruit.

Table 4.5. Farmer focus group responses for benefits of scattered trees in agriculture and pasture land.

Church	Response
Debresena	Fencing, shade, fodder, and medicine
Gombat Michael	Fodder, firewood, fruit, timber, construction wood, shade, and the leaves make the cropland full of nutrients
Alember	Tools for farming, fencing timber wood, and construction wood
Woji	Fodder for livestock, construction wood, timber, tools for farming, fencing, fuelwood, fruit
Robit Bata	Fodder for livestock, firewood, shade, soil fertility
Abalibanos	Fencing, fodder, food, and timber products

The farmer focus groups echoed much of what was described by the farmer surveys (Table 4.5). Every group of farmers, with the exception of Alember, indicated that they use scattered trees for fodder, and every group of farmers but Robit Bata, described how they used the trees for some sort of construction wood. Half of the focus groups suggested that scattered trees are used for fuelwood, shade, and food purposes.

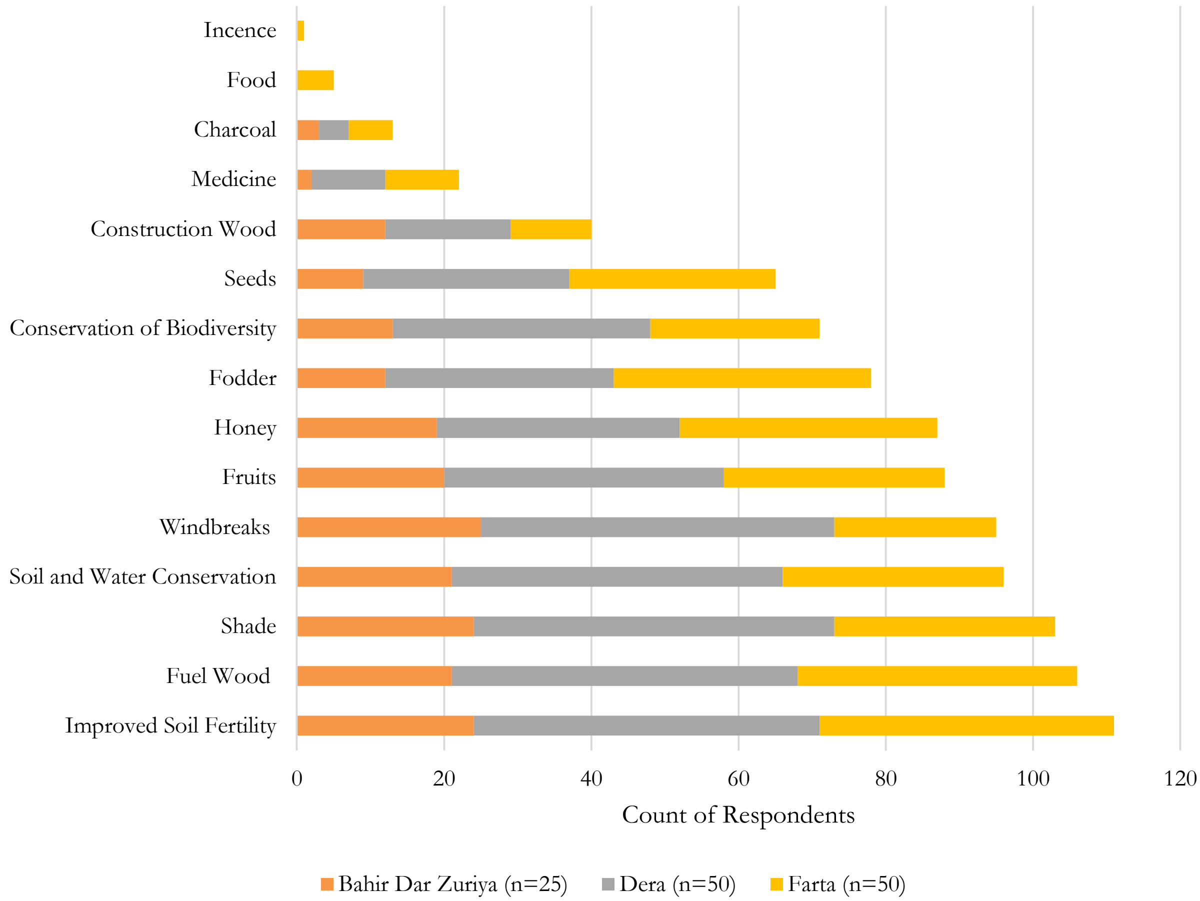


Figure 4.3. Farmers perceived scattered tree benefits separated by site including Banja Shekudad, Bahir Dar Zuriya, Dera and Farta Woredas. The data is described by total counts of farmers who list each benefit. During the survey farmers could list as many benefits as they want.

Scattered Tree Use

Scattered trees provide numerous benefits to the farmers whose land they persist on, however, different scattered tree species provide different benefits. This section illustrates the specific benefits different scattered tree species have, as well as, which species are the most advantageous overall. The household survey asked respondents to indicate whether 12 specific tree species (*Hagenia abyssinnica, Maesa lanceolata forsk, Euphorbia abyssinica, Podocarpus falcatus, Vernonia amygdalina, Acacia abyssinica, Adansonia digitata, Olea europaea, Ficus Vasta Forssk, Croton macrostachyus, Juniperus procera, Cordia Africana)* have certain benefits (firewood, charcoal, medicine, construction, food use, use as tools, fodder, and shade). The benefits of each tree species were asked in the context of the trees being part of a church forest. Therefore the assumption that these specified tree species have the same benefits in a scattered tree context as a forest context was made.

Table 4.6. Number of respondents indicating that the specific tree species is present in their church forests.

Species	Responses
Olea europaea	131
Croton macrostachyus	123
Ficus vasta Forssk	109
Maesa lanceolata Forsk	93
Acacia abyssinica	83
Cordia africana	74
Juniperus procera	71
Adansonia digitata	63
Euphorbia abyssinica	63
Hagenia abyssinnica	35
Vernonia amygdalina	23
Podocarpus falcatus	12
Average	73.3

Table 4.7. Recorded abundance of the specified scattered tree species from.

Scientific Name	Recorded Abundance
Acacia abyssinica	99
Cordia africana	94
Croton macrostachyus	85
Ficus Vasta Forssk	41
Juniperus procera	33
Euphorbia abyssinica	30
Olea eurpoaea	22
Hagenia abyssinnica	7
Podocarpus falcatus	3
Maesa lanceolata Forsk	NA
Vernonia amygdalina	NA
Adansonia digitata	NA

Figure 4.4 illustrates the aggregated benefits of each tree species. Since the benefits of each tree species were only asked if the tree was present in the respondents' church forest, a different number of responses were collected for each species. Each benefit is listed out of 100% so with 8 different benefits each tree species has the potential of having a total of 800%. This percent out of 800 will be called the index of use from here on. Table 4.6 specifies the number of respondents indicating that a certain tree species is present in their church forest and Table 4.7 indicates the number of each tree species in found as scattered trees in the study region. *Olea europaea, Croton Macrostachyus,* and *Ficus casta Forssk* are the most present tree species in the church forests, while *Acacia abyssinica, Cordia africana,* and *Croton Macrostachyus* are the most abundant scattered tree species in the agriculture and pasture settings.

Responses indicate that *Cordia africana* has the highest index of use, followed by *Adonsonia digitata,* and *Ficus vasta Forssk.* The aggregated household benefits of each of the tree species does not seem to relate to the abundance of each of the tree species in the church forests, which is indicated by the number of respondents saying that the species was present. However, when looking at the abundances of scattered tree species compared to the species' index of use a trend is more apparent. The top five most abundant scattered tree species (Table

4.7) are the five trees (excluding *Adonsonia digitata* since it is not found in the scattered tree study regions) with the highest indices of use and the only trees with an above average index of use (Fig. 4.4). Therefore scattered tree species abundances seem to reflect the tree species benefit potential.

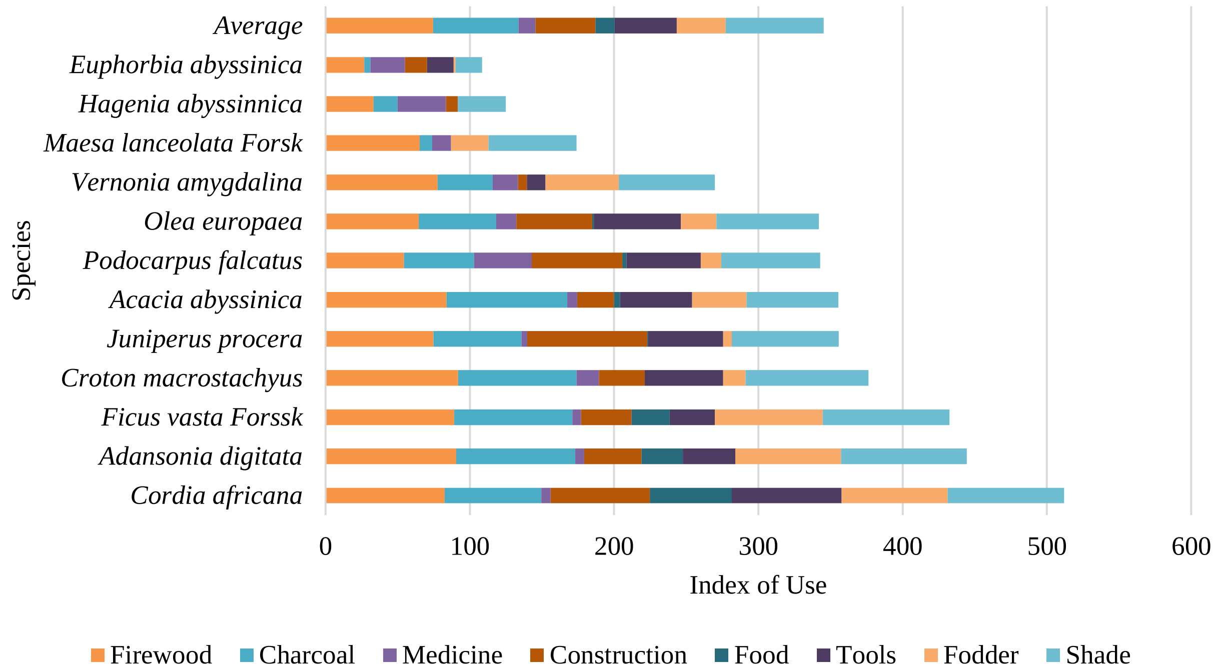


Figure 4.4. Household benefits from specific tree species from church forests. Since each tree was listed a different number of times due to whether the tree was present or absent in each forest percentages were used. Each benefit is listed out of 100%. With 8 benefits each tree species has the potential of having 800%.

The household survey responses illustrate that different tree species have very different household uses, and even if a tree species does not have a high index of use, it could be extremely significant for specific uses. Figure 4.4 summarizes this data, showing the percent of respondents that indicate a specific tree species has a certain household use. Table 4.5 specifies which tree species were listed the most for each use. The data suggests that respondents use different tree species more for different uses, with the exception of *Cordia africana* and *Ficus vasta Forssk*, both of which were listed as being the main tree species for two uses (Table 4.8).

While different species were listed for different uses, a few of the species were consistently listed across the board. *Croton macrotsachyus, Adansonia digitata,* and *Ficus vasta Forssk* are the three highest listed tree species for firewood, fodder, and shade uses, and follow *Acacia abyssinica* as the most listed tree species used for charcoal.

Table 4.8. Most listed tree species for each use

Use	Tree Species
Firewood	*Croton macrostachyus*
Charcoal	*Acacia abyssinica*
Medicine	*Podocarpus falcatus*
Construction	*Juniperus procera*
Food	*Cordia africana*
Tools	*Cordia africana*
Fodder	*Ficus vasta Forssk*
Shade	*Ficus vasta Forssk*

Adansonia digitata (baobab) has the second highest index of use with a score of 444.4 after *Cordia Africana*. The multipurpose characteristic of the *Adanosonia digitata* tree species has been well documented. Most of the tree is edible, including the seeds, leaves, roots, flowers, fruit pulp and bark (Rahul et al., 2015) and provides food for both humans and to their livestock (Wickens, 1980). The species is also known to be used for construction wood, clothing, and has numerous medicinal benefits (Wickens, 1980). Of the respondents 90.5% indicated that *Adanosonia digitata* is a useful species for firewood, as well as, charcoal (82.3%), shade (87.3%), fodder (73.0%), construction (39.7%), and for food (28.6%). The Institute of Biodiversity Conservation (IBC) indicates that *Adanosonia digitata* is a priority tree species in Ethiopia due to its economic value from fruit (IBC, 2012).

Ficus vasta Forssk was the most listed tree species for shade (87.9%) and fodder (74.7%) uses and has the third highest index of use at 432.5. Literature on *Ficus vasta Forssk* uses in Ethiopia include, animal fodder (Senbeta et al., 2013), house and furniture construction, sealant to make beehives (Bahru et al., 2012), fruit consumption (Addis et al., 2005), and having a beneficial effect on soil fertility (Alebachew, 2012).

Croton macrostachyus, which has an index of use of 376.4, is most notably used for firewood, with the most respondents (91.9%) suggesting this use. Respondents also indicate that the tree species is used for shade (85.4%), charcoal (82.1%), tools (54.5%), construction wood (31.7%), and for medicinal purposes (15.4%). The extracts from the fruit of the *Croton macrostachyus* tree is commonly used to treat malaria as well as tuberculosis (Giday et al., 2007). One of the respondents specified that the tree is especially good for constructing beds in addition to holding homemade bee hives.

The *Acacia abyssinica*, which was denoted as the most beneficial tree for making charcoal by the most respondents (83.3%) is also an important tree species for firewood (83.8%), shade (63.5%), tool construction (50.0%), fodder (37.7%), and for construction wood (25.7%). The literature indicates that *Acacia abyssinica* is used mostly to make charcoal as well as for firewood and fodder uses (IBC, 2012; Bussmann, 2011). One of the respondents stated that "acacia trees give shade to the cows and we plant acacia trees around our house."

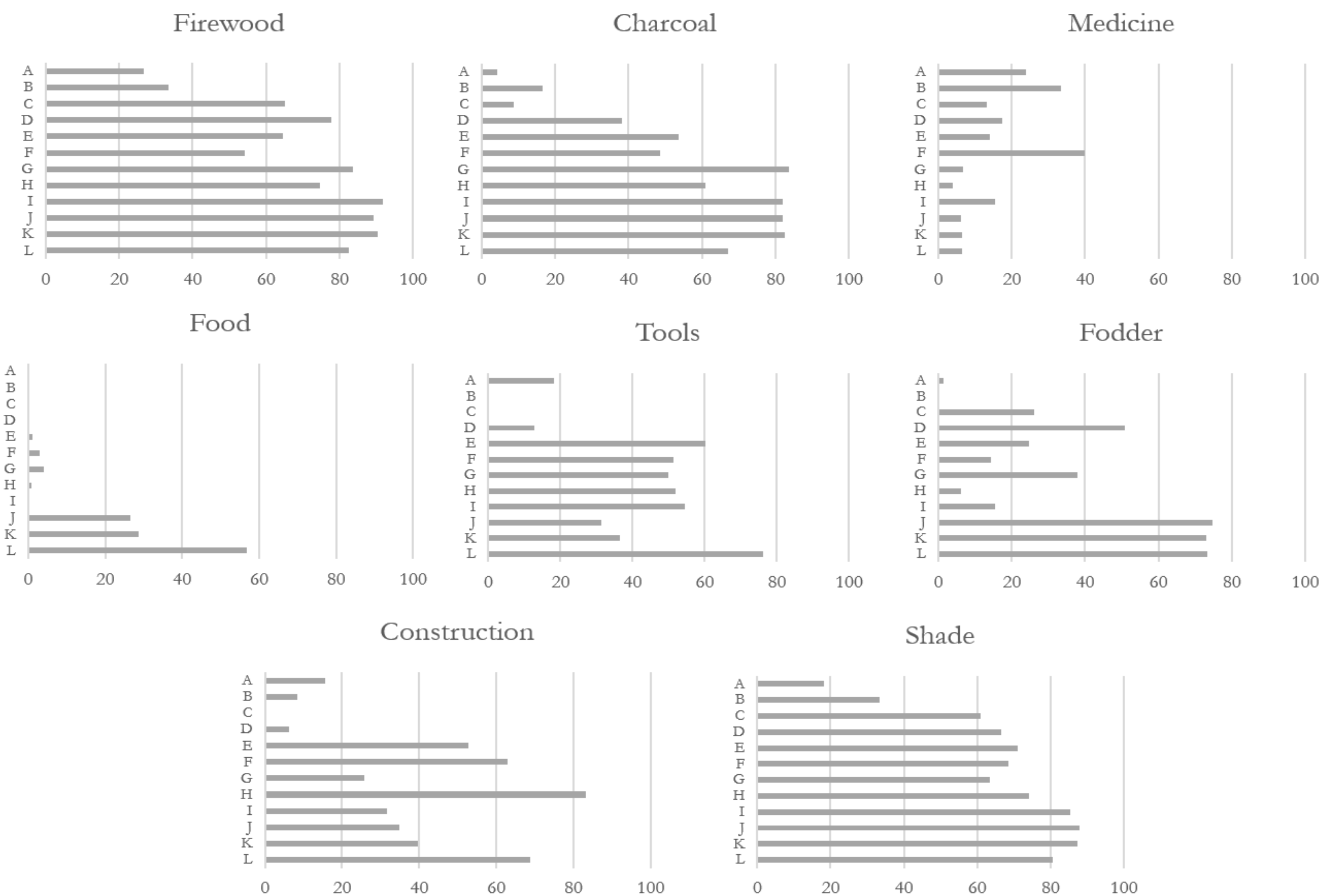
Cordia africana was indicated as an effective tree species for food consumption (56.9%) and tool construction (76.1%) uses by the highest percent of respondents. The fruit of the *Cordia africana* tree is often eaten (Balemie and Kebebew, 2006). Certain respondents said that they use the fruit to make wine and "when you eat this fruit your stomach becomes clean." The timber of the tree is used to make log-hives for bees, as well as barrels for *tej* (honey-beer) (National Museum of Ethiopia, 2016). Other reports indicate that the tree is used widely for walling and poles (Balemie and Kebebew, 2006) and a survey respondent indicated that it is used "to build furniture like beds and tables." For every other use asked about in the study, more than 60% of the respondents suggested that *Cordia africana* was a useful tree species (with the exception of food and medicine, neither of which had a single tree species over 60%). *Cordia africana* is listed as an endangered tree species, as well as, a priority tree species by IBC for its economic benefits from timber and agroforestry (IBC, 2012).

Fully 83% of respondents indicated that *Juniperus procera* was a useful tree species to be used for construction and it was listed as an important species for firewood (74.8%), shade (74.0%), charcoal (61.0%), and for tools (51.9%). Literature on tree species use in Ethiopia indicates that *Juniperus procera* is primarily used for construction wood and for fuel wood (Bussmann et al., 2011). The timber is highly valuable because after it is seasoned it becomes very durable, immune to fungal attacks, termites, and wood-borers (Garner, 1926; Pohjonen and Pukkala, 1992). Chaffey (1982) describes the Juniper tree as the most referred multipurpose tree in Ethiopia due to its use for construction, furniture, firewood, fencing and medicine, as well as, its strong religious and cultural values (Couralet, 2007). *Juniperus procera* is listed as a priority tree species by the Institute of Biodiversity Conservation due to its economic value from timber (IBC, 2012). It is also listed as an endangered tree species in the "high" threat category (IBC, 2012).

Podocarpus falcatus was the most listed tree species for medicinal value, with 40.0% of respondents describing this property. It is often used to treat diarrhea, intestinal parasites, and as a body wash (Enyew et al., 2014). *Podocarpus falcatus* was also described to be used for shade (68.6%), construction (62.9%), firewood (54.3%), tools (51.4%), and for charcoal production (48.6%). The IBC (2012) describes *Podocarpus falcatus* as a priority forest tree species in Ethiopia because it is threatened and is used economically for timber. The threat category of the species is listed as "high" because it is a main characteristic species in moist and dry Afromontane forests (IBC, 2012).

Olea europaea, Vernonia amygdalina, and *Maesa lanceolate Forsk* were near the bottom in terms of index of use score (Fig. 4.4). *Olea europaea* was primarily described as being good for shade (71.0%), as well as for firewood (64.5%), tools (60.2%), charcoal (53.8%), and construction (52.7%). Literature on the subject indicates that *Olea europaea* is recognized in Ethiopia as a good tree species for furniture and house construction, tool handles (Bahru et al., 2012), and use as a toothbrush (Negash, 2007). *Vernonia amygdalina* was indicated by respondents to be a useful tree species for firewood (77.8%), shade (66.7%), and fodder (50.8%), which is confirmed by the literature (Negash, 2007). Social survey data indicates that *Maesa lanceolate Forsk* is predominantly used for fuelwood (65.2%) and shade (60.9%).

Hagenia abyssinnica and *Euphorbia abyssinica* have the lowest indices of use, however they were the second (33.3%) and third (23.9%) most recorded tree species with medicinal value respectively. *Hagenia abyssinnica* is often used to treat hypertension (Enyew et al., 2014) and *Euphorbia abyssinica*, is used to treat external parasite wounds (Getaneh and Girma, 2014) as well as to treat venereal diseases (Enyew et al., 2014). One respondent did indicate that "the main purpose of [*Euphorbia abyssinicai*] is for construction wood because termites don't eat [it]," even though only 15.5% of respondents indicated that they use it for construction wood.



A-*Euphorbia abyssinica,* B-*Hagenia abyssinnica,* C-*Maesa lanceolata Forsk,* D-*Vernonia amygdalina,* E-*Olea europaea,* F-*Podocarpus falcatus,* G-*Acacia abyssinica,* H-*Juniperus procera,* I-*Croton macrostachyus,* J-*Ficus vasta Forssk* , K-*Adansonia digitate,* L-*Cordia africana*

Figure 4.5. Respondent's perceived household benefits for each of the tree species. Each of the numbers on the y-axis correlate with a different tree species and the x-axis is the percent of respondents that indicated each species applies for the selected benefit.

Tree Preferences

The next question that was considered was do benefits and uses of specific tree species reflect the respondent's tree species preferences? The household survey asked respondents to list the five tree species that should be planted in the church forest based on benefits and spiritual values. There were no choices to choose from and the respondents could decide on any tree species including non-native species. Figure 4.6 indicates which tree species were the most preferred by the respondents at five of the church forests including, Debresena, Gombat Michael, Alember, Robit Bata, and Woji. Abalibanos was excluded because the question was not incorporated into the household survey tool there.

The most listed tree species consist of *Juniperus procera L.* (69% of respondents), *Cordia Africana Lam.* (54%), *Eucalyptus spp.* (51%), *Olea europaea L.* (38%), *Mimusops kummel Bruce ex DC.* (24%), and *Croton macrostachyus Del.* (21%). *Juniperus procera L, Cordia Africana Lam.,* and *Croton macrostachyus Del.* also had relatively high indices of use of 355.7, 511.9, and 376.4 respectively, all within the top five of the twelve species mentioned in the last section. *Olea europaea L.* was fourth most listed by respondents as a preferred tree, however it has a relatively low index of use at 343.9. Exotic species including *Eucalyptus spp.* and *Grevillea spp.* were among the top listed tree preferences.

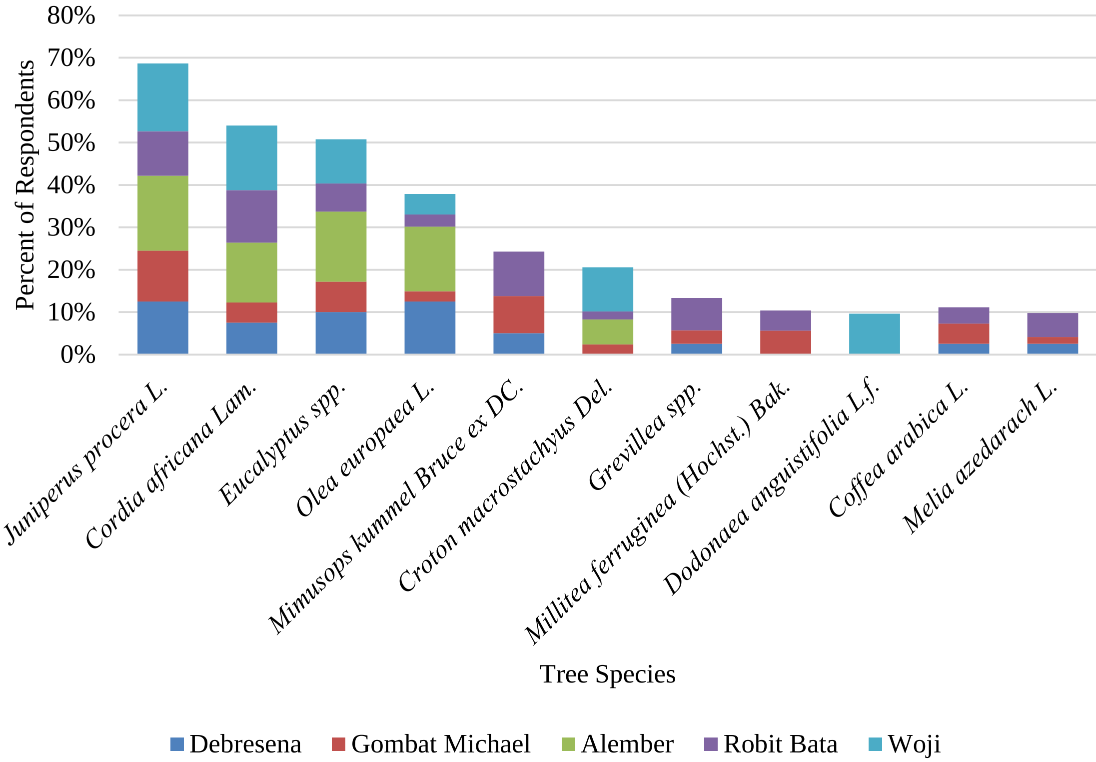


Figure 4.6. Respondents tree Preferences for the five church forests (Question was not asked at Abalibanos)

For each farmer focus group, the farmers described which tree species they would want to plant in their agricultural plots if they had the means to do so. This is tabulated in Table 4.9, with each of the focus groups indicating an extensive list of tree species they would like to plant in their agricultural land. *Cordia Africana* was mentioned by every one of the focus groups as a species they wish to plant. *Croton macrostachyus* was mentioned by half of the focus groups, while the other species that were listed were only mentioned by two focus groups or less.

Table 4.9. Specific trees that the farmers in the farmer focus groups want to plant in the farmland at each of the church forests.

Church	Local Names	Scientific Names
Debresena	Bsana, wanza, embis, girar, tsid, tiffe, lole, donga, homa	*Croton macrostachyus Del., Cordia africana,* embis, *Acacia abyssinica Hochst. ex Benth, Juniperus procera,* tiffe, lole, donga, homa
Gombat Michael	Wanza, bamba, warka, dokma, chebeha because they are good for shade for coffee	*Cordia africana, Ficus sycomorus L, Ficus Vasta Forssk, Syzygium guineense F.white, Ficus thonningii Blume*
Alember	Wanza, girar, bsana	*Cordia africana, Acacia abyssinica Hochst. ex Benth, Croton macrostachyus Del.*
Woji	Sespania, kentafa, serkaba, keteketa, wanza, dokma, zenbaba, enkoyo, gesho	Sespania, kentafa, serkaba, keteketa, *Cordia africana, Syzygium guineense F.white,* zenbaba, enkoyo, *Rhamnus prinoides L'Herit.*
Robit Bata	Wanza, Bamba, warka, chebeha	*Cordia africana, Ficus sycomorus L, Ficus Vasta Forssk, Ficus thonningii Blume*
Ibanos	Wanza, woira, sisana, kanchea, gesho	*Cordia africana, Olea europaea, Croton macrostachyus,* kanchea, *Rhamnus prinoides L'Herit.*

Perceived Drawbacks of Scattered Trees

The farmer survey asked respondents about the negative aspects of scattered trees in their agriculture and pasture fields, explicitly asking if the trees serve as hosts for pests or compete for light, moisture, or nutrients with the crops. The survey then went on to ask the respondents to list *other* perceived negative characteristics of the trees. Of the 175 farmer respondents, 149 (85.1%) indicated that the trees have no negative impact on their land and are purely beneficial. Of the other 26 respondents 2 (1.4%) specified that the trees host pests, 17 (9.7%) suggested that the trees compete with their crops for light, moisture, or nutrients, and another 16 respondents (9.1%) indicated that the trees have other negative factors. Of the 17 respondents indicating that trees compete with their crops and the 16 respondents indicating that there are *other* issues with trees in the field, 15 and 10 of the respondents were from Banja Shekudad Woreda respectively. All 16 of the respondents denoting *other* negative characteristics

Table 4.10. The farmers perceived adverse impacts of the scattered trees from the farmer focus groups.

Church	Response
Debresena	There are no problems; they do not impact the soil. However, eucalyptus does (but that is not an indigenous tree).
Gombat Michael	The trees minimize productivity directly around them but overall they are beneficial.
Alember	They have no Problems.
Woji	The trees have no danger but the shade takes up space and decreases the growth of the crops.
Robit Bata	The trees minimize the crops and they shade the crops, but the advantages outweigh the disadvantages and that is why we keep them.
Ibanos	They pose no danger.

indicated “water drops” as the problem. In agricultural systems, large water droplets falling from a tall tree canopy may cause splash erosion and could initiate more sheetwash than rain falling on bare soil in the open (Ekologi, 1980).

The farmer focus groups from six church forests had very similar responses to the farmers in the farmer surveys (Table 4.10). Half of the focus groups indicated that scattered trees compete with crops in terms of space for cropland and sunlight but they also describe the scattered trees as having positive attributes that outweigh the negatives. The other three church forests indicated that the trees have no problems at all and pose no danger to the agricultural land.

Why do Scattered Trees Persist?

Farmer Focus Groups

As part of the farmer focus group, farmers were directly asked why indigenous trees have persisted in the farmland. Most of the respondents thought this was a silly question and answered that they persist because of nature or because of god, which were used essentially interchangeably (Table 4.10). One of the focus groups mentioned conservation and for the trees to continue to grow and mature conservation is needed. None of the groups mentioned anything about conservation of the trees through use and the need to keep them around out of necessity for their benefits.

Table 4.11. Focus group responses to why do trees still persist in the fields.

Church	Response
Debresena	Nature
Gombat Michael	God-willing
Alember	Nature
Woji	They are growing by themselves and they will need conservation activities to become mature
Robit Bata	Nature
Abalibanos	Nature

Discussion

The scattered trees in the Amhara Region of Ethiopia provide a wide assortment of demonstrated benefits to households and the land they persist on. Survey respondents list direct benefits such as honey, fuel wood, and fruit as the primary benefits from the scattered trees.

When the respondents are asked to list out all the benefits associated with scattered trees, indirect benefits such as, improved soil fertility, shade, soil and water conservation, and windbreaks were listed by more respondents than the direct benefits, with the exception of fuel wood, which is listed second. Despite significant deforestation historically in the Amhara Region, these scattered trees have persisted and even increased in numbers (Chapter 1) because of their unreplaceable direct and indirect benefits.

Households that participate in farming make a choice to keep scattered trees in the agricultural landscape because the benefits received from the trees exceed the benefits that they would receive from agricultural production on that parcel of land. The trees are being conserved through utilization, in which increasing the use of the scattered tree species promotes their conservation. This principle of conservation through use/utilization or the "use it or lose it" model (Hutton and Leader-Williams, 2003) is typically applied to wildlife conservation (Kock, 1995) and is often criticized in a tropical forest context, because the livelihoods of millions of people depends on access to the services and products from the forest, and they worry that too much use will degrade these forest past sustainable levels (Lillesø et al., 2002).

On the other hand, authors argue that conservation requires short-term benefits for local people to be successful (Hutton and Leader-Williams, 2003). Dickinson et al. (1996) suggests that tropical forests can only be conserved if rural communities gain direct economic benefit from harvesting forest products (Dickinson et al., 1996). Lillesø et al. (2002) builds off this argument, suggesting that conservation needs not only direct economic benefits, but these benefits need to witnessed in the short-term. In the context of scattered-tree conservation, Dickinson et al.'s (1996) and Lillesø et al.'s (2002) arguments and the "use it or lose it" model both apply. Scattered trees offer short-term benefits (direct benefits, e.g. food and fuel woods) to the local people who practice successful conservation of these scarce and often endangered resources. The short-term benefits often allow for conservation initiatives and provide long-term benefits (indirect benefits, e.g. soil fertility, shade, soil and water conservation, and windbreaks) in their wake.

The data collected on scattered tree use and diversity confirms this idea of conservation through use. The top five most abundant scattered tree species (Table 4.7) are the five trees (excluding *Adonsonia digitata* since it is not found in the scattered tree study regions) with the highest indices of use and the only trees with an above average index of use (Fig. 4.4). Scattered

tree species abundances seem to reflect the tree species benefit potential and each species' index of use. Therefore scattered tree species have persisted in agricultural landscapes because of their usefulness and have been conserved directly by farmers in order to provide benefits that cannot be provided by agricultural uses of the landscape. However, flipping this argument on its head, it could be just as possible that tree species use reflects the abundance of certain species. If certain tree species have higher abundances then they would be used more often.

Though this study cannot fully disentangle which variable drives the other, the substantial diversity of scattered trees combined with survey and focus group findings suggest the use value of at least some of these species supports their persistence in the landscape. Species that have very low indices of use are still conserved in the landscape due to their unique benefits. For example, *Podocarpus falcatus* which had a low index of use and *Hagenia abyssinnica* and *Euphorbia abyssinica*, which had the two lowest indices of use respectively, were the three tree species most described to have medicinal value. As Balemie, K. and Kebebew (2006), described "this shows that such management of, and acquisition of economic benefits from species might promote local peoples' interest in conservation and maintenance of such locally important and endangered species" (pg.8).

An incredible amount of tree species diversity was found to persist in the agricultural landscape of the Amhara Region, with a species richness of 63 across all the study regions. The persistence of these tree species represents *circa situm* conservation (Hewood and Dulloo, 2005), in which remnant or planted trees are preserved in farmland where natural forest containing the same tree species was once found, but has since been lost or modified due to agricultural expansion (Dawson et al., 2013). These agricultural landscapes are also representative of *in situ* conservation. Since these scattered trees are located near church forest fragments, they have the opportunity to provide alternative sources of products and thereby reduce the extraction from the forest (Dawson et al., 2013). These scattered trees also work to connect church forest fragments as stepping stones or sub-corridors. Since many of the tree species found in the study sites are endangered at different levels, *ex situ* conservation could be important as well, and could take the form of seed collections or genebanks (Dawson et al., 2015).

Conclusions

The future of tree conservation in Northern Ethiopia will likely rely more heavily on *circa situm* conservation in smallholders' agricultural fields. In what ways can *circa situm* conservation be maintained and even enhanced in these landscapes to ensure the persistence of these valuable and incredibly diverse resources?

One method could be through improved smallholder access to tree planting material (Dawson et al., 2009). Planting valuable species on farmland can both improve access to their products for rural people and raise their conservation status. Dawson et al. (2009) suggests that this can be done through the implementation of "diversity fairs" (van der Steeg et al., 2004), which are social events at which farmers would exchange seeds and knowledge and would ultimately enhance diversity in traditional agricultural crops on smallholders' farms. Another thought is to develop market solutions through commercial seed and seedling enterprises, which would result in the development seed exchange and would consequently lead to higher diversity of scattered trees (Graudal and Lillesø, 2007). Lastly, Rolim and Chiarello (2004) propose that the suppression of exotic tree species in the farmland could improve the conservation of tree species being conserved through *circa situm* techniques. In the case of these farm systems, *Eucalyptus spp.* would have to be eradicated, which is unlikely given the current extent of the species and the popularity among rural smallholders. Recent trends of *Eucalyptus spp* planting suggest large increases in its abundance, which could have negative impacts on current indigenous tree populations if uses between eucalyptus and indigenous trees have overlap.

Remnant scattered trees in the Northern Ethiopia tells a unique story of historical deforestation and present-day conservation, in which utilization of the trees and the land drove both. These scattered trees are now integral pieces of the landscape and their persistence is tantamount to the success of rural smallholders. The following quote from a conversation with a survey respondent sums up the future of scattered tree conservation quite well:

"If there are no trees there are no new generations. If there are trees no one goes hungry. The children eat the fruits. We must plant trees for our children."

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