LEUPHANA
UNIVERSITÄT LÜNEBURG

Woody plant biodiversity conservation and ecosystem services in the forest-agriculture mosaic of southwestern Ethiopia

Academic dissertation
Submitted to the Faculty of Sustainability of Leuphana University Lüneburg for the award of the degree
'Doctor of Natural Sciences'
-Dr. rer. nat.-

Submitted by
Girma Shumi Dugo
Born on 02.09.1977 in Arsi-Sire, Ethiopia

Woody plant biodiversity conservation and ecosystem services in the forest-agriculture mosaic of southwestern Ethiopia

Doctoral thesis by Girma Shumi Dugo

May 2019

LEUPHANA
UNIVERSITÄT LÜNEBURG

Woody plant biodiversity conservation and ecosystem services in the forest-agriculture mosaic of southwestern Ethiopia

Academic dissertation
Submitted to the Faculty of Sustainability of Leuphana University Lüneburg for the award of the degree
'Doctor of Natural Sciences'
-Dr. rer. nat.-

Submitted by
Girma Shumi Dugo
Born on 02.09.1977 in Arsi-Sire, Ethiopia

Date of submission: 29.05.2019
Doctoral advisor and reviewer: Prof. Dr. Joern Fischer
Reviewer: Dr. Christine Schmitt
Reviewer: Prof. Dr. Tibor Hartel
Date of disputation: 06.08.2019

Copyright notice

Author´s address:

Leuphana University, Faculty of Sustainability Science

Universitaetsallee 1, 21335 Lüeneburg, Germany

E-mail: girmasd@gmail.com

To my beloved parents *Shumi Dugo Gadaa* & *Sinbiree Galaassaa Tufaa* and to my sister *Jufaaree/Asselefech Shumi Dugo*, whom I lost during my childhood and on April 2004, respectively.

Acknowledgements

"Hundaa ol Waaqayyo asiin na gahe haa galatoomu"

Next to God, first all I wish to thank my supervisor Joern Fischer, for accepting me as PhD student, and mentoring my academic development with great care and interest from start to finish. This interesting PhD would not have been possible without him. He always keen to support, encourage, and inspire to this PhD. He helped me in designing the study, during fieldwork and data analysis, and took time to discuss ideas and manuscript drafts with me. His critical reviews, insights and advices have enormously improved my scientific performance. Thank you Joern for all these marvellous help and support.

I am also deeply indebted to the entire team for motivating and supporting me during my PhD. I am grateful to Jannik Schultner for his unreserved guidance and advises throughout the PhD. He generously helped me in R and GIS, manuscript drafting and reviewing, and also in proofreading of the first chapter of this thesis. I am thankful to Jan Hanspach for his support in R and GIS, manuscript editing, and for editing the first chapter of this thesis. I also indebted to Ine Dorresteijn for her help and support during fieldwork, in various discussions and manuscript drafting and editing. I am also very grateful to Kristoffer Hylander and Feyera Senbeta, who trained me about plant species identification in the field and encouraged me to conduct this PhD. I also indebted to their critical reviews, insights and advices to manuscripts. I am also grateful to my fellow PhD-students Patrícia Rodrigues (Bob), Aisa O. Manlosa, Joao L. Guilherme and Tolera Senbeto for sharing all the ups and downs during fieldwork, valuable discussions and friendship during my PhD years. I am thankful to Patrícia Rodrigues for her kind support and help in GIS and R, and for editing the first chapter of this thesis. I am grateful to Jacqueline Loos for her support and proofreading of the first chapter of this thesis. I would like to thank Marlene Röllig, Andra Ioana Horcea-Milcu, and Tamara Schaal for their kind help during this PhD. I am also grateful to Mr. Christian Buchholz, Mrs. Elissa Dietrichs, Mrs. Elke Ferner, Mrs. Maire-Linda Grünewald, and Dr. Christine Fluche for their quick and industrious administrative support provided to me during this PhD. I am also thankful to Micha Edlich and Julia Zufall for their quick and diligent support in English grammar proofreading of the first chapter of this thesis.

I am very grateful to all farmers for their kindness and sharing their experience with me; to local field assistants: Gaalii, Sulxaan and Ili'aas in Borcho Deka; Dafisii, Mifta and Zakeeri in Kela Harari; Biyyaa and Jagamaa in Kuda Kofi; Negash, Nabso and Mehamed in Bere

Weranigo; Aminu, Amiinu Umaar and Nabso in Difo Mani; and Hawwii and Sefu in Gido Bere for their kind help and support during field data collection, for their time and effort to reach even inaccessible survey sites and to familiarize me with the local people and the landscapes. I am also thankful to leaders of each kebele; leaders and staff in Gera, Setema, and Gumay woreda their support and allowing me to conduct this research. I also indebted to Berhanu Bekele, Dereje Gire, Obsuman Damena, Fikadu (driver) and Fasika Terefe for their tremendous effort and support during fieldwork.

I am grateful to Tola Gemechu and his family, and Kristoffer Hylander's family for their support during my visit to Stockholm, Sweden. I also thank Tola for his unreserved support and encouragement, critical review to manuscript and for editing the first chapter of this thesis. I am thankful to Abebe Tufa for his support and inspiration during fieldwork and this PhD. I am also grateful to Sileshi Nemomissa for his support and allowing me to use the National Herbarium of Addis Ababa University.

This research was funded by grant to Joern Fischer from European Research Council (ERC). I am also grateful to Leuphana University Graduate School for Fund for Young Researchers financial support provided to me for the 12th ALTER–Net Summer School.

Finally, I extend my very special thanks to my family and parents. My wife Birtukan Temesgen thanks so much for your care and support; you made me to achieve this PhD. Our lovely kids, Senna, Naayad and Sifan, I am very proud to have you. Senna, thank you very much for your various support that I can't express in words. I also very much indebted to Naayad and Sifan for refreshing my mind when I am with you. I love you all so much! I am also grateful to my all parents, Batri Shumi, Dechu Shumi and his famiy, Jime (Tayitu) Gelassa, Hayilu Bedhaso and his family, Shibru Hayilu and his family, Tola Hayilu and his family, Borishe Hayilu and his family, Eshetu Dechu and his family, Fikadu Belay and his family, Anbese Fulas, Tesfahun Abebe and his family, Getachew Tola and his family, Bekele Roble and his family, Ayantu Bune and her family, Biniyam G/Medihin, Diso Gelassa, Tsehayi Kebede, Aklilu Mekonin, Tibebu Mekonn, Kasech kebede and her family, Wesene Kebede and all others for their help and support in all social aspects during this PhD years.

Preface

This dissertation is presented as a series of four manuscripts based on empirical research carried out in smallholder-dominated landscapes of southwestern Ethiopia. Chapter 1 provides a general overview of my dissertation, including the overarching goal and specific aims, a summary of all included manuscripts, a synthesis of key findings and implications for future biodiversity and ecosystem services maintenance in rural landscapes of southwestern Ethiopia. Chapter 2 investigates woody plant species response to human-induced forest degradation in the forest. Chapter 3 focus on farmland sections of the landscapes and examines legacy effects of past agricultural land use on woody plant species. Chapter 4 evaluates the supply of multiple ecosystem services and the relationships between woody plant species diversity and ecosystem service diversity in the three major land use types, namely forests with and without coffee management and farmland. Finally, Chapter 5 assesses farmers' woody plant use, property rights and management across the landscapes. Chapters 2 to 5 represent a series of scientific articles which are either published or in revision in international peer reviewed scientific journals. I, the author of this dissertation, conducted all research presented in this dissertation and am the lead author of all manuscripts. A reference to the journal each manuscript is submitted to and the contributing co-authors is presented on the title page of each chapter. The content of each chapter is the same as the journal article, with citation, figure and table labels, and reference list modified to the presentation of this dissertation. All literature cited is presented in a single reference list at the end of the dissertation. For literature with more than seven author lists, I used "et al".

Table of contents

Abstract

The smallholder-dominated landscapes of southwestern Ethiopia support a unique biodiversity with great importance to local livelihoods and high global conservation value. These landscapes, however, are severely threatened by deforestation, forest degradation and the adverse effects of farmland management regimes. These changes have fundamentally altered the structure of the landscapes and threaten their biodiversity and ecosystem services. Managing biodiversity and related services in such rapidly changing landscapes requires a thorough understanding of the effects of land use change and the reliance of local communities on biodiversity.

This dissertation examines woody plant biodiversity patterns and services and presents several recommendations regarding biodiversity and multiple ecosystem services in smallholder-dominated landscapes of southwestern Ethiopia. Using a social-ecological systems approach, I conducted four studies on the complex interactions of local people and woody plant diversity. First, I investigated the effects of human-induced forest degradation on woody plant species. My results suggest that forest biodiversity has been affected by the combined effects of coffee management intensity, landscape context and history at the local and landscape level. Specifically, richness of forest specialist species significantly has decreased with coffee management intensity and in secondary compared to old growth forests, but increased with current distance from forest edge in both primary and secondary forests. These findings highlight the need to maintain undisturbed forest sites to conserve forest biodiversity. Second, I examined legacy effects of past agricultural land use on woody plant biodiversity. My results show that historical distance seems to be the most important variable affecting woody plant composition and distribution in farmland sections of the landscapes. I found evidence for immigration credits for generalist and pioneer species but not for extinction debts for forest specialist species which might be rapidly paid off in farmland. The results suggest not only an unrecognized conservation value of old farmland but also a disturbing loss of forest specialist species. To slow this trend, it is necessary to shift to a cultural landscape development approach and to restore forest specialist species in the landscapes. Third, I evaluated the supply of potential multiple ecosystem services and the relationships between the diversity of woody plant and ecosystem service in the three major land use types, namely forests with and without coffee management and farmland. The results revealed a high multifunctionality of landscapes and showed that ecosystem services significantly increase with woody plant diversity in all types of land use. These findings suggest that the woody plant

diversity and multifunctionality in southwestern Ethiopian landscapes has to be maintained. Fourth, I explored farmers' woody plant use to assess their dependency on and maintenance of woody plants and also considered the influence of property rights and management in this context. I found that local farmers used 95 species for eleven major purposes from all major land uses across the landscapes. I also found that most of the widely used tree species regenerated successfully throughout the landscapes, including in farmland. Local people felt, however, that their property and tree use rights were limited, especially in forests, and that some of the most widely used plant species, including important timber species, appeared to have been overharvested in forests. The results suggest that many species are important for local livelihoods, but a perceived low sense of property rights also seems to adversely affect the management of woody plants, particularly in forests.

By focusing on woody plants and their ecosystem services to local people, this dissertation documents a dramatic loss of native forest biodiversity and rapid changes in the cultural landscapes of southwestern Ethiopia. This study also reveals low levels of perceived property and tree use rights by local people, particularly when it comes to forests, and the present overharvesting of important tree species in forests in particular. This dissertation also highlights current value of the multifunctionality of the landscapes examined here, the increase in ecosystem services diversity with increasing woody plant biodiversity and the importance of woody plant species for local livelihoods. Overall, my findings suggest the need for preservation of intact forest sites and for cultural landscapes development to safeguard biodiversity and multifunctionality of the landscapes in the future. This, in turn, requires holistic and integrated approaches that involve local people and recognize their basic needs of woody plants and their property rights to foster the management of biodiversity and ecosystem services. Maintaining primary forests in and using cultural landscape approaches to the rapidly changing rural setting of southwestern Ethiopia would also contribute to the global effort to halt biodiversity loss.

Chapter 1

Chapter 1

Woody plant biodiversity conservation and ecosystem services in the forest-agriculture mosaic of southwestern Ethiopia

Introduction

The smallholder-dominated landscapes of southwestern Ethiopia are home to a unique remnant of biodiversity of global conservation value (Schmitt 2006; Mittermeier et al. 2011; Aerts et al. 2015). This biodiversity is also important for local livelihoods and the country's economy (Petit 2007; Moat et al. 2017). Currently, these landscapes are under severe pressure due to increasing human land use, which mainly comprises the conversion of forest to farmland, forest degradation and a shift in smallholder farmland management practices towards more intensive agriculture (Hundera et al. 2013; Kassa et al. 2016). Such changes profoundly alter the structure of the landscapes and thereby threaten the biodiversity these landscapes support. Maintaining the biodiversity of and ecosystem services provided by these landscapes also requires a comprehensive understanding of the impact of human-induced changes to the land on biodiversity and related services. In this dissertation, I examined woody plant biodiversity and the services provided by these plants in the forest-agriculture mosaic landscapes of southwestern Ethiopia. My aim was to understand distribution patterns of woody plants and how local people benefit from them and to derive implications for the maintenance of biodiversity and ecosystem services in these landscapes.

Human impacts on ecosystems

From the onset of hunting, gathering, and the use of fire, human impacts on natural ecosystems have escalated throughout the history of humankind (Steffen et al. 2004; Mercer 2015). Although human land use activities have altered the natural ecosystems for the past ten thousand years (MA 2005a; Smith 2007; Steffen 2010), only recently they have amounted to change the environment at the global scale (Steffen et al. 2004; Doughty 2013). With a rapidly growing human population and fast technological advances, humans and their activities are now negatively affecting virtually all ecosystems (Vitousek et al. 1997; Crutzen 2002; MA 2005a; Ellis et al. 2013; Steffen et al. 2015). Humans have transformed 75% of the Earth's terrestrial biosphere (Ellis and Ramankutty 2008; Ellis et al. 2010), mainly to agricultural land (Ramankutty and Foley 1999; Ellis et al. 2010; Foley et al. 2011). The impacts of the pervasive human domination and land use actions include climate change, environmental pollution, introductions of alien species, land degradation, and the destruction of natural and semi-natural ecosystems (Steffen et al. 2004; Foley et al. 2005; MA 2005a). This recent global change affects the state and functioning of the Earth's system and signals the beginning of a new

geological era, the “Anthropocene”, with imminent and potentially dangerous consequences for both the environment and humanity (Ellis et al. 2013; Steffen et al. 2015).

Worldwide biodiversity loss is one of the most significant effects of global change (Sala et al. 2000; Pereira et al. 2010). Biodiversity is understood as the variability among living organisms, including diversity within species, among species and ecosystems (MA 2005a). Current species extinction rates are estimated to be 100 to 1000 times higher than natural extinction rates (Chapin et al. 2000; Pimm et al. 1995). This possibly represents the sixth major extinction event in the history of life (Barnosky et al. 2011; Ceballos et al. 2015). This accelerated human-induced biodiversity loss matters not only because biodiversity is important in its own right, but also it is essential for all life on Earth (Dirzo and Raven 2003; Steffen et al. 2004) including humans (Steffen et al. 2011; Ellis et al. 2013). Loss of biodiversity leads to biotic homogenisation, that is, the process by which ecosystems tend to become more similar in biodiversity over time (Olden and Rooney 2006). This strongly influences the resilience of ecosystems to environmental change (i.e. the capacity of ecosystems to absorb disruption and reform while undergoing change) (Folke et al. 2004; Walker et al. 2004; Rockström et al. 2009), and alters multiple ecosystem functions (i.e. ecological processes that underpin the flow of energy, nutrients and organic matter within an environment) and services (i.e. benefits people get from ecosystems) that ultimately affect human wellbeing (Chapin et al. 2000; MA 2005a; Cardinale et al. 2012). Human wellbeing, in this context, is the state of humans including basic materials for a good life, freedom of choice and action, health, good social relationships, a sense of cultural identity, and security (MA 2005a; Díaz et al. 2006).

Despite growing efforts to address human-mediated rapid biodiversity loss, e.g. by adopting the Convention on Biological Diversity, species are still disappearing at alarming rates (Butchart et al. 2010; Barnosky et al. 2011; Monastersky 2014). Thus, understanding and addressing the underlying causes of human-induced biodiversity loss is a major global challenge to humankind to safeguard the maintenance of biodiversity and ecosystem services for human wellbeing (IPBES 2018).

This dissertation seeks to deliver insights into woody plant biodiversity and the multiple ecosystem services it maintains, at the example of rural southwestern Ethiopia. For this, it makes use of different diversity measures. Species diversity and functional diversity (constituents of biodiversity that influence ecosystem functioning) are important aspects of biodiversity (Chapin et al. 2000; Franklin et al. 2002; Cardinale et al. 2012). I focused on two key measures of plant species diversity: first, the numbers of species present in a given area

and expressed either by species richness or by diversity indices such as Shannon diversity index (Lande 1996); and second, species composition, i.e. the various proportions of different species contributing to the total species pool (Franklin et al. 2002). Regarding ecosystem services, as they do not occur separately (i.e. ecosystems are managed for multiple purposes) (see Eigenbrod 2016; Gamfeldt and Roger 2017; Manning et al. 2018), I focused on ecosystem service diversity which is expressed by Shannon diversity index to measure multifunctionality of land uses in the landscapes (Plieninger et al. 2013). Multifunctionality, in this context, is the ability of ecosystems to simultaneously provide multiple services (O'Farrell and Anderson 2010; Manning et al. 2018). Overall, this dissertation uses woody plant species richness, species Shannon diversity and species composition; and multiple ecosystem services and ecosystem service Shannon diversity to measure biodiversity and related ecosystem services in the forest-agriculture mosaic landscapes of southwestern Ethiopia.

Biodiversity in forests

Forests once covered more than 7.4 billion hectares of the terrestrial surface, of which 3.6 billion hectares were tropical forests (Mercer 2015). Tropical forests harbour more than half of Earth's biodiversity (Asner et al. 2009; Lewis et al. 2015; Mercer 2015). With an estimated 53,000 tree species, these forests are home to the majority of the planet's tree diversity (Slik et al. 2015). Humans have inhabited and used tropical forests for thousands of years, but never has the effect of tropical forest land use been stronger than today (Vitousek et al. 1997; Doughty 2013; Lewis et al. 2015; IPBES 2018). Deforestation and forest degradation represent major problems (Gibson et al. 2011; Kennedy et al. 2013; Barlow et al. 2016). For instance, tropical forest ecosystems were lost at an annual rate of 5.5 million hectares between 2010 and 2015 (Keenan et al. 2015). About 46% and 30% of the remaining 2.5 billion hectares of tropical forests are fragmented and degraded forests, respectively (Mercer 2015). These changes are two major contributors to global biodiversity loss (Laurance et al. 2012; Lewis et al. 2015; Barlow et al. 2016).

Specific land use practices that have contributed to the degradation of tropical forests, including those in strictly protected areas, include conversions to agricultural land, logging, fuelwood collection, cattle grazing in forest, hunting, road expansion or forest management (e.g. for oil palm plantations in Southeast Asia; Edwards et al. 2014 or for coffee production in Ethiopia; Hundera et al. 2013) (Wittemyer et al. 2008; Asner et al. 2009; Laurance et al. 2012; Thompson et al. 2013; Lewis et al. 2015). The proximate causes mentioned above are linked to underlying drivers including demographic pressure, property rights, poverty, policy and

global markets and shape both tropical deforestation and forest degradation (Lambin et al. 2001; Lewis et al. 2015).

The most apparent effects of tropical forest degradation are altered plant species diversity and composition (Lewis et al. 2015; Alroy 2017). In gradually degrading forests, plant species diversity and composition are adversely affected by disturbances at the forest site level, e.g. logging or the removal of plants to facilitate the growth of other ones (Schmitt et al. 2010; Poulsen et al. 2013). Other factors include landscape context (edge effects), i.e. abiotic and biotic changes related with boundaries between forest and non-forest habitats (Harper et al. 2005), and forest history (e.g. primary versus secondary forest) (Chazdon 2008). In the case of site level disturbances, the number of disturbance-adapted and abiotically dispersed species tends to increase abruptly, but richness and abundance of typical forest species (usually large-seeded and slow-growing species) often decreases rapidly (Primack and Lee 1991; Sheil and Heist 2000; Alroy 2017). Such deteriorations in typical forest species can also be indirectly caused by the loss of large vertebrate animals, including seed dispersers and predators, and seedling herbivores (Beckman and Muller-landau 2007; Muller-landau 2007; Poulsen et al. 2013). Similarly, forest edge effects (e.g. accelerated tree damage, tree and seedling mortality and recruitment) can also favour disturbance-adapted and abiotically dispersed species, while also leading to a rapid species turnover and a decline of forest specialist species (Gascon et al. 2000; Harper et al. 2005; Laurance et al. 2006). This is also true for secondary forests regenerating on abandoned agricultural lands and embedded in degraded forests, although these forests may still be home to a wide range of many other species. This is mainly because of past agricultural land use legacy effects and inadequate forest specialist species seed dispersal from degraded neighbouring forests (Foster et al. 2003; Chazdon 2003; Lugo and Helmer 2004; Rozendaal et al. 2019). Understanding how forest degradation affects forest biodiversity and forest specialist species is thus important to the general mitigation of the global loss of biodiversity.

Biodiversity in farmland

Agricultural land use practices, both the conversion of natural ecosystems (e.g. deforestation) and the shift in management regimes (e.g. intensification via increased energy, water and fertilizer consumption), have altered a large proportion of terrestrial ecosystems (DeFries et al. 2004; Foley et al. 2005; Wright 2010). Currently, croplands and pastures, which together occupy about 40% of the terrestrial land surface and exceed the area covered by forests, have become one of the largest biome on Earth (Foley et al. 2005). These changes in farmland use

have caused habitat loss, fragmentation and persistent environmental change for many species (Foster et al. 2003; Mortelliti et al. 2010). They are a key driver of global biodiversity loss (MA 2005a; Wright 2010), although some species can still survive in such highly modified farming landscapes (e.g. Daily et al. 2001; Mayfield and Daily 2005). In some instances, farmers in smallholder-dominated landscapes also deliberately retain or plant certain woody plants in their farmlands (croplands, pastures and homegardens) (Tscharntke et al. 2012; Ango 2016; Jara et al. 2017). Such plants can provide important habitat and movement pathways for other plants, birds and many other species (Perfecto and Vandermeer 2008; Mendenhall et al. 2016; Dorresteijn et al. 2013). They can also provide vital ecosystem services and increase the resilience of a system to environmental change (Walker et al. 2004); Tscharntke et al. 2012; Isbell et al. 2017a).

Some plant species respond to land use and other global change immediately, whereas others show considerable time lags (Lindborg and Eriksson 2004; Jackson and Sax 2010; Krauss et al. 2010). Time-lagged responses can result in legacy effects of land use such as extinction debt or immigration credit (Tilman et al. 1994; Jackson and Sax 2010). Extinction debt occurs when the current community contains specialist species facing extinction (Tilman et al. 1994; Kuussaari et al. 2009; Jackson and Sax 2010). In the case of immigration credit, the current community contains species whose populations gradually immigrate and colonize suitable environment (Jackson and Sax 2010). Both extinction debt and immigration credit are influenced by multiple factors including species life history traits (e.g. longevity, dispersal ability), history of landscape composition and habitat configuration and stochastic processes (Kuussaari et al. 2009; Jackson and Sax 2010; Hylander and Ehrlén 2013). For example, some plant species with long lifespans can persist for more than a century after forest conversion (Vellend et al. 2006; Krauss et al. 2010). Similarly, the colonization, establishment and survival of a species in a new location depends on its dispersal mechanisms and interactions with the existing community (Davis et al. 2000; Sakai et al. 2001; Essl et al. 2015). Time-delayed responses can be also affected by the extent of habitat change in size, quality and connectivity (Jackson and Sax 2010; Pardini et al. 2010; Hylander and Ehrlén 2013). In general, extinction debts and immigration credits are less likely to be found in landscapes with little and isolated habitat after severe land use change (Tilman et al. 1994; Hanski and Ovaskainen 2002; Helm et al. 2006).

An analysis of these kinds of legacy effects of past land use in general and those related to woody plants in particular is important if one is to understand the effects of past human land

use on biodiversity. Results could help researchers to identify, e.g., habitats and species of special conservation status and thereby prevent mistakes when managing biodiversity conditions in human-dominated ecosystems (Foster et al. 2003), particularly in biodiverse smallholder-dominated tropical agricultural landscapes (Wright et al. 2012).

Ecosystem services and human welfare

Biodiversity, which underpins ecosystem processes and properties, provides vital benefits including supporting (e.g. nutrient cycling and primary production), provisioning (e.g. food, timber, fuel, fresh water), regulating (e.g. climate and water regulation) and cultural (e.g. spiritual experience, recreation, education) services to humans (Steffen et al. 2004; MA 2005a; Díaz et al. 2006). Currently, there is substantial theoretical and empirical evidence for the link between biodiversity and ecosystem functions and the provision of ecosystem goods and services to human societies (e.g. Peterson et al. 1998; Cardinale et al. 2011; Isbell et al. 2011; Brockerhoff et al. 2017). Biodiversity increases the ability of ecosystem to adapt to gradual or dramatic global shifts in environmental conditions (Isbell et al. 2015; Hisano et al. 2018). Worldwide, several billion people rely directly on biodiversity via both natural and human-managed ecosystems for their livelihoods (Reed et al. 2017). For these people, biodiversity is inextricably linked to basic functions such as getting food, staying healthy or obtaining shelter (Kaimowitz and Sheil 2007).

The global loss of biodiversity has been affected ecosystem functions and resilience to environmental change and, consequently, the supply of ecosystem services (Chapin et al. 2000; MA 2005a; Díaz et al. 2006). The Millennium Ecosystem Assessment (MA 2005b), for instance, indicated that about 60% of the assessed ecosystem services worldwide had been degraded. Likewise, theoretical and empirical studies, mainly focused on the relationship between species richness and ecosystem functions, have documented the dire consequences of biodiversity loss for ecosystem services (e.g. Peterson et al. 1998; Díaz et al. 2003; Cardinale et al. 2012). The most notable change to ecosystem service are likely to occur and noticeable when there is a local loss of functional species diversity or change in composition and when services are directly or indirectly associated with a particular plant or animal species (Chapin et al. 2000; Díaz et al. 2006). Moreover, a dramatic loss in species richness by drivers such as burning, soil erosion or flooding can have more direct effects to ecosystem service supply than a gradual change in species compositions by forest degradation (Díaz et al. 2006). Consequences of native species loss on ecosystem services can potentially be delayed for many

years and also differ considerably depending on the characteristics of newly introduced species and the services they produce or impair (Chapin et al. 2000; MA 2005a; Poulsen et al. 2013).

Loss of biodiversity denotes not only the loss of provisions such as food but also the loss of choices, hopes, culture, health, social relations and natural insurance for societies around the globe (MA 2005a). Particularly for those who greatly depend on the environment and who, for one reason or another, lead precarious lives, the consequences of biodiversity loss can have complex, interrelated and uncertain outcomes (MA 2005a; Díaz et al. 2006). Hence, recognizing the underlining causes of biodiversity loss in human-dominated landscapes is of paramount importance if one is to mitigate both biodiversity loss and adverse change to ecosystem services and to maintain and improve human wellbeing (Wu 2013).

The case of smallholder-dominated rural landscapes in southwestern Ethiopia

Although it is known for its unique physiographic features, high levels of biodiversity, rich ecosystems and considerable species and genetic diversity, Ethiopia faces a variety of urgent environmental and social challenges (Wakjira 2006; Meshesha et al. 2012). Among the most pressing environmental challenges are biodiversity loss, recurrent drought, deforestation, forest degradation and the loss of soil fertility and water bodies (Gole 2003; Hurni 2007; Meshesha et al. 2012). Current social challenges include the undernourishment of about 24% of Ethiopia's population, poverty and vulnerability that affects around 25 million people and the dependency of about 8 million people on the Productive Safety Net Program (UNDP 2015; Sabates-Wheeler and Devereux 2010; Ango 2016). Ethiopia is the second most populated country in Africa, and about 80% of the population lives in rural areas and strongly depends on the environment for their livelihoods (Ango 2016). All land in Ethiopia, including farmland and forests, is owned by the government (FDRE 1995).

The country's forests once covered about 40% of its total area but had declined to less than 3% by the early 1990s (Wakjira 2006; Meshesha et al. 2012). Southwestern Ethiopia in particular, the focus region of this dissertation, is currently home to most of the remnant forests. The forests have an important global function because they are the centre of origin and diversity of *Coffea arabica*, still harbour the gene pool of wild coffee populations (Anthony et al. 2002) and are part of the Eastern Afromontane Biodiversity Hotspot (Schmitt 2006; Mittermeier et al. 2011). However, they are threatened by deforestation and forest degradation. Deficient forest management and investment policies and poorly defined property rights (e.g. Lemenih

and Kassa 2014; Tura 2018) have been identified as drivers of deforestation (Reusing 2000; Hylander et al. 2013a; Tadesse et al. 2014b; Getahun et al. 2017).

Forest degradation resulting from the intensification of coffee forest management and unsustainable forest use is another key pressure on forest biodiversity in the area (e.g. Hundera et al. 2013; Tadesse et al. 2014a). Coffee, which is important for local livelihoods and Ethiopia's economy (Petit 2007; Moat et al. 2017), is traditionally grown and managed with varying intensity. Intensity ranges from the simple collection of wild forest coffee fruits to intensively managed semi-plantation coffee systems, where undergrowth plants including herbs, shrubs and trees are cleared, canopy trees are selectively thinned out and coffee seedlings densely planted (Teketay 1999; Schmitt et al. 2010; Hundera et al. 2013). In some instances, coffee management intensification also involves the removal and replacement of native trees with exotic species and the use of herbicides, fertilizers and improved coffee varieties (Wiersum et al. 2008; Tadesse et al. 2014a). Forest management for coffee production thereby directly shapes the extent of forest cover and biodiversity loss. Since coffee provides an economic incentive, managing the forest for coffee production has helped to slow down deforestation rates (Hylander et al. 2013a). Nonetheless, shifts in management practices and increasingly intensive coffee production have been linked to local forest degradation and forest biodiversity loss (Schmitt et al. 2010; Aerts et al. 2011; Hundera et al. 2013).

Forest degradation can also result from unsustainable forest utilization, which can be driven by the expansion of commercial farming, demographic pressure or political instability (Lambin et al. 2001; Geist and Lambin 2002; Hosonuma et al. 2012). It can also be attributed to poor resource governance or ill-defined property rights (e.g. Ostrom 2009; Chazdon 2018). Property rights, whether enforced by the government (de jure) or the community (de facto), govern the rights to access and use a resource, to maintain it, to exclude others, and to transfer these rights to others (Schlager and Ostrom 1992). Specifically, the ability of local people to effectively take on a stewardship role for ecosystems and their services can be undermined by ill-defined property rights (Ostrom and Nagendra 2006; Ostrom 2009; RRI 2017). Ill-defined property rights can lead to woody plant overharvesting and, thus, to changes in forest structure and species composition and diversity (e.g. Bergès et al. 2013; Johann and Schaich 2016; McClellan et al. 2018). In the study area, local people heavily depended on forests for their livelihoods, mainly on wood used as fuel or for construction, but also as a sources of farm tools, medicine or spices or as a site for livestock grazing and honey production (Ango 2016; Dorresteijn et al. 2017). For these reasons, forest biodiversity loss due to deforestation and

forest degradation can have undesirable consequences to forest services and the wellbeing of local people.

A major driver of land use change in southwestern Ethiopia is crop-based subsistence agriculture, which regionally began in the mid-nineteenth century (McCann 1995; Kassa et al. 2016). Current agricultural policies, which encourage predominantly cereal crop production via improved seeds and the use of chemical fertilizers, can lead to deforestation and changes in farmland management practices and, hence, biodiverity loss and land degradation (Hylander et al. 2013a; Kassa et al. 2016). Neverthless, despite the dramatic recent changes in land use, the region is still dominated by smallholder farming mainly comprised of croplands, pastures and homegardens (Hylander and Nemomissa 2009; Kumsa et al. 2016; Jara et al. 2017). The farming landscapes matrix is rich in trees and shrubs (e.g. Jara et al. 2017). Farmers strongly rely on these woody plants found in the farming landscapes for many purposes. For example, they create shade for coffee, function as live fences, play a vital role for honey production or provide the material for domestic wood products such as fuelwood, construction wood and farm tools (Ango 2016; Dorresteijn et al. 2017). Woody plants in the farming landscapes can also support important ecosystem functions (Manning et al. 2006) and contribute significantly to local biodiversity (e.g. Gove et al. 2008; Hylander and Nemomissa 2008; Engelen et al. 2017). A loss of woody plant biodiversity, therefore, can have strong and unfavourable consequences for both farmland biodiversity and human wellbeing in the area.

Woody plants and associated ecosystem services in southwestern Ethiopia

The studies comprising this dissertation were conducted in six *kebeles* (the smallest administrative unit in Ethiopia) in the Gera, Gumay and Setema districts of Jimma Zone, Oromia Regional State, in southwestern Ethiopia (Fig. 1.1). One exception is the study included here as Chapter 2, which was conducted in five *kebeles* only. These *kebeles* were selected to reflect gradients in altitude and forest cover. Altitudes ranged from approximately 1500 m to 3000 m above sea level, and forest cover ranged from approximately 11% to 84%. The landscapes in the *kebeles* can be described as a mosaic of land uses and include forests, croplands, pastures and settlements. The forests are typically moist evergreen Afromontane forests (Friis et al. 2010). Agriculture, which also includes cropping and livestock holding, is the main source of livelihoods. Coffee and, to some extent, honey are economically important non-timber forest products in the area. The largest ethnic group in the region is the Oromo, while Amhara, Kefficho and Tigre people are minorities.

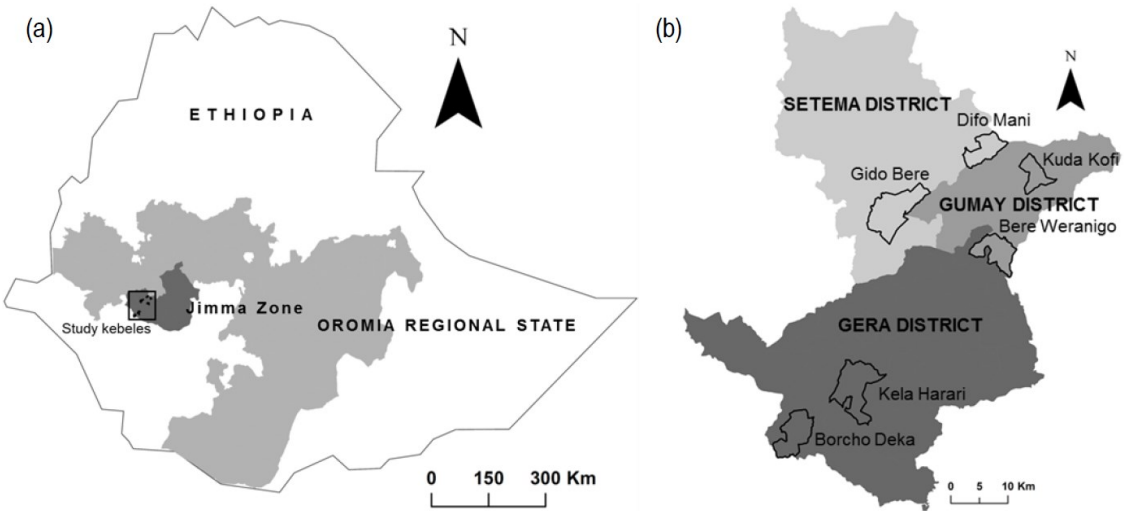


Figure 1.1 Location of (a) study area (square) in southwestern Ethiopia, Oromia Regional State, Jimma Zone; (b) the six *kebeles*: Borcho Deka and Kela Harari in Gera, Bere Weranigo and Kuda Kofi in Gumay and Difo Mani and Gido Bere in Setema district.

I focused on woody plants because they have an important function in local ecosystems. For example, they serve as food for many other species (see Schulze et al. 2004; Manning et al. 2006) or contribute prominently to local biodiversity (Mayfield and Daily 2005; Gove et al. 2008; Hylander and Nemomissa 2008; Engelen et al. 2017). Woody plants provide ecosystem services that are directly or indirectly associated with particular species (Díaz et al. 2006) and most people in the study area heavily depend on these services for their livelihoods (Wakjira and Gole 2007; Ango 2016; Dorresteijn et al. 2017).

Woody plants are relatively easy to identify, and they are rich and abundant in the region as they are in the tropics (e.g. Gole et al. 2008; Ghazoul and Sheil 2010; Slik et al. 2015), which allows for a comparison between different study sites. They are also important indicators of the effects of human land use change on biodiversity (e.g. Chazdon 2003; Schulze et al. 2004; Laurance et al. 2006), and they therefore can be used to assess of woody plant species diversity in response to different forest management and history. Moreover, woody plants exhibit relatively longer time lags in response to land use change than other taxonomic groups, so it is possible to conduct analyses of extinction debt (Krauss et al. 2010) and immigration credit (Jackson and Sax 2010). In this sense they can be regarded focal species for investigating legacy effects of past agricultural land use on woody plant diversity and composition in rapidly changing landscapes.

I also focused on ecosystem services provided by woody plants because these services are directly or indirectly associated with species that are known and used by local people (Díaz et al. 2006; Wakjira and Gole 2007; Ango 2016; Dorresteijn et al. 2017). This allows me to

assess the supply of several related ecosystem services in a given study plot (e.g. de Groot et al. 2010; Burkhard et al. 2012). It also made it possible for me to investigate the multifunctionality of the landscapes and the link between woody plant and ecosystem service diversity in different land use types across landscapes. In addition, it also allowed me to examine local people's woody plant use and management in the context of property rights.

Aims

The overarching goal of this dissertation was to investigate woody plant distribution patterns and related ecosystem services and to derive implications for the future management of biodiversity and ecosystem services in smallholder-dominated landscapes of southwestern Ethiopia. More specifically, I sought to answer the following research questions (Fig. 1.2):

1. How does human-induced forest degradation (site level disturbance, landscape context and forest history) affect woody plant species diversity and composition in forests? (Chapter 2)
2. How does the legacy of past agricultural land use affect woody plant species diversity and composition in farmland? (Chapter 3)
3. How are different ecosystem services and woody plant diversity related to ecosystem service diversity in different types of land use in the landscapes? (Chapter 4)
4. How do local farmers use and manage woody plants under existing and perceived property rights across the landscapes? (Chapter 5)

Conceptual framework and structure of the dissertation

To answer these questions, I used a social-ecological systems framework adapted and modified by Dorresteijn (2015) and Fischer et al. (2015). In smallholder-dominated landscapes, social and livelihood processes are often closely tied to the natural environment. Here, humans directly affect and are influenced by the environment at different scales ranging from the local to the global level. Such strong links between people (the social system) and environmental processes (the ecological system) form the core of social-ecological systems (Berkes et al. 2003; Folke 2006; Fischer et al. 2012). Most of the ecosystem services in these systems are delivered via the joint effects of ecosystem processes and human actions (Reyers et al. 2013; Comberti et al. 2015).

Considering the impact and reliance of humanity on biodiversity in the social-ecological systems (e.g. Isbell et al. 2017b), the studies included in this dissertation are structured into

two parts. In the first part, I focus on the ecosystem and assess the impacts of human land use change on woody plant biodiversity. The empirical studies included in this part address the conservation value of forest sites reflecting different approaches to management and histories (Chapter 2) and legacy effects of past agricultural land use on woody plants (Chapter 3). In the second part, I also focus on the social system and assess human dependence on ecosystem services. The studies included in this part address woody plant species diversity as a predictor of ecosystem services (Chapter 4) and people's use, property rights and management of woody plants (Chapter 5). Using a social-ecological systems framework, a summary and an overview of the structure of the dissertation is provided in Fig. 1.2.

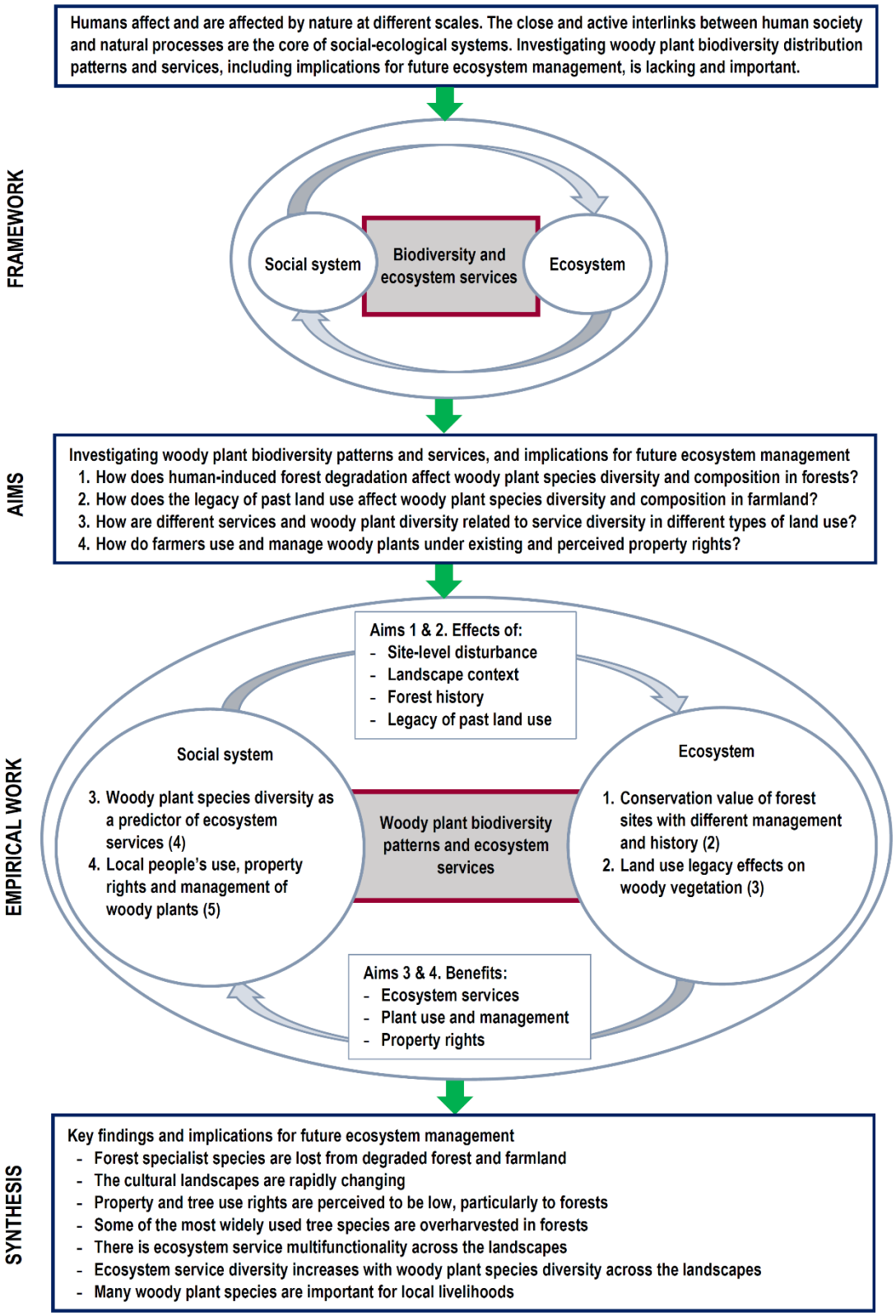


Figure. 1.2 Schematic summary of the dissertation. Starting from the top, the social-ecological system framework adopted from Dorresteijn (2015) and Fischer et al. (2015) for biodiversity and ecosystem services maintenance in rural landscapes of southwestern Ethiopia is presented, followed by specific aims and summaries of empirical studies with specific aims. The chapters providing answers to the specific research questions are mentioned in brackets. The synthesis of the dissertation, i.e., the key findings and implications for future ecosystem management, are presented at the bottom.

Summary of chapters included

Chapter 2 discusses the conservation values of forest sites with different degrees of site level disturbance, landscape contexts and history. To this end, we generated current (2015) and historical (1973) forest maps of the study area in ArcGIS. We then stratified the current forest into four cost distance classes (low, medium, high and very high cost distance) to capture a gradient of forest conditions with respect to human disturbance. We surveyed woody plants in 108 randomly selected 20 x 20 m sites and grouped them into forest specialist, generalist and pioneer species. To evaluate site level disturbance, we quantified coffee dominance as a measure of the actual coffee management intensity at each site; for landscape context, we determined the current distance of the sites to the nearest forest edge; and for forest history, we compared the current with the historical forest map and classified each site as primary forest versus secondary forest. We also included the effects of altitude and heat load of the sites. Our findings show that both species composition and species richness in the forest were shaped by coffee management intensity, landscape context and forest history. One important finding of this study was that richness of forest specialist species significantly decreased with coffee management intensity and in secondary compared to primary forests, but increased with current distance from forest edge in both primary and secondary forests. Therefore, to protect native forest species, it is important to maintain large undisturbed patches of forest and to foster the growth of native species in managed and secondary forests.

Chapter 3 examines legacy effects of past agricultural land use on woody plant species. Using a current map derived from RapidEye satellite images from 2015 (5 m resolution), we determined the proportion of arable land and grazing land (henceforth farmland). We then surveyed woody plants in 72 randomly selected circular 1 ha sites and grouped them into forest specialist, generalist and pioneer species. Next, we determined the current distance of survey sites from the nearest forest edge. We also determined the historical distance of survey sites from the forest edge based on Landsat imagery from 1973 and thereby distinguished between farmland sites that were "permanent" versus those that had been "converted" between 1973 and 2015. In our species richness model, apart from these "legacy variables," we also included the effects of key environmental variables such as site level forest cover, a terrain wetness index, altitude and the type of site (grazing versus arable site) as co-variates. Our results showed that historical distance was the most important variable affecting woody plant composition and distribution in farming landscapes. Generalist and pioneer species richness, but not that of forest specialists, increased with historical distance. Only few old individuals of

forest specialist species remained in both converted and permanent farmlands. Our study indicates that any possible extinction debt for forest specialist species in farmland was rapidly paid off, and we found evidence of immigration credits for generalist and pioneer species in farmland. Immigration credits in particular deserve further attention because the agricultural landscapes are rarely ever regarded in the context of biodiversity by conservationist, who seem to have a preference for forests. Given these findings, conservation policies should consider both forest and farmland. One possible approach would be to develop cultural landscapes, which have been shown to foster species diversity and a culture of land management by the community. This kind of approach might also help stakeholders to reintegrate forest species in the farming landscapes.

Chapter 4 evaluates the multifunctionality of the landscapes and the relationships between the diversity of woody plant species and ecosystem services in different types of land use in the landscapes of southwestern Ethiopia. For this study, we used woody plant species data surveyed in 181 randomly selected 20 x 20 m plots in forest with and without coffee management and in farmland. We also used social data collected during interviews with 180 randomly selected households about the use of and preferences regarding woody plants species for eleven major purposes. Here, our results provide evidence for the multifunctionality of land uses and the benefits of maintaining a high woody plant diversity, particularly in farmland. Ecosystem service diversity increased with woody plant species diversity in all land uses. The increase was steeper in farmland, a result that indicates that both maintaining and losing plants has consequences for multiple key ecosystem services which people rely on such as fuelwood, house construction or farm implements. Notably, the less steep relationship in forests demonstrates functional redundancy in forests, which is also important for resilience to future environmental change. We therefore suggest to explicitly consider and maintain woody plant diversity and multifunctionality via a cultural landscape development approach, as suggested in Chapter 3.

Chapter 5 investigated woody plant use and management by local people based on perceived or actual property rights. To this end, we interviewed 180 households and used woody plant data surveyed in 72 circular 1 ha sites in farmland; and in 63, 46 and 11 20 x 20 m plots in forest without coffee management, forest with coffee management and in homegardens, respectively. We found that 95 different species were used for eleven major purposes. Local people obtained these benefits from farmland and forests (with and without coffee management). Many of the widely used tree species regenerated successfully throughout

the landscapes, including in farmland. However, we also found that local people's property and tree use rights were perceived to be rather limited, in particular when it came to forest with or without coffee management. Our study also demonstrates that some of the most widely used tree species, including important timber species, appeared to be over-harvested in forests. Hence, to encourage the preservation woody plant biodiversity and its local use, an increased recognition of local people's diverse needs for woody plants and of their property rights, including that to forests, is required.

Synthesis

Key findings and implications for biodiversity and ecosystem services maintenance

This dissertation is one of only a few studies simultaneously investigating patterns and benefits of biodiversity in social-ecological systems. It provides a nuanced perspective on patterns of woody plant diversity and the multiple ecosystem services it provides in the smallholder-dominated landscapes of southwestern Ethiopia. Specifically, it provided evidence for forest specialist species loss in degraded forest sites and farmland, and for the rapid change taking place in the cultural landscapes of southwestern Ethiopia. The dissertation also shows that current governance structures such as property and tree use rights among local people are not only limiting access but also make plant use unsustainable, particularly in forests. However, this dissertation also discusses the high levels of plant biodiversity and the multifunctionality of the landscapes, the positive relationship between woody plant biodiversity and ecosystem service diversity in all land use types, and the importance of several woody plant species for local livelihoods across the landscapes. Here, forests take a special role in harbouring both biodiversity and providing essential ecosystem services, but landscapes as a whole are characterized by a high multifunctionality. These findings call for increased recognition and protection of large primary forest sites, for cultural landscapes development, and for sustaining multifunctionality of landscapes. These three interlinked measures are urgently needed because the rapid land use change going on in the landscapes may cause irreversible biodiversity loss and might have severe social impacts in southwestern Ethiopia. Below, I discuss why I regard these issues as key to the future ecosystem management in the landscapes of southwestern Ethiopia.

1. Safeguarding large intact forest sites

This dissertation revealed effects of changes in forest and farmland use on forest biodiversity in rural landscapes of southwestern Ethiopia. Forest specialist species composition and richness

were significantly influenced by the combined effects of site level disturbance, landscape context and forest history (Chapter 2), and forest specialist species' extinction debt was rapidly paid off in farmland (Chapter 3). From these, conversion of forests to farmland, i.e., habitat loss, forest degradation and change in farmland management practices can be considered as major drivers of forest biodiversity loss in the landscapes of southwestern Ethiopia (see also Foster et al. 2003; Laurance 2006; Fischer and Lindenmayer 2007; Gardner et al. 2009; Barlow et al. 2016; Watson et al. 2018). Such loss from the landscapes could eventually lead to the formation of 'novel ecosystems' (i.e., ecosystems with new combinations of species) (Hobbs et al. 2006) and, then to biotic homogenization (Olden and Rooney 2006). This is also likely to cause change in ecosystem services (Chapin et al. 2000; Díaz et al. 2006) and make it difficult if not impossible to restore the system back to a biodiverse state with a native species composition (e.g. DeWalt et al. 2003; Chazdon 2003; Rozendaal et al. 2019). Therefore, such forest biodiversity loss and its critical downstream effects can only be avoided by maintaining substantial old growth forest sites in the landscapes (see also Gibson et al. 2011; Barlow et al. 2007).

Local people greatly depend on many woody plant species from these forests for their basic needs (Chapter 4 and 5), although they perceive property and use rights to forests and trees to be low (Chapter 5). They also strongly rely on the management of forests for coffee production, which forms an essential component of local livelihoods and of Ethiopian's economy (Petit 2007; Moat et al. 2017). Likewise, deforestation – mainly to create new agricultural land – is still continuing in the area, primarily in areas above coffee altitude (i.e. > 2000 m above sea level) (Hylander et al. 2013a; Tadesse et al. 2014b; Getahun et al. 2017). Probably because of these reasons, measures such as the establishment of UNESCO Biosphere Reserves in three similar places with coffee forests in southwestern Ethiopia have not yet succeeded in ensuring the protection of forest biodiversity (Aerts et al. 2015).

Safeguarding large intact forest sites in the landscapes of southwestern Ethiopia therefore requires a more inclusive, amalgamated landscapes level approach (Gardner et al. 2009; Edwards 2016; Chazdon 2018). Above all, such approach needs to engage and negotiate with local people about forest use and property rights (as livelihood depend on many plants, while current levels of such rights are low (Chapter 5)) and to address responsibilities, benefits from biodiversity conservation and how to resolve conflicts over forest misuse (Ostrom and Nagendra 2006; Chan et al. 2007; Faure et al. 2019). This requires devising and implementing strategies that can integrate biodiversity conservation and sustainable development for the

entire landscapes mosaic including forest and farmland. One possible approach is a biosphere reserve approach (Batisse 1982; Bridgewater 2002), which should also emphasise native species conservation in managed (e.g. through a coffee shade certification scheme) and in regenerating forests (Perfecto et al. 2005; Takahashi and Todo 2017; Mitiku et al. 2018). Additionally, advancing cultural landscapes development can foster biodiversity and its multiple benefits on farmland, e.g. via agroforestry practices, including a reintegration of native species into the farming landscapes and through enhancing beneficial connections between managed and natural systems (DeFries et al. 2004; Foley et al. 2005; Ellis and Ramankutty 2008; Kremen and Merenlender 2018). Overall, upholding large intact forest sites for forest biodiversity and the protection of multifunctional landscapes could possibly be effective measures towards ensuring biodiversity conservation and long-term human wellbeing in rural landscapes of southwestern Ethiopia.

2. Cultural landscapes development

The observed correlation between woody plant species richness and older farmland (Chapter 3) indicates a rapid change taking place in the species-rich cultural landscapes of southwestern Ethiopia. Cultural landscapes are places where people have interacted with and shaped nature over long periods of time (Plieninger et al. 2006). They are characterized by a stable and distinct identity, a system of sustainable land uses, and their biodiversity typically reflects a complex history of compositional and structural change (Phillips 1998; Farina 2000; Antrop 2005). Recognizing such values, cultural landscapes development has become an important approach for the restoration of biodiversity and landscapes multifunctionality in the developed world, particularly in Europe, which has had to deal with devastating landscapes change as a result of the industrial revolution (Vos and Meekes 1999; Déjeant-Pons 2006; Wright et al. 2012). In Europe, the commitment to cultural landscapes development is based on society's request for multifunctionality, the interest and engagement of local people, help from national and local authorities, and devolution of landscapes decision and legislation, which favours landscapes solutions (Vos and Meekes 1999).

Similarly, the observed rapid cultural landscapes change in southwestern Ethiopian from growing interest to agricultural intensification (Plieninger et al. 2014), suggests the urgent need for a paradigm shifts towards cultural landscapes development. In cultural landscapes, structures such as diverse land cover resulting from agroforestry, silvopasture, diversified cropping and small patches of trees in farmland, and their spatial heterogeneity and configuration can support key biodiversity attributes (Dorresteijn et al. 2015; Kremen and

Merenlender 2018). Such biodiversity-based land management demands experience rather than intensive technology in cultural landscapes (Kremen and Merenlender 2018). The Oromo people's traditional gadaa system (democratic social institution functioned to prevent abuse; Jalata and Schaffer 2013) in Ethiopia, for instance, has a deep-rooted practise of retaining and protecting *Ficus* and other tree species along rivers, and in farmland, homegardens and coffee shrub patches in the farming landscapes (Getahun 2016; Jara et al. 2017). Supporting such practices through cultural landscapes development may be key for a future sustainable ecosystem management in the biodiverse and multifunctional landscapes of southwestern Ethiopia (Chapter 4 and 5), thereby supplementing primary forest protection and also increasing the resilience of the farming landscapes to environmental change (Loreau et al. 2003; Kremen and Merenlender 2018).

3. Sustaining multifunctionality of the landscapes

Woody plant biodiversity provides important ecosystem services to local communities in southwestern Ethiopia. In these landscapes, we identified a high level of multifunctionality of landscapes and significant associations between woody plant and ecosystem service diversity in all land uses (Chapter 4). Local people depend on many plant species, for example for basic purposes such as house construction, finding fuelwood or producing farm implements (Chapter 5). However, given the dramatic changes in cultural landscapes (Chapter 3), landscapes multifunctionality is under continuous pressure from an increasing commodification of landscapes under the notion of "intensification" (e.g. Tilman et al. 2011; Mueller et al. 2012; Godfray and Garnett 2014; Plieninger et al. 2014). Such top-down driven optimization of landscapes for efficient production of few crops irrespective of local context and local people's needs (see Jiren et al. 2017) can unintentionally degrade landscapes multifunctionality and result in unfavourable environmental and social consequences (Tscharntke et al. 2012; Loos et al. 2014). It can eventually result in irreversible biodiversity loss and possibly a costly ecosystem restoration process after intensification – a situation that many previously industrialized landscapes now face (Foley et al. 2005; Kremen and Merenlender 2018). Thus, a paradigm shift is needed in southwestern Ethiopia. It will be necessary that focuses on local realities and the need for landscapes multifunctionality, e.g. by fostering cultural landscapes development and the safeguarding of intact forest sites, thereby allowing long-term human wellbeing and more sustainable landscapes trajectories (Wu 2013).

Conclusion

The unique biodiversity in southwestern Ethiopia is under severe pressure from deforestation, forest degradation and changing farmland use. Navigating the challenges of maintaining future biodiversity and ecosystem services largely depends on the understanding the responses of biodiversity and ecosystem services to land use change. Using woody plants and their ecosystem services, this dissertation revealed a loss of native forest biodiversity and rapid change taking place in cultural landscapes of southwestern Ethiopia. It pinpointed the problems of local people's limited property and tree use rights, particularly to forests, and the current overharvesting of vital forest species. Nonetheless, this dissertation also highlighted the present multifunctionality of the landscapes, the positive effects of higher woody plant diversity on ecosystem service diversity in all land use types and the importance of many woody plant species for the basic needs of local people. Based on these findings, there is a clear and urgent need to preserve primary forests and to foster cultural landscapes development aimed at safeguarding both native forest biodiversity and the multifunctionality of landscapes. This, in turn, will require holistic and integrated approaches that can engage local people, recognize their needs of woody plants and their property rights, and foster ecosystem management across the landscapes. Guaranteeing the persistence of intact forests and the cultural landscapes, as well as sustaining landscapes multifunctionality in southwestern Ethiopia, would contribute substantially to the challenging but crucial goal to halt biodiversity loss locally and globally.

Chapter 2

Chapter 2

Conservation value of moist evergreen Afromontane forest sites with different management and history in southwestern Ethiopia

Girma Shumi, Patrícia Rodrigues, Jannik Schultner, Ine Dorresteijn, Jan Hanspach, Kristoffer Hylander, Feyera Senbeta and Joern Fischer

Biological Conservation (2019), 232: 117-126

Highlights

- We sampled woody plant biodiversity across gradients of forest disturbance sites
- The effects of forest disturbances on native forest species were investigated
- Unmanaged coffee forest, interior and primary forest sites harbored many native species
- Safeguarding large undisturbed forest sites are key to maintaining native species
- Prioritizing native species in managed and regenerating forests is also crucial

Abstract

Tropical forest ecosystems harbor high biodiversity, but they have suffered from ongoing human-induced degradation. We investigated the conservation value of moist evergreen Afromontane forest sites across gradients of site-level disturbance, landscape context and forest history in southwestern Ethiopia. We surveyed woody plants at 108 randomly selected sites and grouped them into forest specialist, pioneer, and generalist species. First, we investigated if coffee dominance, current distance from the forest edge, forest history, heat load and altitude structured the variation in species composition using constrained correspondence analysis. Second, we modelled species richness in response to the same explanatory variables. Our findings show that woody plant community composition was significantly structured by altitude, forest history, coffee dominance and current distance from forest edge. Specifically, (1) total species richness and forest specialist species richness were affected by coffee management intensity; (2) forest specialist species richness increased, while pioneer species decreased with increasing distance from the forest edge; and (3) forest specialist species richness was lower in secondary forest compared to in primary forest. These findings show that coffee management intensity, landscape context and forest history in combination influence local and landscape level biodiversity. We suggest conservation strategies that foster the maintenance of large undisturbed forest sites and that prioritize local species in managed and regenerating forests. Creation of a biosphere reserve and shade coffee certification could be useful to benefit both effective conservation and people's livelihoods.

Keywords: **Biosphere reserve; Coffee management; Disturbance; Edge effects; Forest history; Landscape context**

Introduction

Tropical forest ecosystems host the richest terrestrial biodiversity and provide important local, regional and global human benefits through provisioning, regulating, supporting and cultural ecosystem services (MA 2005a; Lewis et al. 2015). However, tropical primary forests, including strictly protected areas, are suffering from human induced degradation (Wittemyer et al. 2008; Gibson et al. 2011; Melo et al. 2013). While tropical deforestation has long received attention, forest degradation and its consequences are increasingly also considered to be important (Edwards et al. 2014; Edwards 2016; Barlow et al. 2016).

In a context of gradual forest degradation, forest species diversity and composition (i.e. the various proportions of different species) are shaped by three major factors, namely (i) site-level disturbance (e.g., see Schmitt et al. 2010), (ii) landscape context, and (iii) forest history (e.g. primary versus secondary forest) (Chazdon 2008; Barlow et al. 2016). Site-level disturbance includes recurrent and unsustainable logging, hunting, forest fire, fuelwood collection, livestock grazing, and forest management for coffee production (Hundera et al. 2013; Thompson et al. 2013). Such disturbance, in turn, is related to various socio-economic drivers from the level of households to global markets, and can take place legally or illegally (Lambin et al. 2001; Lewis et al. 2015). Forest landscape context influences forest composition via edge effects, which are the abiotic and biotic changes associated with boundaries between forest and non-forest habitats (Harper et al. 2005; Ewers and Didham 2006; Laurance et al. 2006). Forest history can result in various legacy effects, including immigration credits (Shumi et al. 2018) that cause delays in species recovery within secondary forest (Foster et al. 2003; Chazdon 2008).

Different woody plant species can be expected to respond differently to forest sites with different degrees of site level disturbance, landscape contexts and histories. Slow growing, shade-tolerant specialist species should persist primarily in relatively stable or less disturbed sites, whereas faster growing pioneer and generalist species may favor more disturbed sites (Sheil and Heist 2000). For instance, Primack and Lee (1991) noticed a change in species composition from shade-tolerant to pioneer species in sites disturbed by logging in Bornean rainforests. Pioneer and generalist species should respond positively to edge effects, while forest specialist species should respond negatively and should be more abundant in sites deep within the forest (Harper et al. 2005). Species recovery in secondary forest should depend on the extent and intensity of past land use, as well as the surrounding vegetation – for example,

most tropical secondary forests on post-agricultural land are dominated by fast-growing pioneer species (Foster et al. 2003; Chazdon 2008). Although these mechanisms are intuitively appealing, relatively few studies have systematically compared largely undisturbed primary sites with disturbed sites, or have separately assessed the effect of site level disturbance, landscape context and forest history.

Here, we investigate woody plant species composition and richness in forest sites spanning gradients in site-level disturbance (especially coffee management, although we are aware of other disturbances such as firewood collection, logging and grazing), landscape context (distance from the edge) and forest history (primary versus secondary forest) in southwestern Ethiopia. The vegetation in the region is moist evergreen Afromontane forest (Friis et al. 2010). It is the center of origin and diversity of *Coffea arabica* L., still harbors the gene pool of wild coffee populations (Anthony et al. 2002), and is part of the Eastern Afromontane Biodiversity Hotspot (Schmitt 2006). Over the last few decades, deforestation for agricultural land, settlements and timber extraction has been rapid in the area (Reusing 2000; Tadesse et al. 2014b; Getahun et al. 2017). Moreover, local people use the forest to obtain fuelwood, construction wood, and farm tools, as well as for livestock grazing, medicine, spices, honey and coffee production (Ango 2016; Dorresteijn et al. 2017).

Traditionally, coffee is grown and managed in Afromontane forests with varying intensity, ranging from relatively undisturbed wild forest coffee fruit collection to intensively managed semi-plantation coffee systems, where undergrowth plants including herbs, shrubs and trees are cleared; canopy trees are selectively thinned out; and additional coffee seedlings are planted to increase coffee yield (Schmitt et al. 2010; Hundera et al. 2013). In some instances, intensification also involves the removal and replacement of native trees with exotic species, use of herbicides, fertilizers and improved coffee varieties (Wiersum et al. 2008; Tadesse et al. 2014a). There are two divergent observations about coffee forest management. On the one hand, via providing an economic incentive, managing the forest for coffee production has historically helped to slow down deforestation rates (Hylander et al. 2013a). However, at the same time, increasingly intensive coffee production has been linked to forest degradation and loss of local biodiversity (Schmitt et al. 2010; Aerts et al. 2011; Hundera et al. 2013).

Considering ongoing and historical site-level and landscape-level changes, as well as the global importance of moist evergreen Afromontane forests, we sought to investigate how woody plant species composition and richness vary along a gradient of (1) coffee management;

(2) forest landscape context (from forest edge to deep inside the forest); and (3) forest history (secondary versus primary forest).

Methods

Study area

The study was conducted in five *kebeles* (the smallest administrative unit in Ethiopia) of three districts (woredas): Gera, Gummay and Setema of Jimma Zone, Oromia Regional State, southwestern Ethiopia (Fig. 2.1). The study area comprised a mosaic of land use types, with forest cover ranging from 37 to 84 percent in the five *kebeles*, while arable land, grazing land and settlements accounted for the rest. The region comprises undulating slopes and flat plateaus, with elevation ranging from 1500 to 3000 m above sea level. The area has a warm moist climate, driven by the dynamics of the inter-tropical convergence zone, with 1500-2000 mm of annual rainfall, and a 20 °C mean annual temperature. The area has unimodal rainfall patterns, with some rain throughout most of the year, and more substantial summer rain primarily from June to September (Friis et al. 2010; Schmitt et al. 2013; Ango 2016).

The dominant tree species in moist evergreen Afromontane forest include *Olea welwitschii*, *Pouteria adolfi-friederici*, *Schefflera abyssinica*, *Prunus africana*, *Albizia* spp., *Syzygium guineense*, and *Cordia africana* (Cheng et al. 1998). *Coffea arabica* is native to the forest and grows naturally at altitudes between 1000 and 2000 m above sea level (Schmitt 2006; Senbeta et al. 2014). Coffee and to a lesser degree honey are economically important non-timber forest products. Agriculture including crops and livestock is the main source of livelihoods, and can lead to degradation (e.g. via overgrazing) and encroachment of forested areas (Kassa et al. 2016).

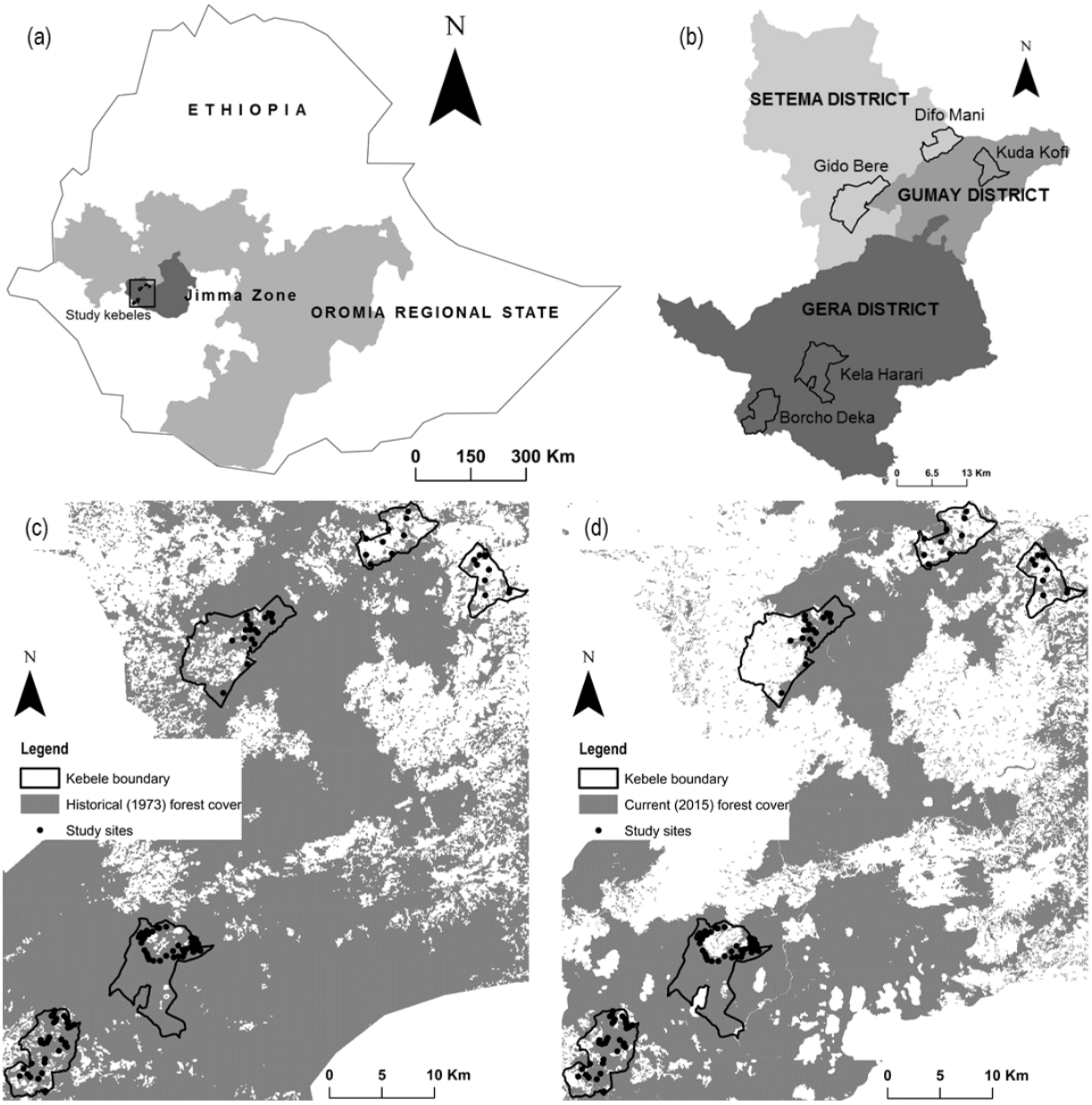


Figure 2.1 Overview of (a) location of the study area (square) in Ethiopia; (b) study area with the five study *kebeles* highlighted; (c) historical (1973) forest cover (grey colour) and survey sites (black points); and (d) current (2015) forest cover (grey colour) and survey sites (black points).

Land cover mapping and study site selection

Our design sought to capture broad gradients in site-level conditions, landscape contexts and histories. To this end, first we generated a current map of woody versus non-woody vegetation, from RapidEye satellite images from 2015 (5 m resolution) using an automatic image classification, based on Maximum Likelihood in ArcGIS. We also determined historical forest cover using supervised image classification of Landsat imagery from 1973 (Landsat 1-MSS, obtained from http://www.usgs.gov/).

Then, using the current forest map, we stratified the forest in a way that most likely captured the expected full gradients of forest conditions, especially with respect to human disturbances. Here, we assumed that forest disturbances could be closely related with accessibility, as a proxy for the likely level of human interference – remote sites deep within the forest may be less disturbed than highly accessible areas. Based on this, we stratified the current forest into four cost distance classes (low, medium, high and very high cost distance), using the cost distance analysis tool in ArcGIS, which takes into account the distance to a given point and uses a penalty for steep slopes (which reduce accessibility). Then, we determined the proportion of forest cover and hence, the proportion of cost distance classes within each kebele using the above mentioned current land cover map. Finally, we randomly selected a total of 108, 20 m by 20 m sites, distributed across the five kebeles (ranging between 9 and 38 sites per kebele) and across the four cost distance classes (29 in low, 21 in medium, 20 high, and 38 very high cost distance). In general, such randomly located sites stratified by cost distance have the advantage of being unbiased by subjective classification (but see Hundera et al. 2013; Tadesse et al. 2014a) and proximity to roads. The disadvantage is that our approach was not fully balanced with respect to other environmental or forest conditions; such as primary versus secondary forests (e.g. we actually got very few interior secondary forests, see below).

Woody plant surveys

We surveyed woody plants from November 2015 to January 2016, and from April to May 2017. At each of the 108 sites, we recorded all individuals of tree and shrub species with height ≥ 1.5 m. As the existence of young trees is typically correlated with the presence of seedlings (recent regeneration) in a given site (e.g. Fischer et al. 2009), for logistical reasons, we chose not to count individuals < 1.5 m in height for this study. We identified plants that were readily identifiable in the field. For species that were difficult to identify in the field, specimens were collected, pressed, dried and transported to the National Herbarium at Addis Ababa University for identification. Nomenclature followed the Flora of Ethiopia and Eritrea (1989-2006). Species were further segregated into forest specialist, generalist and pioneer species (Appendix 2A) based on relevant literature (Flora of Ethiopia and Eritrea 1989-2006; Teketay 1997; Tesfaye et al. 2002; Hundera et al. 2013). For each site, we quantified (1) total species richness, (2) forest specialist richness, (3) pioneer species richness, and (4) generalist species richness.

Forest and environmental parameters

To account for the actual coffee management intensity in situ at each site (Fig. 2.2), we quantified coffee dominance. Coffee dominance was measured as ranging from 0 to 1, and was determined as the ratio of the number of coffee plants to the total number of woody plants in each site (Rodrigues et al. 2018). This measure of coffee dominance was used because it is a countable, objective measure of how many stems of a given site are coffee, out of all stems. In undisturbed or unmanaged coffee forest, coffee plant density is very low, while in intensively managed coffee forest, it is much higher typically and constitutes > 50 % of all plants (Schmitt 2006). The high dominance of coffee in intensively managed sites results from shrub and small tree species other than coffee being systematically removed by coffee growers (Hundera et al. 2013). Low values of "coffee dominance" therefore indicate a high likelihood of coffee occurring at natural densities, while high values of coffee dominance indicate human interference. To account for landscape context as distinct from cost distance (which was used only to guide site selection), we determined the current Euclidean distance of the center of the survey sites from the nearest current forest edge. We also compared the current (2015) forest map with the historical (1973) forest map to classify each site as primary forest (forested in both 1973 and 2015) versus secondary forest (forested in 2015, but farmland in 1973). This way, after our initial site selection, we classified 95 sites as primary forest sites and 13 as secondary forest. A summary of study sites by their cost distance classes and current distances from the nearest forest edge in both primary and secondary forests is provided in Table 2.1.

Figure 2.2 Overview of forest disturbances and coffee management gradients in southwestern Ethiopia: (a) relatively undisturbed or unmanaged interior coffee forest site; (b) slightly managed interior coffee forest site; (c) managed semi-plantation coffee forest site; and (d) intensively managed semi-plantation coffee forest site.

Table 2.1 Number of the surveyed 20 m by 20 m sites in terms of forest strata and current Euclidean distance from the nearest forest edge in primary and secondary forests (see Methods for details).

	Category	Sites in primary forest (forested in both 1973 and 2015)	Sites in secondary forest (forested in 2015, but farmland in 1973)	Total
Forest strata	Low cost distance	22	7	29
	Medium cost distance	19	2	21
	High cost distance	18	2	20
	Very high cost distance	36	2	38
	Total	95	13	
Current distance from forest edge	Edge sites (with < 100 m from edge)	26	9	35
	Interior sites (with > 100 m from edge)	69	4	73
	Total	95	13	

Finally, we quantified other environmental variables that we believed might affect woody plant composition and richness as covariates, namely altitude and heat load of the sites. The ASTER Digital Elevation Model (30 m resolution; https://reverb.echo.nasa.gov/) was used to derive altitude; heat load was calculated following the procedures described by Olsson et al. (2009). An overview of all variables ultimately used for statistical analysis and their description is provided in Table 2.2.

Table 2.2 Definition and description of the explanatory variables used to model plant species richness.

Type	Variable	Definition and method
Fixed effect	Current distance	The distance in m from the center of the site to the nearest current (2015) forest edge (Fig. 1c).
	Coffee dominance	The ratio of the number of coffee plants to total number of woody plants in a given site
	Altitude	Altitude above sea level derived from the ASTER DEM.
	Heat load	Measure of potential incident radiation and temperature, estimated from aspect and slope (Olsson et al. 2009)
	Forest type	Forest land use with two factors – primary forest since 1973 and secondary forest restored after 1973 from farmland.
Random effect	*Kebele*	Smallest administrative unit within which sites were nested.
	Dummy	Observation level random effect to account for overdispersion.

Data analysis

First, we investigated which environmental variables drive community composition. Second, we modelled total species richness, richness of forest specialist, generalist and pioneer species in response to the explanatory variables (Table 2.2).

Using the log-transformed abundance data of all species (except *Coffea arabica*) in all study sites, we conducted constrained correspondence analysis (CCA) to assess how environmental predictors could explain species composition. We tested if plant community

composition and study site scores correlated with coffee dominance, current distance from the forest edge, forest type, heat load, and altitude, using the CCA from the 'vegan' package (Oksanen et al. 2018) in R (R Core Team 2018). Prior to this, we conducted a detrended correspondence analysis (DCA) to determine the length of the compositional gradient, which denotes the degree of species turnover in the community (Hill and Gauch 1980). All explanatory variables except altitude were log-transformed, and all predictors were tested for significance ($p < 0.05$) using 999 permutations. We specified *kebele* to account for the non-independence of the samples within a *kebele*.

We then used generalized linear mixed effects models (GLMMs) with a Poisson error structure to investigate the effects of local and landscape level explanatory variables (Table 2.2) on richness of (1) total species, (2) forest specialist species, (3) generalist species and (4) pioneer species. In all cases, we specified *kebele* (to account for grouping in experimental units) and an observation-level dummy variable (to account for overdispersion) as random effects. Prior to modelling, we checked for possible correlations among explanatory variables. Most correlations were below 0.2, but there was a stronger correlation between coffee dominance and altitude (correlation coefficient $r = 0.6$). In this case, we still included both variables in the regression models, but checked that all models had a variance inflation factor of < 2. Furthermore, we log-transformed coffee dominance, current distance to the forest edge, and heat load to remove skew, and scaled all continuous variables to zero mean and unit variance to obtain directly comparable coefficients. Finally, to visualize local and landscape level effects, we predicted species richness in response to coffee dominance and current distance to the forest edge.

Results

Species composition analysis

A total of 113 (including one unidentified) species of trees and shrubs, representing 40 families, were recorded from all sites (Appendix 2A). Of these, 45 were forest specialist, 30 were generalist, and 38 were pioneer (including two planted) species. The most abundant species were *Coffea arabica* (a forest specialist occurring at 78 sites), *Maytenus arbutifolia* (generalist at 64 sites), *Chionanthus mildbraedii* (forest specialist at 55 sites), *Vernonia auriculifera* (pioneer at 50 sites), *Dracaena afromontana* (forest specialist at 37 sites), and *Justicia schimperiana* (generalist at 33 sites) (Appendix 2A).

The first DCA axis had a length of 3.89 standard deviations, indicating almost a complete species turnover along the main compositional gradient. The CCA ordination indicated that different groups of species occupied different locations but with substantial overlap (Fig. 2.3a). The CCA showed that woody plant community composition was significantly correlated with several explanatory variables (F = 2.333, p < 0.001; Fig. 2.3b). Woody plant community composition was significantly associated with altitude (F = 4.483, p < 0.001), forest history – secondary forest (F = 2.342, p < 0.001), coffee dominance (F = 2.959, p < 0.001) and current distance from forest edge (F = 2.928, p < 0.001).

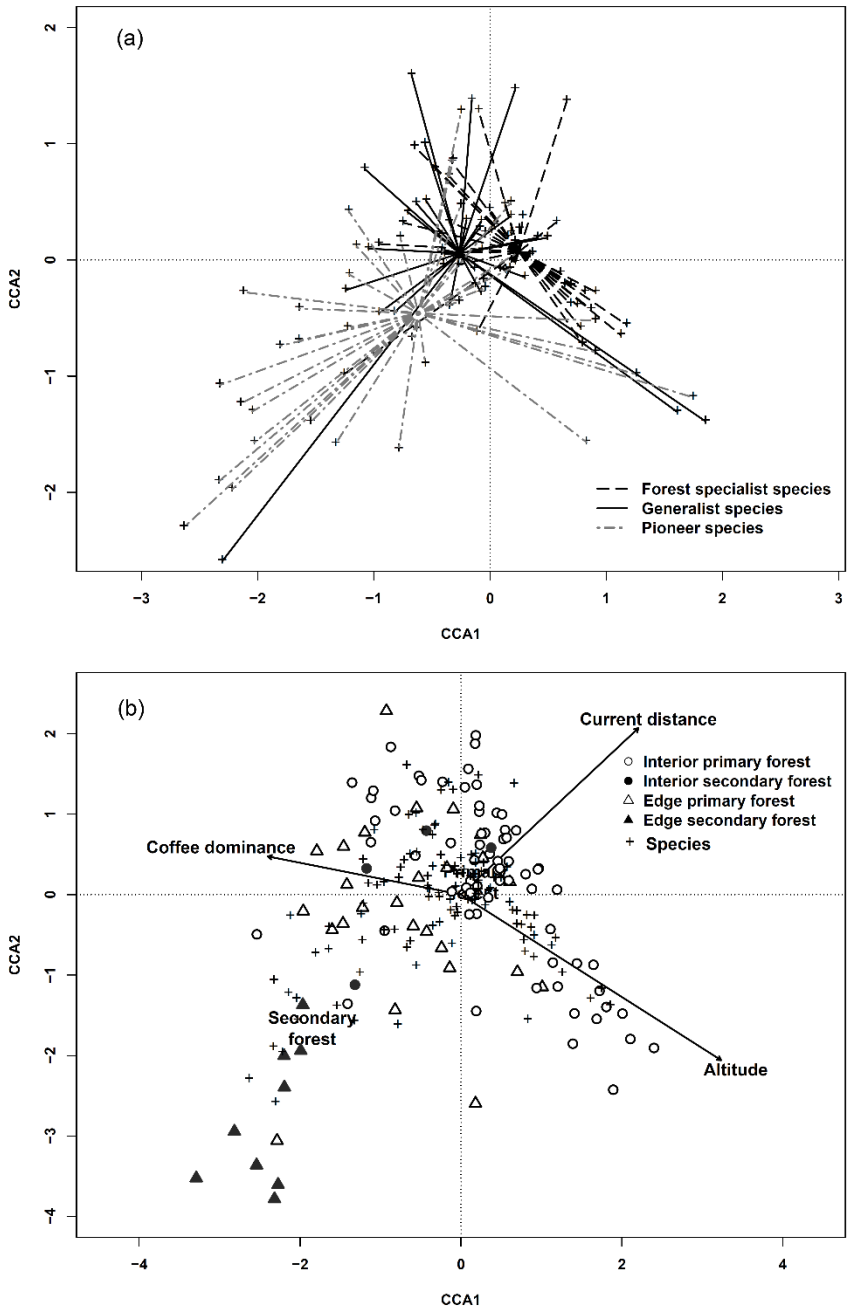


Figure 2.3 CCA ordination. (a) CCA biplot showing woody plant species (indicated by "+" sign) (except *Coffea arabica*) based on log-transformed abundance data. Species were grouped and connected to their group's centroid by lines: forest specialist species (black long-dash lines), generalist species (black lines) and pioneer species (gray two-dash lines). (b) CCA biplot of all 108 study sites (indicated by circles and triangles), all 112 species (except *Coffea arabica*) (indicated by "+" sign) and the significant environmental variables. Study sites were classified by their current distance from the nearest forest edge, with >100 m edge distance as forest interior sites (circles), and < 100 m edge distance as edge sites (triangles); and also by forest type: primary forest sites (unshaded circles and triangles), and secondary forest sites (black-shaded circles and triangles). Explanatory variables significantly correlated with plant community composition ($p < 0.001$) were altitude, current distance, coffee dominance and forest type- secondary forest.

Species richness models

Total species richness and forest specialist species richness were negatively related to coffee dominance (Table 2.3; Fig. 2.4a, d). Richness of forest specialist species increased significantly in both primary and secondary forests with current distance from the forest edge (Table 2.3; Fig. 2.4e, f), while richness of pioneer species decreased significantly in both primary and secondary forests with current distance from the forest edge (Table 2.3; Fig. 2.4h, i). A lower richness of forest specialist species was found in secondary as opposed to primary forest (Table 2.3; Fig. 2.4f). In addition, richness of total species was negatively related to altitude and heat load, and richness of generalists and pioneer species declined with altitude (Table 2.3).

Table 2.3 Results of generalized linear mixed effects models for total species richness, forest specialist species richness, pioneer species richness and generalist species richness. Explanatory variables were continuous except for forest type. The coefficient for forest type indicates the difference between primary and secondary forest, with primary forest being the reference level. Significance levels are indicated by: *P < 0.05; **P < 0.01; ***P < 0.001.

Response	Term	Coefficient	Standard error	*Z-value*	*P*-value
Total species richness	Intercept	2.761	0.142	19.485	<0.001 ***
	Current distance	-0.000	0.031	-0.009	0.993
	Coffee dominance	-0.148	0.038	-3.908	<0.001 ***
	Heat load	-0.065	0.028	-2.284	0.022 *
	Altitude	-0.145	0.046	-3.188	0.001 **
	Forest type	-0.024	0.110	-0.220	0.826
Forest specialist species richness	Intercept	2.209	0.171	12.924	<0.001 ***
	Current distance	0.137	0.043	3.220	0.001 **
	Coffee dominance	-0.193	0.051	-3.766	<0.001 ***
	Heat load	-0.058	0.036	-1.609	0.108
	Altitude	-0.088	0.060	-1.466	0.143
	Forest type	-0.344	0.167	-2.067	0.039 *
Pioneer species richness	Intercept	0.765	0.071	10.774	<0.001 ***
	Current distance	-0.305	0.063	-4.825	<0.001 ***
	Coffee dominance	-0.146	0.079	-1.849	0.065
	Heat load	-0.024	0.063	-0.372	0.710
	Altitude	-0.163	0.082	-1.971	0.049 *
	Forest type	0.318	0.176	1.812	0.070
Generalist species richness	Intercept	1.377	0.203	6.780	<0.001 ***
	Current distance	-0.087	0.049	-1.772	0.076
	Coffee dominance	-0.046	0.059	-0.782	0.434
	Heat load	-0.065	0.052	-1.252	0.211
	Altitude	-0.260	0.078	-3.356	<0.001 ***
	Forest type	0.029	0.177	0.163	0.871

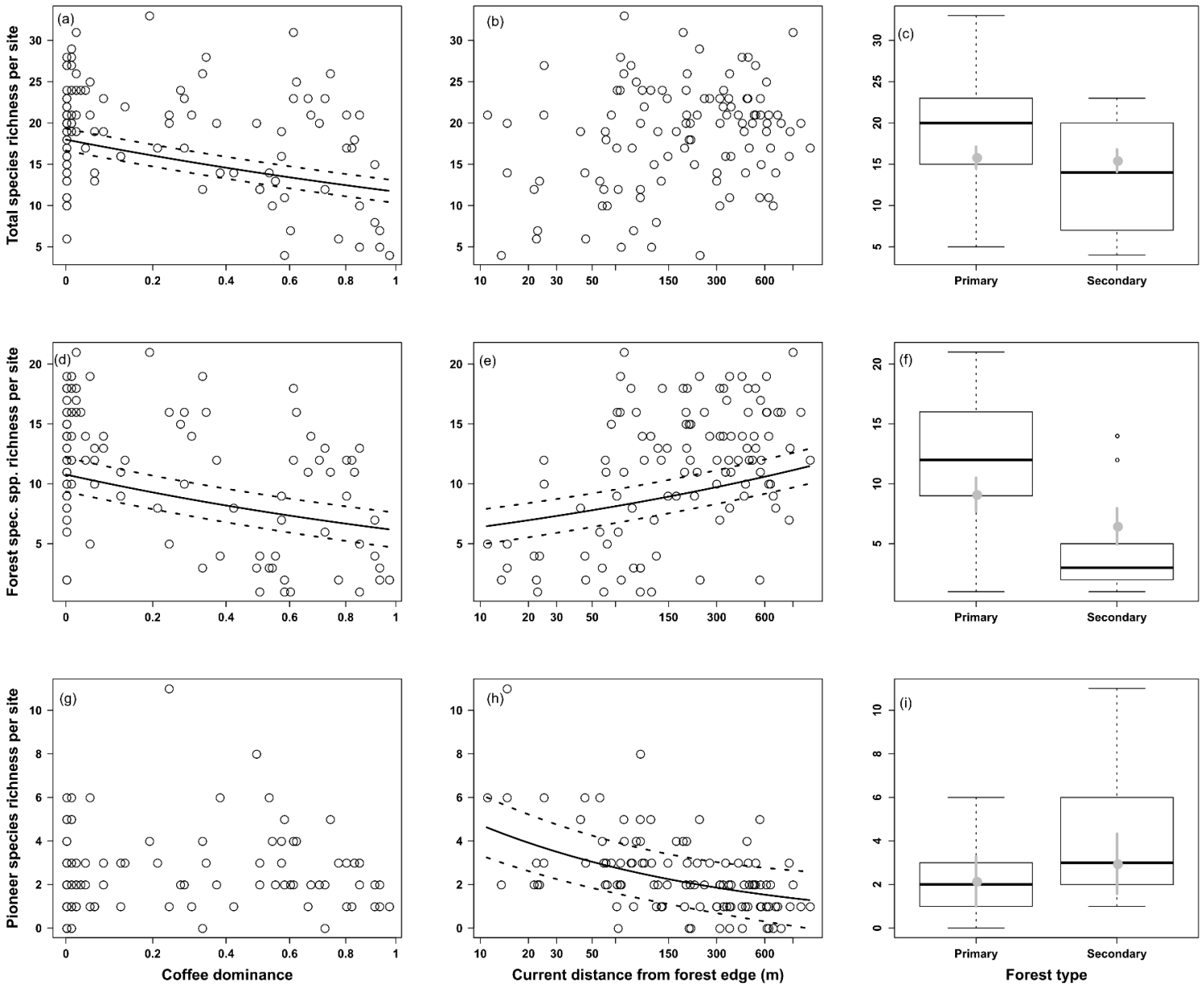

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
Total species richness per site
Forest spec. spp. richness per site
Pioneer species richness per site
Coffee dominance
Current distance from forest edge (m)
Forest type
Primary
Secondary

Figure 2.4 Effects of coffee management, current distance from nearest forest edge, and forest type on richness of total species (panels (a), (b) and (c)), forest specialist species (panels (d), (e) and (f)), and pioneer species (panels (g), (h) and (i)) based on the generalized liner mixed effects models. Solid black regression lines indicate model predictions for primary forest while all other variables were held constant at their means; and dashed lines indicate 95% confidence intervals. The x-axes display original values but both coffee dominance and current distances were scaled and used on a logarithmic scale in the models. The box-and-whisker plots (c, f, i) illustrate the relationship between forest type and species richness, where the grey dot represents the predicted means and the grey lines the corresponding 95% confidence intervals.

Discussion

Focusing on biodiverse moist evergreen Afromontane forest, we found evidence of site-level disturbance, landscape context, and forest history effects on woody plant species composition and richness. First, we observed significant negative effects of coffee management intensity on total species richness and forest specialist species richness. Second, we identified contrasting landscape context effects, namely a positive effect of distance from the current forest edge on forest specialist species richness, and a negative effect on pioneer species richness. Third, we found significantly lower forest specialist richness in secondary versus primary forest.

Unlike many other studies in the region (and elsewhere in the tropics) (e.g. Gole 2003; Hundera et al. 2013; Tadesse et al. 2014a), using a spatially randomized design based on cost distance and a large data set, we were able to cover large gradients of forest conditions in relation to coffee management, landscape context and forest history. Our findings revealed independent effects of all three gradients, highlighting the importance of their recognition in developing appropriate conservation strategies. We discuss these findings and their implications for conservation in relation to other studies, particularly from Ethiopia and other tropical regions.

The merit of shade coffee systems for biodiversity conservation and ecosystem services has received considerable attention globally (Jha et al. 2014; Tadesse et al. 2014a; Rodrigues et al. 2018). Coffee is grown across southwestern Ethiopia (Senbeta and Denich 2006; Schmitt et al. 2010; Hundera et al. 2013) as well as in Latin America and elsewhere in the tropics (Perfecto et al. 1996; Philpott et al. 2003; Hernández-Martínez et al. 2009), often under the shade of native trees. However, a major difference in Ethiopia is that Arabica coffee is a native, primary component of forest ecosystems (Schmitt 2006; Aerts et al. 2011). Here, traditional coffee management intensity ranges from very low disturbance forest systems to semi-plantation systems (Teketay 1999; Wiersum et al. 2008; Tadesse et al. 2014a). Our findings revealed negative effects of intensively managed coffee systems on native species composition

and diversity as opposed to undisturbed coffee forest sites. Several native tree species, such as *Cassipourea malosana*, *Chionanthus mildbraedii*, *Pouteria adolfi-friederici*, and *Trichilia dregeana* appeared to be affected by intensive coffee management. This is consistent with other studies in southwestern Ethiopia, which also found strong negative effects on native plant species (Gole 2003; Schmitt et al. 2010; Hundera et al. 2013) and on forest and dietary specialist birds (Gove et al. 2008; Rodrigues et al. 2018), suggesting loss and homogenization of biodiversity in increasingly simplified forest coffee systems.

At a landscape level, edge effects are known to have negative consequences on native forest species (Murcia 1995; Gascon et al. 2000; Wiens 2002). However, landscape context and site effects are often confounded and therefore usually difficult to differentiate in their respective influences on biodiversity (Harper et al. 2005). Here, we found edge-mediated landscape effects on species composition and richness that were not related to coffee management. Our findings show that sites closer to the forest edge differ in native species composition from sites in the interior forest. Of the forest specialist species, for example, *Chionanthus mildbraedii*, *Pouteria adolfi-friederici*, *Podocarpus falcatus*, and *Schefflera abyssinica* appeared to be most strongly affected by edge effects. Furthermore, edge influence extended relatively deep into the forest, with forest species richness continuously increasing deep into the forest, strongly affecting up to 100m from the edge but potentially reaching several hundred metres into the forest (Fig. 2.4e). Our empirical findings are consistent with earlier southwestern Ethiopian studies that showed forest and dietary specialist bird species diversity (Rodrigues et al. 2018) and understory epiphytic fern and epiphyllous bryophyte cover (Hylander et al. 2013b) to increase towards the interior of the forest. As to the distance of edge influence, the edge effect in our study area was comparable to edge effects reported elsewhere in the tropics (Harper et al. 2005), such as 100 to 300 m in central Amazonian lowland rainforest (Laurance et al. 1998) and 500 m in tropical forest in Queensland, Australia (Laurance 1991). A possible driver for the edge effects in our study area may be the relatively intensive use of forest edges by local people, which includes but is not restricted to coffee growing. Local people in the region greatly depend on wood and non-wood forest products such as fuelwood, construction materials including poles and timber, farm and household tools, and honey (Ango 2016; Dorresteijn et al. 2017). While forest edges may be hotspots of such human uses, people in the region further penetrate the forest to find and use resources from considerable distances (Hylander et al. 2013b), thereby potentially causing far-reaching edge effects (Didham and Lawton 1999; Gascon et al. 2000; Cadenasso et al. 2003). These findings

highlight the general importance of maintaining largely undisturbed forest interior locations for native species conservation (Gibson et al. 2011; Barlow et al. 2007).

Secondary forests in our study area hosted significantly lower forest specialist species richness and differed in composition compared to primary, old-growth forests. At the species level, for example, *Cassipourea malosana* and *Trichilia dregeana* did not occur at secondary forest sites, and *Pouteria adolfi-friederici* and *Syzygium guineense* occurred at only one interior secondary forest site (noting that we had only four interior sites of secondary forest in total). Such decreases in native tree species richness in secondary forest have been noted consistently in the tropics (Chazdon 2003; Lugo and Helmer 2004; Wright 2005). Possible reasons for lower native tree species richness in secondary forest are land use legacy effects of past agricultural land use (e.g. loss of individual trees or propagules, habitat change, inadequate seed dispersal, or loss of soil fertility; Shumi et al. 2018; Thompson et al. 2002; Arroyo-Rodríguez et al. 2017) coupled with the inherently slow natural restoration and restocking with slow-growing tree species. Our findings demonstrate that secondary forests, which we also found to differ in species composition from primary forests, may take up to 40 years (assuming that the oldest regrowth could have occurred immediately after 1973) and longer to attain a similar composition to remnant forest. This matches closely with other forest ecosystems, where recovery in species composition takes several decades – e.g. 30-40 years in Atlantic secondary forest in southern Brazil (Zanini et al. 2014), 80 years in south-eastern Puerto Rico (Marin-Spiotta et al. 2007), and 70-100 years in central Panama (DeWalt et al. 2003). Overall, while our results clearly underline the primary importance of safeguarding old growth native forests (see Gibson et al. 2011; Barlow et al. 2007), they also highlight the need for assisted and natural recovery of forests (Chazdon 2008; Crouzeilles et al. 2017).

Conservation implications

Our study revealed a combination of site-level, historical and landscape-level effects on Ethiopian forest biodiversity. Because coffee is important for local livelihoods and Ethiopia's economy (Petit 2007; Moat et al. 2017), pressure on forest biodiversity from coffee management intensification is potentially high (e.g. Hundera et al. 2013; Tadesse et al. 2014a). Further forest degradation could also result from an increasing number of local people heavily depending on forest products (Ango 2016; Dorresteijn et al. 2017). Moreover, imperfect forest management and investment policies, and poorly defined property rights (e.g. Lemenih and Kassa 2014; Tura 2018) have also exposed Ethiopian forests to recurrent deforestation (e.g.

Tadesse et al. 2014b; Getahun et al. 2017), particularly in areas above coffee altitude (e.g. Hylander et al. 2013a).

Biodiversity conservation in southwestern Ethiopia and similar systems elsewhere requires integrated strategies that foster appropriate local and forest landscape management (Gardner et al. 2009; Edwards 2016; Chazdon 2018). One option could be to further promote the biosphere reserve approach, which can integrate sustainable development and biodiversity conservation (Batisse 1982; Bridgewater 2002). Eco-friendly coffee certification schemes could additionally help to maintain specialist species in managed coffee forests (Perfecto et al. 2005; Takahashi and Todo 2017). Given the high dependence of local livelihoods on forest products and the vulnerable biodiversity in southwestern Ethiopia, however, any approach must carefully weigh social and ecological costs and benefits.

Acknowledgements

The study was funded through a European Research Council (ERC) Consolidator Grant (FP7-IDEAS-ERC, Project ID 614278) to J. Fischer (SESyP). We thank the Governments of Ethiopia and Oromia Regional State for their permission to conduct the research. We also thank the staff of the different woreda and kebele offices and the local farmers for their cooperation. We thank field assistants and drivers for their support.

Supplementary Material for Chapter 2

Appendix 2A. List of tree and shrub species encountered in all 108 studied forest sites, their family and local names, guild (forest specialists, pioneers and generalists species) and habit, total abundance from all sites and the number of sites they occurred in.

Scientific name	Family name	Local name	Guild	Habit	Abundance	Species occurrence (no. of sites)
Abutilon longicuspe Hochst. ex A. Rich	MALVACEAE	Inchinii dalacha	Pioneer	Shrub	6	2
Acacia abyssinica Hochst. ex Benth.	FABACEAE	Sondii adii	Pioneer	Tree	2	2
Acanthus eminens C.B.Cl.	ACANTHACEAE	Baalan-waraantee	Forest specialist	Shrub	903	22
Alangium chinense (Lour.) Harms	ALANGIACEAE	Daanissaa	Pioneer	Tree	11	7
Albizia gummifera (J. F. Gmel.) C.A. Sm.	FABACEAE	Ambabeessa	Generalist	Tree	311	33
Albizia schimperiana Olivo	FABACEAE	Ambabeessa adii	Generalist	Tree	92	29
Allophylus abyssinicus (Hochst.) Radikofer	SAPINDACEAE	See´o/Seehoo	Forest specialist	Tree	232	41
Allophylus macrobotrys Gilg	SAPINDACEAE	Saahoo	Generalist	Tree	8	4
Apodytes dimidiata E. Mey. ex Arn.	ICACINACEAE	Wandabiyyoo	Forest specialist	Tree	48	21
Bersama abyssinia Fresen.	MELIANTHACEAE	Lolchisiaa	Forest specialist	Tree	379	71
Bridelia micrantha (Hochst.) Baill.	EUPHORBIACEAE	Minaanduloo	Pioneer	Small tree	8	1
Brucea antidysenterica J. F. Mill.	SIMAROUBACEAE	Qomanyoo	Forest specialist	Shrub to tree	154	34
Calpurnia aurea (Ait.) Benth.	FABACEAE	Ceekaa	Pioneer	Small tree	122	5
Canthium oligocarpum Hiern subsp. Oligocarpum	RUBIACEAE	Baalsadii	Forest specialist	Shrub to tree	113	34
Cassipourea malosana (Baker) Alston	RHIZOPHORACEAE	Ilkee	Forest specialist	Tree	136	25
Celtis africana Burm. f.	ULMACEAE	Qayii	Generalist	Tree	125	25
Chionanthus mildbraedii (Gilg & Schellenb.) Stearn	OLEACEAE	Gagamaa	Forest specialist	Tree	1526	55
Clausena anisata (Willd.) Benth.	RUTACEAE	Ulmaayii	Generalist	Shrub to tree	766	56
Clerodendrum myricoides (Hochst.) Vatke	LAMIACEAE	Maraasisaa	Pioneer	Shrub	7	3
Coffea arabica L.	RUBIACEAE	Buna	Forest specialist	Small tree	10006	78
Cordia africana Lam.	BORAGINACEAE	Waddeessa	Generalist	Tree	102	29
Crossopteryx febrifuga (G.Don) Benth.	RUBIACEAE	Unknown/ Kanhinbekkamine	Generalist	Tree	2	1
Crotalaria exaltata Polhill	FABACEAE	Bilbiilee	Pioneer	Shrub	1	1
Croton macrostachyus Del.	EUPHORBIACEAE	Bakaniissa/Makkanniisa	Pioneer	Tree	350	61
Dalbergia lactea Vatke	FABACEAE	Unknown	Pioneer	Tree	15	5
Deinbollia kilimandscharica Taub.	SAPINDACEAE	Unknown	Forest specialist	Tree	2	2
Diospyros abyssinica subsp. abyssinica (Hiern) F. White	EBENACEAE	Lookkoo gurraacha	Forest specialist	Tree	58	12
Dombeya torrida (J. F. Gmel.) P. Bamps	STERCULIACEAE:	Daanissaa	Pioneer	Shrub to tree	13	5
Dracaena afromontana Mildbr.	DRACAENACEAE	Algee	Forest specialist	Shrub	1250	37
Dracaena fragrans (L.) KerGawl.	DRACAENACEAE	Eemoo	Planted	Shrub to tree	974	19
Dracaena steudneri Engl.	DRACAENACEAE	Bubiftuu/Yubdoo	Forest specialist	Shrub to tree	50	15
Ehretia cymosa Thonn.	BORAGINACEAE	Ulaagaa	Generalist	Shrub to tree	153	34
Ekebergia capensis Sparrm	MELIACEAE	Orooroo/Somboo	Forest specialist	Tree	22	8
Elaeodendron buchananii (Loes) Loes.	CELASTRACEAE	Lookkoo	Generalist	Tree	177	30
Entada abyssinica Steud. ex A. Rich.	FABACEAE	Ambaltaa	Pioneer	Tree	2	2
Erythrina brucei Schweinf.	FABACEAE	Beroo	Pioneer	Tree	2	2
Erythrococca abyssinica Pax	EUPHORBIACEAE	Agabaatee	Generalist	Shrub	71	13
Erythrococca trichogyne (Muell. Arg.) Prain	EUPHORBIACEAE	Qayii	Forest specialist	Small tree	212	22
Eucalyptus camaldulensis Dehnh.	MYRTACEAE	Baargamoo dimaa	Pioneer-planted	Tree	6	2
Eugenia bukobensis Engl.	MYRTACEAE	Unknown	Forest specialist	Small tree	2	1
Euphorbia abyssinica Gmel.	EUPHORBIACEAE	Adaamii	Pioneer	Tree	4	3
Fagaropsis angolensis (Engl.) Milne	RUTACEAE	Qomanyoo	Forest specialist	Tree	28	9
Ficus exasperata Vahl.	MORACEAE	Baalansofii	Pioneer	Small tree	10	3
Ficus glumosa Del.	MORACEAE	Anuunnuu (unknown)	Generalist	Tree	1	1
Ficus ovata Vahl	MORACEAE	Qelenxoo	Generalist	Small tree	1	1
Ficus sur Forssk.	MORACEAE	Harbu	Generalist	Tree	99	28
Ficus thonningii Blume	MORACEAE	Dambii	Generalist	Small tree	11	4
Ficus vasta Forssk	MORACEAE	Qilxuu	Pioneer	Tree	3	3
Flacourtia indica (Burm.f) Merr.	FLACOURTIACEAE	Akuukuu	Generalist	Small tree	17	9
Galiniera saxifraga (Hochst.) Bridson	RUBIACEAE	Mixoo-sare (Unknown)	Forest specialist	Small tree	675	65
Grewia ferruginea Hochst. Ex A. Rich.	TILIACEAE	Laanqanoo	Pioneer	Shrub	8	3
Hallea rubrostipulata (K. Schum.) J.-F. Leroy	RUBIACEAE	Anuunuu	Forest specialist	Tree	4	2
Hibiscus macranthus Hochst. ex A. Rich.	MALVACEAE	Inchinii daalacha	Pioneer	Shrub	1	1
Hypericum revolutum Vahl	GUTTIFERAE	Uleefonii	Pioneer	Small tree	1	1
Ilex mitis (L.) Radlk.	AQUIFOLIACEAE	Qetoo/Kofoo	Forest specialist	Tree	76	12
Justicia schimperiana (Hochst. ex Nees) T. Anders.	ACANTHACEAE	Dhuummupaa	Generalist	Shrub	1567	33
Lannea schweinfurthii (Engl.) Engl.	ANACARDIACEAE	Booqqoo	Generalist	Tree	6	5
Lannea welwitschii (Hiem) Engl.	ANACARDIACEAE	Anuunuu	Forest specialist	Tree	3	2
Lepidotrichilia volkensii (Giirke) Leroy	MELIACEAE	Seehoo	Forest specialist	Tree	139	20
Macaranga capensis (Baill.) Sim	EUPHORBIACEAE	Wongoo	Forest specialist	Tree	470	43
Maesa lanceolata Forssk.	MYRSINACEAE	Abbayyii	Generalist	Tree	270	51
Manilkara butugi Chiov.	SAPOTACEAE	Gawoo	Forest specialist	Tree	1	1
Maytenus arbutifolia (A. Rich.) Wilczek	CELASTRACEAE	Ombooroo/Kombolcha	Generalist	Shrub	1590	64

Maytenus senegalensis (Lam.) Exell	CELASTRACEAE	Ombooroo	Pioneer	Shrub	26	4
Maytenus sp.	CELASTRACEAE	Qooraatii	Generalist	Shrub	95	10
Maytenus undata (Thunb.) Blakelock	CELASTRACEAE	Qoolaatii	Generalist	Shrub	16	3
Millettia ferruginea (Hochst.) Bak.	FABACEAE	Astiraa	Forest specialist	Small tree	654	62
Mimusops kummel A. DC.	SAPOTACEAE	Qoolaatii	Generalist	Tree	29	9
Myrsine africana L.	MYRSINACEAE	Qacama	Generalist	Shrub	9	1
Nuxia congesta R.Br. ex Fresen.	LOGANIACEAE	Qacama	Forest specialist	Small tree	1	1
Ocimum lamiifolium Hochst. ex Benth.	LAMIACEAE	Damaakkase	Pioneer	Shrub	2	1
Olea welwitschii (Knobl.) Gilg & Schellenb.	OLEACEAE	Bayaa	Forest specialist	Tree	91	36
Oxyanthus speciosus subsp. stenocarpus DC	RUBIACEAE	Imbiraangoo	Forest specialist	Shrub	139	22
Pavetta abyyssinica Fresen.	RUBIACEAE	Xumaanee	Forest specialist	Small tree	637	21
Pentas schimperiana subsp. schimperiana (A. Rich.) Vatke	RUBIACEAE	Simararuu	Pioneer	Shrub	2	2
Phoenix reclinata Jacq.	ARECACEAE	Meexxii	Pioneer	Tree	51	10
Phyllanthus mooneyi M Gilbert	EUPHORBIACEAE	Kechema	Pioneer	Shrub	20	3
Phyllanthus ovalifolius Forssk.	EUPHORBIACEAE	Qacama	Generalist	Small tree	58	5
Phyllanthus reticulatus Poir	EUPHORBIACEAE	Qacama	Pioneer	Shrub	65	6
Pittosporum viridiflorum Sims	PITTOSPORACEAE	Soolee	Forest specialist	Small tree	39	16
Plectranthus garckeanus (Vatke) J.K. Morton	LAMIACEAE	Yaryoo	Generalist	Shrub	5	1
Podocarpus falcatus Mirb.	PODOCARPACEAE	Birbirsa	Forest specialist	Tree	29	12
Polyscias fulva (Hiern) Harms	ARALIACEAE	Daraku/Kariyoo	Forest specialist	Tree	20	17
Pouteria adolfi-friederici (Engl.) Baehni	SAPOTACEAE	Qararoo	Forest specialist	Tree	181	41
Premna schimperi Engl.	LAMIACEAE	Maraasisaa	Pioneer	Small tree	4	2
Prunus africana (Hook. f.) Kalkm.	ROSACEAE	Oomoo	Forest specialist	Tree	66	12
Psidium goajava L.	MYRTACEAE	Zayitunaa	Pioneer-planted	Small tree	15	2
Psychotria orophila Petit	RUBIACEAE	Wandabiyyoo	Forest specialist	Small tree	806	34
Rhamnus prinoides L'Herit.	RHAMNACEAE	Geeshee	Pioneer	Shrub	37	7
Ritchiea albersii Gilg	CAPPARIDACEAE	Agabaatee	Pioneer	Small tree	3	2
Rothmannia urcelliformis (Hiern) Robyns	RUBIACEAE	Mixoo	Forest specialist	Small tree	169	35
Rytigynia neglecta (Hiern) Robyns	RUBIACEAE	Mixoo	Forest specialist	Shrub	596	42
Sapium ellipticum (Krauss) Pax	EUPHORBIACEAE	Bosoqa	Generalist	Tree	48	10
Sarcocephalus latifolius (Smith) Bruce	RUBIACEAE	Diboo	Pioneer	Small tree	25	1
Schefflera abyssinica (Hochst. ex A. Rich.) Harms	ARALIACEAE	Gatamaa/Bottoo	Forest specialist	Tree	28	19
Schefflera myriantha (Bak.) Drake	ARALIACEAE	Bottoo	Forest specialist	Small tree	3	1
Senna occidentalis (L.) Links	FABACEAE	Salaamakii dimaa	Pioneer	Shrub	226	16
Senna petersiana (Bolle) Lock	FABACEAE	Salaamakii adii	Pioneer	Shrub	199	19
Solanecio gigas (Vatke) C. Jeffrey	ASTERACEAE	Doomboorokoo	Pioneer	Shrub	70	11
Solanecio mannii (Hook. f) C. Jeffrey	ASTERACEAE	Haamitii-baloo	Forest specialist	Small tree	41	10
Solanum giganteum Jacq.	SOLANACEAE	Unknown	Generalist	Shrub	1	1
Syzygium guineense subsp. guineense F. White	MYRTACEAE	Baddeessa	Forest specialist	Tree	361	58
Teclea nobilis Del.	RUTACEAE	Hadhessaa	Forest specialist	Small tree	253	28
Trichilia dregeana Sond.	ASTERACEAE	Anuunuu	Forest specialist	Tree	146	20
Unidentified sp.1	RUBIACEAE	Mixoo	Generalist	Shrub	180	12
Vepris dainellii (Pichi-Serm.) Kokwaro	RUTACEAE	Hadhessaa babalaa	Forest specialist	Small tree	675	69
Vernonia adoensis Sch. Bip. ex Walp.	ASTERACEAE	Tuurujee	Pioneer	Shrub	8	2
Vernonia amygdalina Del.	ASTERACEAE	Ibicha	Generalist	Shrub	112	21
Vernonia auriculifera Hiern.	ASTERACEAE	Reejii	Pioneer	Shrub	1287	49
Vernonia hochstetteri Sch. Bip. ex Walp.	ASTERACEAE	Xasee	Pioneer	Shrub	16	5
Vernonia sp.1	ASTERACEAE	Reejii Arbaa	Pioneer	Shrub	3	1
Vernonia sp.2	ASTERACEAE	Sooyyama	Generalist	Shrub	12	4
Vernonia thomsoniana Olivo & Hiern ex Oliv.	ASTERACEAE	Sooyyama	Pioneer	Shrub	8	2

Chapter 3

Chapter 3

Land use legacy effects on woody vegetation in agricultural landscapes of southwestern Ethiopia

Girma Shumi, Jannik Schultner, Ine Dorresteijn, Patrícia Rodrigues, Jan Hanspach, Kristoffer Hylander, Feyera Senbeta and Joern Fischer

Diversity and Distributions (2018), 24:1136–1148

Abstract

Aim: Past land use legacy effects – extinction debts and immigration credits – might be particularly pronounced in regions characterized by complex and dynamic landscape change. The aim of this study was to evaluate how current woody plant species distribution, composition and richness related to historical and present land uses.

Location: A smallholder farming landscape in southwestern Ethiopia.

Methods: We surveyed woody plants in 72 randomly selected 1 ha sites in farmland, and grouped them into forest specialist, generalist and pioneer species. First, we investigated woody plant composition and distribution using non-metric multidimensional scaling. Second, we modelled species richness in response to historical and current distance from the forest edge. Third, we examined diameter class distributions of trees in recently converted versus permanent farmland.

Results: Historical distance was a primary driver of woody plant composition and distribution. Generalist and pioneer species richness increased with historical distance. Forest specialists, however, did not respond to historical distance. Only few old individuals of forest specialist species remained in both recently converted and permanent farmlands.

Main conclusions: Our findings suggest that any possible extinction debt for forest specialist species in farmland at the landscape scale was rapidly paid off, possibly because farmers cleared large remnant trees. In contrast, we found substantial evidence of immigration credits in farmland for generalist and pioneer species. This suggests that long-established farmland may have unrecognised conservation values, though apparently not for forest specialist species. We suggest that conservation policies in southwestern Ethiopia should recognize not only forests, but also the complementary value of the agricultural mosaic – similarly to the case of European cultural landscapes. A possible future priority could be to better reintegrate forest species in the farmland mosaic.

Keywords: **Agricultural mosaic; Biodiversity conservation; Extinction debt; Immigration credit; Novel ecosystems; Nurse tree effect**

Introduction

Remnant woody plants in agroecosystems provide habitat and movement pathways for plants, birds, reptiles and many other species (Perfecto and Vandermeer 2008; Dorresteijn et al. 2013; Mendenhall et al. 2016). However, the expansion and intensification of cropland and pastures has transformed a large proportion of the planet's land surface and is a key driver of biodiversity loss (MA 2005a; Flinn and Marks 2007; Wright 2010), causing habitat loss, fragmentation and persistent ecosystem changes (Foster et al. 2003; Mortelliti et al. 2010).

While some species respond to landscape changes immediately, others exhibit a time delayed response (Lindborg and Eriksson 2004). Such time delayed responses can result in two contrasting legacy effects, namely (a) an extinction debt – where the current community contains species whose populations cannot be sustained in the long term (Tilman et al. 1994; Kuussaari et al. 2009), versus (b) an immigration credit – where the environment sis suitable for colonization by some species, which will gradually immigrate (Jackson and Sax 2010). Understanding such legacy effects is crucial for devising appropriate conservation strategies. Yet, relatively few studies have investigated legacy effects of historical land use on present-day biodiversity (but see Lindborg and Eriksson 2004; Metzger et al. 2009; Culbert et al. 2017). Of the notable exceptions, most have focused on aggregate patterns of species richness and composition (e.g., McNeely and Schroth 2006; Tolera et al. 2008; Häger et al. 2014), paying relatively little attention to differences between species of different conservation status or habitat affinity. When disaggregating species, however, it is possible that the same system experiences extinction debts and immigration credits in different locations. For example, an agricultural frontier landscape may temporarily retain relict forest species in recently cleared farmland (an extinction debt), but may gradually accumulate new communities of generalist and pioneer species in longer-established farmland (an immigration credit; Fig. 3.1).

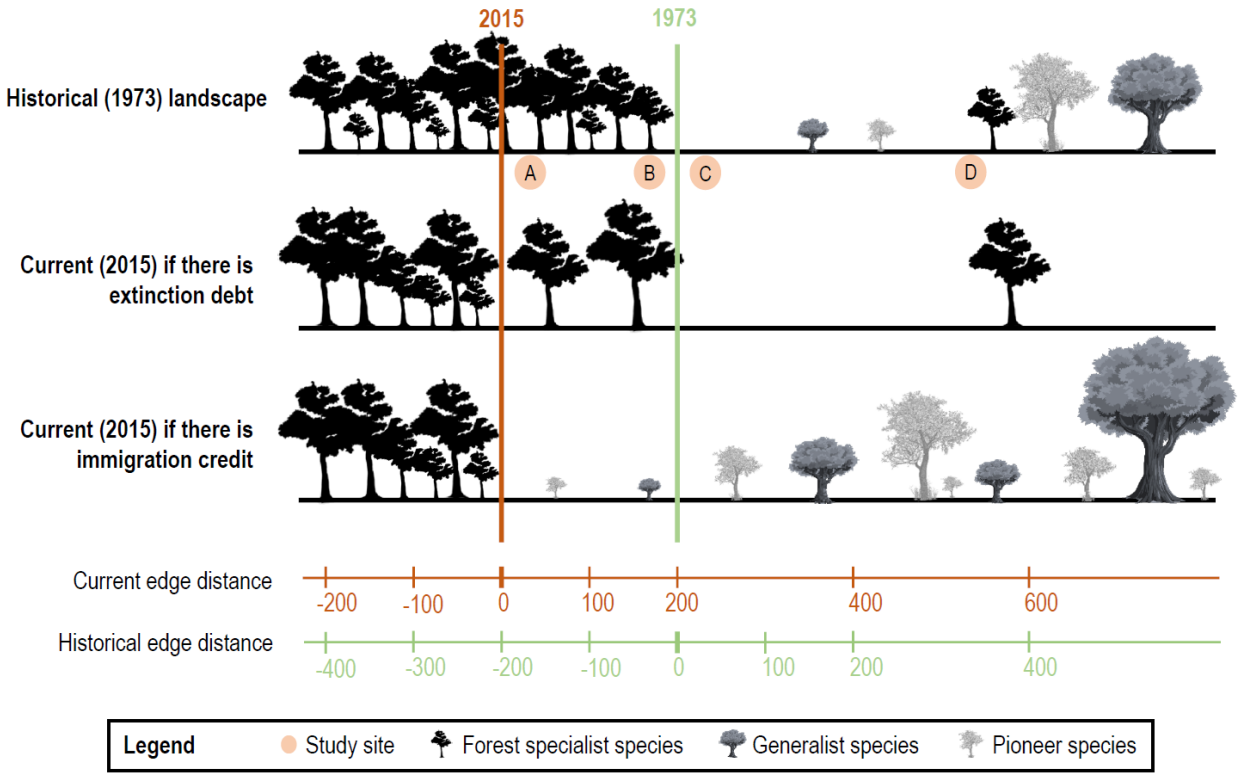


Figure 3.1 Conceptual framework figure of the historical landscape, and its complex and dynamic change in response to various management practices. For example, tree retention and planting can lead to an extinction debt – persistence of forest specialist species, while establishment and survival of new generalist and pioneer species within the farmland can lead to an immigration credit.

Both extinction debt and immigration credit are influenced by multiple factors including species life history traits (e.g., longevity, dispersal capacity), history of landscape composition and habitat configuration, the extent of habitat change, and stochastic processes (Kuussaari et al. 2009; Jackson and Sax 2010; Hylander and Ehrlén 2013). For example, some long-lived forest trees species can persist for more than a century after forest fragmentation (Vellend et al. 2006). In contrast, short-lived butterfly species showed no remaining extinction debt 40 years after habitat change (Krauss et al. 2010). Likewise, the establishment and survival of a species in a new location is contingent on its dispersal mechanisms and interactions with the existing community (Davis et al. 2000; Sakai et al. 2001; Essl et al. 2015). Time delayed responses can also depend on the extent of habitat change in size, quality and connectivity (Jackson and Sax 2010; Pardini et al. 2010; Hylander and Ehrlén 2013). Typically, extinction debts and immigration credits are less likely to exist in landscapes with little and isolated habitat, after severe disturbance (Tilman et al. 1994; Hanski and Ovaskainen 2002; Helm et al. 2006).

In this study, we evaluated legacy effects in an agricultural region in southwestern Ethiopia. Here, crop-based subsistence agriculture began in the mid-nineteenth century

(McCann 1995) and since the 1970s has become a major driver of land use change (Kassa et al. 2016). Currently, agricultural policies encourage cereal crop production by distributing improved seeds and chemical fertilizers, which may induce further deforestation and land degradation (Hylander et al. 2013a; Kassa et al. 2016). Because of the high rate of deforestation and high concentration of endemic plant and bird species, the region is considered part of the Eastern Afromontane biodiversity hotspot (Reusing 2000; Schmitt 2006). Despite ongoing land use change, the region is still dominated by smallholder farming, and still comprises a mosaic of forest patches, homegardens and pastures (Hylander and Nemomissa 2009; Kumsa et al. 2016). The landscape matrix is rich in trees (Fig. 3.2) (e.g., Jara et al. 2017), which are used for many purposes – for example as shade for coffee, live fences, honey production or for domestic wood products (Ango et al. 2014). Trees in the landscape matrix can be assumed to fulfill important ecosystem functions (Manning et al. 2006) and contribute substantially to local biodiversity (e.g., Gove et al. 2008; Hylander and Nemomissa 2008; Engelen et al. 2016).

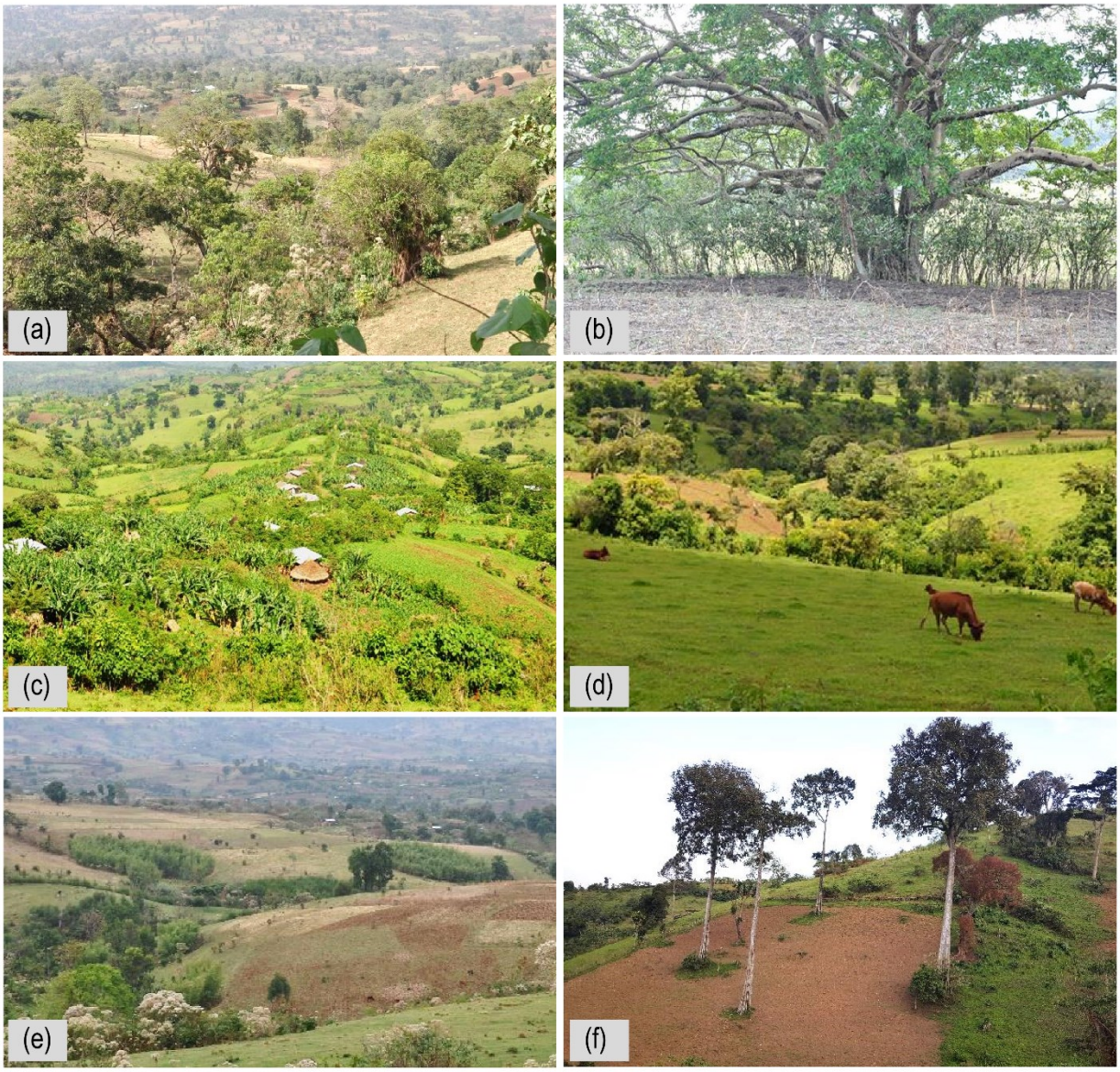


Figure 3.2 (a) Patches of trees and scattered trees in the farmland. (b) Patch of coffee under a tree surrounded by farmland. (c) Home gardens and live fences surrounded by farmland. (d) Grazing land. (e) Woodlots of exotic tree species surrounded by farmland. (f) Retained trees after recent conversion of forest to farmland.

Considering ongoing complex and dynamic landscape changes in southwestern Ethiopia, it is plausible that species diversity and composition could be affected by legacy effects. Such effects can be expected to be particularly pronounced for long-lived woody species. To account for legacy effects and develop appropriate conservation strategies, we therefore sought to understand the possible presence of both extinction debts and immigration credits in the region. Focusing on woody species within the farmed sections of the landscapes (that is, outside large tracts of forest), we reasoned that both an extinction debt and an immigration credit could be inferred when present day species diversity was better described by past rather than present day landscape characteristics (Hanski 2000; Lindborg and Eriksson 2004; Kuussaari et al. 2009). An extinction debt following habitat loss and fragmentation was assumed to occur when

locations that were historically within the forest had retained high forest species richness, while locations historically within farmland had few species. In a system that is characterised by gradual loss of forest cover (Hylander et al. 2013a), locations that were historically far from the forest edge (i.e. deep within farmland; point D in Fig. 3.1) can be assumed to have been converted earlier than locations closer to the historical forest edge (point C in Fig. 3.1), while locations forested at the historical reference time were converted even later (points B and A in Fig. 3.1, respectively). For instance, in another agricultural landscape in southern Ethiopia, the richness of forest specialist epiphytic plants decreased with distance to forest (Hylander and Nemomissa 2017). In contrast, an immigration credit was assumed to occur in the opposite case – when locations that were historically far from the forest (and are still far from forest) have more species than locations that were historically close to the forest. Such a situation would imply that farmland, once established, gains species through time (Fig. 3.1) (Hanski 2000; Jackson and Sax 2010; Lira et al. 2012), because of gradual increases in structural complexity and the gradual, natural addition of non-forest species to the community. For example, native Oromo people in Ethiopia may choose to retain and protect fig trees (*Ficus* spp.), practice home garden agroforestry, use trees for traditional coffee management (Fig. 3.2) (Getahun 2016; Jara et al. 2017); and in many locations in farmland, simply allow for natural regeneration processes of "useful" species to take place.

Using this framing, we hypothesised the following:

1. Present-day land use variables, especially current distance from the forest edge, influence woody plant species richness, composition and distribution.
2. Legacy effects of historical land use influence woody plant community composition, distribution and species richness, with possible extinction debts for forest specialist species, and possible immigration credits for species that can regenerate in farmland environments.
3. Legacy effects may also be detectable from site level population structures – for example, large diameter forest specialist trees may have largely disappeared in long-established farmland but may still persist in recently converted farmland.

Methods

Study area

The study was conducted in the rural landscapes of six *kebeles* (the smallest administrative unit in Ethiopia), located in Gera, Gumay and Setema districts of Jimma Zone, Oromia Regional State, southwestern Ethiopia (Fig. 3.3). The study *kebeles* comprised a mosaic of land use types, with forest cover ranging from 11 to 84 percent, while arable land, grazing land and settlements accounted for the rest. In the study area, coffee is an economically important cash crop. It is grown at different levels of intensity, mostly in patches of remnant forest, and occurs primarily between 1550 and 1900 m altitude.

Site selection

Within each *kebele*, we determined the proportion of arable land and grazing land (hereafter, jointly referred to as "farmland") using a land cover map generated via supervised image classification of a RapidEye satellite image from 2015. We randomly selected 72 circular 1 ha survey sites across the six *kebeles* – 53 in arable land and 19 in grazing land, assigned proportionally to the occurrence of arable land and grazing land in each *kebele*. Here, although the centre of these sites was always located in arable land or grazing land, in some instances the edge of the sites also comprised other land uses, such as life fences, homegardens or small plantings or remnant patches of trees.

Woody plant surveys

We surveyed woody plants from 01 November 2015 to 30 January 2016 in all 72 sites. We recorded all individuals of tree and shrub to subshrub species with height ≥ 1.5 m, and also measured and recorded diameter at breast height (DBH) of all individuals with DBH ≥ 5 cm. As the occurrence of young trees is typically correlated with the presence of seedlings (recent regeneration) in a given site (e.g., Fischer et al. 2009), for logistical reasons, we chose not to count individuals < 1.5 m in height for this study. We identified plants that were readily identifiable in the field. For species that were difficult to identify in the field, specimens were collected, pressed, dried and transported to the National Herbarium at Addis Ababa University for identification. Very few specimens of relatively rare species could not be identified to species level, and were identified to genus level, or in one case treated as an "unidentified" species. Species were further grouped as forest specialist, generalist and pioneer based on relevant literature (Flora of Ethiopia and Eritrea 1989-2006; Teketay 1997; Tesfaye et al. 2002;

Hundera et al. 2013; see Table 3.S1). Nomenclature follows the Flora of Ethiopia and Eritrea (1989-2006).

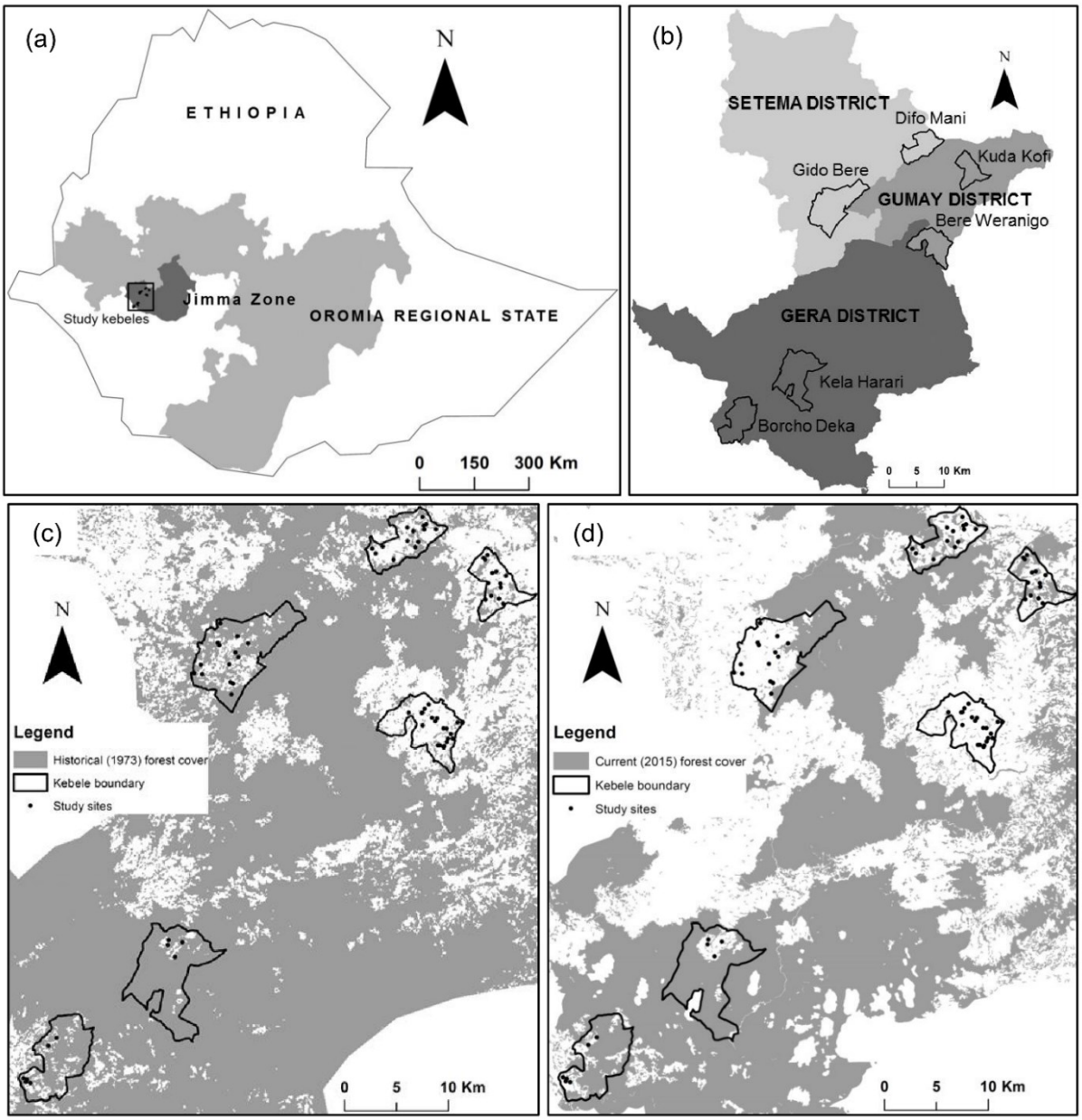


Figure 3.3 Location of (a) study area (square) in Ethiopia, Oromia Regional State, Jimma Zone; (b) the six *kebeles*: Difo Mani and Gido Bere in Setema district, Bere Weranigo and Kuda Kofi in Gumay, and Borcho Deka and Kela Harari in Gera; (c) historical (1973) forest and farmland cover and study sites (black bullets); and (d) current (2015) forest and farmland cover and study sites (black bullets).

Land use characteristics and environmental parameters

We distinguished between current distance versus historical distance from the forest edge, to obtain proxies for current landscape position, and historical landscape position of farmland sites relative to a gradually reclining forest edge (Hylander et al. 2013a; Lindborg and Eriksson 2004). Current distance was derived from the RapidEye land cover classification (Fig. 3.3d).

All current distances were positive, denoting the distance from the centre of the survey site to the nearest current forest patch of at least 1 ha in area (Fig. 3.1). Historical forest cover was derived from a supervised image classification of a Landsat image from 1973 (Landsat 1-MSS, obtained from http://www.usgs.gov/) using ArcGIS 10.2 (Fig. 3.3c). We calculated the historical distance of our current study sites from the nearest historical forest edge, again considering only forest patches of at least 1 ha in area. Notably, historical distances to the forest edge were positive when the current farmland site was historically farmland (points C and D in Fig. 3.1), and negative when the current farmland site was historically forested (points A and B in Fig. 3.1). This way, we distinguished between "permanent" farmland sites (those historically also farmland) versus "converted" farmland sites (those historically forested; Table 3.1). Notably, for this study, all sampling sites were selected within current farmland (i.e. excluding the few instances where farmland had changed into forest; see Table 3.1).

Table 3.1 Overview of the surveyed 1 ha sites in terms of their current and historical landscape position relative to forest patches of at least 1 ha in size.

	Sites with current (2015) distance < 100m	Sites with current (2015) distance > 100m	Total
Sites with historical (1973) distance > 100m	9	16	25
Sites with historical (1973) distance < 100m	10	15	25
Sites historically (1973) inside the forest	10	12	22
Total	29	43	

We also considered other key environmental variables that we believed might affect woody plant richness and composition as co-variates, namely site-level forest cover (i.e. the current proportion of woody vegetation cover within the 1 ha circular site as a measure of available wooded habitat); a terrain wetness index; altitude; and the type of site (grazing versus arable site). The ASTER Digital Elevation Model (obtained from https://reverb.echo.nasa.gov/) was used to derive altitude and the wetness index (following Fischer et al. (2010)). All variables were calculated in ArcMap 10.2. These variables were not of primary interest but were included because they may account for additional variability in the data. An overview of the variables and their description is provided in Table 3.2.

Table 3.2 Definition and description of the explanatory variables used to model plant species richness.

Type	Variable	Definition and method
Fixed effect	Current distance	The distance in m of the centre of the site from nearest current (2015) forest edge (Fig. 3d)
	Historical distance	The distance in m of the centre of the site from nearest historical (1973) forest edge (Fig. 3c)
	Altitude	Altitude above sea level derived from the ASTER DEM
	Site forest cover	Proportion of woody vegetation cover within 1 ha study site calculated from classified RapidEye image (2015)
	Wetness index	Measure of potential soil wetness, estimated by the topographic position in the landscape and the slope (after Fischer et al. 2010)
	Land use type	Farmland use with two factors (i.e. arable land vs. grazing land)
Random effect	*Kebele*	Smallest administrative unit within which sites were nested
	Dummy	Observation level random effect to account for overdispersion

Statistical analysis

The analysis followed three steps. First, we investigated patterns in community composition. Second, we modelled total richness of all plant species combined (i.e. pooled), as well as richness of forest specialist, generalist and pioneer species in response to the explanatory variables (Table 3.2). Third, we examined site level population structure of all trees of forest specialist, generalist, and pioneer species in converted and permanent farmland by comparing DBH size class frequency distributions.

Species composition analysis

Using the presence-absence data of species in all study sites, we conducted non-metric multidimensional scaling (NMDS, with Bray-Curtis distance measure) to visualize general patterns of species composition. We tested if the study site scores correlated with historical distance, current distance, site forest cover, land use type, wetness index, altitude, and converted versus permanent farmland status, using the 'envfit' function in the 'vegan' package in R (Oksanen et al. 2017).

Species richness models

We used generalized linear mixed effects models (GLMMs) with a Poisson error structure to investigate the effects of current distance, historical distance, site forest cover, land use type (arable versus grazing), wetness index and altitude on richness of (1) all woody species, (2) forest specialist species, (3) generalist species and (4) pioneer species. Our primary interest in these models was in the effects of current and historical distance, while other variables were included primarily to filter out unwanted variability. In all cases, we specified *kebele* (to

account for grouping in experimental units) and an observation-level dummy variable (to account for overdispersion) as random effects (Table 3.2). Prior to modelling, we checked for possible correlations among explanatory variables – all correlations were below 0.4. Furthermore, we log-transformed current distance and site forest cover to remove skew, and scaled all continuous variables to zero mean and unit variance to obtain standardized coefficients. We assessed the models using 'DHARMa', an R package for residual diagnostics of GLMMs that uses a simulation-based approach (Hartig 2016). Finally, to visualize effects, we predicted species richness values and their 95% confidence intervals in response to historical distance and current distance to the forest edge.

DBH size class distribution

As a proxy for site-level population structure, we investigated DBH size class distribution of (1) forest specialist tree species, (2) generalist tree species, and (3) pioneer tree species, using data pooled across sites. We compared the mean number of individuals per hectare across diameter classes in converted versus permanent farmland sites.

Results

Overview and species composition

A total of 110 (one unidentified) species of trees, shrubs and subshrubs, representing 48 families were recorded from all study sites (Table 3.S1). Non–metric multidimensional scaling (NMDS, two dimensional ordination; stress = 0.237) showed distinct locations occupied by forest specialist species when compared to generalist and pioneer species (Fig. 3.4a). Historical distance to forest was positively correlated with generalist and pioneer species, clustering in the more distant farmland sites (Fig. 3.4b). Forest specialist species were positively associated with higher altitudes (Fig. 3.4b).

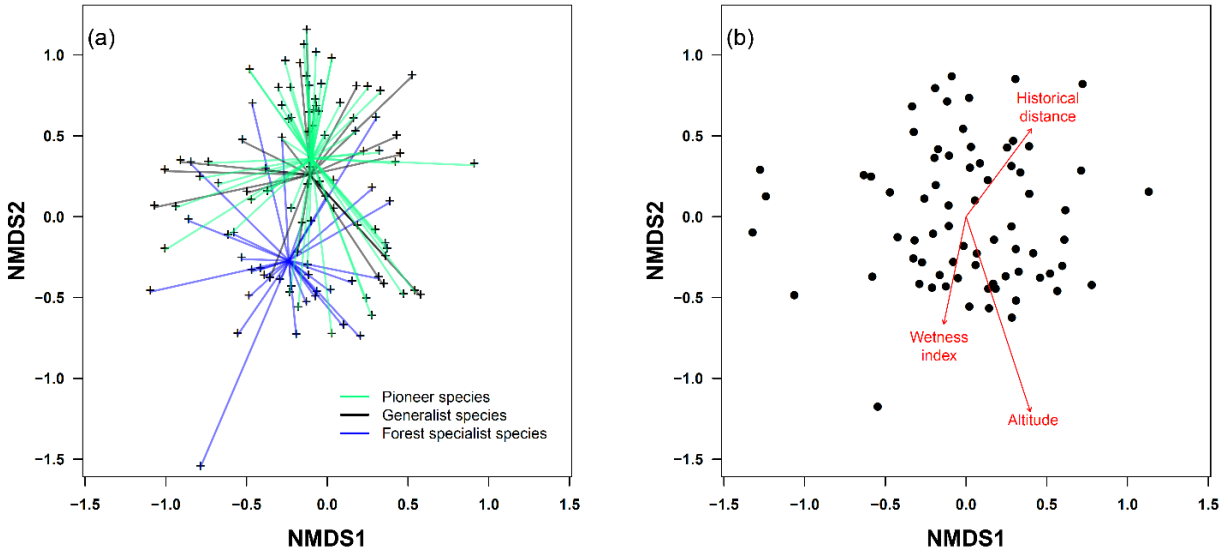


Figure 3.4 (a) Non-metric multidimensional scaling (NMDS, two-dimensional, stress = 0.237) of woody plant species (indicated by "+" sign) based on presence/absence data. Species were grouped according to guilds and connected to their guilds' centroid by lines: forest specialist species (blue lines), generalist species (black lines) and pioneer species (green lines). (b) NMDS ordination of all 72 study sites (black dots), superimposed by significantly correlated ($P < 0.05$) environmental variables (Table 3.2).

Species richness models

Richness of generalist and pioneer species – but not forest specialist species – increased with historical distance from the forest edge (Table 3.3; Fig. 3.5c, e). A lower richness of generalists was found in grazing land than in arable land (Table 3.3).

As expected, richness of all species groups was positively related to the amount of forest cover available at a site (Table 3.3). Richness of all species combined and pioneer species declined with topographic wetness, and altitude was negatively related to all species combined, generalist and pioneer species richness (Table 3.3).

Table 3.3 Results of generalized linear mixed effects models for total plant species richness, forest specialist species richness, pioneer species richness and generalist species richness. Predictor terms are continuous except for land use type. Coefficient for land use type indicates the difference between grazing and arable land, with arable land being the reference level. Significance levels are indicated by: *P < 0.05; **P < 0.01; ***P < 0.001.

Response	Term	Coefficient	Standard error	*P*-value
All species richness	Intercept	2.506	0.068	<0.001 ***
	Historical distance	0.063	0.060	0.292
	Current distance	0.021	0.064	0.746
	Site forest cover	0.314	0.063	<0.001 ***
	Wetness index	-0.155	0.062	0.013 *
	Altitude	-0.192	0.065	0.003 **
	Land use type	-0.105	0.121	0.386
Forest specialist species richness	Intercept	0.843	0.168	<0.001 ***
	Historical distance	-0.153	0.153	0.316
	Current distance	0.029	0.100	0.769
	Site forest cover	0.391	0.106	<0.001 ***
	Wetness index	-0.014	0.098	0.890
	Altitude	0.238	0.149	0.110
	Land use type	0.071	0.209	0.734
Pioneer species richness	Intercept	1.649	0.087	<0.001 ***
	Historical distance	0.149	0.073	0.041 *
	Current distance	-0.034	0.081	0.674
	Site forest cover	0.239	0.077	0.002 **
	Wetness index	-0.232	0.080	0.004 **
	Altitude	-0.334	0.082	<0.001 ***
	Land use type	-0.008	0.164	0.961
Generalist species richness	Intercept	1.517	0.065	<0.001 ***
	Historical distance	0.132	0.059	0.026 *
	Current distance	0.038	0.063	0.541
	Site forest cover	0.332	0.057	<0.001 ***
	Wetness index	-0.107	0.062	0.085
	Altitude	-0.236	0.065	<0.001 ***
	Land use type	-0.276	0.137	0.043 *

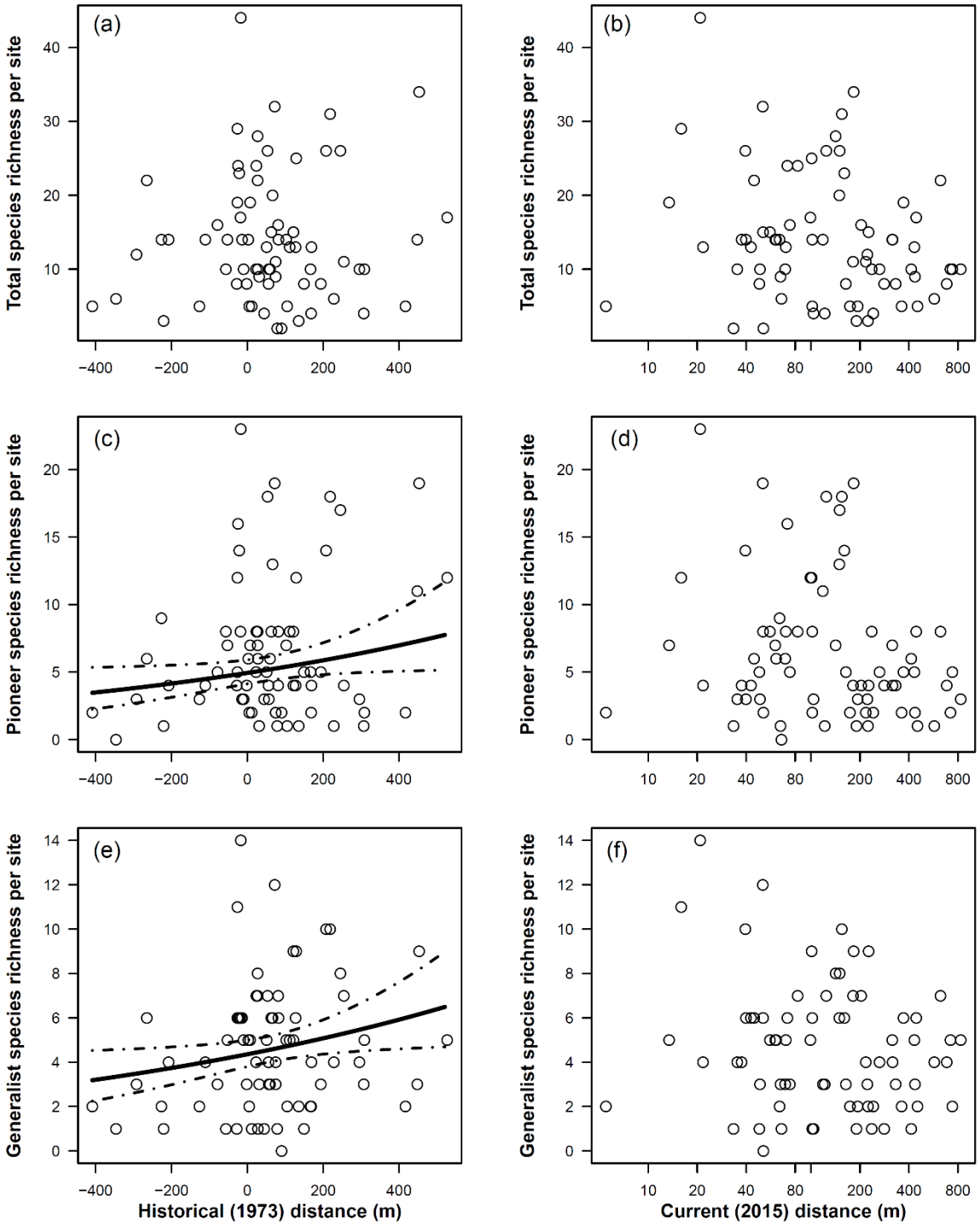


Figure 3.5 Effects of historical and current land use on the species richness of total species (panels (a) and (b)), pioneer species (panels (c) and (d)), and generalist species (panels (e) and (f)). Solid lines indicate model predictions for arable land while other variables were held constant at their means; dashed lines indicate 95% confidence intervals. The x-axes display original values but all distances are scaled and current distances are on a logarithmic scale.

DBH size class distribution

The site level population structure of different species of forest specialists – but not generalist and pioneer species – differed between recently converted versus permanent farmland (Fig. 3.6a-f). In converted farmland, trees of forest specialist species were represented with many individuals in the lowest DBH classes and a few individuals in the highest class (Fig. 3.6a). Permanent farmland also had many young individuals, but hosted slightly fewer large individuals (Fig. 3.6b). Generalist and pioneer species generally were represented with a relatively large number of small individuals followed by a gradual decrease in individuals towards higher size classes – with diameters following an inverted J-shaped distribution in both converted and permanent farmland (Fig. 3.6c, d, e, f).

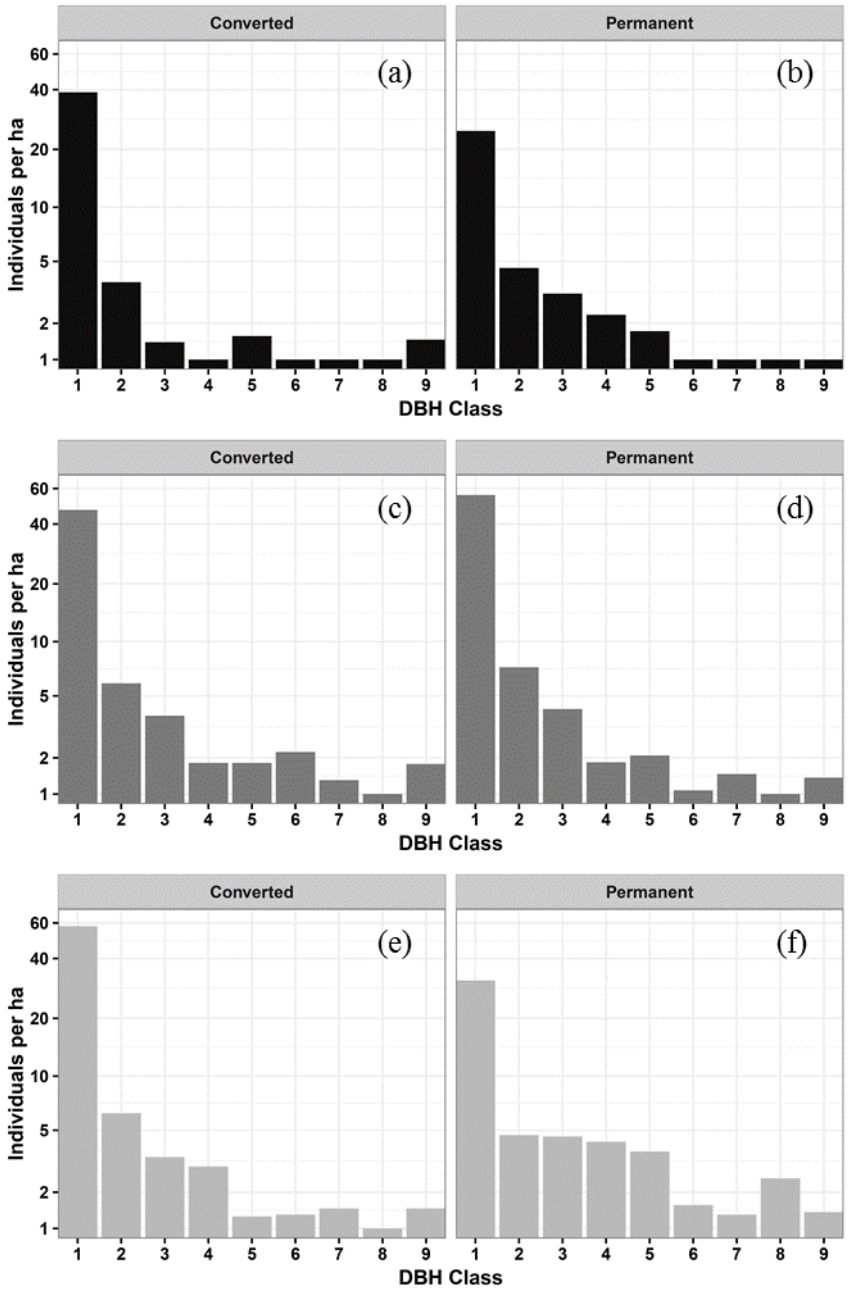


Figure 3.6 Diameter at breast height (DBH) size class distribution of individuals/ha of (a) and (b) trees of forest specialist species; (c) and (d) generalist species; and (e) and (f) pioneer species in converted and permanent land use, respectively. The y-axes display original densities on a logarithmic scale. DBH classes are 1 < 5 cm; 2 = 5.1-10 cm; 3 = 10.1-20 cm; 4 = 20.1-30 cm; 5 = 30.1-40 cm; 6 = 40.1-50 cm; 7 = 50.1-60 cm; 8 = 60.1-70 cm and 9 > 70 cm.

Discussion

Delayed effects pose a major challenge to conservation because they can be easily overlooked (Kuussaari et al. 2009; Jackson and Sax 2010; Hylander and Ehrlén 2013). Focusing on a biodiverse region characterised by dynamic changes in forest and farmland cover, we found evidence of past land use legacy effects, with statistically significant effects of historical land cover variables on richness of generalist and pioneer species.

We found only partial confirmation of our first hypothesis, that present-day land use structures – including grazing land vs. arable land, and current distance from the forest edge – influenced woody plant species richness, composition and distribution. Only generalist species richness was affected by farmland type. In contrast, our second hypothesis – that legacy effects of historical land use would influence woody plant species – was largely confirmed. We identified significant relationships between historical distance and richness of generalist and pioneer species. However, unexpectedly, no association was found between forest specialist species richness and historical distance from the forest edge. The dominant legacy effect identified through this second hypothesis thus was that of an immigration credit, rather than extinction debt.

Our third hypothesis – that diameter size distributions would show legacy effects – had only weak support. As compared to permanent farmland, recently converted farmland had slightly more large relict forest trees, which may be interpreted as a site-level extinction debt. In contrast, the site-level population structure for trees of other groups of species was close to what might be expected for natural populations in both converted and permanent farmland sites. In the following, we discuss these findings in relation to the concepts of extinction debt versus immigration credit, and we try to explain what may have led to these delayed effects of land cover change.

Regarding extinction debts, we found only weak support for forest specialist species (see above). This suggests that whatever extinction debt exists for forest species appears to be rapidly "paid off" after conversion of forest to farmland. A possible driver may be farmers' management practices. Farmers in the same landscapes were previously found to have removed big trees selectively to create open fields and reduce damage of crop raiding wild mammals, which may use big trees for shelter (Ango et al. 2014). Similarly, farmers may also be discouraged from retaining big forest species on their farmland by conservation policies that

prohibit using the wood of many native species (Lemenih and Kassa 2014). The few remaining older forest trees that we recorded in farmland can therefore be expected to soon disappear.

Surprisingly, we found substantial evidence of immigration credits in farmland. Immigration credits were identified for generalist and pioneer species richness. We interpret this finding in relation to three ideas – possible nurse tree effects in increasingly old farmland, the development of a novel ecosystem, and subsequently, the gradual evolution of a cultural landscape.

A nurse tree effect describes the process by which an existing tree facilitates the establishment, survival, and growth of colonizers through improved microclimatic conditions, increased water and nutrient availability, protection against herbivory, provision of shelter for seed-dispersing birds and mammals, and sometimes attraction of pollinators (Feyera et al. 2002; Bruno et al. 2003; Padilla and Pugnaire 2006). For example, in Ethiopia plantations of exotic trees had a nurse effect for the establishment and growth of various native plants (Feyera et al. 2002; Telila et al. 2015). Similarly, invasion of weed plants was facilitated by a native nitrogen-fixing shrub in California coastal prairie (Maron and Connors 1996). Nurse tree effects might also be assisted by deliberate (e.g., in some Oromo landscapes people preserve and protect *Ficus* trees (Getahun 2016)) or inadvertent human actions, because the colonizing species involved often have associations with human disturbance (Sax and Brown 2000). Through time, human actions combined with a small number of trees planted or retained in farmland thus could provide a nurse tree function to other species – resulting in an accumulation of species through time, and thus explaining the positive effect on species richness of increasingly isolated old farmland sites.

Possibly facilitated by nurse tree processes, changes in tree communities with historical distance could thus signal the development of "novel ecosystems" (Milton 2003; Hobbs et al. 2006; Hobbs et al. 2009). Novel ecosystems are characterized by new combinations of species, often including a mixture of native, introduced and planted species. For example, land-use change has resulted in novel bird species assemblages in Australia (Lindenmayer et al. 2008), new associations of native and non-native perennial plants in tropical agroforestry systems (Ewel 1999), including in southwestern Ethiopia (Jara et al. 2017; Hylander and Nemomissa 2017). Moreover, novel ecosystems are characterized by altered potential ecosystem functions and human agency – that is, they result from deliberate or unintentional human action (Hobbs et al. 2006). Novel ecosystems may be considered as threats to the structures, coherence and identity of existing landscapes (Antrop 2005), but also as opportunities for their potential to

deliver new sets of benefits, both ecologically and socially – as shown, for example, for a novel forest ecosystem on Ascension Island (Wilkinson 2004). Concerns about novel ecosystems should be viewed in terms of their sustainability, and questions of its relative value in terms of the ecosystem functions and services provided or lost (Hobbs et al. 2006). For instance, nutrient cycling rates do not necessarily depend on particular species in a particular location and, hence, substitution of one species by another may have limited impact – resulting, in this context, in no measurable consequence for ecosystem functioning (Ewel and Putz 2004). By contrast, the location of particular species in particular places should, by definition, be a key consideration of what to conserve or restore and where, and thus remains a key focus of conservation policies (Hobbs et al. 2009).

Assuming that species-rich farmland (especially adjacent to traditional coffee farming practices (e.g., Gove et al. 2008; Hylander and Nemomissa 2008; Jara et al. 2017) is more desirable than species-poor farmland, one may also consider that the observed immigration credit of trees in farmland signals the gradual emergence of a unique, species-rich cultural landscape. Cultural landscapes are places where people have interacted with and shaped nature over long periods of time (Plieninger et al. 2006). They are characterized by a stable and distinct identity, a system of sustainable land uses, and their biodiversity typically mirrors a complex history of compositional and structural change (Phillips 1998; Farina 2000; Antrop 2005). Recognizing this, biodiversity conservation in cultural landscapes is an important conservation paradigm in the developed world, particularly in Europe, and especially after devastating landscape changes following the industrial revolution (Vos and Meekes 1999; Déjeant-Pons 2006; Wright et al. 2012). In Europe, the appreciation of cultural landscapes is based on society's demand for multi-functionality, interest and engagement of farmers, support from national and local authorities, and finally, decentralization of landscape ruling and legislation, which favours regional solutions (Vos and Meekes 1999). Against this backdrop, our results serve as a potential warning sign for obvious changes already taking place in Ethiopia, and suggest an urgent need for new approaches to biodiversity conservation across entire landscape mosaics. Key properties underpinning the biodiversity values of cultural landscapes include a diversity of land covers and their spatial heterogeneity (Dorresteijn et al. 2015). To the best of our knowledge, the idea of thinking about agricultural landscapes as cultural landscapes is poorly established in Africa, but our findings suggest this idea deserves further consideration.

Conservation implications

Through the use of satellite imagery and field data, we revealed biodiversity effects of current and historical land use for landscapes in southwestern Ethiopia. Our study showed distinct legacy effects, most notably an immigration credit in farmland for generalist and pioneer species richness and composition. Such legacy effects can lead to novel species combinations and novel ecosystems, which may be seen as a threat to the structure, coherence and identity of existing systems; or as an opportunity for the development of sustainable cultural landscapes. To safeguard valuable biodiversity in agricultural landscapes of southwestern Ethiopia and other similar parts of the globe, we suggest to: (1) broaden the focus of conservation policies to encompass the entire landscape mosaic including both forest and farmland; (2) manage agricultural landscapes as a cultural landscape, actively fostering species diversity; (3) consider possible benefits of maintaining forest specialist species in the farmland mosaic, both for human use and biodiversity conservation; and (4) harness research opportunities that existing yet rapidly disappearing traditional farming systems provide to understand social-ecological dynamics.

Acknowledgements

The study was funded through a European Research Council (ERC) Consolidator Grant to Joern Fischer. We sincerely thank all farmers, and the *kebele*, *woreda*, zonal and Oromia regional authorities for their permission and support of our research. We thank field assistants and drivers for their support. We also thank two anonymous reviewers for constructive suggestions that greatly helped us to further improve our manuscript.

Data accessibility

All data used for the analysis are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.1kd43s5.

Supplementary Material for Chapter 3

Table 3.S1. List of tree, shrub and subshrub species encountered in all 72 studied farmland plots, their local names, their category (forest specialists, pioneers and generalists species) and the number of sites they occurred at.

Species name	Local name	Family name	Species category	Habit	Species occurrence (nr. of sites)
Abutilon longicuspe Hochst. ex A. Rich.	Inchinii daalacha	MALVACEAE	Pioneer	Shrub	1
Acacia abyssinica Hochst. ex Benth.	Laafto/Sondii adii/dimaa	FABACEAE	Pioneer	Tree	27
Acacia polyacantha Subsp. *campylacantha* (Hochst. ex A. Rich.) Brenan	Sondii dimaa/adii	FABACEAE	Pioneer	Tree	11
Acanthus eminens C.B.Cl.	Baalan-waraantee	ACANTHACEAE	Forest	Shrub	1
Acanthus sennii Chiov.	Sookoruu	ACANTHACEAE	Generalist	Shrub	17
Albizia gummifera (J. F. Gmel.) C.A. Sm.	Ambabeessa	FABACEAE	Generalist	Tree	18
Albizia schimperiana Olivo	Ambabeessa adii	FABACEAE	Generalist	Tree	29
Allophylus abyssinicus (Hochst.) Radikofer	Seehoo	SAPINDACEAE	Forest	Tree	9
Annona senegalensis Pers.	Liba-barree	ANNONACEAE	Pioneer	Shrub to tree	1
Apodytes dimidiata E. Mey. ex Arn.	Wandabiyoo	ICACINACEAE	Forest	Tree	7
Aspilia africana (Pers.) Adams	Hadaa adii	ASTERACEAE	Pioneer	Subshrub	8
Bersama abyssinia Fresen.	Lolchiisaa	MELIANTHACEAE	Forest	Tree	28
Bridelia micrantha (Hochst.) Baill.	Minaanduloo	EUPHORBIACEAE	Pioneer	Small tree	9
Brucea antidysenterica J.F. Mill.	Qomanyoo/Booqqoo	SIMAROUBACEAE	Forest	Shrub to tree	34
Calpurnia aurea (Ait.) Benth.	Cheekaa	FABACEAE	Pioneer	Small tree	12
Canthium oligocarpum Subsp. *oligocarpum* Hiern.	Baal-sadii	RUBIACEAE	Forest	Shrub to tree	3
Celtis africana Burm. f.	Qayii	ULMACEAE	Generalist	Tree	13
Clausena anisata (Willd.) Benth.	Ulmaayii	RUTACEAE	Generalist	Shrub to tree	9
Clerodendrum myricoides (Hochst.) Vatke	Maraasissaa/Agoo/Urgessaa/Xaaxesaa	LAMIACEAE	Pioneer	Shrub	13
Clutia abyssinica Jaub. & Spach.	Harchumee	EUPHORBIACEAE	Pioneer	Subshrub	1
Coffea arabica L.	Buna	RUBIACEAE	Forest	Small tree	9
Combretum molle R. Br. ex G. Don	Adajaboo	COMBRETACEAE	Pioneer	Tree	6
Cordia africana Lam.	Waddeessa	BORAGINACEAE	Generalist	Tree	28
Crotalaria exaltata Polhill	Bilbiilee	FABACEAE	Pioneer	Shrub	3
Crotalaria sp.	Qomanyoo	FABACEAE	Pioneer	Shrub	3
Croton macrostachyus Del.	Bakaniissa/Makkanniisa	EUPHORBIACEAE	Pioneer	Medium tree	49
Discopodium penninervium Hochst.	Reejii araba	SOLANACEAE	Generalist	Shrub to tree	13
Dombeya torrida (J. F. Gmel.) P. Bamps	Daannisa	STERCULIACEAE	Pioneer	Shrub to tree	5
Dracaena fragrans (L.) Ker Gawl.	Eemoo	DRACAENACEAE	Forest	Shrub to tree	3
Dracaena steudneri Engl.	Bubiftuu/Yubdoo	DRACAENACEAE	Forest	Shrub to tree	5
Ehretia cymosa Thonn.	Ulaagaa	BORAGINACEAE	Generalist	Shrub to tree	19
Ekebergia capensis Sparrm	Orooroo/Somboo	MELIACEAE	Forest	Tree	7
Elaeodendron buchananii (Loes) Loes.	Lookkoo/Bosoqqa	CELASTRACEAE	Generalist	Medium tree	4
Embelia schimperi Vatke	Haanku	MYRSINACEAE	Pioneer	Shrub or tree	1
Entada abyssinica Steud. ex A. Rich.	Hambaltaa	FABACEAE	Pioneer	Tree	10

Erythrina abyssinica Lam. ex DC.	Waleensuu	FABACEAE	Pioneer	Tree	4
Erythrina brucei Schweinf.	Beroo	FABACEAE	Pioneer	Tree	1
Erythrococca abyssinica Pax	Agabaatee	EUPHORBIACEAE	Generalist	Shrub	1
Fagaropsis angolensis (Engl.) Milne	Qomanyoo	RUTACEAE	Forest	Tree	1
Ficus exasperata Vahl.	Baalan-soofii	MORACEAE	Pioneer	Small tree	4
Ficus ovata Vahl	Qelenxoo	MORACEAE	Generalist	Small tree	1
Ficus sp.	Maxuuxii/Tinii	MORACEAE	Pioneer	Small tree	2
Ficus sur Forssk.	Harbu/Harbu adii	MORACEAE	Generalist	Medium tree	20
Ficus sycomorus L.	Odaa	MORACEAE	Pioneer	Medium tree	1
Ficus thonningii Blume	Dambii	MORACEAE	Generalist	Small tree	4
Ficus vasta Forssk.	Qilxu	MORACEAE	Pioneer	Medium tree	8
Flacourtia indica (Burm.f) Merr.	Akuukuu	FLACOURTIACEAE	Generalist	Small tree	14
Galiniera saxifraga (Hochst.) Bridson	Mixoo-saree/Simararuu/Simararuu dimaa	RUBIACEAE	Forest	Small tree	11
Gardenia ternifolia Schumach. & Thonn.	Gaambelaa	RUBIACEAE	Pioneer	Small tree	3
Grewia ferruginea Hochst. Ex A. Rich.	Laankanoo	TILIACEAE JUSS.	Pioneer	Shrub	8
Hibiscus diversifolius Jacq.	Inchinii dimaa	MALVACEAE	Pioneer	Shrub	3
Hypericum revolutum Vahl	Ulee-foonii	GUTTIFERAE	Pioneer	Small tree	1
Ilex mitis (L.) Radlk.	Qetoo/Kefoo	AQUIFOLIACEAE	Forest	Medium tree	1
Indigofera arrecta Hochst. ex A. Rich.	Henaa/Enaa	FABACEAE	Pioneer	Shrub	7
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Dhummugaa	ACANTHACEAE	Generalist	Shrub	12
Lantana trifolia L.	Kusaayyee	VERBENACEAE	Pioneer	Shrub	1
Leonotis ocymifolia (Burm. f) Iwarsson	Kan hinbekamine	LAMIACEAE	Pioneer	Shrub	1
*Lepidotrichilia volkensii (*Giirke) Leroy	Seehoo	MELIACFAE	Forest	Tree	1
Lippia adoensis Hochst. ex Walp.	Kusaayyee	VERBENACEAE	Pioneer	Shrub	5
Macaranga capensis (Baill.) Sim	Wongoo	EUPHORBIACEAE	Forest	Tree	3
Maesa lanceolata Forssk.	Abbayyii	MYRSINACEAE	Generalist	Tree	42
Maytenus arbutifolia (A. Rich.) Wilczek	Ombooroo/Kombolcha	CELASTRACEAE	Generalist	Shrub	30
Maytenus gracilipes (Welw. ex Oliv.) Exell	Ombooroo/Kombolcha	CELASTRACEAE	Forest	Shrub	8
Maytenus senegalensis (Lam.) Exell	Kombolcha guraacha/Ombooroo	CELASTRACEAE	Pioneer	Shrub	9
Maytenus sp.	Qoraatii	CELASTRACEAE	Generalist	Shrub	1
Millettia ferruginea (Hochst.) Bak.	Astiraa	FABACEAE	Forest	Small tree	27
Nuxia congesta R.Br. ex Fresen.	Qachama	LOGANIACEAE	Forest	Small tree	1
Ocimum lamiifolium Hochst. ex Benth.	Damaakkase	LAMIACEAE	Pioneer	Shrub	4
Ocimum urticifolium Roth	Kefoo qamu/Kefoo qamalee	LAMIACEAE	Pioneer	Shrub	13
Olea welwitschii (Knobl.) Gilg & Schellenb.	Bayaa	OLEACEAE	Forest	Tree	1
Pentas schimperiana Subsp. *schimperiana* (A. Rich.) Vatke	Simararuu	RUBIACEAE	Pioneer	Shrub	3
Phoenix reclinata Jacq.	Meexxii	ARECACEAE	Pioneer	Tree	13
Phyllanthus mooneyi M Gilbert	Qachama	EUPHORBIACEAE	Pioneer	Subshrub	11
Phyllanthus reticulatus Poir	Qachama	EUPHORBIACEAE	Pioneer	Shrub	1
Phytolacca dodecandra L'Herit.	Andoodee	PHYTOLACCACEAE	Pioneer	Scrambling shrub	4
Piliostigma thonningii (Schumach.) Milne-Redh.	Leeluu	FABACEAE	Pioneer	Tree	1
Pittosporum viridiflorum Sims	Soolee/Soolee adii	PITTOSPORACEAE	Forest	Small tree	3
Plectranthus sp.	Toogoo/Teejoo	LAMIACEAE	Generalist	Trailing shrub	3
Podocarpus falcatus Mirb.	Birbirsa	PODOCARPACEAE	Forest	Tree	2
Polyscias fulva (Hiern) Harms	Daraku/Kariyoo	ARALIACEAE	Forest	Medium tree	2
Pouteria adolfi-friederici (Engl.) Baehni	Qararoo	SAPOTACEAE	Forest	Tree	1

Premna schimperi Engl.	Maraasisaa/Urgesaa	LAMIACEAE	Pioneer	Small tree	5
Prunus africana (Hook. f.) Kalkm.	Oomoo	ROSACEAE	Forest	Small tree	13
Rhamnus prinoides L'Herit.	Geeshee	RHAMNACEAE	Pioneer	Shrub	23
Rhus ruspolii Engl.	Xaaxesaa	ANACARDIACEAE	Pioneer	Shrub	7
Ritchiea albersii Gilg	Agabaatee/Hadhessaa dhalaa	CAPPARIDACEAE	Pioneer	Small tree	2
Rothmannia urcelliformis (Hiern) Robyns	Mixoo	RUBIACEAE	Forest	Small tree	2
Rytigynia neglecta (Hiern) Robyns	Mixoo	RUBIACEAE	Forest	Shrub	15
Sapium ellipticum (Krauss) Pax	Seeddoo/Bosoqqa	EUPHORBIACEAE	Generalist	Medium tree	7
Sarcocephalus latifolius (Smith) Bruce	Diboo	RUBIACEAE	Pioneer	Small tree	5
Schefflera abyssinica (Hochst. ex A. Rich.) Harms	Gatamaa	ARALIACEAE	Forest	Medium tree	1
Senna occidentalis (L.) Links	Salaamakii dimaa	FABACEAE	Pioneer	Shrub	13
Senna petersiana (Bolle) Lock	Salaamakii adii/Sootaloo	FABACEAE	Pioneer	Shrub	12
Senna sp.	Salaamakii araba	FABACEAE	Pioneer	Shrub	7
Solanecio gigas (Vatke) C. Jeffrey	Doomboorokoo	ASTERACEAE	Pioneer	Shrub	1
Solanecio mannii (Hook. f) C. Jeffrey	Haamitii baloo	ASTERACEAE	Forest	Small tree	2
Stereospermum kunthianum Cham.	Bootoroo	BIGNONIACEAE	Pioneer	Small tree	11
Syzygium guineense Subsp. *guineense* F. White	Baddeessa	MYRTACEAE	Forest	Medium tree	7
Teclea nobilis Del.	Hadhessaa mixirii	RUTACEAE	Forest	Small tree	2
Terminalia laxitlora Engl. & Diels	Dabaqaa	COMBRETACEAE	Pioneer	Tree	3
Trichilia dregeana Sond.	Anuunuu	MELIACEAE	Forest	Tree	1
Unidentified sp.	Mixoo	RUBIACEAE	Generalist	Unidentified	2
Vernonia adoensis Sch. Bip. ex Walp.	Turujee/Sooyyama	ASTERACEAE	Pioneer	Shrub	16
Vernonia amygdalina Del.	Ibicha	ASTERACEAE	Generalist	Shrub	46
Vernonia auriculifera Hiern.	Reejii	ASTERACEAE	Pioneer	Shrub	65
Vernonia bipontini Vatke	Sooyyama/Qaawulee	ASTERACEAE	Pioneer	Shrub	4
Vernonia hochstetteri Sch. Bip. ex Walp.	Xasee/Qaawulee/Sooyyama	ASTERACEAE	Pioneer	Shrub	9
Vernonia leopoldi (Sch. Bip. ex Walp.) Vatke	Qaawulee	ASTERACEAE	Pioneer	Shrub	2
Vernonia sp.	Xasee dimaa	ASTERACEAE	Generalist	Shrub	1
Vernonia thomsoniana Olivo & Hiern ex Oliv.	Sooyyama	ASTERACEAE	Pioneer	Shrub	11

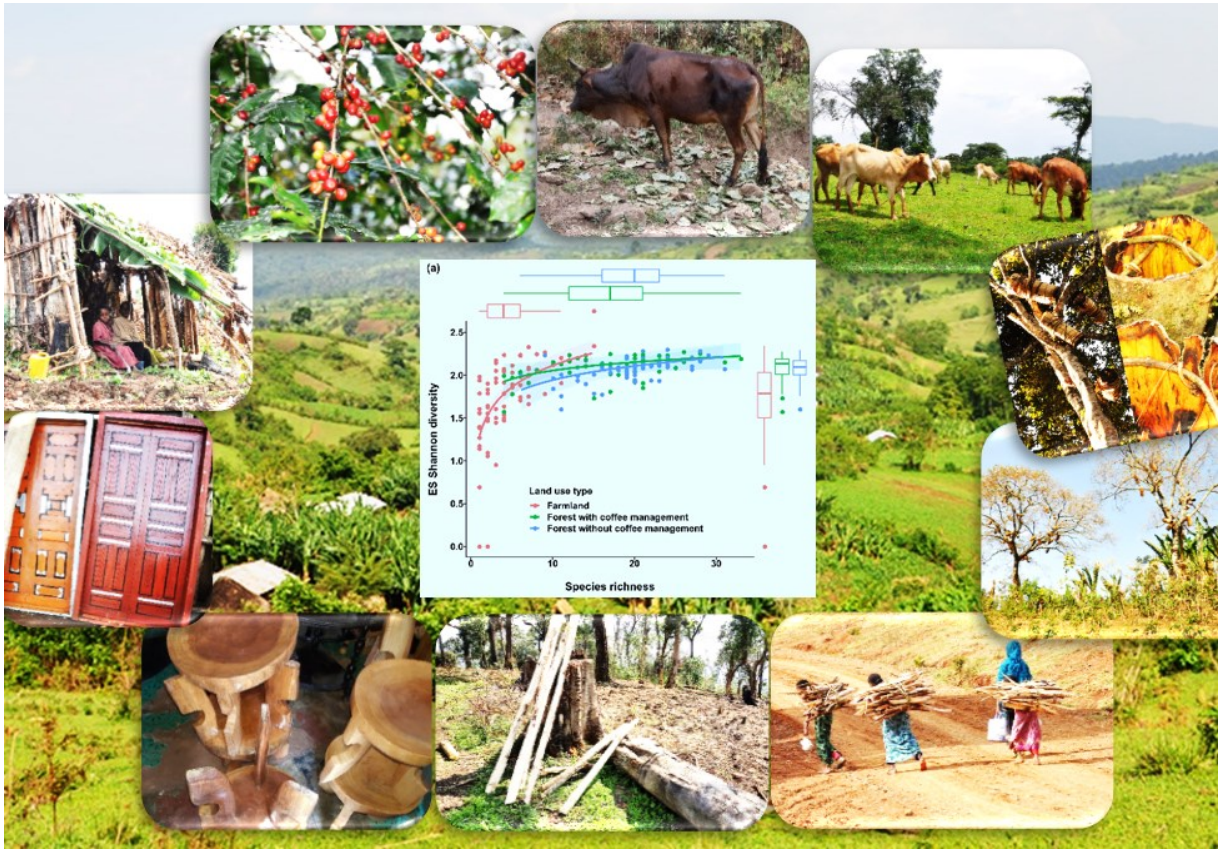
Chapter 4

Chapter 4

Woody plant species diversity as a predictor of ecosystem services in a social-ecological system of southwestern Ethiopia

Girma Shumi, Jannik Schultner, Patrícia Rodrigues, Jan Hanspach, Werner Haerdtle, Kristoffer Hylander, Feyera Senbeta and Joern Fischer

Manuscript submitted to Landscape ecology



Abstract

Context: Human-dominated landscapes in the tropics need to be managed both for biodiversity conservation and for the provision of ecosystem services (ES). Nevertheless, identifying effective strategies for both biodiversity conservation and ES management still remains a challenge.

Objectives: The objectives of this study were to quantify woody plant species diversity and multiple ES in forests and farmland, and investigate the relationship between woody species diversity and ES diversity in these land use types.

Methods: The study was conducted in southwestern Ethiopia. We surveyed woody plants in 181 randomly selected 20 m by 20 m plots, and we interviewed 180 randomly selected households about woody plant benefits. We then (a) quantified woody plant species diversity and ES diversity in the survey plots; and (b) investigated the relationship between woody plant species diversity and ES diversity.

Results: We recorded 128 woody plant species. Most ES were available in all land uses, although they differed in their mean availability. ES diversity was positively related with woody plant species diversity in all land uses, particularly so in farmland.

Conclusions: Our findings suggest that all examined land use types were multifunctional, and that maintaining high woody plant species diversity strongly benefits ES diversity, particularly in agroecosystems. Given these findings, we suggest to: (1) promote landscape multifunctionality via appropriate policies and management incentives, especially in farmland; and (2) expand mixed-data, social-ecological research on the relationship between ES diversity and biodiversity.

Keywords: Biodiversity conservation; Ecosyste service diversity; Human wellbeing; Land management; Landscape sustainability; Multifunctionality

Introduction

The ecosystem services (ES) framework has become an important tool to link biodiversity conservation and human wellbeing (Díaz et al. 2015), especially since the Millennium Ecosystem Assessment (MA 2005a). A fundamental tenet of this framework is that biodiversity and ecosystem functions are positively related to the provision of ecosystem goods and services to human societies (e.g. Peterson et al. 1998; Cardinale et al. 2011; Isbell et al. 2011; Brockerhoff et al. 2017), and that their protection should be an important priority in times of global shifts in environmental conditions (Isbell et al. 2015; Hisano et al. 2018). Biodiversity thus is not only important in its own right, but also because of its direct links to human wellbeing (e.g. Fisher et al. 2014).

Nevertheless, identifying effective solutions in real-world landscapes for combining biodiversity conservation and ES management remains challenging (Díaz et al. 2006; IPBES 2018). Through coining 'landscape sustainability science', Wu (2013) framed how the delivery of multiple ES to human societies could be maintained in human-modified landscapes through the management of key landscape attributes, including patches of native vegetation. Managing landscapes for biodiversity and ES is important particularly in the 'global south', where local people directly depend on nature's contribution for their basic livelihoods (e.g. food, fuelwood, water, and shelter; see Rasmussen et al. 2017; Reed et al. 2017). However, deforestation and forest degradation is an ongoing problem in many regions, with severe consequences on ecosystems and biodiversity (Gibson et al. 2011; Kennedy et al. 2013; Barlow et al. 2016). Tropical forest ecosystems, for instance, were lost at an annual rate of 5.5 million hectares from 2010 to 2015 (Keenan et al. 2015), and native forest species with high conservation and functional value often suffer from negative effects of human use and forest disturbances (Barlow et al. 2016; Rodrigues et al. 2018; Shumi et al. 2019). In addition to this, agroecosystems in many regions also harbour important biodiversity, but have received less attention in the conservation arena (Perfecto and Vandermeer 2008; Wright et al. 2012; Shumi et al. 2018).

Tackling biodiversity loss in the global south and elsewhere via successful integration of biodiversity and ES management needs further understanding of actual biodiversity-ES diversity relationships. Yet, empirical data that examine how biodiversity relates to the provision of multiple ES in different land use types across real landscapes remains scarce (Mitchell et al. 2015; Eigenbrod 2016; Brockerhoff et al. 2017). With the exception of some

theoretical and experimental explorations (e.g. Maestre et al. 2012; Gamfeldt et al. 2013; Allan et al. 2015), few studies have systematically examined biodiversity-ES diversity relationships across gradients of land use intensity within human-modified landscapes, which is arguably where such relationships matter most. Additionally, most biodiversity-ES diversity studies to date have considered the effects of species diversity on individual ES (Schwartz et al. 2000; Cardinale et al. 2012; Lefcheck et al. 2015), despite the fact that real-world ecosystems are typically managed for multiple ES (Hector and Bagchi 2007; Eigenbrod 2016). In some instances, studies have also suffered from a disparity between the assessed ES and the actual ES people depend on in a specific landscape (Balvanera et al. 2014; Díaz et al. 2018). As a result, important aspects of biodiversity and its association with multiple ES in a given landscape may be overlooked, with potential negative repercussions for effective conservation management (Gamfeldt et al. 2008; Wu 2013; Eigenbrod 2016).

In this study, we investigated the relationship between woody plant species diversity and ES diversity across land use gradients in a landscape in southwestern Ethiopia. The region comprised a mosaic of different land use types, including forest ecosystems (forest with and without coffee management), smallholder farmland (primarily arable land and pastures), and to a lesser extent shade coffee patches, homegardens and settlement areas. The forest in the study area is under acute pressure from rapidly expanding agriculture and settlements (Tadesse et al. 2014b; Getahun et al. 2017) as well as ongoing forest disturbances (Rodrigues et al. 2018; Shumi et al. 2019). The smallholder agroecosystems also support high biodiversity (see Engelen et al. 2016; Gove et al. 2008; Hylander and Nemomissa 2008), but have been largely overlooked in existing conservation strategies (Shumi et al. 2018). Notwithstanding these conservation challenges, local people strongly depend on multiple ES provided by the forest-agriculture mosaic for their day-to-day livelihoods (Ango et al. 2014; Dorresteijn et al. 2017).

Against this background, we collected ecological and social data on woody plant species and the ES provided by different species. More specifically, we linked social data on local people's multiple benefits obtained from woody plant species with ecological data on woody plant species (presence, abundance and size) occurring in farmland (arable land and grazing) and forest (with and without coffee management). The aims of the study were to:

(a) Quantify woody plant species diversity and multiple ES in three land use types: in forest with coffee management, in forest without coffee management, and in farmland; and
(b) Investigate the relationship between woody plant species diversity and ES diversity in these three land use types.

We hypothesized that (1) different land use types provide different ES profiles, and (2) woody plant species diversity is positively related with multiple ES in all three land use types. Both hypotheses have possible implications for the protection of biodiversity and the provision of multiple ES, which is vital for long-term wellbeing in human-dominated landscapes.

Methods

Study area

The study was conducted in a smallholder-dominated landscape, within which we focused on six *kebeles* (the smallest administrative unit in Ethiopia) located in the Gera, Gumay and Setema districts of Jimma Zone, Oromia Regional State, southwestern Ethiopia (Fig. 4.1). The study *kebeles* comprised a mosaic of land use types, with forest cover ranging from 11 to 84 %, while arable land, grazing land and settlements accounted for the rest. The human population of the study *kebeles* ranged from 3230 to 9975 people per *kebele* (Dorresteijn et al. 2017). The largest ethnic group in the study area is the Oromo, while Amhara, Kefficho and Tigre people are minorities.

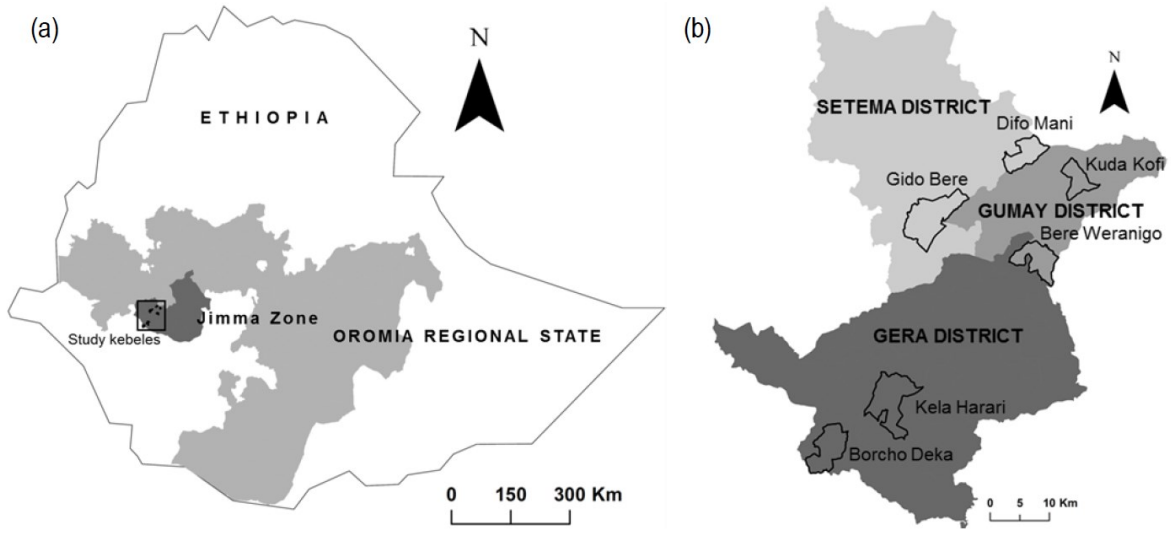


Figure 4.1 Location of (a) study area (square) in Ethiopia, Oromia Regional State, Jimma Zone; (b) the six kebeles: Difo Mani and Gido Bere in Setema district, Bere Weranigo and Kuda Kofi in Gumay, and Borcho Deka and Kela Harari in Gera.

The natural vegetation in the study area has been classified as moist evergreen Afromontane forest (Friis et al. 2010). Dominant tree species in the forest include *Olea welwitschii*, *Pouteria adolfi-friederici*, *Schefflera abyssinica*, *Prunus africana*, *Albizia* spp., *Syzygium guineense*, and *Cordia africana* (Cheng et al. 1998). The study area is part of the centre of origin and diversity of *Coffea arabica*, and still harbours the gene pool of wild coffee

populations (Anthony et al. 2002). It is also a part of the Eastern Afromontane Biodiversity Hotspot (Schmitt 2006; Mittermeier et al. 2011). The study area comprises undulating slopes and flat plateaus, with elevation ranging from 1500 to 3000 m above sea level. It has a warm moist climate within the inter-tropical convergence zone, with 1500-2000 mm of annual rainfall, and a 20 °C mean annual temperature. Annual rainfall patterns are unimodal, with a wet season peak from June to September (Friis et al. 2010; Schmitt et al. 2013; Ango 2016).

The dominant land cover types were forest with and forest without coffee management, and farmland (i.e. primarily arable and grazing land). All land, including forest, is owned by the government (FDRE 1995). Customary forest use rights are in place in some locations to manage forest for honey and coffee production (Wakjira and Gole 2007). Crop-based agricultural land management in the area began in the mid-19th century and has become a major driver of land use change since the 1970s in particular (Kassa et al. 2016). Smallholder agriculture including crops and livestock is the main source of livelihoods. Coffee and to a lesser degree honey are economically important non-timber forest products in the area.

Data collection

Woody plant survey

We surveyed woody plants from November 2015 to January 2016, and April to May 2017. Prior to woody plant surveys, using ArcGIS 10.2, we determined the proportion of farmland and forest within each *kebele* using a land cover map generated via supervised image classification of a RapidEye satellite image from 2015. We then randomly selected 181 20 m by 20 m plots (72 in farmlands, 46 in forests with coffee management and 63 in forests without coffee management) distributed across the six *kebeles* (22 to 42 plots per *kebele*).

In each plot, all individuals of tree and shrub species with a height ≥ 1.5 m were recorded. We also measured the diameter at breast height (DBH) of all individuals with DBH ≥ 5 cm and identified them to the species level in the field. For species that were difficult to identify in the field, specimens were collected, pressed, dried and transported to the National Herbarium at Addis Ababa University for identification. Nomenclature follows the Flora of Ethiopia and Eritrea (1989-2006).

Data on ES

To generate data on multiple ES, we combined the ecological data collected as described above with social data. Social data were collected through a household survey from February to March 2017 in the same study area. Here, we interviewed 180 randomly selected households and assessed the use and preference of woody plant species for 11 purposes. These purposes were: fuelwood, fencing material, farm implements, honey production, house construction, household utilities, poles and timber, medicine, animal fodder, shade for coffee cultivation, and soil fertility maintenance. The selection of these purposes was based on a pilot study and existing literature (Wakjira and Gole 2007; Ango 2016). Local people sourced these benefits from forest with and without coffee management and farmland.

We then used the following datasets to generate data on multiple ES: (1) woody plant species presence, abundance and DBH recorded per plot; (2) the list of woody plant species reported to be used for each purpose, i.e. the benefit local people actually experience and depend on, inferred from household surveys (see Table 4.S1); and (3) reasonable diameter thresholds, that is, the minimum size an individual woody plant species needs to attain to be useful for a particular purpose (e.g. an individual of a species needs to attain ≥ 5 cm DBH to be useful for house wall and roof construction; Table 4.1). Using this information, we developed a woody plant species presence-ES matrix, and determined the ES available in each plot surveyed for woody vegetation. In this matrix, we assigned "1" in the column of a given purpose (hereafter ecosystem service) for an individual of a species present in a given plot, if (a) the species was reported to be used by local people for that service, and (b) the individual of this species met the size threshold criteria for service; we otherwise assigned "0" if these criteria were not fulfilled. For example, a survey plot may have had three individuals of *Cordia africana* (e.g. one with 5 cm DBH, one with 9 cm, and one with 20 cm). We knew from the household survey that *Cordia africana* was used by local people for poles and timber (as well as other ES; see Table 4.S1); and we had set a size threshold of 10 cm DBH for species to be useful as "poles and timber". Hence, in this case, we noted two times "0", and one time "1" in the column "poles and timber" for *Cordia africana* in this plot (i.e. only one individual fulfilled the criteria for the ES poles and timber). *Cordia africana* was also used for the ES "fuelwood" (Table 4.S1), but without a size threshold (Table 4.1). We thus noted three times "1" in the fuelwood column for this species in this plot (i.e. all individuals fulfilled the criteria for the ES fuelwood). We followed this procedure for every individual of every woody species recorded in each plot, for each of the 11 ES considered. Summing the individuals in a given plot for a

given service thus gave the number of individual woody plants that provided a particular ES in a given plot (see also de Groot et al. 2010; Burkhard et al. 2012). Notably, this method provides an inventory of the potential ES provisioning of a given plot, rather than the actual provisioning – for example, a plot with a lot of firewood present may not actually be used for firewood collection; and a plot with a lot of coffee shade trees may not actually be used to grow shade coffee.

Table 4.1 List of uses of woody plants, including description and threshold size. This list was used to determine the ES provided in each survey plot. Note that only suitable tree/shrub species were considered for each purpose.

Use/purpose		Description	Threshold
House construction	**House wall and roof construction**	Wood used for wall and roof construction	DBH ≥ 5 cm
	Wall and roof fixing	Small wood used for fixing wall and roof	Any size (can be split)
Farm implements	**Handle**	Wood used as beam handle for ploughing	DBH 5-10 cm
	Yoke	Wood used as yoke for ploughing	DBH 10-30 cm
	Beam	Wood used as beam for ploughing	DBH 10-20 cm (can be prepared)
Fuelwood	**Firewood and charcoal**	Parts (leaf, bark or wood) of trees/shrubs used for cooking, lighting and heating	Any size (can be split)
Honey production	**Beehive making**	Small wood used for making or fixing the wall of beehives	DBH < 5 cm
		Wood or bark used for making beehives	DBH > 20 cm (can be prepared)
	Beehive hanging	Intermediate and large/old trees/shrubs preferred for beehive hanging	DBH > 20 cm
	Bee forage	Shrub/small trees suitable for bee forage	Any size
		Large/old trees suitable for bee forage	DBH > 10 cm
Fence	**Live fence**	Living trees/shrubs serving as fence	Any size
	Dead wood fence	Wood used for fencing	Any size
Medicine		Parts (leaf, bark or wood) of trees/shrubs used for healing human or animals	Any size
Coffee shade		Small planted trees/shrubs providing coffee shade	DBH ≥ 5 cm
		Retained or planted trees/shrubs that can serve as coffee shade	DBH > 10 cm
Household utilities		Wood used to make small household utilities or tools	DBH > 10 cm
Soil fertility		Trees/shrubs contributing to soil fertility	Any size
Animal fodder		Parts (leaf, twigs or bark) of trees/shrubs used as animal fodder	Any size
Poles and timber		Wood used for poles and timber	DBH ≥ 10 cm

Data analysis

The analysis followed three steps. First, we quantified woody plant species diversity in different land use types. Second, we examined the type and mean extent of ES provided by each land use type. Third, we investigated woody plant species diversity-ES diversity relationships in the three land use types.

Woody plant species diversity

We determined species richness and the Shannon diversity index (based on species presence and abundance) for a given plot in each land use type. We chose to quantify both species richness and Shannon diversity (defined according to Spellerberg and Fedor (2003)) because both are widely used and provide meaningful measures of species diversity (Lande 1996). We also illustrated the cumulative species richness within a land use type using plot-level species accumulation curves.

Multiple ES

Prior to ecosystem service analyses, we first determined the abundance of each ecosystem service from the woody plant species-ES matrix (see above). Second, we standardized each ecosystem service to values between 0 and 1 by dividing the abundance of a given ecosystem service in a given plot by its maximum abundance found within the entire study area (i.e. across all land use types). We then determined the mean extent of each ecosystem service provided by each land use type. Finally, we determined the 'ES Shannon diversity index' per plot. This index allows for an assessment of the multifunctionality of a given plot, and thus of land use types (Plieninger et al. 2013).

Relationship between biodiversity and ES diversity

We used linear mixed effects models with a Gaussian error distribution structure to investigate the relationship between: (i) ES Shannon diversity in response to species richness, and (ii) ES Shannon diversity in response to species Shannon diversity. In both cases, we also fitted land use type as an additional explanatory variable. We log-transformed the variable species richness to account for its skewed distribution. We used '*kebele*' as a random factor in the models to account for grouping in experimental units. Finally, to visualise the modelled relationships, we predicted and plotted ES Shannon diversity values and their 95% confidence intervals in response to species richness and species Shannon diversity for each land use.

Results

Woody plant diversity

We identified 128 woody plant species (with one unidentified specimen at species level, and with six planted exotic species), representing 43 families in the 181 plots analysed (Table 4.S2). Of these, 11% occurred exclusively in farmland, 10% in forest without coffee management and 7% in forest with coffee management (Fig. 4.2a). Of all species, 72% occurred in more than one land use type (Fig. 4.2a). Species accumulation curves illustrated that forests with and without coffee management had a similar increase in cumulative species richness (Fig. 4.2b). As expected, farmland had a lower species richness and more gradual increase in cumulative species richness than forests (Fig. 4.2b).

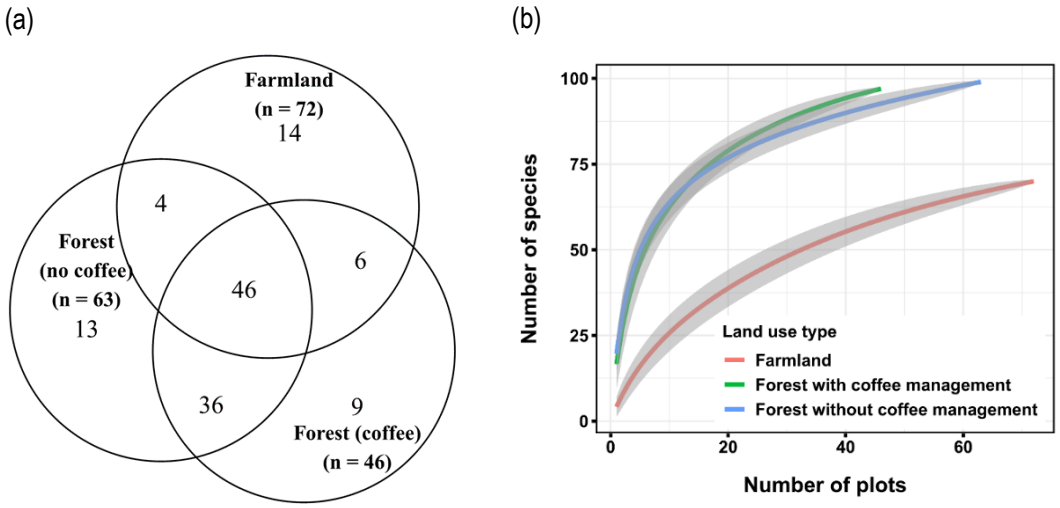


Figure 4.2 (a) Number of woody plant species that occurred exclusively in or was shared by the different land use types, namely, farmland, forest (coffee) = forest with coffee management, and forest (no coffee) = forest without coffee management. (b) Species accumulation curves in the three land use types, where shaded areas indicate 95% confidence intervals.

Ecosystem service provision

Almost all ES were provided by all land use types, although their mean abundance value differed (Fig. 4.3). Mean provisioning of house construction, fuelwood, and honey production ES were the highest within forest with coffee management, while household utilities, potential coffee shade species, fencing materials and poles and timber ES were most readily available within forest without coffee management (Fig. 4.3) (evidently, potential coffee shade species were not actually used for coffee cultivation in this environment). Conversely, mean provisioning of fencing materials, fuelwood and house construction were higher than other

services in farmland, but mean values for fencing materials and house construction here were still lower than in forests (Fig. 4.3).

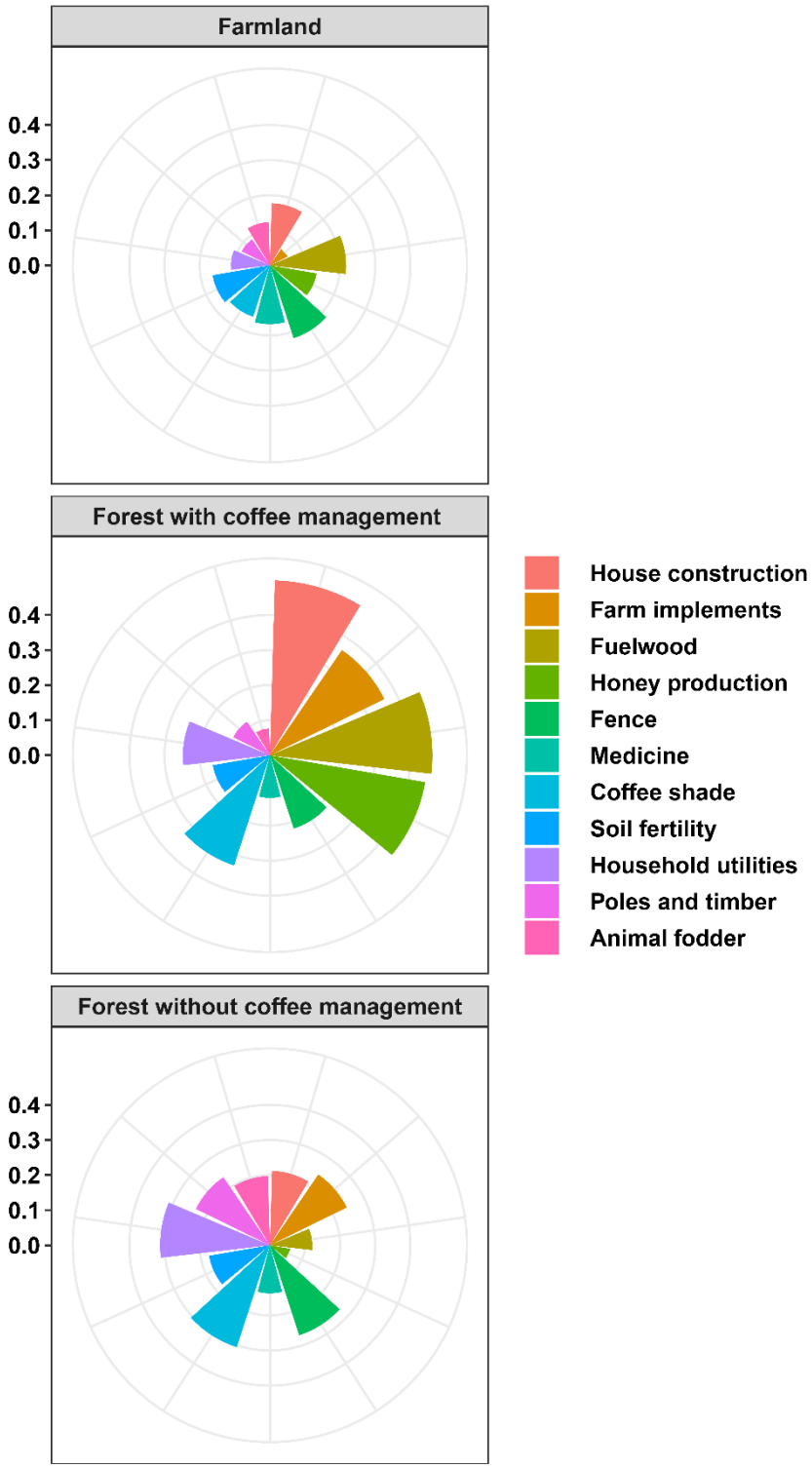


Figure 4.3 Type and mean values of ecosystem services in farmland (arable land and grazing land), forest with coffee management, and forest without coffee management. Note that each ecosystem service was determined based on people's actual use of woody plant species and their presence in each land use type in the study area.

Relationships between ES diversity and woody plant species diversity

ES diversity was positively related to woody plant species diversity in all land use types, typically with higher values of ES diversity in forests than in farmland (Table 4.2; Fig. 4.4a, b). However, there were also significant interaction effects between land use type and both species richness and species Shannon diversity (Table 4.2). ES Shannon diversity significantly increased with species richness in farmland and in forest with coffee management, but, for a given level of species richness, ES diversity increased more rapidly in farmland than in forest with coffee management (Table 4.2; Fig. 4.4a). More specifically, ES diversity decreased strongly when the species richness was lower than 10 species in farmland. For all sites with species richness of approximately 10 or more, relatively little ES diversity was added to a given site. Similarly, the ES Shannon diversity significantly increased with species Shannon diversity in all land use types, but, for a given level of species diversity, ES diversity increased more rapidly in farmland than in forests (Table 4.2; Fig. 4.4b). That is, multifunctionality increased only very slowly in both forest types, while the increase in ES diversity was significantly steeper in farmland; in other words a low species diversity had higher ES diversity in coffee forests than in farmland (Fig. 4.4a, b).

Table 4.2 Results of linear mixed effects models for ES Shannon diversity. Predictor terms are continuous except for land use types. The coefficient for land use type indicates the difference between farmland, forest with coffee management, and forest without coffee management, with farmland being the reference level. Significance levels are indicated by: * where P < 0.05, ** where P < 0.01, *** where P < 0.001.

Response	Term	Coefficient	Standard error	P-value
ES Shannon diversity	Intercept	1.275	0.063	<0.001 ***
	Forest with coffee management	0.453	0.206	0.029 *
	Forest without coffee management	0.121	0.301	0.688
	Species richness	0.364	0.039	<0.001 ***
	Forest with coffee management : Species richness	-0.222	0.082	0.007 **
	Forest without coffee management : Species richness	-0.126	0.107	0.240
	Intercept	1.353	0.063	<0.001 ***
	Forest with coffee management	0.498	0.112	<0.001 ***
	Forest without coffee management	0.383	0.183	0.038 *
	Species Shannon diversity index	0.411	0.051	<0.001 ***
	Forest with coffee management : Species Shannon diversity	-0.228	0.082	0.006 **
	Forest without coffee management : Species Shannon diversity	-0.246	0.093	0.009 **

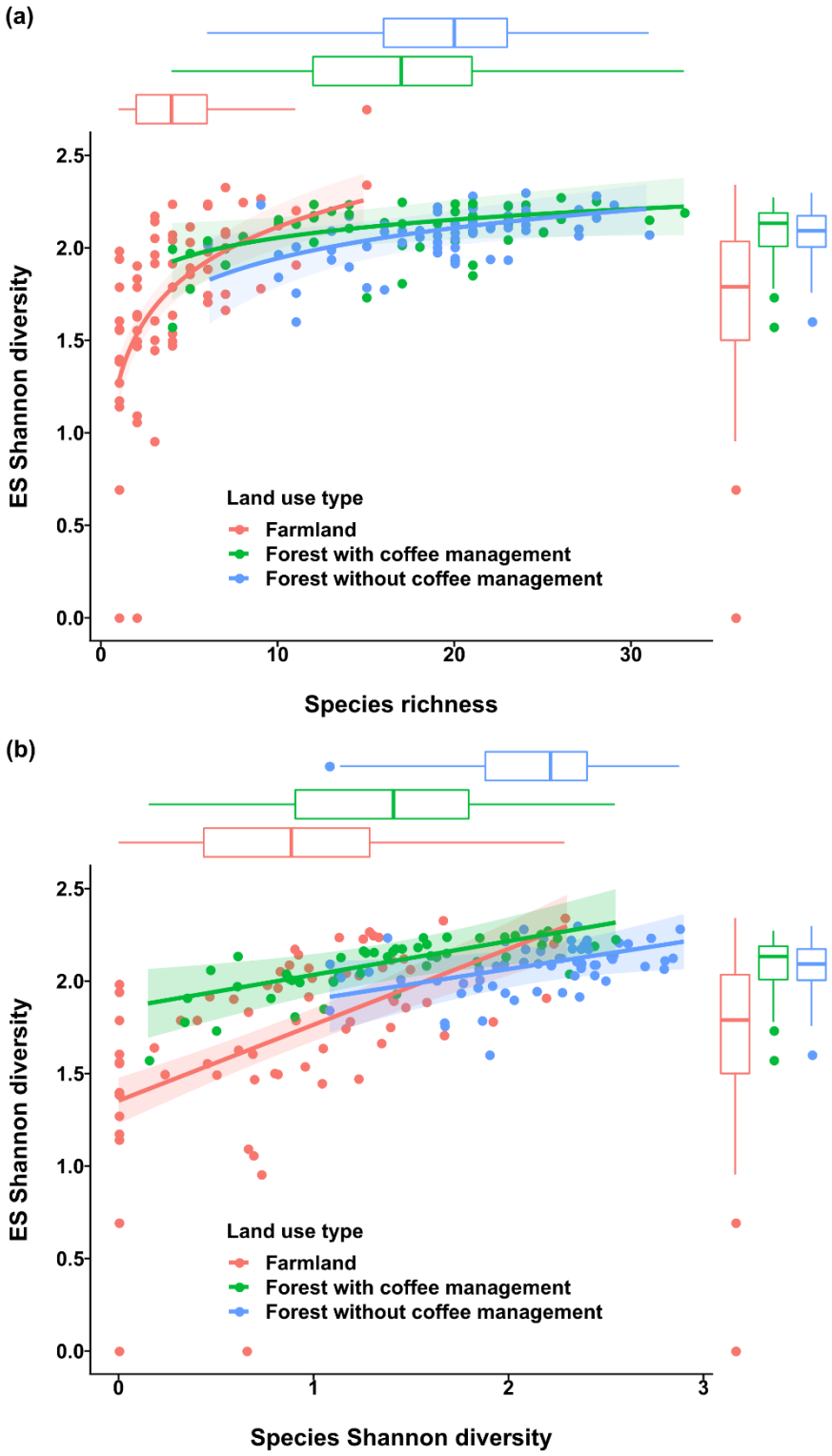


Figure 4.4 Relationship between (a) woody plant species richness and ES Shannon diversity, and (b) species Shannon diversity and ES Shannon diversity, in farmland (red line and box), forest with coffee management (green line and box), and forest without coffee management (blue line and box). Regression lines represent the predicted ES Shannon diversity and shaded areas their 95% confidence intervals for each land use.

Discussion

Most theoretical and experimental studies to date have assessed biodiversity and ES relationships by relating species diversity patterns to ecosystem functions or processes (e.g. see Díaz et al. 2003; de Groot et al. 2010; Trogisch et al. 2017), rather than to actual ES. In other instances, assessed ES have differed from those that people actually depend upon in a specific landscape (Balvanera et al. 2014; Díaz et al. 2018). Moreover, although many landscapes are managed for multiple ES (Hector and Bagchi 2007; Eigenbrod 2016), several existing studies have focused on individual ES (Schwartz et al. 2000; Cardinale et al. 2012). Here, using extensive field data on ES that people actually depend on together with data on woody plant species from different land use types, we documented the existence of landscape multifunctionality and a positive relationship between ES diversity and woody plant species diversity.

With respect to our first hypothesis – i.e. that different land use types provide different ES profiles – we found landscape multifunctionality in all three assessed land use types, but with higher availability of ES in forests. A possible reason for such multifunctionality could be that the management of the overall land mosaic targets both the fulfilment of multiple human needs as well as the safeguarding of key landscape attributes (Forman 1990; Wu 2013). Such multifunctionality contrasts with highly industrialized agricultural landscapes, such as those illustrated by Foley et al. (2005), which are typically managed for maximum provisioning of a very small range of services. In our case study area, according to empirical findings by Jiren et al. (2017), many local people favoured multifunctionality-oriented integrated land management, rather than wishing to segregate biodiversity conservation and ES management. Furthermore, landscape multifunctionality through biodiversity management may have evolved historically, particularly in the farmland sections of the landscape, as indicated by a high woody plant species richness in old farmland found in one of our earlier studies (Shumi et al. 2018). Multifunctional land use, which is currently practised in study area, has clear parallels with recent recommendations for sustainable land use (Kremen and Merenlender 2018), and mirrors patterns of multifunctionality in European cultural landscapes such as in Central Romania (Hanspach et al. 2014). Our finding of higher presence/abundance of multiple ES in forests than in farmland is likely to be due to the higher species richness and abundance of woody plants in forests. This is consistent with other studies (e.g. Gamfeldt et al. 2013; Brockerhoff et al. 2017), which showed that the quantity of ES in forests typically increases with tree species richness and abundance.

Consistent with our second hypothesis – i.e. that woody plant species diversity was related to ES diversity – we confirmed a positive relationship between these two variables in all three land use types. Our empirical findings agree with models (e.g. Peterson et al. 1998; Cardinale et al. 2011) and experimental studies (e.g. Tilman et al. 2006; Letourneau et al. 2011; Isbell et al. 2011; Liang et al. 2016) that illustrate positive biodiversity-ES diversity relationships. In our study, the increase in ES diversity was steeper in farmland than in forests, suggesting two different aspects of multifunctionality of farmland (see above) in addition to agricultural production. First, high ES diversity in species-rich farmland sites suggests that maintaining farmland biodiversity can be important to enhance the supply of multiple ES in farmland, as noted elsewhere (e.g. Isbell et al. 2017a). Second, low ES diversity in species-poor farmland sites suggests that a loss of woody plant species diversity – for example due to shifts in land management or external drivers such as climate change – could cause a decrease in multiple ES provisioning (Peterson et al. 1998; Naeem et al. 2002), with possible consequences for the wellbeing of local people (Allan et al. 2015). Notably, ES diversity in farmland was lower than in sites with similar species diversity in coffee forests. This implies that farmland has a higher dominance of certain species (providing the same ES) and is less actively managed for multifuntionallity than coffee forests. This parallels examples where intensified farming, as compared to diversified agroecosystems, reduced ES supply (Kremen and Miles 2012; Allan et al. 2015). Especially in the face of external shocks, such as extended droughts or severe weather events (Bergengren et al. 2011; Moat et al. 2017; Sintayehu 2018), maintaining diversified agroecosystems could be important for sustainable ES supply (e.g. Isbell et al. 2015; Isbell et al. 2017a).

Compared to farmland, ES diversity increased less steeply in forests with additional woody plant species being present, suggesting a high level of functional redundancy in forests. Such redundancy indicates that the functional consequences that are related to a loss of woody plant species may (at least partly) be mitigated by other species; conversely, the addition of more woody plant species to the already diverse forest system may contribute only little to increase multifunctionality. Such redundancy of species in highly species-rich systems has been noted in models and experimental studies (e.g. Peterson et al. 1998; Naeem et al. 2002; Cardinale et al. 2012). Maintaining functional redundancy can be valuable to enhance system resilience to multiple drivers of landscape change (Naeem and Li 1997; Yachi and Loreau 1999; Ives et al. 2000; Loreau et al. 2003), including climate change (e.g. Isbell et al. 2015; Isbell et al. 2017a; Hisano et al. 2018).

Implications for sustainability

There is a growing interest to commodify landscapes along the lines of "sustainable intensification" (e.g. Tilman et al. 2011; Mueller et al. 2012; Godfray and Garnett 2014). However, optimizing landscapes for effective production irrespective of local context can inadvertently degrade landscape multifunctionality, leading to unfavourable environmental and local livelihood consequences (Tscharntke et al. 2012; Loos et al. 2014). In contrast to widespread calls for intensification, which focus on a few crops only, our study underlines the benefits of landscape multifunctionality for both people and biodiversity. In line with the idea of landscape sustainability (Wu 2013), we encourage the strengthening of efforts that manage landscapes for both biodiversity and ES. Multifunctional smallholder landscapes, as the one documented here, harbour high biodiversity and supply a diverse set of ES. The maintenance of such landscapes, in turn, can circumvent the potentially costly restoration of ES after intensification – a situation that many previously industrialised landscapes in the Global North now face (Foley et al. 2005; Kremen and Merenlender 2018).

Conclusion

By combining data on woody plant species and ES that people depend upon, we documented landscape multifunctionality and positive ES diversity-biodiversity relationships in southwestern Ethiopia. Our study showed multifunctionality in both farmland and forest, as well as a strong link between woody plant species diversity and ES diversity, particularly in farmland areas of the landscape. We suggest (1) to promote policies that recognize local needs and strengthen landscape multifunctionality by drawing on the positive relationship between biodiversity and ES diversity, and (2) to conduct further social-ecological studies that use mixed data to elicit socially relevant relationships between biodiversity and ES diversity.

Acknowledgements

The study was funded through a European Research Council (ERC) Consolidator Grant (FP7-IDEAS-ERC, Project ID 614278) to J. Fischer (SESyP). We thank the Governments of Ethiopia and Oromia Regional State for their permission to conduct the research. We also thank the staff of the different woreda and kebele offices and the local farmers for their cooperation. We thank field assistants and drivers for their support.

Supplementary Material for Chapter 4

Table 4.S1 List of woody plant species benefiting local people; number of purposes that a species serves; list of uses of a species. Purpose: 1 = house construction, 2 = farm implements, 3 = fuelwood, 4 = honey production/beehives, 5 = fences, 6 = medicine, 7 = coffee shade, 8 = household utilities, 9 = soil fertility, 10 = animal fodder, 11 = poles and timber, and 12 = other uses (e.g. beehive smoking, walking stick, cleaning). "x" denotes a benefit, "-" a lack thereof.

Species name	No. of uses of a species	Use											
		1	2	3	5	5	6	7	8	9	10	11	12
Abutilon longicuspe	3	X	x	-	x	-	-	-	-	-	-	-	-
Acacia abyssinica	6	X	-	X	x	-	-	x	-	x	x	-	-
Acacia polyacantha	4	X	-	X	x	-	-	x	-	-	-	-	-
Albizia gummifera	7	X	-	X	x	-	-	x	x	x	-	-	x
Albizia schimperiana	7	X	-	X	x	-	-	x	x	x	-	-	x
Allophylus abyssinicus	6	X	x	X	-	x	x	-	x	-	-	-	-
Apodytes dimidiata	4	X	x	-	x	-	-	-	x	-	-	-	-
Aspilia africana	1	-	-	X	-	-	-	-	-	-	-	-	-
Bersama abyssinia	3	X	-	X	-	-	x	-	-	-	-	-	-
Bridelia micrantha	2	-	-	-	-	x	x	-	-	-	-	-	-
Brucea antidysenterica	1	-	-	-	-	-	x	-	-	-	-	-	-
Calpurnia aurea	6	X	x	-	-	x	x	-	x	-	-	-	x
Cassipourea malosana	2	X	x	-	-	-	-	-	-	-	-	-	-
Celtis africana	6	-	x	X	-	x	x	-	x	-	x	-	-
Chionanthus mildbraedii	3	X	x	-	-	x	-	-	-	-	-	-	-
Clausena anisata	5	X	x	-	-	x	x	-	-	-	-	-	x
Clerodendrum myricoides	2	X	-	-	-	-	x	-	-	-	-	-	-
Coffea arabica	5	X	x	X	x	-	-	-	-	-	-	-	x
Cordia africana	8	X	x	X	x	-	-	x	x	x	-	x	-
Croton macrostachyus	9	X	x	X	x	x	x	x	x	x	-	-	-
Cupressus lustanica	7	X	x	X	-	x	-	-	x	-	-	x	x
Diospyros abyssinica	2	X	x	-	-	-	-	-	-	-	-	-	-
Dombeya torrida	1	-	-	X	-	-	-	-	-	-	-	-	-
Dracaena afromontana	1	-	-	-	-	-	-	-	-	-	x	-	-
Dracaena fragrans	2	-	-	-	-	x	-	-	-	-	x	-	-
Dracaena steudneri	4	-	-	-	-	x	-	x	-	x	x	-	-
Ehretia cymosa	5	X	x	X	-	x	-	-	x	-	-	-	-
Ekebergia capensis	6	X	x	X	x	-	-	-	x	-	-	x	-
Elaeodendron buchananii	6	X	x	X	x	x	-	x	-	-	-	-	-
Erythrina abyssinica	4	-	-	X	x	x	-	-	x	-	-	-	-
Erythrina brucei	5	-	-	X	x	x	x	-	-	x	-	-	-
Eucalyptus camaldulensis	6	X	x	X	x	x	-	-	x	-	-	-	-
Eucalyptus citriodora	6	X	x	X	x	x	-	-	x	-	-	-	-
Eucalyptus globulus	6	X	x	X	x	x	-	-	x	-	-	-	-
Euphorbia abyssinica	4	X	-	-	x	x	-	-	x	-	-	-	-
Fagaropsis angolensis	3	X	-	-	x	-	x	-	-	-	-	-	-
Ficus sur	7	-	-	X	x	-	-	x	x	x	x	x	-
Ficus vasta	7	X	x	X	x	-	-	x	x	x	-	-	-
Flacourtia indica	4	X	x	X	-	-	x	-	-	-	-	-	-
Galiniera saxifraga	3	X	x	-	-	-	-	-	-	-	x	-	-
Gardenia ternifolia	2	-	x	-	-	-	-	-	x	-	-	-	-
Grewia ferruginea	2	-	-	-	-	x	-	-	-	-	x	-	-
Hibiscus diversifolius	1	-	-	-	-	-	-	-	-	-	x	-	-
Ilex mitis	1	-	x	-	-	-	-	-	-	-	-	-	-
Indigofera arrecta	1	-	-	-	-	-	x	-	-	-	-	-	-
Justicia schimperiana	3	X	-	-	-	x	x	-	-	-	-	-	-
Lannea welwitschii	2	-	-	X	-	-	x	-	-	-	-	-	-
Macaranga capensis	4	X	x	X	-	x	-	-	-	-	-	-	-
Maesa lanceolata	7	X	-	X	-	x	x	x	-	x	x	-	-
Maytenus arbutifolia	2	-	-	X	-	x	-	-	-	-	-	-	-
Maytenus gracilipes	1	-	x	-	-	-	-	-	-	-	-	-	-
Millettia ferruginea	8	X	x	X	x	x	-	x	-	x	x	-	-
Mimusops kummel	4	X	x	-	-	-	-	x	-	-	-	-	X
Myrsine africana	3	X	-	-	x	x	-	-	-	-	-	-	-
Ocimum lamiifolium	1	-	-	-	-	-	x	-	-	-	-	-	-
Olea welwitschii	7	X	x	X	x	x	-	x	-	-	-	-	X
Oxyanthus speciosus	3	X	x	-	-	x	-	-	-	-	-	-	-
Phoenix reclinata	1	X	-	-	-	-	-	-	-	-	-	-	-
Pittosporum viridiflorum	2	X	-	-	-	-	-	-	-	-	-	-	X

Podocarpus falcatus	4	X	-	-	-	-	-	-	x	-	-	x	X
Polyscias fulva	4	X	x	-	x	-	-	-	-	-	-	x	-
Pouteria adolfi-friederici	8	X	x	X	x	-	-	x	x	x	-	x	-
Premna schimperi	1	X	-	-	-	-	-	-	-	-	-	-	-
Prunus africana	9	X	x	X	x	-	-	x	x	x	-	x	X
Psychotria orophila	3	X	-	-	-	x	-	-	-	-	x	-	-
Rhamnus prinoides	2	X	-	-	-	x	-	-	-	-	-	-	-
Ritchiea albersii	1	-	x	-	-	-	-	-	-	-	-	-	-
Rothmannia urcelliformis	2	-	x	-	-	x	-	-	-	-	-	-	-
Rytigynia neglecta	4	X	x	-	x	x	-	-	-	-	-	-	-
Sapium ellipticum	3	X	-	X	-	-	-	-	-	-	x	-	-
Schefflera abyssinica	4	-	x	-	x	-	-	x	-	x	-	-	-
Senna petersiana	1	-	-	-	-	x	-	-	-	-	-	-	-
Sesbania sesban	2	-	-	-	-	-	-	x	-	-	x	-	-
Solanecio mannii	1	-	-	-	-	-	x	-	-	-	-	-	-
Stereospermum kunthianum	2	-	x	-	x	-	-	-	-	-	-	-	-
Syzygium guineense	8	X	-	X	x	x	-	x	x	-	x	x	-
Teclea nobilis	2	-	x	-	-	-	-	-	-	-	-	-	X
Terminalia laxitlora	6	-	x	X	x	-	-	x	-	-	x	-	X
Vepris dainellii	1	-	x	-	-	-	-	-	-	-	-	-	-
Vernonia amygdalina	9	X	x	X	x	x	x	x	-	x	x	-	-
Vernonia auriculifera	8	X	x	X	x	x	x	x	-	x	-	-	-
Vernonia hochstetteri	1	-	-	-	x	-	-	-	-	-	-	-	-
Vernonia thomsoniana	6	X	-	X	x	x	x	-	-	x	-	-	-

Table 4.S2 List of woody plant species encountered in all 192 surveyed plots in different land use types (farmland, forest with and forest without coffee management), their scientific family and their local name, their category (forest specialist, pioneer, generalist or planted species), habit, number of sites they occurred in, and their abundance.

					Abundance and occurrence of species by land use type					
					Farmland		Forest with coffee management		Forest without coffee management	
Scientific name	**Family**	**Local name**	**Species category**	**Habit**	Occurrence (no. sites)	Abundance	Occurrence (no. sites)	Abundance	Occurrence (no. sites)	Abundance
Abutilon longicuspe	MALVACEAE	Inchinii daalacha	Pioneer	Shrub	0	0	1	3	1	3
Acacia abyssinica	FABACEAE	Sondii adii	Pioneer	Tree	12	38	2	2	0	0
Acacia polyacantha	FABACEAE	Sondii dimaa	Pioneer	Tree	3	19	0	0	0	0
Acanthus eminens	ACANTHACEAE	Baalan-waraantee	Forest specialist	Shrub	0	0	4	226	18	677
Alangium chinense	ALANGIACEAE	Daannisa	Pioneer	Tree	0	0	4	6	3	5
Albizia gummifera	FABACEAE	Ambabeessa	Generalist	Tree	3	27	11	62	22	249
Albizia schimperiana	FABACEAE	Ambabeessa adii	Generalist	Tree	14	53	18	48	11	44
Allophylus abyssinicus	SAPINDACEAE	See'oo	Forest specialist	Tree	1	2	8	133	33	99
Allophylus macrobotrys	SAPINDACEAE	Saahoo	Generalist	Tree	0	0	0	0	4	8
Apodytes dimidiate	ICACINACEAE	Wandabiyoo	Forest specialist	Tree	2	2	2	2	19	46
Aspilia africana	ASTERACEAE	Hadaa adii	Pioneer	Shrub	2	9	0	0	0	0
Bersama Abyssinia	MELIANTHACEAE	Lolchiisaa	Forest specialist	Tree	9	30	22	115	50	286
Bridelia micrantha	EUPHORBIACEAE	Minaanduloo	Pioneer	Small tree	3	13	1	8	0	0
Brucea antidysenterica	SIMAROUBACEAE	Qomanyoo	Forest specialist	Shrub to tree	12	51	13	59	22	98
Calpurnia aurea	FABACEAE	Cheekaa	Pioneer	Small tree	1	7	4	118	1	4
Canthium oligocarpum	RUBIACEAE	Baal-sadii	Forest specialist	Shrub to tree	0	0	7	40	27	73
Cassipourea malosana	RHIZOPHORACEAE	Ilke	Forest specialist	Tree	0	0	5	29	20	107
Celtis africana	ULMACEAE	Qayii	Generalist	Tree	2	5	17	91	8	34
Chionanthus mildbraedii	OLEACEAE	Gagamaa	Forest specialist	Tree	0	0	21	338	34	1188
Clausena anisate	RUTACEAE	Ulmaayii	Generalist	Shrub to tree	0	0	24	307	32	459
Clerodendrum myricoides	LAMIACEAE	Maraasissaa	Pioneer	Shrub	6	35	1	1	2	6
Coffea Arabica	RUBIACEAE	Buna	Forest specialist	Small tree	3	60	46	9683	32	323
Cordia africana	BORAGINACEAE	Waddeessa	Generalist	Tree	12	44	20	86	9	16
Crossopteryx febrifuga	RUBIACEAE	Unknown	Generalist	Tree	0	0	1	2	0	0
Crotalaria exaltata	FABACEAE	Bilbiilee	Pioneer	Shrub	0	0	1	1	0	0
Croton macrostachyus	EUPHORBIACEAE	Bakaniissa	Pioneer	Tree	21	140	27	83	35	271
Cupressus lustanica	CUPERESSACEAE	Gaatiraa faranjii	Planted	Tree	2	16	0	0	0	0
Dalbergia lacteal	FABACEAE	Unknown	Pioneer	Tree	0	0	2	2	3	13
Deinbollia kilimandscharica	SAPINDACEAE	Unknown	Forest specialist	Tree	0	0	0	0	2	2
Diospyros abyssinica	EBENACEAE	Lookkoo gurraacha	Forest specialist	Tree	0	0	9	42	3	16
Discopodium pennlnervium	SOLANACEAE	Reejii araba	Generalist	Tree	3	33	0	0	1	4
Dombeya torrida	STERCULIACEAE:	Daannisa	Pioneer	Shrub to tree	2	3	0	0	5	13
Dracaena afromontana	DRACAENACEAE	Algee	Forest specialist	Shrub	0	0	4	28	33	1222
Dracaena fragrans	DRACAENACEAE	Eemoe	Planted	Shrub to tree	0	0	8	231	11	743
Dracaena steudneri	DRACAENACEAE	Bubiftuu/Yubdoo	Forest specialist	Shrub to tree	2	4	6	18	9	32
Ehretia cymosa	BORAGINACEAE	Ulaagaa	Generalist	Shrub to tree	4	33	24	97	10	56
Ekebergia capensis	MELIACEAE	Orooroo	Forest specialist	Tree	2	2	2	4	6	18
Elaeodendron buchananii	CELASTRACEAE	Lookkoo	Generalist	Tree	1	5	18	39	12	138
Entada abyssinica	FABACEAE	Hambaltaa	Pioneer	Tree	2	3	2	2	0	0
Erythrina abyssinica	FABACEAE	Waleensuu	Planted	Tree	7	75	0	0	0	0
Erythrina brucei	FABACEAE	Beroo	Pioneer	Tree	16	221	1	1	1	1

Erythrococca abyssinica	EUPHORBIACEAE	Agabaatee	Generalist	Shrub	0	0	9	56	4	15
Erythrococca trichogyne	EUPHORBIACEAE	Qayii	Forest specialist	Small tree	0	0	9	98	13	114
Eucalyptus camaldulensis	MYRTACEAE	Baargamo dimaa	Planted	Tree	1	4	1	1	1	5
Eucalyptus citriodora	MYRTACEAE	Baargamo	Planted	Tree	1	1	0	0	0	0
Eucalyptus globulus	MYRTACEAE	Baargamo adii	Planted	Tree	2	100	0	0	0	0
Eugenia bukobensis	MYRTACEAE	Unknown	Forest specialist	Small tree	0	0	0	0	1	2
Euphorbia abyssinica	EUPHORBIACEAE	Adaamii	Pioneer	Tree	4	111	2	2	1	2
Fagaropsis angolensis	RUTACEAE	Qomanyoo	Forest specialist	Tree	0	0	7	25	2	3
Ficus exasperate	MORACEAE	Baalan-soofii	Pioneer	Small tree	1	3	2	3	1	7
Ficus glumosa	MORACEAE	Anuunuu (unknown)	Generalist	Tree	0	0	0	0	1	1
Ficus ovata	MORACEAE	Qelenxoo	Generalist	Small tree	0	0	1	1	0	0
Ficus sur	MORACEAE	Harbu	Generalist	Tree	3	15	9	34	19	65
Ficus thonningii	MORACEAE	Dambii	Generalist	Small tree	1	3	3	10	1	1
Ficus vasta	MORACEAE	Qilxu	Pioneer	Tree	1	1	2	2	1	1
Flacourtia indica	FLACOURTIACEAE	Akuukuu	Generalist	Small tree	2	5	3	7	6	10
Galiniera saxifrage	RUBIACEAE	Mixoo-sarer (Unknown)	Forest specialist	Small tree	0	0	16	89	49	586
Gardenia ternifolia	RUBIACEAE	Gaambelaa	Pioneer	Small tree	1	2	0	0	0	0
Grewia ferruginea	TILIACEAE	Laankanoo	Pioneer	Shrub	1	1	3	8	0	0
Hallea rubrostipulata	RUBIACEAE	Anuunuu	Forest specialist	Tree	0	0	1	2	1	2
Hibiscus diversifolius	MALVACEAE	Inchinii dimaa	Pioneer	Shrub	1	20	0	0	0	0
Hibiscus macranthus	MALVACEAE	Inchinii daalacha	Pioneer	Shrub	0	0	1	1	0	0
Hypericum revolutum	GUTTIFERAE	Ulee-foonii	Pioneer	Small tree	0	0	0	0	1	1
Ilex mitis	AQUIFOLIACEAE	Qetoo/Kefoo	Forest specialist	Tree	1	1	1	12	11	64
Indigofera arrecta	FABACEAE	Henaa/Enaa	Pioneer	Shrub	2	11	0	0	0	0
Justicia schimperiana	ACANTHACEAE	Dhummugaa	Generalist	Shrub	4	95	16	488	17	1079
Lannea schweinfurthii	ANACARDIACEAE	Booqqoo	Generalist	Tree	0	0	4	4	1	2
Lannea welwitschii	ANACARDIACEAE	Anuunuu	Forest specialist	Tree	0	0	2	3	0	0
Lepidotrichilia volkensii	MELIACEAE	Seehoo	Forest specialist	Tree	1	3	5	44	15	95
Macaranga capensis	EUPHORBIACEAE	Wongoo	Forest specialist	Tree	0	0	16	165	27	305
Maesa lanceolate	MYRSINACEAE	Abbayyii	Generalist	Tree	14	118	18	59	33	211
Manilkara butugi	SAPOTACEAE	Gawoo	Forest specialist	Tree	0	0	1	1	0	0
Maytenus arbutifolia	CELASTRACEAE	Ombooroo	Generalist	Shrub	11	126	24	840	40	750
Maytenus gracilipes	CELASTRACEAE	Kombolcha	Forest specialist	Shrub	3	20	0	0	0	0
Maytenus senegalensis	CELASTRACEAE	Ombooroo	Pioneer	Shrub	3	23	1	2	3	24
Maytenus sp.	CELASTRACEAE	Qoraatii	Generalist	Shrub	0	0	6	70	4	25
Maytenus undata	CELASTRACEAE	Kolaatii	Generalist	Shrub	0	0	0	0	3	16
Millettia ferruginea	FABACEAE	Astiraa	Forest specialist	Small tree	9	50	33	388	30	272
Mimusops kummel	SAPOTACEAE	Qolaatii	Generalist	Tree	0	0	5	11	4	18
Myrsine africana	MYRSINACEAE	Qachama	Generalist	Shrub	0	0	0	0	1	9
Nuxia congesta	LOGANIACEAE	Qachama	Forest specialist	Small tree	1	1	0	0	1	1
Ocimum lamiifolium	LAMIACEAE	Damaakkase	Pioneer	Shrub	0	0	1	2	0	0
Olea welwitschii	OLEACEAE	Bayaa	Forest specialist	Tree	0	0	11	28	25	63
Oxyanthus speciosus	RUBIACEAE	Imbraangoo	Forest specialist	Shrub	0	0	6	38	16	101
Pavetta abyyssinica	RUBIACEAE	Xummaanee	Forest specialist	Small tree	0	0	2	15	19	622
Pentas schimperiana	RUBIACEAE	Simararuu	Pioneer	Shrub	0	0	0	0	3	3
Phoenix reclinata	ARECACEAE	Meexxii	Pioneer	Tree	3	58	1	1	9	50
Phyllanthus mooneyi	EUPHORBIACEAE	Qachama	Pioneer	Shrub	1	7	2	11	1	9
Phyllanthus ovalifolius	EUPHORBIACEAE	Qachama	Generalist	Small tree	0	0	3	11	2	47
Phyllanthus reticulatus	EUPHORBIACEAE	Qachama	Pioneer	Shrub	0	0	3	14	3	51

Pittosporum viridiflorum	PITTOSPORACEAE	Soolee	Forest specialist	Small tree	0	0	6	15	10	24
Plectranthus garckeanus	LAMIACEAE	Yaryoo	Generalist	Shrub	0	0	1	5	0	0
Podocarpus falcatus	PODOCARPACEAE	Birbirsa	Forest specialist	Tree	0	0	0	0	12	29
Polyscias fulva	ARALIACEAE	Daraku/Kariyoo	Forest specialist	Tree	0	0	8	9	9	11
Pouteria adolfi-friederici	SAPOTACEAE	Qararoo	Forest specialist	Tree	0	0	7	21	35	161
Premna schimperi	LAMIACEAE	Maraasisaa	Pioneer	Small tree	0	0	2	4	0	0
Prunus Africana	ROSACEAE	Oomoo	Forest specialist	Tree	1	1	3	3	9	63
Psidium goajava	MYRTACEAE	Zayituunaa	Planted	Small tree	1	8	2	15	0	0
Psychotria orophila	RUBIACEAE	Wandabiyoo	Forest specialist	Small tree	0	0	9	149	25	657
Rhamnus prinoides	RHAMNACEAE	Geeshee	Pioneer	Shrub	3	30	3	21	4	16
Ritchiea albersii	CAPPARIDACEAE	Agabaatee	Pioneer	Small tree	0	0	0	0	2	3
Rothmannia urcelliformis	RUBIACEAE	Mixoo	Forest specialist	Small tree	1	4	22	138	13	31
Rytigynia neglecta	RUBIACEAE	Mixoo	Forest specialist	Shrub	3	32	13	105	29	491
Sapium ellipticum	EUPHORBIACEAE	Bosoqqa	Generalist	Tree	3	9	4	5	6	43
Sarcocephalus latifolius	RUBIACEAE	Diboo	Pioneer	Small tree	1	5	1	25	0	0
Schefflera abyssinica	ARALIACEAE	Gatamaa	Forest specialist	Tree	0	0	6	7	13	21
Schefflera myriantha	ARALIACEAE	Bottoo	Forest specialist	Small tree	0	0	0	0	1	3
Senna occidentalis	FABACEAE	Salaamakii dimaa	Pioneer	Shrub	3	20	13	166	3	60
Senna petersiana	FABACEAE	Salaamakii adii	Pioneer	Shrub	4	31	12	178	7	21
Sesbania sesban	FABACEAE	Sasbaaniyaa	Planted	Shrub	3	13	0	0	0	0
Solanecio gigas	ASTERACEAE	Doomboorokoo	Pioneer	Shrub	1	2	2	20	9	50
Solanecio mannii	ASTERACEAE	Haamitii baloo	Forest specialist	Small tree	0	0	2	2	8	39
Solanum giganteum	SOLANACEAE	Unknown	Generalist	Shrub	0	0	0	0	1	1
Stereospermum kunthianum	BIGNONIACEAE	Bootoroo	Pioneer	Small tree	2	5	0	0	0	0
Syzygium guineense	MYRTACEAE	Baddeessa	Forest specialist	Tree	1	1	12	69	47	293
Teclea nobilis	RUTACEAE	Hadhessaa	Forest specialist	Small tree	0	0	7	46	21	207
Terminalia laxitlora	COMBRETACEAE	Dabaqaa	Pioneer	Tree	1	1	0	0	0	0
Trichilia dregeana	ASTERACEAE	Anuunuu	Forest specialist	Tree	0	0	6	25	14	121
Unidentified sp.	RUBIACEAE	Mixoo	Generalist	Shrub	0	0	3	60	9	120
Vepris dainellii	RUTACEAE	Hadhessaa babal'a	Forest specialist	Small tree	0	0	19	165	50	510
Vernonia adoensis	ASTERACEAE	Turujee	Pioneer	Shrub	2	7	1	5	1	3
Vernonia amygdalina	ASTERACEAE	Ibicha	Generalist	Shrub	13	89	7	32	14	80
Vernonia auriculifera	ASTERACEAE	Reejii	Pioneer	Shrub	36	805	25	650	25	688
Vernonia bipontini	ASTERACEAE	Sooyyama	Pioneer	Shrub	1	5	0	0	0	0
Vernonia hochstetteri	ASTERACEAE	Xasee	Pioneer	Shrub	2	11	1	10	4	6
Vernonia sp.1	ASTERACEAE	Xasee-dimaa	Generalist	Shrub	0	0	0	0	1	3
Vernonia sp.2	ASTERACEAE	Reejii araba	Pioneer	Shrub	0	0	2	9	2	3
Vernonia thomsoniana	ASTERACEAE	Sooyyama	Pioneer	Shrub	1	4	0	0	2	8

Chapter 5

Chapter 5

Local people's use, property rights and management of woody plants: a social-ecological system perspective from southwestern Ethiopia

Girma Shumi, Ine Dorresteijn, Jannik Schultner, Kristoffer Hylander, Feyera Senbeta, Jan Hanspach, Tola Gemechu Ango and Joern Fischer

Manuscript submitted to Ecosystems and People

Abstract

Many people in less developed countries depend on woody plants, but management of woody plants is often unsustainable. We assessed people's use, perceived property rights and management of woody plants in farmland and forests in a landscape of southwestern Ethiopia. We interviewed 180 households and surveyed woody plants in 192 plots. We found that ninety-five species were used for eleven major purposes. The majority of plants (52) were used for house construction followed by farm implements (42), fuelwood (38) and honey production (37). These benefits were sourced from farmland and forest with and without coffee management. Our study discovered a perceived low sense of property and tree use rights, especially in forest with and without coffee management. We found abundant regeneration of the most widely used tree species in all land use types. However, despite such successful regeneration, some species including important timber species, appeared to be over-harvested in forests. To improve biodiversity outcomes and sustainable use, it would be beneficial to recognize local people's diverse needs for woody plants and grant them appropriate property rights. Conservation policies should encompass the entire landscape and empower local farmers to proactively manage tree populations while providing safeguards against overuse.

Keywords: **Biodiversity conservation; Human wellbeing; Local people; Property rights; Social-ecological systems; Sustainable use and management; Woody plants**

Introduction

Biodiversity provides ecosystem services that are essential for human wellbeing (MA 2003; Díaz et al. 2018). The benefits of biodiversity are particularly evident in the case of woody plants, especially in less wealthy countries, where many people directly depend on trees in their daily lives (Rasmussen et al. 2017; Reed et al. 2017). However, the sustainable management of woody plants for long-term human wellbeing still remains a challenge (MA 2003; Díaz et al. 2006; Díaz et al. 2015).

Numerous direct and indirect local (e.g. forest conversion to farmland by smallholders), regional (e.g. property rights) and global (e.g. markets for commodity crops such as coffee) level drivers influence biodiversity conservation and ecosystem services management (Lambin et al. 2001; Geist and Lambin 2002; Díaz et al. 2015). Understanding such multiple and bi-directional links between nature and people, in turn, can be facilitated through taking a social-ecological systems perspective (e.g. Bennett et al. 2015). Among others, questions that require investigation relate to the ways in which people use different species of woody plants; how property rights hinder or facilitate the use and conservation of woody plants; and whether species are managed sustainably or not. To the best of our knowledge, these interrelated issues have not been investigated simultaneously to date.

Globally, several billion people rely on woody plants for their livelihoods (Kaimowitz and Sheil 2007; Reed et al. 2017). The benefits people obtain from woody plants may involve both direct and indirect services associated with particular plant species (Díaz et al. 2006). These benefits are important to meet basic needs and mitigate income insufficiency of rural households (FAO 2014; Reed et al. 2017). Among others, trees and shrubs provide food, timber, fuelwood, shelter, farm tools, fodder, and medicine (FAO 2014; Iiyama et al. 2014). Woody plants also contribute to indirect benefits such as hosting agricultural crop pollinators or enhancing soil fertility, water infiltration and flood protection (FAO 2014; Rasmussen et al. 2017).

Despite such important benefits, human land use has been a major driver of biodiversity loss, influencing all taxa including woody plants (e.g. Keenan et al. 2015; Barlow et al. 2016; IPBES 2018). Unsustainable use of woody plant species can be driven by expansion of commercial farming, demographic pressure or political instability (Lambin et al. 2001; Geist and Lambin 2002; Hosonuma et al. 2012). It can also be attributed to imperfect resource governance or ill-defined property rights (e.g. Ostrom 2009; Chazdon 2018). Property rights,

whether enforced by the government (de jure) or the community (de facto), govern the rights to access and use a resource, maintain it, exclude others, and transfer these rights to others (Schlager and Ostrom 1992). In this context, local people's ability to effectively take on a stewardship role for the ecosystems and woody plants they depend on can be undermined by ill-defined property rights (Ostrom and Nagendra 2006; Ostrom 2009; RRI 2017). Consequently, ill-defined property rights may affect forest management, causing change in forest structure, and species composition and diversity (e.g. Bergès et al. 2013; Johann and Schaich 2016; McClellan et al. 2018). For example, in Ethiopia, a lack of clear property rights has been observed to affect tree retention and management by rural households (Mekonnen 2009), and conservation policies that prohibit the use of timber species have discouraged farmers from planting and conserving these species (Kassa et al. 2011; Lemenih and Kassa 2014).

Although both the uses of tree species as well as issues of property rights have received some research attention (see above), to date, such work has rarely been linked to ecological field data on the distribution, abundance, and demographic profiles of trees. Such data is important, however, to objectively ascertain which species are managed sustainably, and which are not. A given species can be recognized as a sustainably managed species if it has viable population despite the extraction of goods and services (Charnley and Poe 2007; Kuhlman and Farrington 2010). For example, natural populations of tree species typically have many small individuals followed by progressively fewer older aged individuals – an inverted J-shaped distribution of tree diameters, which indicates successful regeneration as well as maintenance of increasingly older aged individuals ensuring future recruitment capacity and use of the species (Wakjira 2006; Mwavu and Witkowski 2009). In contrast, unsustainably managed tree species often have a discontinuous pattern of populations (i.e. tree diameter distributions) – certain size classes may be missing, or regeneration may be insufficient to replace existing adults. Two key reasons for unsustainable demographic profiles are overharvesting, which has negative repercussions for the availability of seed sources for future recruitment of tree species (Mwavu and Witkowski 2009); and management that prevents natural tree regeneration (Fischer et al. 2009).

For this study, we focused on a social-ecological system in southwestern Ethiopia as a case study. Here, the rural community depends heavily on woody plants for their basic needs (Ango 2016; Dorresteijn et al. 2017). According to the constitution of Federal Democratic Republic of Ethiopia (FDRE) (1995), the state owns all land, including forests, and local

communities have limited use rights. In addition, current forest management and private investment policies may further undermine people's sense of property rights (Lemenih and Kassa 2014; Tura 2018). Nevertheless, some communities still continue to apply customary use rights to their local forests (Wakjira and Gole 2007). Most recently, the Ethiopian government has identified the protection and rehabilitation of degraded forests for ecosystem services provision as key for its green economy development strategy (FDRE 2011). It has also enacted a new forest law – Proclamation No. 1065/2018 (FDRE 2018) – which recognizes private forest development and ownership, and participatory forest management that may further improve local people's woody plant use and conservation for livelihoods.

Drawing on the rationale outlined above, we aimed to:

1. Assess local people's uses of woody plant species, segregated by different purposes and sources (e.g. farmland versus forest);
2. Uncover how people perceived their property rights, namely land tenure security, woody plant use rights, and sense of ownership and management in forest and farmland; and
3. Investigate population viability of the most widely used tree species in forest and farmland.

Methods

Study area

The study was conducted in subsistence-dominated rural landscapes of six *kebeles* (the lowest administrative unit) located in the Gera, Gumay and Setema districts of Jimma Zone, Oromia Regional State, southwest Ethiopia (Fig. 5.1). The *kebeles* were selected to span a gradient in forest cover, ranging from 11 – 84% within a *kebele* (Fig. 5.1c, d). The region is characterised by a mosaic of forest, farmland (arable land, grazing land and homegardens) and settlements. The forest in the area is moist evergreen Afromontane forest, and part of the Eastern Afromontane Biodiversity Hotspot. The dominant tree species in the forest include *Olea welwitschii, Pouteria adolfi-friederici, Schefflera abyssinica, Prunus africana, Albizia spp., Syzygium guineense,* and *Cordia africana* (Cheng et al. 1998). Coffee (*Coffea arabica*) is native to the forest and grows naturally at altitudes between 1000 and 2000 m above sea level (Schmitt, 2006; Senbeta et al. 2014). Coffee is widely promoted at altitudes between 1500 to 1800 m asl, within its ecological optimum, and is generally grown under a canopy of native shade trees (Teketay 1999).

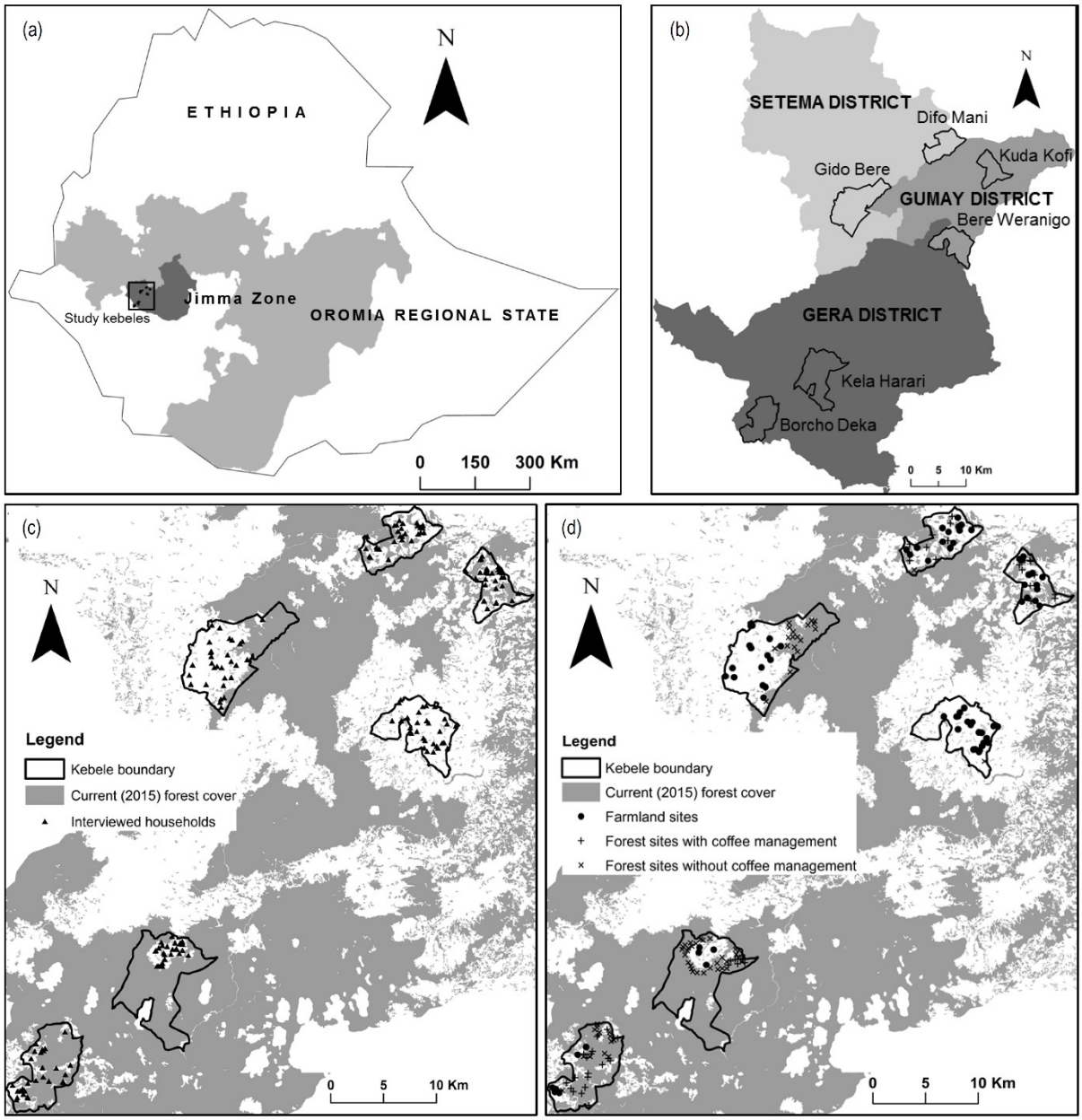


Figure 5.1 (a) Study area (square) in Jimma Zone, Ethiopia; (b) the six *kebeles*: Difo Mani and Gido Bere in Setema district, Bere Weranigo and Kuda Kofi in Gumay, and Borcho Deka and Kela Harari in Gera; (c) interviewed households (black triangles); and (d) woody plant survey points: in farmland (black circles), in forest with coffee management ("+" sign), and in forest without coffee management ("x" sign). In (c) and (d) grey colour represents current forest cover.

The largest ethnic group in the region is the Oromo, while Amhara, Kefficho and Tigre people are minorities. Agriculture including crops and livestock is the main source of livelihoods. Unlike for the forests, the government has issued land use certificates for farmland and some coffee plots, mainly for those rehabilitated from farmlands, since 2003, to facilitate land tax collection and improve tenure security.

Data collection

Household survey

We assessed local people's woody plant uses and perception of their property rights in two steps. We first conducted an exploratory pilot study from July to September 2015 to obtain a basic understanding of people's use of woody plants and their sources. We used open-ended questionnaires in the six *kebeles*, and interviewed a total of 72 households. For this, 12 households were randomly selected from satellite images in each *kebele*, without prior information about these households.

Second, we conducted the main study from February to March 2017 using questionnaires consisting of primarily closed questions. The questionnaire was structured into four main sections: general background information on the household; uses and preferences of woody plant species by source (farmland, forest with coffee management, forest without coffee management, government plantation forest; see Table 5.S1); tree/forest use rights and sense of ownership; and land tenure security and tree/forest management (for details, see Appendix 5A). Based on the pilot study and existing literature (Wakjira and Gole 2007; Ango 2016) we categorized woody plant uses into 11 major classes (Table 5.1).

We interviewed 180 randomly selected households (30 per *kebele*, including renewed interviews with the 12 households of the pilot study plus 18 additional households). The 18 additional households from each *kebele* were selected in the same way as those for the pilot study. The respondents were household heads or their spouses. All respondents remained anonymous to protect their privacy. Before a given interview, we introduced the objectives of our study and informed interviewees about procedural aspects such as the voluntary nature of participation in the interview.

Table 5.1 Overview of the uses of woody plants in southwest Ethiopia in terms of ecosystem services, and their description and importance for meeting basic human needs. Woody plant use classification to basic human needs follows FAO (2014).

Ecosystem service	Specific use	Description and importance
Provisioning and/or cultural	Fuelwood	Firewood and charcoal used for cooking, heating and lighting. Helps to satisfy physiological, safety and security needs.
	Fences	Dried or live woody fences. Satisfy safety and security needs.
	Farm implements	Wooden handle, yoke and beam used for ploughs, i.e. crop production. Help to fulfil physiological, safety and security needs.
	Honey production	Plants used for beehive making and suspension, and bee flora. Helps to fulfil physiological and cultural needs.
	House construction	Sticks and wood (other than poles and timber) used to build houses' walls and roofs. Satisfies physiological, safety and security needs.
	Household utilities	Wooden household items, e.g. coffee table and chairs. Helps to satisfy cultural needs.
	Poles and timber	Wood prepared used for construction and carpentry, e.g. poles for wall and roof reinforcement, timber for doors and furniture. Help to satisfy physiological, safety, security and cultural needs.
	Medicine	Plant parts used for treating people and livestock. Helps to meet physiological, safety, security and cultural needs.
	Animal fodder	Plant parts browsed by livestock, or cut and fed to livestock. Helps to fulfil physiological, safety and security needs.
	Coffee shade	Planted or maintained trees for coffee shading. Helps to fulfil physiological, safety, security and cultural needs.
Regulating	Soil fertility	Planted or maintained trees supporting soil fertility. Helps to fulfil physiological, safety, security and cultural needs.

Woody plant survey

We surveyed woody plants in the same six *kebeles* where we conducted the household surveys, from November 2015 to January 2016, and April to May 2017. Prior to the plant surveys, using ArcGIS 10.2, we determined the proportion of farmland and forest within each *kebele* using a land cover map generated via supervised image classification of a RapidEye satellite image from 2015 using ArcGIS 10.2. Then, we randomly selected a total of 192 survey plots, distributed across the six *kebeles* (25 – 43 plots per *kebele*). Of these, we assessed 72, 1-ha circular plots in farmland (53 and 19 plots in arable land and grazing land, respectively). We also assessed 120, 20 m by 20 m plots in forest and homegarden (63, 46, and 11 plots in forest without coffee management, forest with coffee management, and homegarden, respectively). We used different plot sizes in farmland and forest because of very different densities in trees, as well as for logistic reasons (1 ha plots would not be feasible in dense forest). We did not survey plantation forests because they are even-aged forests often planted with exotic trees, and managed almost exclusively by the government.

In each plot, all individuals of tree and shrub species with a height ≥ 1.5 m were recorded. We also measured and recorded diameter at breast height (DBH) of all individuals with DBH ≥ 5 cm. We identified plants that were readily identifiable in the field. For species that were

difficult to identify in the field, specimens were collected, pressed, dried and transported to the National Herbarium at Addis Ababa University for identification. Nomenclature follows the Flora of Ethiopia and Eritrea.

Data analysis

Socioeconomic data analysis

The socioeconomic data consisted of two major datasets. The first dataset covered a household's background information, uses and preferences of woody plants and their sources. We summarized the characteristics of respondents by calculating averages (e.g. for age) or proportions (e.g. percentage respondents native to the area). With respect to the *specific purposes* of a given woody species, we determined the total number of species used by local people for all purposes, total number of species for each purpose, and number of purposes of a species. Furthermore, we identified species of particularly low replaceability, by calculating the "redundancy" of species for a given purpose. To this end, first we determined the number of commonly used species for each purpose. Here, we used ≥ 30 households as a threshold to define commonly used species for a given purpose. Second, for each purpose, we determined the redundancy of common species (i.e. the number of readily available commonly used alternative species) and total redundancy (i.e. the total number of alternative species for a given purpose). In addition to looking at the specific purposes of particular species, we also defined the most widely used tree and shrub species in the landscape, *regardless of the purpose* they served. For this, first we determined the total number of households that used a species for one or more purposes. Then, we determined the upper quartile (the top 25%) of the frequency of households mentioning the species mostly. Then, we identified these species as the most widely used species in the landscape. Finally, we determined the proportion of households visiting each source for woody plant use.

The second dataset consisted of local people's perceived land tenure security, wood plant use rights, sense of ownership and management. Land tenure security was determined from two pieces of information: (1) from whether households felt tenure security for the source they visited or not, and (2) from whether respondents held a land ownership certificate for the source they visited or not. We also determined the percentage of respondents who believed they had wood extractive use rights from a given source of woody plants. Finally, we determined the percentage of respondents who felt a sense of ownership and responsibility to protect and manage woody plants in the source they visited for their use.

Woody plant data analysis

We investigated the abundance of all woody plant species, and the DBH size class distributions of naturally regenerating, widely used tree species, separately by pooling all plots within each of the three sources (farmland, forest with and without coffee management). For each tree species, we categorized individuals into diameter classes. To determine DBH profiles, we calculated total numbers of individuals of a tree species in each diameter class across all study plots by source. We then visually categorized DBH distribution profiles, grouping profiles of similar shape. Finally, we determined the percentage of species exhibiting a particular profile shape in each source.

Results

Characteristics of the respondents

Respondents were on average in their forties and the majority were male (Table 5.S2). The average household size of respondents was six; half of the respondents were illiterate, and 79% of respondents were native to the area (Table 5.S2). All respondents had homegardens, 94% used arable land, 73% used private grazing land and additionally, 24% accessed communal grazing land (Table 5.S2). Fifty-seven percent of the respondents used inherited forest with coffee management; 13% owned forest with coffee management legally granted by the *kebele* authority; and 15% of respondents used inherited forest without coffee management. Half of the respondents had access to communal forest without coffee management. Almost none of the respondents accessed government plantation forest (Table 5.S2).

Use and preference of woody plants and their sources

Of 158 recorded tree and shrub species (Table 5.S3), local people used 90 species, including 17 exotic species (Table 5.S4). They reported that they also used five additional tree and shrub species, which did not occur in the studied plots (Table 5.S4). With respect to the total number of species for each purpose, 52 species were used for house construction, 42 for farm implements, 38 for fuelwood, 37 for honey production, and 11 for poles and timber (Table 5.2, Table 5.S4). Species used for animal fodder, household utilities, medicine, poles and timber, and soil fertility had few readily available alternatives ($\leq$ 2 species; Table 5.2). The most versatile species, i.e. species with the highest number of different uses, were *Croton macrostachyus*, *Vernonia amygdalina*, *Cordia africana*, *Millettia ferruginea*, *Pouteria adolfi-friederici*, *Vernonia auriculifera* and *Syzyium guineense* (Table 5.3, Table 5.S4). Of all locally

used species, 17 tree and four shrub species were identified as the most widely used species, i.e. each of these species were mentioned to be used by ≥ 67 respondents regardless of the number purposes they served in the landscape (Table 5.3). Of these species, *Erythrina brucei*, *Ehretia cymosa*, *Ocimum lamiifolium*, *Chionanthus mildbraedii*, *Cordia africana*, *Albizia* spp., and *Croton macrostachyus* were used most extensively.

Table 5.2 Use of woody plants, total number of species for each use, total number of commonly used species by at least 30 households for each purpose (e.g. house construction use has 8 commonly and 44 non commonly preferred species), the redundancy of a commonly used species with readily available commonly preferred alternatives (e.g. for house construction purpose, it was 8-1 = 7 species), redundancy of a commonly preferred species with non-commonly preferred alternatives (e.g. for house construction purpose, it was 45-1 = 44 species), and total redundancy of a commonly preferred species with all species (for house construction purpose, it was 52-1 = 51 species. Note that also individual species may be used for multiple purposes (see Table 5.S4).

Use	Total number of used species	Number of commonly used species	Redundancy of a commonly used species with commonly used alternative species	Redundancy of a commonly used species with non-commonly used alternative species	Total redundancy
House construction	52	8	7	44	51
Farm implements	42	10	9	32	41
Fuelwood	38	9	8	29	37
Honey production/ beehives	37	13	12	24	36
Fences	36	8	7	28	35
Medicine	25	2	1	23	24
Coffee shade	23	6	5	17	22
Household utilities	21	3	2	18	20
Soil fertility	18	2	1	16	17
Animal fodder	17	1	0	16	16
Poles and timber	11	2	1	9	10

Table 5.3 List of the most widely used tree and shrub species (i.e. each species mentioned to be used by ≥ 67 households for one or more purposes) in the landscape. Note that *Albizia* spp. stands for *Albizia gummifera* and *Albizia schimperiana*, and *Eucalyptus* spp. for more than two species of *Eucalyptus*; major source: fl = farmland, fwcm = forest with coffee management, fwocm = forest without coffee management. Small tree treated as a tree for this study.

Scientific name	Local name	No. of uses of species	No. of households preferred a species	Species category or mode of regeneration	Major source	Habit
Albizia spp.	Ambabbessa	7	152	Generalist	fl, fwcm, fwocm	Tree
Chionanthus mildbraedii	Gagamaa	3	154	Forest specialist	fwcm, fwocm	Tree
Coffea arabica	Buna	5	68	Forest specialist	fl, fwcm, fwocm	Small tree
Cordia africana	Waddessa	8	153	Generalist	fl, fwcm, fwocm	Tree
Croton macrostachyus	Bakkannissa	9	151	Pioneer	fl, fwcm, fwocm	Tree
Ehretia cymosa	Ulaagaa	5	160	Generalist	fl, fwcm, fwocm	Small tree
Erythrina brucei	Beroo	5	176	Planted	fl	Tree
Eucalyptus spp.	Baargamoo	6	143	Planted	fl	Tree
Euphorbia abyssinica	Adaamii	4	116	Planted	fl	Tree
Ficus sur	Harbuu	7	88	Generalist	fl, fwcm, fwocm	Tree
Galiniera saxifrage	Simararuu	3	84	Forest specialist	fl, fwcm, fwocm	Small tree
Justicia schimperiana	Dhummugaa	3	76	Generalist	fl, fwcm, fwocm	Shrub
Millettia ferruginea	Astiraa	8	133	Forest specialist	fl, fwcm, fwocm	Small tree
Ocimum lamiifolium	Dammaakkasse	1	158	Pioneer	fl	Shrub
Olea welwitschii	Bayaa	7	110	Forest specialist	fwcm, fwocm	Tree
Pouteria adolfi-friederici	Qararoo	8	105	Forest specialist	fwcm, fwocm	Tree
Rytigynia neglecta	Miixoo/Miixoo adii	4	80	Forest specialist	fl, fwcm, fwocm	Shrub
Syzygium guineense	Baddeessa	8	67	Forest specialist	fl, fwcm, fwocm	Tree
Teclea nobilis	Hadheessa/Mitrii	2	81	Forest specialist	fwcm, fwocm	Small tree
Vernonia amygdalina	Ebicha	9	148	Generalist	fl, fwcm, fwocm	Shrub
Vernonia auriculifera	Reejii	8	103	Pioneer	fl, fwcm, fwocm	Shrub

Except for government plantation forest, respondents used woody plants from all major sources (Table 5.4). Over 90% of households visited forests with coffee management for farm implements, fuelwood, and household utilities; all households visited farmland for fences, and 87% for house construction, and 83% for medicine. Forests without coffee management were visited by 81% of households for farm implements, and by 65% households for beehives and house construction wood (Table 5.4).

Table 5.4 Woody plant extractive uses, percentage of respondents visiting major sources for use of woody plants for specific purpose. Major sources included farmland (areal land, grazing (private and communal) land, and homegarden); forest with coffee management (inherited and legally acquired from *kebele* authority); and forest without coffee management (inherited and communal). For farmland n = 180; for forest with coffee management n = 114; and for forest without coffee management n = 97.

	% Households visiting major source for use of woody plants			
Use	Farmland	Forest with coffee management	Forest without coffee management	Government plantation forest
House construction	87	74	65	0
Farm implements	67	94	81	1
Fuelwood	74	93	65	1
Honey production – beehives	46	62	58	0
Fences	100	74	57	0
Medicine	83	54	38	1
Household utilities	53	90	51	0
Animal fodder	38	27	20	0
Poles and timber	39	86	44	0

Tenure security, use rights and sense of ownership and management

Although 93% of respondents had a farmland certificate, only 36% felt secure tenure (Fig. 5.2). Fewer (45%) respondents had a land certificate for a forest plot with coffee management, and only 25% felt secure tenure; and virtually none had a certificate and felt secure tenure for forest without coffee management land use (Fig. 5.2). The percentage of respondents who felt they had wood extractive use rights varied by source and type of extractive use (Table 5.5). Perceived use rights were most prevalent for sourcing house construction wood, particularly from farmland and forest with coffee management (Table 5.5). In contrast, for household utilities and poles and timber in particular, perceived extractive use rights were much more limited from all land uses (Table 5.5). The majority of respondents felt a sense of ownership and responsibility for management of woody plants in farmland and in forest with coffee management, but fewer felt ownership and responsibility for forest without coffee management (Table 5.5).

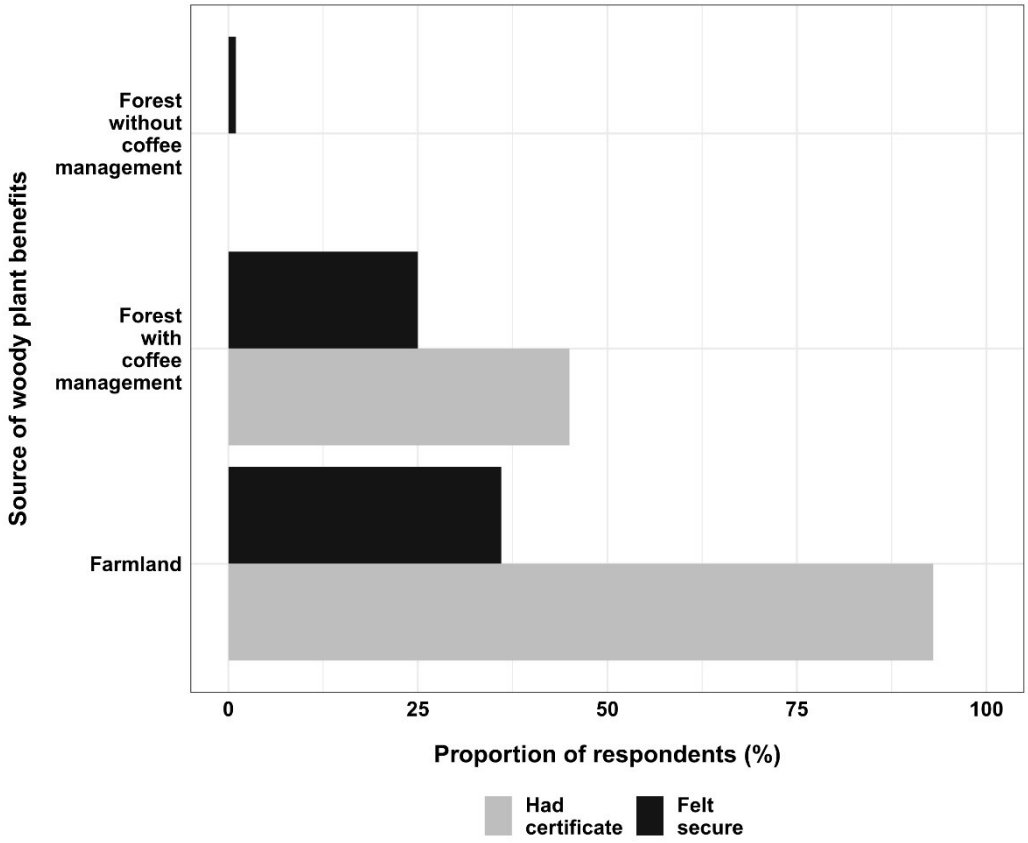


Figure 5.2 Proportion of respondents who had land use certificate and felt/perceived tenure security to major sources (i.e. land use types) of woody plant benefits.

Table 5.5 Major source, percentage of respondents who felt extractive use rights, sense of woody plant ownership and responsibility of management in major source (i.e. land use type) they associated with in the landscape. Note that farmland (n = 180), including areal land, grazing (private and communal) land, homegarden; forest with coffee management (n = 114), including inherited and legally acquired; and forest without coffee management (n = 97), including inherited and communal.

	% Households who felt wood extractive use rights			% Households felt sense of ownership	% Households felt management responsibility
Source	House construction	House utilities	Poles and Timber		
Farmland	98	36	4	83	96
Forest with coffee management	89	28	4	78	90
Forest without coffee management	65	21	3	19	12
Plantation (governmental)	0	0	0	0	1

Woody plant abundance and population structures

A total of 158 (including one unidentified) species of trees and shrubs, representing 50 families, were recorded from all plots (Table 5.S3). Of these, *Vernonia auriculifera*, *Erythrina brucei*, *Acanthus sennii* were abundant in farmland; *Coffea arabica*, *Maytenus arbutifolia*, *Vernonia auriculifera* in forest with coffee management; and *Dracaena afromontana*, *Chionanthus mildbraedii* and *Justicia schimperiana* in forest without coffee management (Table 5.S3).

Unlike species used for honey production, farm implements, and fuelwood, species used for poles and timber (an extractive use with few readily available alternative species (Table 5.2)) had low abundance in the landscape (Table 5.S3, Table 5.S4).

Naturally regenerating widely used tree species were nine (including the two Albizia species) in farmland and 13 in forests (Fig. 5.S1; Table 5.3). Of these, poles and timber tree species were three in farmland, and four in forests (Fig. 5.S2; Table 5.S4). The population profiles of these the most widely used tree species was categorized into one of three major distribution profiles in a given type of source (Fig. 5.3). The first profile indicated a *healthy population structure* characterized by many individuals in lower size classes followed by progressively fewer individuals in larger size classes, as illustrated for example by *Millettia ferruginea* in farmland (Fig. 5.3a). This profile was exhibited by 90% of the most widely used tree species in farmland, by 75% species in forest without coffee management, and by 55% of species in forest with coffee management (Fig. 5.4a). The second diameter profile had *selectively removed individuals* in some age classes, typified by a species with many individuals in the lowest size class followed by fewer individuals in lower and/or intermediate size classes and proportionally more individuals in larger size classes, as illustrated for example by *Syzygium guineense* in forest with coffee management (Fig. 5.3b). This distribution was demonstrated by 30% species in forest with coffee management, and by 10% of species in forest without coffee management. However, this distribution was not found in farmland (Fig. 5.4a). The third diameter profile indicated *poor regeneration and lack of old trees*, characterised by a species with few individuals in both small and large size classes, as illustrated for example by *Olea welwitschii* in forest with coffee management (Fig. 5.3c). This profile was exhibited by 15% of species in both types of forest, and 10% in farmland (Fig. 5.4a). Diameter distribution profiles of the most widely used tree species also varied in different sources by the type of purposes of the species, especially for poles and timber species (Fig. 5.4b). Population profiles of poles and timber species were much less healthy in forests than in farmland (Fig. 5.4b). Especially in forest without coffee management, only 25% of poles and timber species exhibited a healthy population structure (Fig. 5.4b).

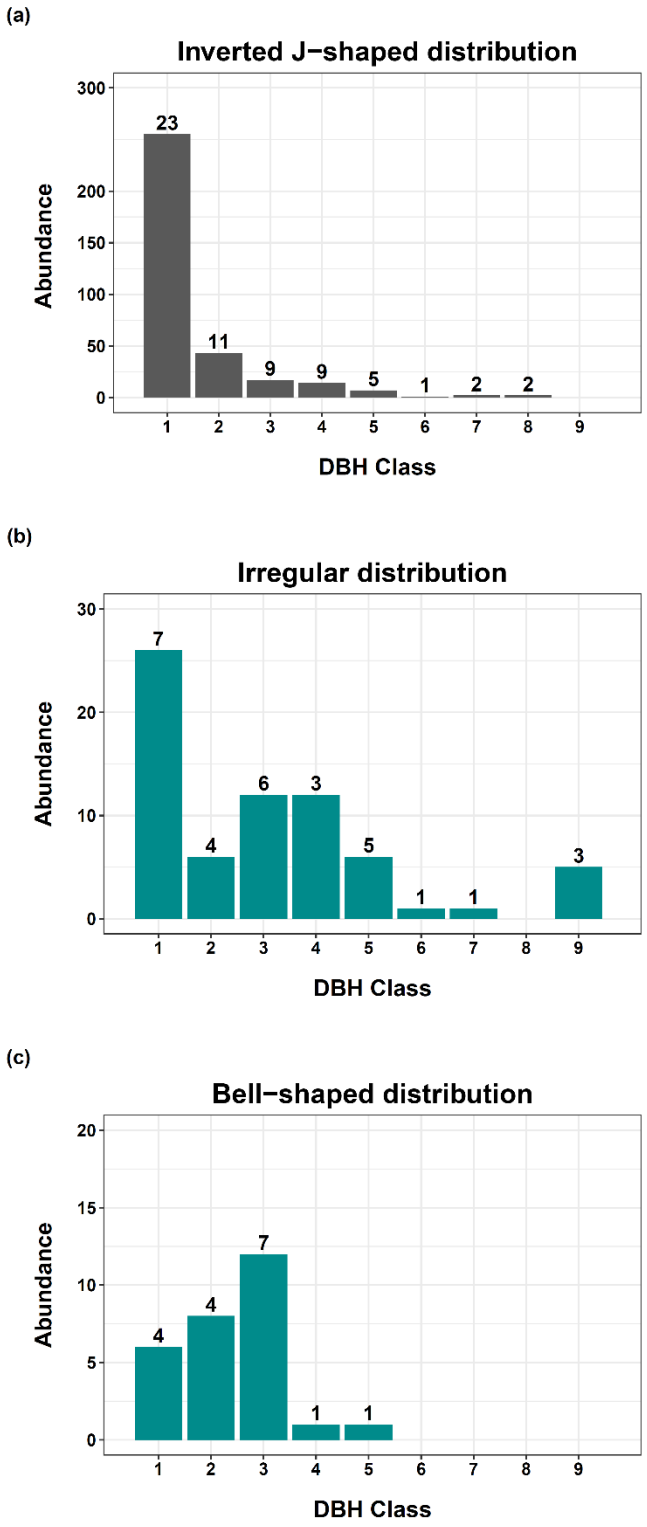


Figure 5.3 Typical diameter at breast height (DBH) distribution profiles of the most widely used tree species. (a) Inverted J-shaped distribution (healthy population profile): a near-natural population structure, exemplified by *Millettia ferruginea* from farmland; (b) irregular distribution (selective removal population profile): population with most individuals in the lowest size class, an irregular number of individuals of intermediate size, and larger number of larger individuals, exemplified by *Syzygium guineense* from forest with coffee management; and (c) bell-shaped distribution (poor regeneration and lack of old trees population profile): population with few both small and large individuals, exemplified by *Olea welwitschii* from forest with coffee management. DBH classes are 1 = < 5 cm; 2 = 5.1-10 cm; 3 = 10.1-20 cm; 4 = 20.1-30 cm; 5 = 30.1-40 cm; 6 = 40.1-50 cm; 7 = 50.1-60 cm; 8 = 60.1-70 cm; and 9 = > 70 cm. Numbers above bars refer to the number of plots in which individuals in the size class occurred.

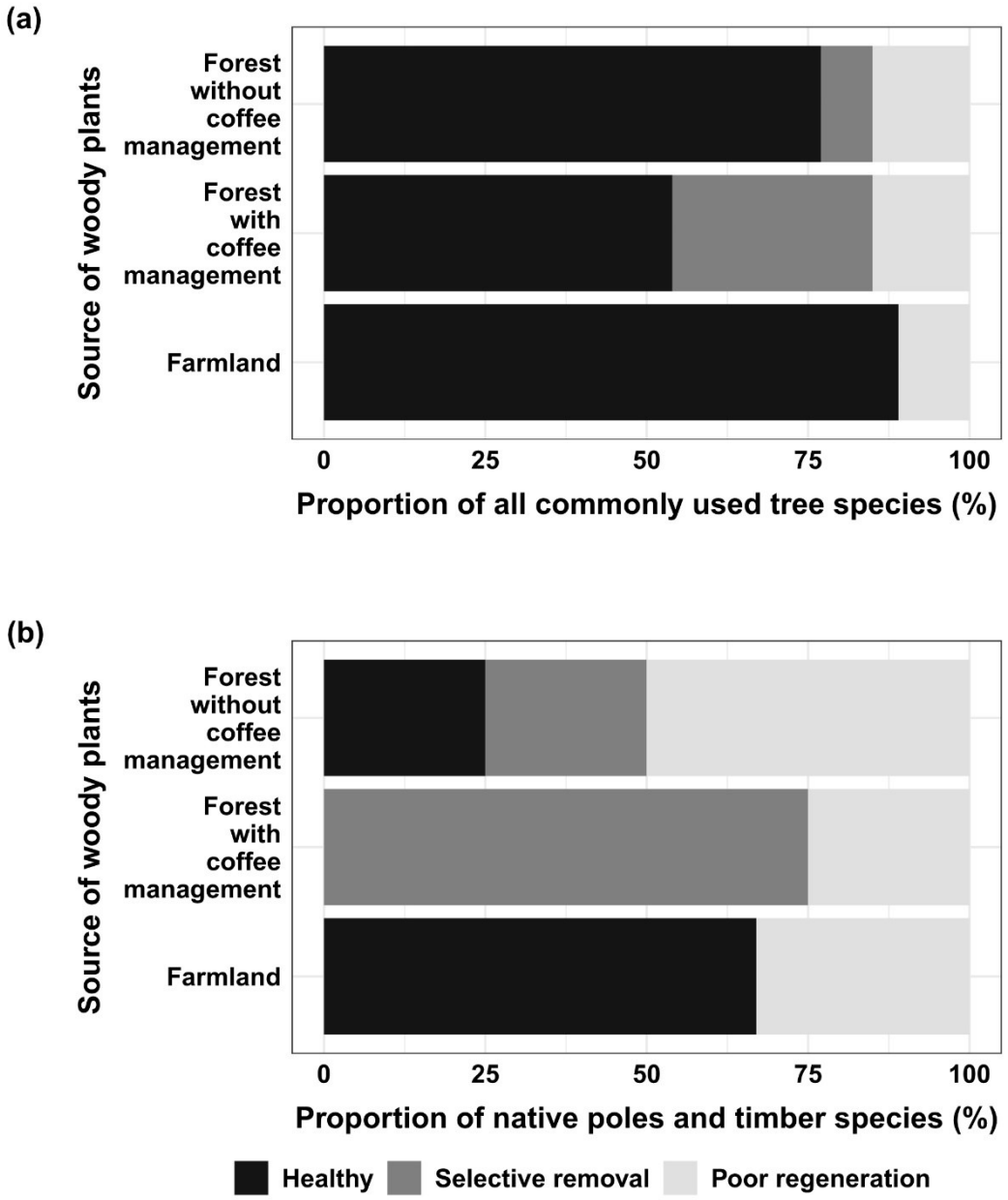


Figure 5.4 (a) Proportion of all of naturally regenerating most widely used tree species with healthy population profile (inverted J-shaped distribution; dark shaded); selective removal population profile (irregular distribution; dark grey shaded); and poor regeneration and lack of old trees population profile (bell-shaped distribution; light grey shaded) across major land use types or sources of woody plant benefits. (b) Proportion of the most widely used poles and timber species with healthy population profile (inverted J-shaped distribution; dark shaded); selective removal population profile (irregular distribution; dark grey shaded); and poor regeneration and lack of old trees population profile (bell-shaped distribution; light grey shaded) across major land use types. Note that naturally growing most widely used tree species were nine, including the two *Albizia* species, in farmland and 13 in forests (see Table 5.3 and Fig. 5.S1). Of these, poles and timber species were three (*Cordia africana*, *Ficus sur*, and *Syzygium guineense*) in farmland; and four (*Cordia africana*, *Ficus sur*, *Pouteria adolfi-friederici*, and *Syzygium guineense*) in forest (see Table 5.3 and Fig. 5.S2).

Discussion

Ensuring landscape sustainability via integrated land management for biodiversity and ecosystem services is an important priority for human societies (Wu 2013; Kremen and Merenlender 2018). However, many obstacles prevent farmers from actually practicing sustainable land management, including ill-defined property rights (RRI 2017; Kremen and Merenlender 2018). In biodiverse landscapes of southwestern Ethiopia, we found that many species of woody plants were used to generate benefits for the well-being of rural households, sourced from different land uses across the landscape including farmland, forest with and forest without coffee management. However, we also uncovered a low perception of tenure security and extractive use rights, particularly for poles and timber species. Perceived tenure security was higher for farmland, where the majority of respondents also held land use certificates, but was much lower for forest without coffee management. We also found that insecure land tenure and limited use rights, particularly in forest without coffee management, in turn reduced the sense of ownership and responsibility to manage and conserve woody plants. Ecologically, we found that most of the most widely used tree species had good regeneration throughout the landscape, including in farmland. From a sustainable management and use perspective, we found that nearly all species showed healthy population profiles in farmland, and about three quarters in forest without coffee management – but only about half in forest with coffee management. This difference was particularly high for poles and timber, a use with few redundant species in the landscape. More than two thirds of such species exhibited a healthy population structure in farmland, as compared to one quarter and none in forest without coffee management and forest with coffee management, respectively. In the following we discuss these findings in detail, focusing on the importance of woody plants for rural livelihoods, and woody plant management in relation to revealed property rights in major sources.

Trees and shrubs are essential for the livelihoods of rural households (Kaimowitz and Sheil 2007; Rasmussen et al. 2017; Reed et al. 2017). Our findings revealed the importance of many species for local people's livelihoods in southwestern Ethiopia. Tree and shrub species provided fuelwood, medicine, construction materials, household utilities, farm implements, fences, poles and timber, animal fodder, honey production, coffee shade and soil fertility improvement, which are vital for the subsistence of rural farmers (FAO 2014; Reed et al. 2017). Our findings are consistent with other studies, for example by Faye et al. (2011) in five regions of Burkina Faso, Mali, Niger and Senegal, and by Quandt (2016) in Tanzania, who demonstrated a similar level of social significance of trees and shrubs for rural livelihoods.

Likewise, a study by Iiyama et al. (2014) corroborated that the majority of rural households (> 90%) in sub-Saharan Africa still depend on fuelwood for cooking. Reed et al. (2017) also showed that trees and shrubs increase crop yields when integrated and managed properly.

Our findings further confirmed local people's reliance on a range of different sources, including farmland, forest with and forest without coffee management. This multifunctionality of the landscape is in agreement with Reed et al. (2017) and Kremen and Merenlender (2018), who emphasised the need to integrate trees and forest patches within rural landscapes for improved livelihoods and biodiversity conservation. Interestingly, our findings highlighted that local people appreciated landscape multifunctionality, rather than seeing biodiversity conservation and extractive uses of the environment as mutually exclusive (Fischer et al. 2017; Jiren et al. 2017). Multifunctional landscapes concurrently fulfil basic needs such as food, wood and cultural needs, while also contributing to biodiversity conservation (O'Farrell and Anderson 2010; Wu 2013; Kremen and Merenlender 2018).

From a property rights perspective, land is a vital livelihood asset and its accessibility has many implications for rural people and land management (e.g. Tura 2018; Kremen and Merenlender 2018). Beside forests, the smallholder farmland matrix in southwestern Ethiopia harbours many trees and shrubs, including both retained and planted species (Ango 2016; Jara et al. 2017). Perhaps surprisingly, our findings revealed healthy population structures in farmland for nearly all of the most widely used tree species, including poles and timber species. Here, unlike in other parts of the world, such as Australia (Fischer et al. 2009) or Romania (Hartel et al. 2013), our findings showed successful regeneration and preservation of successively aged individuals. Possible reasons could be relatively low intensity use of the agricultural landscape, including the existence of small patches of trees, coffee shrubs under shade trees, homegardens and live fences in or around pastures and small fields (Ango 2016; Jara et al. 2017). In addition, relatively secure tenure in farmland may also provide an incentive for farmers to sustainably manage trees in farmland (Yami and Snyder 2015; McClellan et al. 2018).

In contrast to farmland, our findings in forest with coffee management showed discontinuous population structures for the majority of the most widely used species, particularly for timber species – which regenerated successfully but for which older age classes were extracted quite heavily, and potentially at unsustainable levels. Here, the likely reasons could be (i) insecure tenure and limited use rights, particularly of timber species; as well as (ii) intensive use pressure on this forest, especially for coffee production. From a property rights

perspective, our findings are consistent with other studies indicating that a lack of clear property rights can negatively influence local people's stewardship role for the ecosystems and woody plants they depend on (Mekonnen 2009; RRI 2017). For example, studies by Kassa et al. (2011) and Lemenih and Kassa (2014) in Ethiopia indicated that a lack of timber use rights negatively affected local people's timber tree species maintenance in the forest. In our study area, a local farmer asked: "Why would I retain a *Cordia africana* tree, a highly valued timber species, in my forest with coffee management, which I then cannot use?" (pers. comm.). Indeed, of the three studied sources, forest with coffee management was used most widely for highly extractive uses (Table 4), suggesting that strong use pressure led to the discontinuous population structures of species in coffee forest (Wakjira 2006; Mwavu and Witkowski 2009). Moreover, forest with coffee is typically actively managed by local people for coffee production (Teketay 1999; Schmitt et al. 2010). As shown in other studies (e.g., Hundera et al. 2013; Kumsa et al. 2016), such management entails farmers frequently removing young and intermediate sized trees, so as to avoid competition with coffee. This was also the typical pattern found in our study; that many species, including the most widely used tree species, had low numbers of small and intermediate sized trees despite abundant regeneration. Hence, unclear property rights, coffee production and extensive use pressure in this forest together most likely lead to unsustainable population structures.

Similarly to forest with coffee management, our findings in forest without coffee management also revealed a discontinuous population structure of some species, and especially of timber species. A possible reason could be local people's perceived ill-defined property rights (insecurity tenure, limited use rights, low sense of ownership and management), as revealed in our study (cp. Schlager and Ostrom 1992; Johann and Schaich 2016; RRI 2017). A likely additional reason is that illegal timber production has increased in the area in recent years due to the provision of licenses for metal and woodwork as a strategy to create job opportunities for young people (pers. comm. with metal and wood work microenterprises in Gera district). This is at odds with conservation-oriented forest policies that prohibit the use of timber species (Lemenih and Kassa 2014). Thus, despite some conservation-oriented policies, our findings suggest that even important tree species are not effectively protected in this forest at present.

Notably, the observed disturbed population structures in our study, particularly of timber species, were different from population structures that have been reported in community managed forests elsewhere, where forest tenure, use rights and management decisions are negotiated and devolved to the local community. For instance, Gobeze et al. (2009) confirmed

natural population structures of tree species in the community managed Bonga coffee forest, in a broadly similar environment to that studied here. Similarly, Yietagesu (2013) worked in south-eastern Ethiopia, and there revealed the effective maintenance of commercial timber species in community managed forest. Although it is difficult to reach definitive conclusions, this comparison with other locations suggests that local people's woody plant retention and sustainable use may well be influenced by property rights (tenure security, use rights, sense of ownership and management) in our study area, too.

Conclusion

By using a social-ecological system perspective, we revealed bidirectional links between nature and people. Our study showed the importance of several woody plants for rural households and of the multifunctionality of rural landscapes. Our study discovered a perceived low sense of property rights, especially for trees in forest with and without coffee management. Likewise, our study showed successful regeneration of most of the most widely used tree species throughout the landscape, including in farmland. However, despite successful regeneration, some species appeared to be over-harvested, especially in forest with coffee management. Our findings suggest that a perceived low sense of property rights seemed to negatively affect the sustainable management of woody plants in forests, particularly in forest with coffee management. To strengthen the synergies between biodiversity and people in southwestern Ethiopia and other similar landscapes, we suggest to: (1) recognize local people's livelihood needs of woody plants and their property rights to land, including the right to manage and use woody plants; and (2) design conservation policies that encompass the entire landscape mosaic including farmland, empowering local people while also providing safeguards against overuse.

Acknowledgements

The study was funded through a European Research Council (ERC) Consolidator Grant (FP7-IDEAS-ERC, Project ID 614278) to J. Fischer (SESyP). We thank Dereje Gire and Obsuman Damena for their tremendous effort to talk to the local people. We thank all the respondents for their participation. We thank the Governments of Ethiopia and Oromia Regional State for their permission to conduct the research. We also thank the staff of the different woreda and kebele offices and the local people for their cooperation. The survey procedure was cleared by the ethics committee of Leuphana University Lueneburg.

Supplementary Material for Chapter 5

Table 5.S1 Overview of woody plant sources, i.e. land use types from which woody plant used for different purposes, their category and description.

Source	Category	Description and importance
Farmland	Arable land	Land/fields mainly used for crop cultivation
	Private grazing land	Private fallow or pasture land used for livestock grazing
	Communal grazing land	Communal pasture land, managed and used jointly for livestock grazing
	Homegarden	Enclosed areas surrounding homes, which comprise planted and retained woody plants, also used for production of vegetables, fruits, and some cereal crops
Forest with coffee management	Inherited	Informally, local people owned the forest by inheritance and managed it with customary use rights for coffee production, but legally trees (forest) are owned by the state
	Legally owned	Local people owned the forest by legal provision from *kebele* authorities and managed for coffee production, but still trees (forest) are owned by the state
Forest without coffee management	Inherited	Informally, local people owned the forest by inheritance and managed it with customary use rights for honey production, but legally it is owned by the state
	Communal	Local people access and use forest without coffee management with de facto open access for all types of uses, but formally owned by state
Plantation forest	Government forest	Mostly delineated and strictly protected plantation forest, often planted with some exotic tree species, and owned by the state

Table 5.S2 Characteristics of respondents in each *kebele* by their average percentage of age, gender, family size, educational level, native to the area, ethnic group, and woody plant sources they are visiting.

	Kebele						
Variable	Borcho Deka	Kela Harari	Difo Mani	Gido Bere	Bere Weranigo	Kuda Kofi	Averages %
Average age of respondents (years ± SE 2.1 to 2.9)	46.7	46.3	48.3	43.5	45.1	49.4	46.6
Gender of respondents (%)							
Male	96.7	86.7	70.0	80.0	73.3	83.3	82
Female	3.3	13.3	30.0	20.0	26.7	16.7	18
Average household size (members ± SE 0 to 1)	6	7	6	7	6	6	6
Education level of respondents (%)							
Illiterate	40.0	56.7	60.0	40.0	53.3	40.0	48
Adult education	10.0	10.0	10.0	20.0	16.7	16.7	14
Formal education	50.0	33.3	30.0	36.7	30.0	43.3	37
Respondents native to the area (%)	83.3	86.7	60.0	83.3	83.3	80.0	79
Ethnic groups (%)							
Oromo	93.3	100	83.3	100	100	96.7	96
Others (Amhara, Kefficho and Tigre)	6.7	0	16.7	0	0	3.3	4
Respondents visiting the source (%)							
Arable land	93.3	93.3	93.3	96.7	93.3	96.7	94
Grazing land private	73.3	93.3	56.7	86.7	83.3	43.3	73
Grazing land communal	3.3	0	83.3	36.7	6.7	13.3	24
Homegarden	100.0	100.0	100.0	100.0	100.0	100.0	100
Coffee forest inherited	83.3	93.3	63.3	3.3	0	96.7	57
Coffee forest obtained legally	30.0	20.0	20.0	0	0	10.0	13
Forest without coffee inherited	13.3	76.7	0	0	0	0	15
Communal forest	43.3	76.7	76.7	76.7	0	36.7	52
Government plantation forest	0	0	0	0	0	3.3	1

Table 5.S3. List of woody plant species encountered in all 192 surveyed plots in major sources (farmland, forest with and without coffee management), their family and local names, their category (forest specialists, pioneers generalists and planted species), habit, the number of sites they occurred in and their abundance.

					Abundance and occurrence of species by land use type					
					Farmland		Forest with coffee management		Forest without coffee management	
Scientific name	**Family name**	**Local name**	**Species category**	**Habit**	Occurrence (no. sites)	Abundance	Occurrence (no. sites)	Abundance	Occurrence (no. sites)	Abundance
Abutilon longicuspe	MALVACEAE	Inchinii daalacha	Pioneer	Shrub	1	4	1	3	1	3
Acacia abyssinica	FABACEAE	Sondii adii	Pioneer	Tree	27	429	2	2	-	-
Acacia polyacantha subsp. *Campylacantha*	FABACEAE	Sondii dimaa	Pioneer	Tree	11	115	-	-	-	-
Acanthus eminens	ACANTHACEAE	Baalan-waraantee	Forest specialist	Shrub	1	15	4	226	18	677
Acanthus sennii	ACANTHACEAE	Sookoruu	Generalist	Shrub	17	5035	-	-	-	-
Alangium chinense	ALANGIACEAE	Daannisa	Pioneer	Tree	-	-	4	6	3	5
Albizia gummifera	FABACEAE	Ambabeessa	Generalist	Tree	19	224	11	62	22	249
Albizia schimperiana	FABACEAE	Ambabeessa adii	Generalist	Tree	29	461	18	48	11	44
Allophylus abyssinicus	SAPINDACEAE	See'oo	Forest specialist	Tree	9	50	8	133	33	99
Allophylus macrobotrys	SAPINDACEAE	Saahoo	Generalist	Tree	-	-	-	-	4	8
Annona senegalensis	ANNONACEAE	Liba-barree	Pioneer	Shrub to tree	1	5	-	-	-	-
Apodytes dimidiate	ICACINACEAE	Wandabiyoo	Forest specialist	Tree	7	11	2	2	19	46
Aspilia africana	ASTERACEAE	Hadaa adii	Pioneer	Shrub	8	642	-	-	-	-
Bersama Abyssinia	MELIANTHACEAE	Lolchiisaa	Forest specialist	Tree	28	403	22	115	50	286
Bridelia micrantha	EUPHORBIACEAE	Minaanduloo	Pioneer	Small tree	9	59	1	8	-	-
Brucea antidysenterica	SIMAROUBACEAE	Qomanyoo	Forest specialist	Shrub to tree	34	615	13	59	22	98
Calpurnia aurea	FABACEAE	Cheekaa	Pioneer	Small tree	12	99	4	118	1	4
Canthium oligocarpum subsp. *oligocarpum*	RUBIACEAE	Baal-sadii	Forest specialist	Shrub to tree	3	43	7	40	27	73
Carica papaya	CARICACEAE	Paapaayee	Planted	Tree	1	15	-	-	-	-
Cassipourea malosana	RHIZOPHORACEAE	Ilke	Forest specialist	Tree	-	-	5	29	20	107
Catha edulis	CELASTRACEAE	Caatii	Planted	Tree	17	2670	-	-	-	-
Celtis africana	ULMACEAE	Qayii	Generalist	Tree	14	110	17	91	8	34
Chionanthus mildbraedii	OLEACEAE	Gagamaa	Forest specialist	Tree	-	-	21	338	34	1188
Citrus medica	RUTACEAE	Turunjee	Planted	Shrub to tree	2	6	-	-	-	-
Citrus sinensis	RUTACEAE	Burtukaana	Planted	Shrub to tree	4	5	-	-	-	-
Clausena anisate	RUTACEAE	Ulmaayii	Generalist	Shrub to tree	9	308	24	307	32	459
Clerodendrum myricoides	LAMIACEAE	Maraasissaa	Pioneer	Shrub	13	373	1	1	2	6
Clutia abyssinica	EUPHORBIACEAE	Harchumee	Pioneer	Shrub	1	5	-	-	-	-
Coffea Arabica	RUBIACEAE	Buna	Forest specialist	Small tree	33	1525	46	9683	32	323
Combretum molle	COMBRETACEAE	Adajaboo	Pioneer	Tree	6	30	-	-	-	-
Cordia africana	BORAGINACEAE	Waddeessa	Generalist	Tree	30	276	20	86	9	16
Crossopteryx febrifuga	RUBIACEAE	Unknown	Generalist	Tree	-	-	1	2	-	-
Crotalaria exaltata	FABACEAE	Bilbiilee	Pioneer	Shrub	3	75	1	1	-	-
Crotalaria sp.	FABACEAE	Qomanyoo	Pioneer	Shrub	3	18	-	-	-	-
Croton macrostachyus	EUPHORBIACEAE	Bakaniissa	Pioneer	Tree	49	1367	27	83	35	271
Cupressus lustanica.	CUPERESSACEAE	Gaatiraa faranjii	Planted	Tree	14	225	-	-	-	-

Dalbergia lacteal	FABACEAE	Unknown	Pioneer	Tree	-	-	2	2	3	13
Deinbollia kilimandscharica.	SAPINDACEAE	Unknown	Forest specialist	Tree	-	-	-	-	2	2
Diospyros abyssinica subsp. *abyssinica*	EBENACEAE	Lookkoo gurraacha	Forest specialist	Tree	-	-	9	42	4	20
Discopodium pennlnervium	SOLANACEAE	Reejii arbaa	Generalist	Tree	13	235	-	-	-	-
Dombeya torrida	STERCULIACEAE:	Daannisa	Pioneer	Shrub to tree	5	21	-	-	5	13
Dracaena afromontana	DRACAENACEAE	Algee	Forest specialist	Shrub	-	-	4	28	33	1222
Dracaena fragrans	DRACAENACEAE	Eemoe	Planted	Shrub to tree	8	401	8	231	11	743
Dracaena steudneri	DRACAENACEAE	Bubiftuu/Yubdoo	Forest specialist	Shrub to tree	5	14	6	18	9	32
Ehretia cymosa	BORAGINACEAE	Ulaagaa	Generalist	Shrub to tree	19	196	24	97	10	56
Ekebergia capensis	MELIACEAE	Orooroo	Forest specialist	Tree	7	23	2	4	6	18
Elaeodendron buchananii	CELASTRACEAE	Lookkoo	Generalist	Tree	4	52	18	39	12	138
Embelia schimperi	MYRSINACEAE	Haanku	Pioneer	Shrub or tree	1	1	-	-	-	-
Entada abyssinica	FABACEAE	Hambaltaa	Pioneer	Tree	10	40	2	2	-	-
Erythrina abyssinica	FABACEAE	Waleensuu	Planted	Tree	23	1177	-	-	-	-
Erythrina brucei	FABACEAE	Beroo	Pioneer	Tree	57	4591	1	1	1	1
Erythrococca abyssinica	EUPHORBIACEAE	Agabaatee	Generalist	Shrub	1	1	9	56	4	15
Erythrococca trichogyne	EUPHORBIACEAE	Qayii	Forest specialist	Small tree	-	-	9	98	13	114
Eucalyptus camaldulensis	MYRTACEAE	Baargamo dimaa	Planted	Tree	13	2052	1	1	1	5
Eucalyptus citriodora	MYRTACEAE	Baargamo	Planted	Tree	1	22	-	-	-	-
Eucalyptus globulus	MYRTACEAE	Baargamo adii	Planted	Tree	11	442	-	-	-	-
Eucalyptus spp.	MYRTACEAE	Baargamo	Planted	Tree	1	241	-	-	-	-
Eugenia bukobensis	MYRTACEAE	Unknown	Forest specialist	Small tree	-	-	-	-	1	2
Euphorbia abyssinica	EUPHORBIACEAE	Adaamii	Pioneer	Tree	18	1674	2	2	1	2
Fagaropsis angolensis	RUTACEAE	Qomanyoo	Forest specialist	Tree	1	1	7	25	2	3
Ficus exasperate	MORACEAE	Baalan-soofii	Pioneer	Small tree	4	56	2	3	1	7
Ficus glumosa	MORACEAE	Anuunuu (unknown)	Generalist	Tree	-	-	-	-	1	1
Ficus ovata	MORACEAE	Qelenxoo	Generalist	Small tree	1	6	1	1	-	-
Ficus sp.	MORACEAE	Tinii	Pioneer	Small tree	2	17	-	-	-	-
Ficus sur	MORACEAE	Harbu	Generalist	Tree	20	117	9	34	19	65
Ficus sycomorus	MORACEAE	Odoa	Pioneer	Tree	1	2	-	-	-	-
Ficus thonningii	MORACEAE	Dambii	Generalist	Small tree	4	23	3	10	1	1
Ficus vasta	MORACEAE	Qilxu	Pioneer	Tree	8	14	2	2	1	1
Flacourtia indica	FLACOURTIACEAE	Akuukuu	Generalist	Small tree	14	63	3	7	6	10
Galiniera saxifrage	RUBIACEAE	Mixoo-sarer (Unknown)	Forest specialist	Small tree	12	131	16	89	49	586
Gardenia ternifolia	RUBIACEAE	Gaambelaa	Pioneer	Small tree	3	24	-	-	-	-
Grevillea robusta	PROTEACEAE	Graaviilaa	Planted	Tree	10	63	-	-	-	-
Grewia ferruginea	TILIACEAE	Laankanoo	Pioneer	Shrub	8	73	3	8	-	-
Hallea rubrostipulata	RUBIACEAE	Anuunuu	Forest specialist	Tree	-	-	1	2	1	2
Hibiscus diversifolius	MALVACEAE	Inchinii dimaa	Pioneer	Shrub	3	189	1	1	-	-
Hibiscus macranthus	MALVACEAE	Inchinii daalacha	Pioneer	Shrub	-	-	-	-	-	-
Hypericum revolutum	GUTTIFERAE	Ulee-foonii	Pioneer	Small tree	1	10	-	-	1	1
Ilex mitis	AQUIFOLIACEAE	Qetoo/Kefoo	Forest specialist	Tree	1	1	1	12	11	64
Indigofera arrecta	FABACEAE	Henaa/Enaa	Pioneer	Shrub	7	61	-	-	-	-
Justicia schimperiana	ACANTHACEAE	Dhummugaa	Generalist	Shrub	12	695	16	488	17	1079

Lannea schweinfurthii	ANACARDIACEAE	Booqqoo	Generalist	Tree	-	-	4	4	1	2
Lannea welwitschi	ANACARDIACEAE	Anuunuu	Forest specialist	Tree	-	-	2	3	-	-
Lantana trifolia	VERBENACEAE	Kusaayyee	Pioneer	Shrub	1	2	-	-	-	-
Leonotis ocymifolia	LAMIACEAE	Unknown	Pioneer	Shrub	1	7	-	-	-	-
Lepidotrichilia volkensii	MELIACEAE	Seehoo	Forest specialist	Tree	1	3	5	44	15	95
Lippia adoensis	VERBENACEAE	Kusaayyee	Pioneer	Shrub	5	69	-	-	-	-
Macaranga capensis	EUPHORBIACEAE	Wongoo	Forest specialist	Tree	3	28	16	165	27	305
Maesa lanceolate	MYRSINACEAE	Abbayyii	Generalist	Tree	43	1308	18	59	33	211
Malus sylvestris	ROSACEAE	Applii	Planted	Tree	2	5	-	-	-	-
Mangifera indica	ANACARDIACEAE	Maangoo	Planted	Tree	7	19	-	-	-	-
Manilkara butugi	SAPOTACEAE	Gawoo	Forest specialist	Tree	-	-	1	1	-	-
Maytenus arbutifolia	CELASTRACEAE	Ombooroo	Generalist	Shrub	31	1278	24	840	40	750
Maytenus gracilipes	CELASTRACEAE	Kombolcha	Forest specialist	Shrub	8	150	-	-	-	-
Maytenus senegalensis	CELASTRACEAE	Ombooroo	Pioneer	Shrub	9	177	1	2	3	24
Maytenus sp.	CELASTRACEAE	Qoraatii	Generalist	Shrub	1	44	6	70	4	25
Maytenus undata	CELASTRACEAE	Kolaatii	Generalist	Shrub	-	-	-	-	3	16
Millettia ferruginea	FABACEAE	Astiraa	Forest specialist	Small tree	30	341	33	388	30	272
Mimusops kummel	SAPOTACEAE	Qolaatii	Generalist	Tree	-	-	5	11	4	18
Myrsine africana	MYRSINACEAE	Qachama	Generalist	Shrub	-	-	-	-	1	9
Nuxia congesta	LOGANIACEAE	Qachama	Forest specialist	Small tree	1	1	-	-	1	1
Ocimum lamiifolium	LAMIACEAE	Damaakkase	Pioneer	Shrub	4	73	1	2	-	-
Ocimum urticifolium	LAMIACEAE	Damaakkase	Pioneer	Shrub	14	456	-	-	-	-
Olea welwitschii	OLEACEAE	Bayaa	Forest specialist	Tree	1	1	11	28	25	63
Oxyanthus speciosus subsp. *stenocarpus*	RUBIACEAE	Imbraangoo	Forest specialist	Shrub	-	-	6	38	16	101
Pavetta abyyssinica	RUBIACEAE	Xummaanee	Forest specialist	Small tree	-	-	2	15	19	622
Pentas schimperiana subsp. *schimperiana*	RUBIACEAE	Simararuu	Pioneer	Shrub	3	17	-	-	3	3
Persea Americana	LAURACEAE	Abokaadoo	Planted	Tree	10	21	-	-	-	-
Phoenix reclinata	ARECACEAE	Meexxii	Pioneer	Tree	13	378	1	1	9	50
Phyllanthus mooneyi	EUPHORBIACEAE	Qachama	Pioneer	Shrub	11	147	2	11	1	9
Phyllanthus ovalifolius	EUPHORBIACEAE	Qachama	Generalist	Small tree	-	-	3	11	2	47
Phyllanthus reticulatus	EUPHORBIACEAE	Qachama	Pioneer	Shrub	1	15	3	14	3	51
Phytolacca dodecandra	PHYTOLACCACEAE	Andoodee	Pioneer	Shrub	4	64	-	-	-	-
Piliostigma thonningii	FABACEAE	Leeluu	Pioneer	Tree	1	2	-	-	-	-
Pinus patula	PINACEAE	Piinasii	Planted	Tree	1	2	-	-	-	-
Pittosporum viridiflorum	PITTOSPORACEAE	Soolee	Forest specialist	Small tree	3	4	6	15	10	24
Plectranthus garckeanus	LAMIACEAE	Yaryoo	Generalist	Shrub	-	-	1	5	-	-
Plectranthus sp.	LAMIACEAE	Toogoo	Generalist	Shrub	3	18	-	-	-	-
Podocarpus falcatus	PODOCARPACEAE	Birbirsa	Forest specialist	Tree	2	18	-	-	12	29
Polyscias fulva	ARALIACEAE	Daraku/Kariyoo	Forest specialist	Tree	2	23	8	9	9	11
Pouteria adolfi-friederici	SAPOTACEAE	Qararoo	Forest specialist	Tree	1	1	7	21	35	161
Premna schimperi	LAMIACEAE	Maraasisaa	Pioneer	Small tree	5	42	2	4	-	-
Prunus africana	ROSACEAE	Oomoo	Forest specialist	Tree	14	24	3	3	9	63
Prunus persica	ROSACEAE	Kuukoo	Planted	Tree	2	5	-	-	-	-
Psidium goajava	MYRTACEAE	Zayituunaa	Planted	Small tree	10	65	2	15	-	-

Psychotria orophila	RUBIACEAE	Wandabiyoo	Forest specialist	Small tree	-	-	9	149	25	657
Rhamnus prinoides	RHAMNACEAE	Geeshee	Pioneer	Shrub	24	205	3	21	4	16
Rhus ruspolii	ANACARDIACEAE	Xaaxesaa	Pioneer	Shrub	7	22	-	-	-	-
Ritchiea albersii	CAPPARIDACEAE	Agabaatee	Pioneer	Small tree	2	10	-	-	2	3
Rothmannia urcelliformis	RUBIACEAE	Mixoo	Forest specialist	Small tree	2	9	22	138	13	31
Rytigynia neglecta	RUBIACEAE	Mixoo	Forest specialist	Shrub	15	370	13	105	29	491
Sapium ellipticum	EUPHORBIACEAE	Bosoqqa	Generalist	Tree	7	57	4	5	6	43
Sarcocephalus latifolius	RUBIACEAE	Diboo	Pioneer	Small tree	5	94	1	25	-	-
Schefflera abyssinica	ARALIACEAE	Gatamaa	Forest specialist	Tree	1	2	6	7	13	21
Schefflera myriantha	ARALIACEAE	Bottoo	Forest specialist	Small tree	-	-	-	-	1	3
Senna occidentalis	FABACEAE	Salaamakii dimaa	Pioneer	Shrub	13	120	13	166	3	60
Senna petersiana	FABACEAE	Salaamakii adii	Pioneer	Shrub	13	289	12	178	7	21
Senna sp.	FABACEAE	Salaamakii arabaa	Pioneer	Shrub	7	744	-	-	-	-
Sesbania sesban	FABACEAE	Sasbaaniyaa	Planted	Shrub	22	137	-	-	-	-
Solanecio gigas	ASTERACEAE	Doomboorokoo	Pioneer	Shrub	1	6	2	20	9	50
Solanecio mannii	ASTERACEAE	Haamitii baloo	Forest specialist	Small tree	2	4	2	2	8	39
Solanum giganteum	SOLANACEAE	Unknown	Generalist	Shrub	-	-	-	-	1	1
Stereospermum kunthianum	BIGNONIACEAE	Bootoroo	Pioneer	Small tree	11	129	-	-	-	-
Syzygium guineense subsp. *guineense*	MYRTACEAE	Baddeessa	Forest specialist	Tree	7	15	12	69	47	293
Teclea nobilis	RUTACEAE	Hadhessaa	Forest specialist	Small tree	2	3	7	46	21	207
Terminalia laxitlora	COMBRETACEAE	Dabaqaa	Pioneer	Tree	3	12	-	-	-	-
Trichilia dregeana	ASTERACEAE	Anuunuu	Forest specialist	Tree	1	2	6	25	14	121
Unidentified sp.	RUBIACEAE	Mixoo	Generalist	Shrub	2	16	3	60	9	120
Vepris dainellii	RUTACEAE	Hadhessaa babal'a	Forest specialist	Small tree	-	-	19	165	50	510
Vernonia adoensis	ASTERACEAE	Turujee	Pioneer	Shrub	16	958	1	5	1	3
Vernonia amygdalina	ASTERACEAE	Ibicha	Generalist	Shrub	48	1129	7	32	14	80
Vernonia auriculifera	ASTERACEAE	Reejii	Pioneer	Shrub	70	8539	25	650	25	688
Vernonia bipontini	ASTERACEAE	Sooyyama	Pioneer	Shrub	4	360	-	-	-	-
Vernonia hochstetteri	ASTERACEAE	Xasee	Pioneer	Shrub	9	158	1	10	4	6
Vernonia leopoldi	ASTERACEAE	Qaawulee	Pioneer	Shrub	2	71	-	-	-	-
Vernonia sp.1	ASTERACEAE	Xasee-dimaa	Generalist	Shrub	1	6	-	-	-	-
Vernonia sp.2	ASTERACEAE	Reejii arbaa	Pioneer	Shrub	-	-	-	-	1	3
Vernonia sp.3	ASTERACEAE	Sooyyama	Generalist	Shrub	-	-	2	9	2	3
Vernonia thomsoniana	ASTERACEAE	Sooyyama	Pioneer	Shrub	11	768	-	-	2	8

Table 5.S4 List of woody plant species used by households; number of households used a species for different purposes; number of uses of a species; list of use/s of a species and its primary and secondary use; and species abundance by *kebele* and major source; and total abundance across the landscape. HHs = households; use type: 1 = house construction, 2 = farm implements, 3 = fuelwood, 4 = honey production/beehives, 5 = fences, 6 = medicine, 7 = coffee shade, 8 = household utilities, 9 = soil fertility, 10 = animal fodder, 11 = poles and timber, and 12 = other uses (e.g., beehives smoking, walking stick, cleaning); major source: FL = farmland, Cof = forest with coffee management, and No-cof = forest without coffee management. "x" denotes used, and "-" denotes not used for. Respondents reported the use of five species, not recorded in all studied plots i.e. had 0 total abundance, e.g., *Hagenia abyssinica*. *Albizia* spp. represents *Albizia gummifera* and *Albizia schimperiana*, and *Eucalyptus* spp. represents more than two species of *Eucalyptus*. Further analysis was not conducted for use categorized as "other uses (12)" as they were not uniformly known and used throughout study area.

Species name	No. HHs preferred species	No. of uses	Use												Primary use	Secondary use	Species abundance by *kebele* and major source															Total abundance
																	Borcho Deka			Kela Harari			Difo Mani			Gido Bere			Bere Weranigo			Kuda Kofi			
			1	2	3	4	5	6	7	8	9	10	11	12			FL	Cof	No-cof	FL	Cof	No-cof	FL	Cof	No-cof	FL	Cof	No-cof	FL	Cof	No-cof	FL	Cof	No-cof	
Erythrina brucei	176	5	-	-	x	x	x	x	-	-	x	-	-	-	5	9	112	1	1	1345	-	-	600	-	-	238	-	-	1609	-	-	687	-	-	4593
Ehretia cymosa	160	5	X	x	x	-	x	-	-	x	-	-	-	-	2	5	11	67	22	-	8	1	122	18	1	49	-	32	-	-	-	14	4	-	349
Ocimum lamiifolium	158	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	-	2	-	-	-	-	46	-	-	-	-	-	27	-	-	-	-	-	75
Chionanthus mildbraedii	154	3	X	x	-	-	x	-	-	-	-	-	-	-	2	1	-	70	449	-	256	363	-	12	45	-	-	331	-	-	-	-	-	-	1526
Cordia africana	153	8	X	x	x	x	-	-	x	x	x	-	x	-	11	8	14	19	7	-	3	1	121	20	1	1	-	7	4	-	-	136	44	-	378
Albizia spp.	152	7	X	-	x	x	-	-	x	x	x	-	-	x	7	4	-	21	138	14	53	103	424	24	-	189	-	52	22	-	-	36	12	-	1088
Croton macrostachyus	151	9	X	x	x	x	x	x	x	x	x	-	-	-	4	6	20	31	25	182	12	152	136	17	3	456	-	87	206	-	4	367	23	-	1721
Vernonia amygdalina	148	9	X	x	x	x	x	x	x	-	x	X	-	-	4	10	91	28	50	55	-	12	515	4	-	153	-	18	243	-	-	72	-	-	1241
Eucalyptus spp.	143	6	X	x	x	x	x	-	-	x	-	-	-	-	1	2	4	-	5	-	-	-	1748	-	-	423	-	-	270	-	-	312	1	-	2763
Millettia ferruginea	133	8	X	x	x	x	x	-	x	-	x	X	-	-	3	7	54	282	119	16	49	92	40	10	-	52	-	55	175	-	6	4	47	-	1001
Euphorbia abyssinica	116	4	X	-	-	x	x	-	-	x	-	-	-	-	5	4	779	1	-	563	-	-	3	1	2	82	-	-	247	-	-	-	-	-	1678
Olea welwitschii	110	7	X	x	x	x	x	-	x	-	-	-	-	x	2	4	-	20	5	1	7	15	-	1	-	-	-	43	-	-	-	-	-	-	92
Pouteria adolfi-friederici	105	8	X	x	x	x	-	-	x	x	x	-	x	-	11	4	-	11	12	-	10	113	-	-	-	1	-	35	-	-	1	-	-	-	183
Vernonia auriculifera	103	8	X	x	x	x	x	x	x	-	x	-	-	-	5	3	190	223	91	607	-	450	3049	219	-	934	-	96	2533	-	51	1242	208	-	9893
Ficus sur	88	7	-	-	x	x	-	-	x	x	x	X	x	-	8	4	41	18	4	21	16	42	22	-	-	11	-	19	10	-	-	12	-	-	216
Galiniera saxifraga	84	3	X	x	-	-	-	-	-	-	-	X	-	-	2	10	-	69	124	-	12	165	-	8	-	50	-	297	81	-	-	-	-	-	806
Teclea nobilis	81	2	-	x	-	-	-	-	-	-	-	-	-	x	2	12	-	7	6	-	13	8	1	21	12	2	-	181	-	-	-	-	5	-	256
Rytigynia neglecta	80	4	X	x	-	x	x	-	-	-	-	-	-	-	5	1	17	26	46	-	69	302	151	9	1	179	-	142	4	-	-	19	1	-	966
Justicia schimperiana	76	3	X	-	-	-	x	x	-	-	-	-	-	-	1	5	-	166	416	224	111	553	-	97	-	-	-	110	471	-	-	-	114	-	2262
Coffea Arabica	68	5	X	x	x	x	-	-	-	-	-	-	-	x	2	4	124	5266	77	58	1227	165	841	1571	31	64	-	50	78	-	-	360	1619	-	11531
Syzygium guineense	67	8	X	-	x	x	x	-	x	x	-	X	x	-	1	3	2	29	10	3	37	198	-	3	-	8	-	84	-	-	1	2	-	-	377
Polyscias fulva	63	4	X	x	-	x	-	-	-	-	-	-	x	-	4	11	-	4	6	11	5	3	-	-	-	12	-	2	-	-	-	-	-	-	43
Acacia abyssinica	62	6	X	-	x	x	-	-	x	-	x	X	-	-	3	7	-	-	-	-	-	-	274	2	-	53	-	-	23	-	-	79	-	-	431
Macaranga capensis	62	4	X	x	x	-	x	-	-	-	-	-	-	-	1,3	5	9	144	160	9	21	125	-	-	-	10	-	20	-	-	-	-	-	-	498
Elaeodendron buchananii	55	6	X	x	x	x	x	-	x	-	-	-	-	-	1,2	4	27	23	37	-	16	71	7	-	-	18	-	30	-	-	-	-	-	-	229
Celtis africana	53	6	-	x	x	-	x	x	-	x	-	X	-	-	2	3	-	8	3	-	4	27	72	49	4	-	-	-	-	-	-	38	30	-	235
Maesa lanceolata	53	7	X	-	x	-	x	x	x	-	x	X	-	-	3	5	285	41	99	294	2	100	457	10	-	47	-	12	60	-	-	165	6	-	1578
Schefflera abyssinica	53	4	-	x	-	x	-	-	x	-	x	-	-	-	4	2,7,9	-	6	9	-	1	6	-	-	-	2	-	6	-	-	-	-	-	-	30
Calpurnia aurea	48	6	X	x	-	-	x	x	-	x	-	-	-	x	2	5	-	-	-	-	-	-	62	45	-	-	-	4	37	-	-	-	73	-	221

Vernonia thomsoniana	44	6	X	-	x	x	x	x	-	-	x	-	-	-	4	5	-	-	-	-	-	-	617	-	-	-	-	8	-	-	-	151	-	-	776
Dracaena fragrans	40	2	-	-	-	-	x	-	-	-	-	X	-	-	5	10	42	228	694	16	-	-	14	3	42	-	-	7	112	-	-	217	-	-	1375
Erythrina abyssinica	40	4	-	-	x	x	x	-	-	x	-	-	-	-	5	4	-	-	-	-	-	-	-	-	-	777	-	-	400	-	-	-	-	-	1177
Ficus vasta	38	7	X	x	x	x	-	-	x	x	x	-	-	-	4	7	1	-	-	-	-	1	10	-	-	-	-	-	-	-	-	3	2	-	17
Prunus africana	37	9	X	x	x	x	-	-	x	x	x	-	x	x	3	8	3	2	-	-	-	53	10	1	-	7	-	10	2	-	-	2	-	-	90
Sesbania sesban	30	2	-	-	-	-	-	-	x	-	-	X	-	-	7	10	-	-	-	2	-	-	62	-	-	6	-	-	18	-	-	49	-	-	137
Mimusops kummel	28	4	X	x	-	-	-	-	x	-	-	-	-	x	2	1	-	6	8	-	-	-	-	5	10	-	-	-	-	-	-	-	-	-	29
Cassipourea malosana	22	2	X	x	-	-	-	-	-	-	-	-	-	-	2	1	-	12	15	-	17	38	-	-	5	-	-	49	-	-	-	-	-	-	136
Acanthus sennii	21	2	-	-	x	-	x	-	-	-	-	-	-	-	5	3	-	-	-	-	-	-	4425	-	-	-	-	-	14	-	-	596	-	-	5035
Allophylus abyssinicus	21	6	X	x	x	-	x	x	-	x	-	-	-	-	3	2	-	3	25	1	8	35	42	117	3	6	-	36	1	-	-	-	5	-	282
Myrsine africana	17	3	X	-	-	x	x	-	-	-	-	-	-	-	1	5	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	9
Dracaena steudneri	15	4	-	-	-	-	x	-	x	-	x	X	-	-	10	9	1	11	20	-	3	-	2	4	-	4	-	12	-	-	-	7	-	-	64
Premna schimperi	15	1	X	-	-	-	-	-	-	-	-	-	-	-	1		-	2	-	-	-	-	42	2	-	-	-	-	-	-	-	-	-	-	46
Sapium ellipticum	15	3	X	-	x	-	-	-	-	-	-	X	-	-	3, 10	1	40	4	7	-	1	-	6	-	-	-	-	36	-	-	-	11	-	-	105
Psychotria orophila	14	3	X	-	-	-	x	-	-	-	-	X	-	-	1	5	-	17	31	-	132	581	-	-	-	-	-	45	-	-	-	-	-	-	806
Vernonia hochstetteri	14	1	-	-	-	x	-	-	-	-	-	-	-	-	4		-	-	-	52	-	5	93	10	-	-	-	1	-	-	-	13	-	-	174
Clausena anisata	13	5	X	x	-	-	x	x	-	-	-	-	-	x	5	6	3	231	93	5	12	109	296	64	4	3	-	253	1	-	-	-	-	-	1074
Bersama abyssinia	12	3	X	-	x	-	-	x	-	-	-	-	-	-	3	6	-	33	21	24	44	169	45	34	3	173	-	71	152	-	22	9	4	-	804
Cupressus lustanica	12	7	X	x	x	-	x	-	-	x	-	-	x	x	1	2,5,8	-	-	-	-	-	-	3	-	-	124	-	-	98	-	-	-	-	-	225
Rhamnus prinoides	12	2	X	-	-	-	x	-	-	-	-	-	-	-	5	5	12	5	-	29	-	7	8	3	-	41	-	9	93	-	-	22	13	-	242
Stereospermum kunthianum	12	2	-	x	-	x	-	-	-	-	-	-	-	-	2	4	-	-	-	-	-	-	50	-	-	-	-	-	-	-	-	79	-	-	129
Clerodendrum myricoides	9	2	X	-	-	-	-	x	-	-	-	-	-	-	1	6	242	-	2	8	1	4	87	-	-	5	-	-	-	-	-	31	-	-	380
Ekebergia capensis	9	6	X	x	x	x	-	-	-	x	-	-	x	-	4	3	-	-	-	13	2	15	-	-	-	4	-	3	6	-	-	-	2	-	45
Lannea welwitschii	9	2	-	-	x	-	-	x	-	-	-	-	-	-	6	3	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Podocarpus falcatus	9	4	X	-	-	-	-	-	x	-	-	x	x		1	11	-	-	-	-	-	22	-	-	-	18	-	7	-	-	-	-	-	-	47
Acacia polyacantha	8	4	X	-	x	x	-	-	x	-	-	-	-	-	7	3	-	-	-	-	-	-	1	-	-	34	-	-	-	-	-	80	-	-	115
Flacourtia indica	8	4	X	x	x	-	-	x	-	-	-	-	-	-	2	1,3,6	-	-	1	4	6	-	48	1	1	1	-	8	-	-	-	10	-	-	80
Oxyanthus speciosus	8	3	X	x	-	-	x	-	-	-	-	-	-	-	2	1	-	22	59	-	16	15	-	-	-	-	-	27	-	-	-	-	-	-	139
Apodytes dimidiata	7	4	X	x	-	x	-	-	-	x	-	-	-	-	1	4,8	1	1	2	5	1	39	-	-	-	1	-	5	4	-	-	-	-	-	59
Grevillea robusta	7	3	-	-	-	-	-	-	x	-	x	-	-	x	9	12	-	-	-	-	-	-	-	-	-	2	-	-	41	-	-	20	-	-	63
Hagenia abyssinica	7	4	X	-	-	-	-	x	-	x	-	-	x	-	1	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Maytenus arbutifolia	7	2	-	-	x	-	x	-	-	-	-	-	-	-	3	5	604	279	195	39	307	345	324	221	-	56	-	210	252	-	-	13	33	-	2878
Terminalia laxitlora	7	6	-	x	x	x	-	-	x	-	-	X	-	x	3	4	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	5	-	-	12
Abutilon longicuspe	6	3	X	x	-	x	-	-	-	-	-	-	-	-	2	1,4	-	-	-	-	-	3	4	-	-	-	-	-	-	-	-	-	3	-	10
Fagaropsis angolensis	6	3	X	-	-	x	-	x	-	-	-	-	-	-	1	6	-	25	2	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	29
Lippia adoensis	6	2	X	-	-	-	x	-	-	-	-	-	-	-	1	5	-	-	-	-	-	-	65	-	-	-	-	-	-	-	-	4	-	-	69
Dracaena afromontana	5	1	-	-	-	-	-	-	-	-	-	X	-	-	10	-	-	4	226	-	24	946	-	-	-	-	-	50	-	-	-	-	-	-	1250
Gardenia ternifolia	5	2	-	x	-	-	-	-	-	x	-	-	-	-	2	8	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	2	-	-	24
Phoenix reclinata	5	1	X	-	-	-	-	-	-	-	-	-	-	-	1		40	-	13	-	-	-	9	1	-	329	-	37	-	-	-	-	-	-	429
Diospyros abyssinica	4	2	X	x	-	-	-	-	-	-	-	-	-	-	2	1	-	40	-	-	-	3	-	2	13	-	-	-	-	-	4	-	-	-	62

Ficus sycomorus	4	4	-	-	x	x	-	-	-	-	x	-	x	-	3,4, 9,1 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Rothmannia urcelliformis	4	2	-	x	-	-	x	-	-	-	-	-	-	-	2	5	-	40	26	-	-	-	3	4	1	-	-	4	-	-	-	6	94	-	178
Combretum molle	3	2	-	-	x	x	-	-	-	-	-	-	-	-	3	4	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	22	-	-	30
Mangifera indica	3	2	-	-	-	x	-	x	-	-	-	-	-	-	4	6	-	-	-	-	-	-	13	-	-	-	-	-	-	-	-	6	-	-	19
Persea americana	3	2	-	-	-	x	-	-	x	-	-	-	-	-	7	4	7	-	-	3	-	-	2	-	-	-	-	-	5	-	-	4	-	-	21
Salix subserrata	3	1	-	x	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Vepris dainellii	3	1	-	x	-	-	-	-	-	-	-	-	-	-	2	-	-	85	149	-	31	105	-	49	51	-	-	205	-	-	-	-	-	-	675
Bridelia micrantha	2	2	-	-	-	-	x	x	-	-	-	-	-	-	5,6	-	-	-	-	-	-	-	29	-	-	-	-	-	-	-	-	30	8	-	67
Brucea antidysenterica	2	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	11	33	50	61	23	42	16	3	-	315	-	3	212	-	3	-	-	-	772
Grewia ferruginea	2	2	-	-	-	-	x	-	-	-	-	X	-	-	5,1 0	-	-	-	-	-	-	-	61	3	-	-	-	-	-	-	-	12	5	-	81
Olea capensis	2	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Pittosporum viridiflorum	2	2	X	-	-	-	-	-	-	-	-	-	-	x	1	-	-	12	17	-	-	6	-	-	1	1	-	-	-	-	-	3	3	-	43
Aspilia africana	1	1	-	-	x	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	615	-	-	-	-	-	-	-	-	27	-	-	642
Dombeya torrida	1	1	-	-	x	-	-	-	-	-	-	-	-	-	3	-	-	-	-	13	-	12	-	-	-	-	-	1	8	-	-	-	-	-	34
Hibiscus diversifolius	1	1	-	-	-	-	-	-	-	-	-	X	-	-	10	-	-	-	-	-	-	-	189	-	-	-	-	-	-	-	-	-	-	-	189
Ilex mitis	1	1	-	x	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	12	60	-	-	-	-	-	4	1	-	-	-	-	-	77
Indigofera arrecta	1	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	-	-	-	-	-	-	48	-	-	-	-	-	-	-	-	13	-	-	61
Landolphia buchananii	1	1	-	-	-	x	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Maytenus gracilipes	1	1	-	x	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	24	-	-	126	-	-	-	-	-	-	-	-	150
Ocimum urticifolium	1	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	6	-	-	-	-	-	449	-	-	-	-	-	-	-	-	-	-	-	455
Ritchiea albersii	1	1	-	x	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	10	-	-	-	-	3	-	-	-	-	-	-	13
Senna petersiana	1	1	-	-	-	-	x	-	-	-	-	-	-	-	5	-	24	129	15	-	-	-	136	3	-	-	-	6	-	-	-	129	46	-	488
Solanecio mannii	1	1	-	-	-	-	-	x	-	-	-	-	-	-	6	-	-	1	-	4	1	21	-	-	-	-	-	18	-	-	-	-	-	-	45
Terminalia schimperiana	1	1	X	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

Figure 5.S1 Diameter at breast height (DBH) distribution profiles of all of the most widely used tree species in their major sources, i.e. in farmland (dark grey shaded bars), in forest with coffee management (cyan), and in forest without coffee management (green). (a) Inverted J-shaped (healthy) distribution type; (b) irregular (selective removal) distribution type; and (c) bell-shaped (poor regeneration) distribution type. DBH classes are 1 = < 5 cm; 2 = 5.1-10 cm; 3 = 10.1-20 cm; 4 = 20.1-30 cm; 5 = 30.1-40 cm; 6 = 40.1-50 cm; 7 = 50.1-60 cm; 8 = 60.1-70 cm; and 9 = > 70 cm. *Albizia* spp. = *Albizia gummifera* and *Albizia schimperiana*. Numbers above bars refer to the number of plots in which the individuals in the size class occurred at.

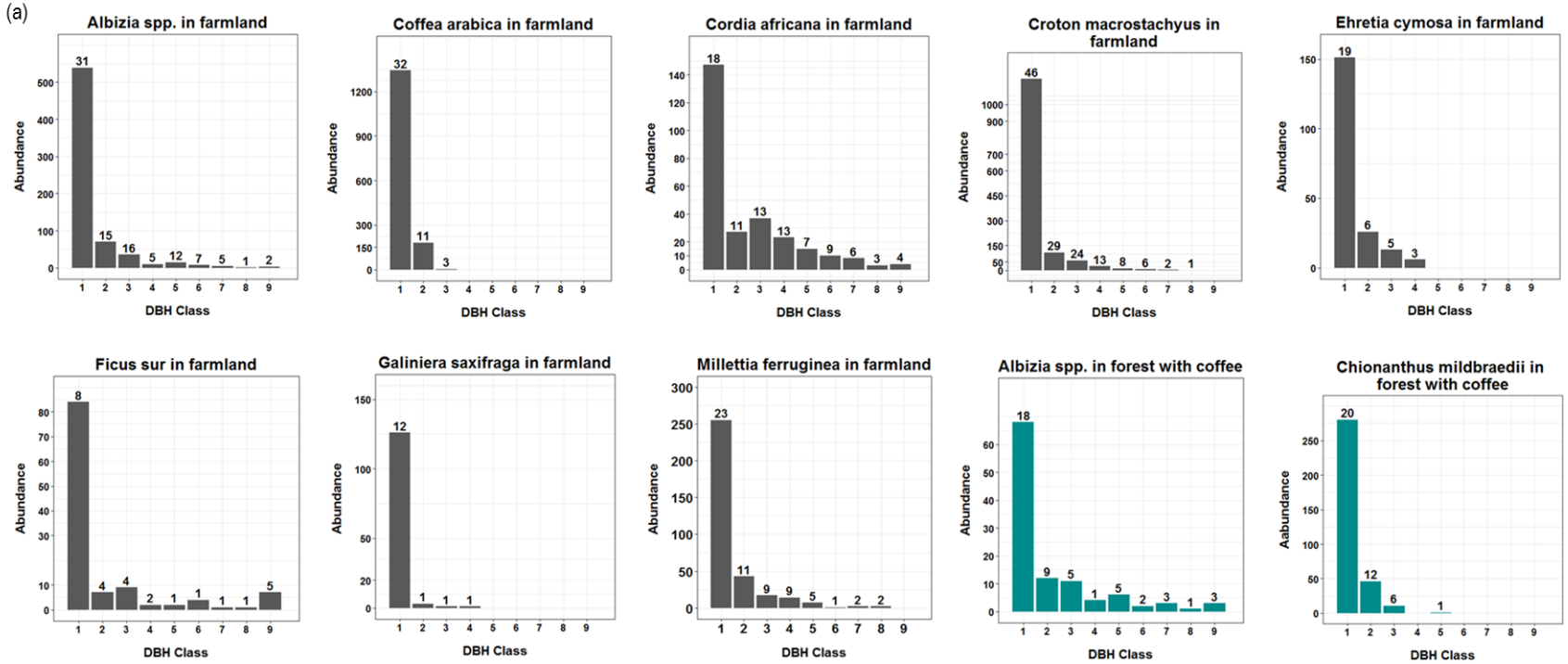


Figure 5.S1 Continued

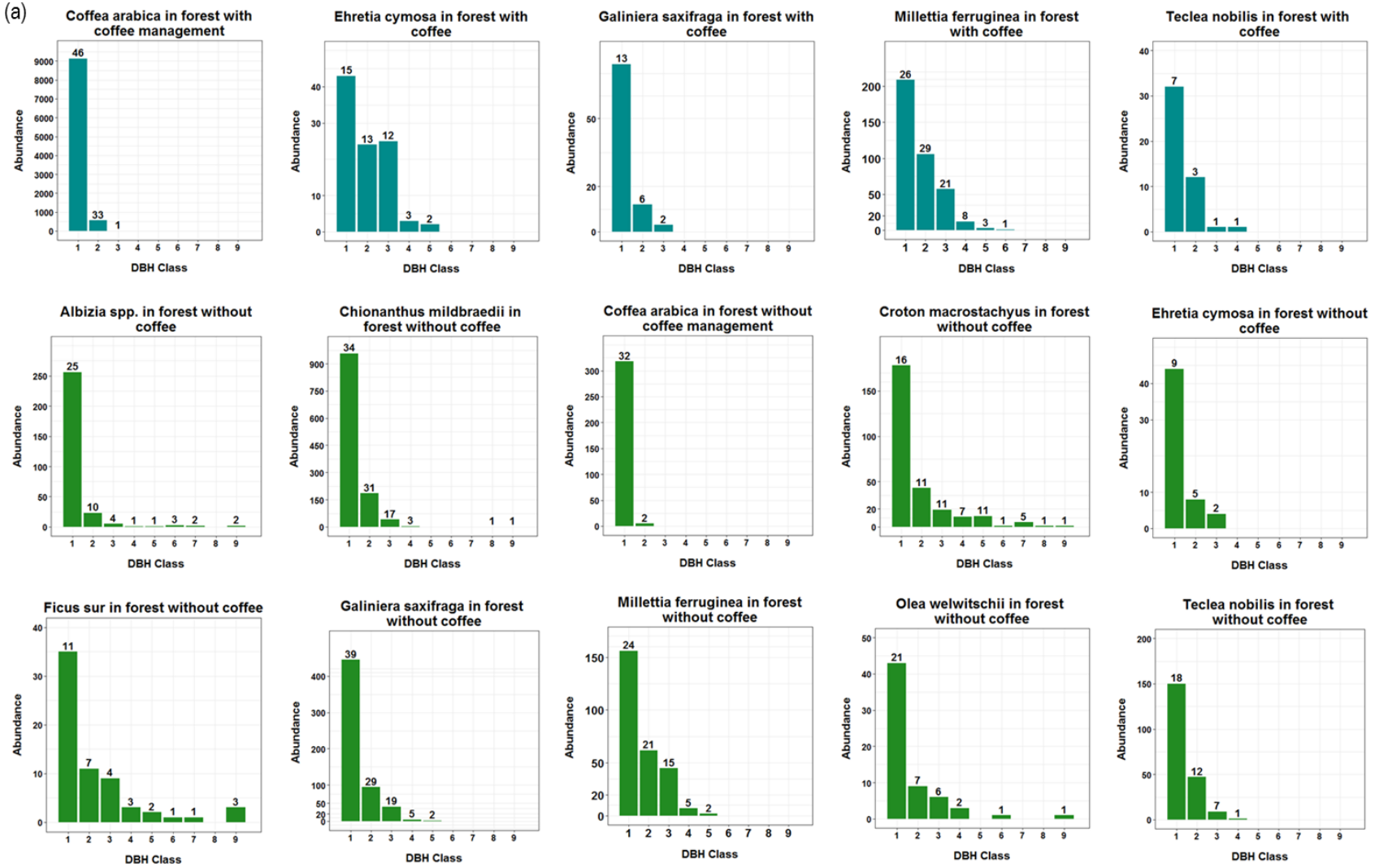


Figure 5.S1 Continued

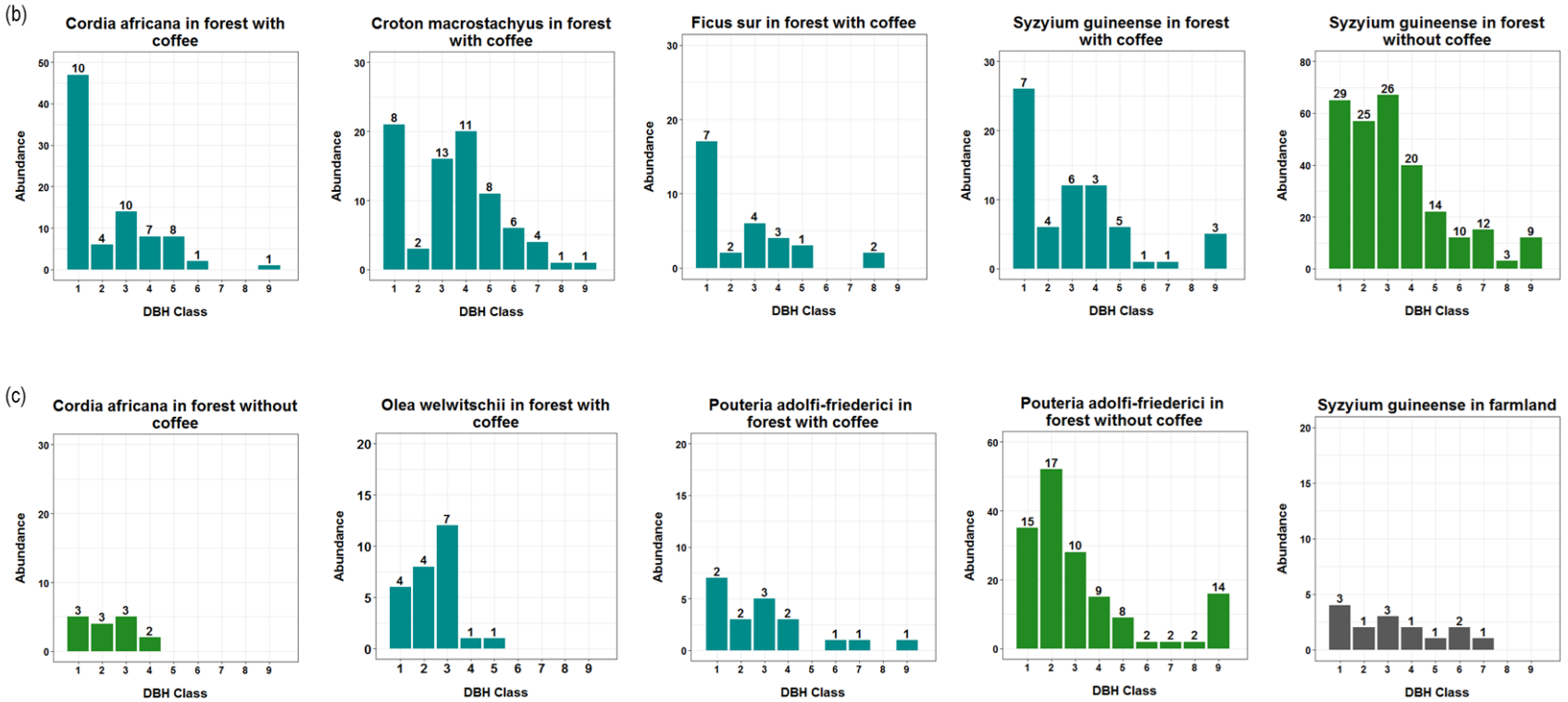
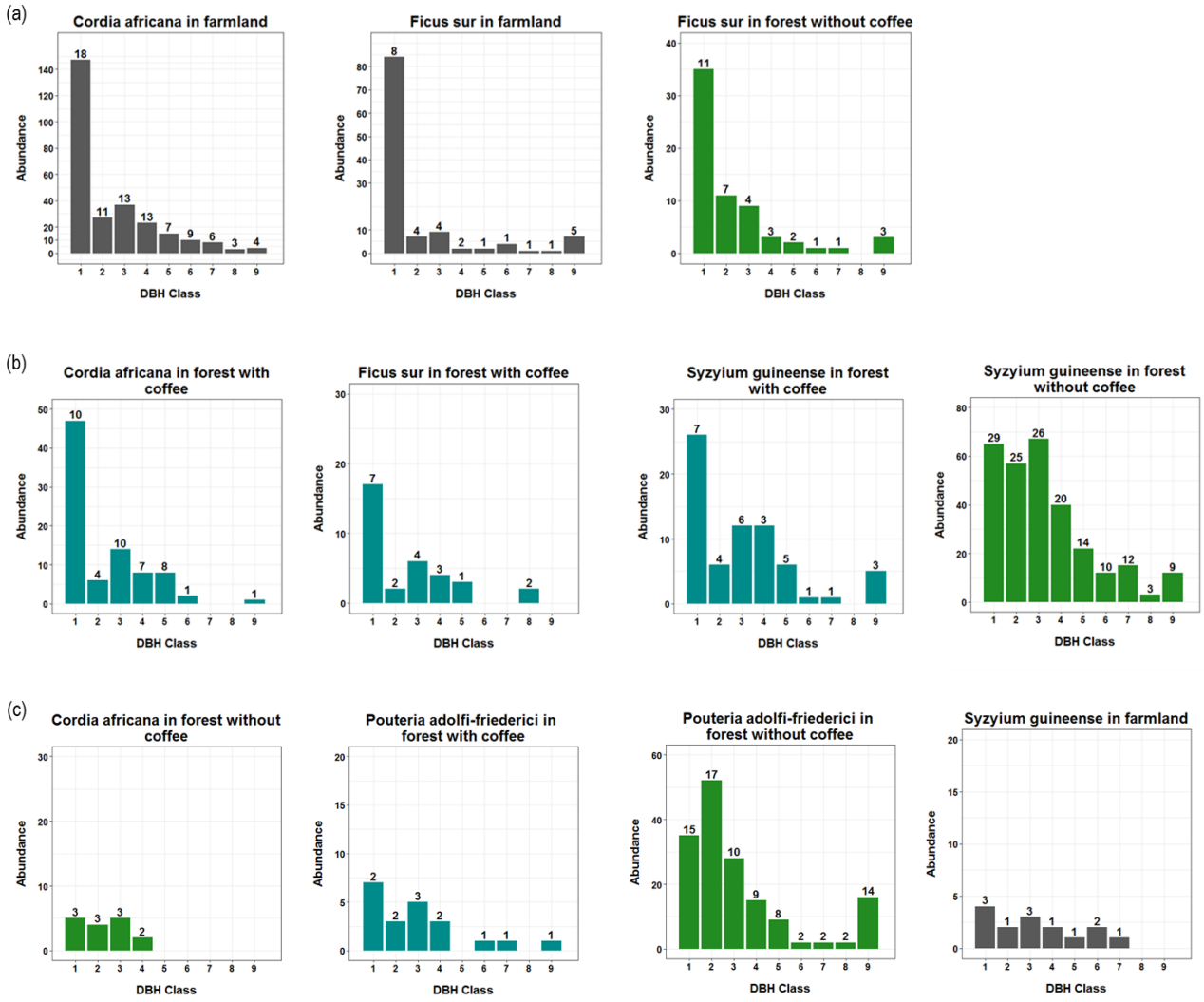


Figure 5.S2 Diameter at breast height (DBH) distribution profiles of the most widely used poles and timber tree species in their major sources, i.e. in farmland (dark grey shaded bars), in forest with coffee management (cyan), and in forest without coffee management (green). (a) Inverted J-shaped (healthy) distribution type; (b) irregular (selective removal) distribution type; and (c) bell-shaped (poor regeneration) distribution type. For DBH classes see the above Fig. S1. Numbers above bars refer to the number of plots in which the individuals in the size class occurred at.



Appendix 5A Questionnaire, which was translated into local *Oromifaa* language, and used for household survey.

I. General background information on household *(Note: A household is made of people that live together in one house and share a meal)* ***(Please escape this part for core HHs)***.

1.1 Gender of interviewee: O male O female	1.2 Age:	1.3 Religion: O Muslim O Orthodox O Protestant O Catholic O Others, _____
1.4 Marital Status: O Single O Married O Divorced O Widowed O Other_____	1.5 Household Size: _____ Adult1 O m O f Adult2 O m O f, Child3 O m O f Child1 O m O f, Child4 O m O f Child2 O m O f ,Child5 O m O f	1.4 Education Adult1 _____ Child4 _____ Adult2 _____ Child5 _____ Child1 _____ Child6 _____ Child2 _____ Child3 _____
1.7 Are you native to/ born in this kebele? O yes O no	1.8 If not born in the kebele, from where you are: O Within Oromia O Other: _____	10 When did you settle in this particular spot? O _____ (Ethiopian year) O A long time ago but I cannot recall O Always been here O Born here, left, and came back on _____
1.11 Did your parents live in this region? O Yes O No If no, where? _____	1.12.Ethnic group *(do not ask directly- try to infer from Q 1.8-1.11)*: O Oromo O Amhara O Tigree O Kefa O Others, _____	1.13 Do you have land? O yes O no If yes, which? (check more than one or any that apply) O *homegarden* O *crop fields* O grazing land O coffee forest O Other (specify): _____

II. Household's woody plant use by species preference

1. Which tree species do your household use for the following ecosystem services? Mention at least three of them by local name (could be identified) for each uses, note that AR=arable land, GR=grazing, HG= homegarden, FWCMOI = Forest with coffee management owned by inheritance, FWOCMOI = Forest without coffee management owned by inheritance, CF= communal, FWCMOL = Forest with coffee management owned legally from *kebele* authorities, Y=yes, N=no. Please note for source check (write 1, 2,3) more than one or any that apply.

No.	Ecosystem services (ES)	Specific ES use	Woody plant species providing ES (uses) in decreasing order of importance (1= the most important, 2nd, then the 3rd)			Source			
						Farmland		Forest	Others (specify)
						Maintained naturally regenerated tree	Planted		
			1	2	3				
1	Fuelwood								
	Dried firewood	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Live firewood	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Charcoal	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
2	Wood for house furniture (house utilities) e.g., handles	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
3	Wood for farm implements								
	Handle	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Yoke	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Beam	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
4	Wood for house construction								
	Wall	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Roof	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
5	Timber/pole	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
6	Honey production								
	Beehive making	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___

	Beehive hanging	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Bee forage (flowers for honey making)	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
7	Fodder for animals (cut and feeding, and letting the cattle to browse trees)	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
8	Coffee shade	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
9	Soil fertility enhancers	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
10	Fence								
	Dried	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
	Live	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
11	Medicine	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___
12	Other (specify)_____	O Y, O N				___AR, __ GR, __ HG	___AR, __ GR, __ HG	__FWCMOI, __CF, __FWOCMOI, __FWCMOL	___Others___

III. Tree/forest use right and management (tree sovereignty)

1. Do you have use right to dead and alive trees for uses mentioned above? Note: AR = arable land, GR = grazing, HG = homegarden, FWCMOI = Forest with coffee management owned by inheritance, FWOCMOI = Forest without coffee management owned by inheritance, CF = communal, FWCMOL = Forest with coffee management owned legally from *kebele* authorities. Fill with Y = yes, N = No, not app. = not applicable.

No	Ecosystem services (ES)	**Use right**	
		Dead wood from trees/shrubs grown on	**Live wood from trees/shrub grown on**
1	Fuelwood	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
2	Wood for furniture (house utilities)	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
3	Wood for farm implements	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
4	Wood for house construction	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app..	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
5	Timber/pole	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
6	Honey production (for beehive making)	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
7	Fodder for animals	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
8	Coffee shade	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
9	Soil fertility enhancers	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
10	Fence	_____AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
11	Medicine	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.
12	Other (specify)_____	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.	___AR, ___GR, ___HG, ___ FWCMOL,___ FWCMOI, ___CF, ___ FWOCMOI ___not app.

2. If you do not have use right to at least one of the ESs or uses, how do you use them?
   O By asking kebele leaders for authorization/permission
   O illegally by taking from somewhere
   O purchasing,
   O others (specify) _____
3. Do you have sense of ownership for trees that you used for specific uses you mentioned above in question 1 of part I?
   O yes, O no
4. If yes, for trees grown on which land? For trees on:
   O Arable land, O Homegarden, O Grazing (private and communal) land,
   O Owned forest with coffee management by customary right/inheritance,
   O Forest without coffee management owned by customary right/inheritance
   O Forest with coffee management owned legally from *kebele* authorities
   O Communal forest
   O Government plantation forest
   O others, specify_____
5. If your answer is "yes for question 3 and then, answered to question 4" or "no" for question 3, why? Please explain your answer:
   _____
   _____
   _____
6. If your answer for tree use right and sense of ownership is yes, then, do you think that you have also responsibility for trees that you used for specific uses you mentioned above in question 1 of part I?
   O yes, O no, O not applicable
7. If yes, how do you managed trees on

	Conservation (e.g., retaining, planting or transplanting their seedlings and grow them)	Management (e.g., weeding, pruning, pollarding, replacing)	Protection e.g., protect from encroachers/illegal loggers, fire, animal attack	Others (specify)
AR				
GR				
HG				
FWCMOL				
FWCMOI				
FWOCMOI				
CF				
Government plantation forest				

If you have additional points on tree use right or questions e.g., 1,2,3, 6,7 in general, please explain them (if any)

_____
_____
_____
_____

IV. Land tenure security and forest ownership

1. Do you have land use or access right?
   O yes, O no,
   If yes, for which land?
   - O Arable land, O Homegarden, O Grazing (private and communal) land,
   - O Owned forest with coffee management by customary right/inheritance,
   - O Forest without coffee management owned by customary right/inheritance
   - O Forest with coffee management owned legally from kebele authorities
   - O Communal forest
   - O Government plantation forest
2. Do you have a land ownership certificate?
   O yes, O no,
   If yes, for which land (could be multiple answers)
   - O Arable land, O Homegarden, O Grazing (private and communal) land,
   - O Owned forest with coffee management by customary right/inheritance,
   - O Forest without coffee management owned by customary right/inheritance
   - O Forest with coffee management owned legally from kebele authorities
   - O Communal forest
   - O Government plantation forest
3. If your answer for question 2 is "yes" and you have a land ownership certificate for the land you mentioned on question 2, what is your feeling or perception about your land tenure security or land use right by having a land ownership certificate to it? Or do you feel secured in your land tenure ship?
   O yes, O no, Why?
   _____
   _____
   _____.
4. Do you have the right to inherit a land for which you have:
   a) Land ownership certificate?
   O yes, O no why? _____
   b) Use right?
   O yes, O no, why? _____
   c) O Not applicable

5. What type of right do you have over natural forest? If it is not applicable on 1 &2
   a) O Customary use right
   b) O Legally bind use right –e.g., land certificate in PFM or individually
   c) O Not applicable
   d) O Others (specify)_____
   _____
6. Who owns the nearby forest to which you have use right to get the ES or uses mentioned above?
   a) O Government
   b) O Community –e.g., PFM certificate
   c) O Individually by customary right e.g., kobbo holding system, inherited
   d) O Private, legally provided by *kebele* authorities/government or bought as investor
   e) O Not applicable
   f) O Others (specify)_____
7. What do you like to recommend about trees/shrubs use, land tenure security, trees/ forest land ownership, use right and responsibility in relation to current situation and future woody plant species maintenance or conservation?

_____
_____

_____
_____
_____

That completes the survey. Thank you very much for sharing your time and this valuable information with us.

For enumerators: please remind the interviewee that we are here not to solve all community problems rather we collect such information, analysis and give feedback or share our learning to you/ your community (like the factsheet given to you), to kebele and woreda leaders and higher policy makers, and NGOs help to find new ways of addressing the problems.

Then

Do you have any question for us before we close? Again, thank you and I wish you a good day.

References

Refernces

Aerts R, Berecha G, Honnay O (2015) Protecting coffee from intensification. Science 347, 139.

Aerts R, Hundera K, Berecha G et al (2011) Semi-forest coffee cultivation and the conservation of Ethiopian Afromontane rainforest fragments. For. Ecol. Manage. 261, 1034–1041.

Allan E, Manning P, Alt F et al (2015) Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol. Lett. 18, 834–843.

Alroy J (2017) Effects of habitat disturbance on tropical forest biodiversity. Proc. Natl. Acad. Sci. USA 114, 6056–6061.

Ango TG (2016) Ecosystem services and disservices in an agriculture—forest mosaic: a study of forest and tree management and landscape transformation in southwestern Ethiopia. Dissertation, Stockholm University, Stockholm.

Ango TG, Börjeson L, Senbeta F, Hylander K (2014) Balancing ecosystem services and disservices: smallholder farmers' use and management of forest and trees in an agricultural landscape in southwestern Ethiopia. Ecol. Soc. 19(1): 30.

Anthony F, Combes MC, Astorga C, Bertrand B, Graziosi G, Lashermes P (2002) The origin of cultivated Coffea arabica L. varieties revealed by AFLP and SSR markers. Theor. Appl. Genet. 104, 894–900.

Antrop M (2005) Why landscapes of the past are important for the future. Landsc. Urban Plan. 70, 21–34.

Arroyo-Rodríguez V, Melo FPL, Martínez-Ramos M et al (2017) Multiple successional pathways in human-modified tropical landscapes: new insights from forest succession, forest fragmentation and landscape ecology research. Biol. Rev. 92, 326–340.

Asner GP, Rudel TK, Aide TM, Defries R, Emerson R (2009) A contemporary assessment of change in humid tropical forests. Conserv. Biol. 23, 1386–1395.

Balvanera P, Siddique I, Dee L et al (2014) Linking biodiversity and ecosystem services: Current uncertainties and the necessary next steps. Bioscience 64, 49–57.

Barlow J, Gardner TA, Araujo IS et al (2007) Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proc. Natl. Acad. Sci. USA 104, 18555–18560.

Barlow J, Lennox GD, Ferreira J et al (2016) Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature 535, 144–147.

Barnosky AD, Matzke N, Tomiya S et al (2011) Has the Earth's sixth mass extinction already arrived? Nature 471, 51–57.

Batisse M (1982) The Biosphere Reserve: a tool for environmental conservation and management. Environ. Conserv. 9, 101–111.

Beckman NG, Muller-landau HC (2007) Differential effects of hunting on pre-dispersal seed predation and primary and secondary seed removal of two Neotropical tree species 39, 328–339.

Bennett EM, Cramer W, Begossi A et al (2015) Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain. 14, 76–85.

Bergengren JC, Waliser DE, Yung YL (2011) Ecological sensitivity: A biospheric view of climate change. Clim. Change 107, 433–457.

Bergès L, Avon C, Verheyen K, Dupouey JL (2013) Landownership is an unexplored determinant of forest understory plant composition in Northern France. For. Ecol. Manage. 306, 281–291.

Berkes F, Colding J, Folke C (2003) Navigating social–ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge, New York.

Bridgewater PB (2002) Biosphere reserves: special places for people and nature. Environ. Sci. Policy 5, 9–12.

Brockerhoff EG, Barbaro L, Castagneyrol B et al (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers. Conserv. 26, 3005–3035.

Bruno JF, Stachowicz JJ, Bertness MD (2003) Inclusion of facilitation into ecological theory. Trends in Ecology and Evolution 18, 119–125.

Burkhard B, Kroll F, Nedkov S, Müller F (2012) Mapping ecosystem service supply, demand and budgets. Ecol. Indic. 21, 17–29.

Butchart SHM, Walpole M, Collen B et al (2010) Global Biodiversity: indicators of recent declines. Science 328, 1164–1168.

Cadenasso ML, Pickett STA, Weathers KC, Jones CG (2003) A framework for a theory of

ecological boundaries. Bioscience 53, 750–758.

Cardinale BJ, Duffy JE, Gonzalez A et al (2012) Biodiversity loss and its impact on humanity. Nature 486, 59–67.

Cardinale BJ, Matulich KL, Hooper DU et al (2011) The functional role of producer diversity in ecosystems. Am. J. Bot. 98, 572–592.

Ceballos G, Ehrlich PR, Barnosky AD, Garcia A, Pringle RM, Palmer TM (2015) Accelerated modern human-induced species losses: entering the sixth mass extinction. Sci. Adv. 1:e1400253.

Chan KMA, Pringle RM, Ranganathan J et al (2007) When agendas collide: human welfare and biological conservation. Conserv. Biol. 21, 59–68.

Chapin III FS, Zavaleta ES, Eviner VT et al (2000) Consequences of changing biodiversity. Nature 405, 234–242.

Charnley S, Poe MR (2007) Community forestry in theory and practice: where are we now? Annu. Rev. Anthropol. 36, 301–336.

Chazdon RL (2003) Tropical forest recovery: legacies of human impact and natural disturbances. Perspect. Plant Ecol. Evol. Syst. 6, 51–71.

Chazdon RL (2008) Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320, 1458–1460.

Chazdon RL (2018) Protecting intact forests requires holistic approaches. Nat. Ecol. Evol. 2, 915.

Cheng S, Hiwatashi Y, Imai H, Naito M, Numata T (1998) Deforestation and degradation of natural resources in Ethiopia: forest management implications from a case study in the Belete-Gera forest. J. For. Res. 3, 199–204.

Comberti C, Thornton TF, de Echeverria WV, Patterson T (2015) Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. Glob. Environ. Chang. 34, 247–262.

Crouzeilles R, Ferreira MS, Chazdon RL et al (2017) Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests. Sci. Adv. 3, 1–8.

Crutzen PJ (2002) Geology of mankind. Nature 415, 23.

Culbert PD, Dorresteijn I, Loos J, Clayton MK, Fischer J, Kuemmerle T (2017) Legacy effects of past land use on current biodiversity in a low-intensity farming landscape in Transylvania (Romania). Landscape Ecology 32, 429–444.

Daily GC, Ehrlich PR, Sánchez-Azofeifa GA (2001) Countryside biogeography: use of human-dominated habitats by the avifauna of southern Costa Rica. Ecol. Appl. 11, 1–13.

Davis MA, Grime JP, Thompson K (2000) Fluctuating resources in plant communities: a general theory of invasibility. J. Ecol. 88, 528–534.

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complex. 7, 260–272.

DeFries RS, Foley JA, Asner GP (2004) Land-use choices: balancing human needs and ecosystem function. Front. Ecol. Environ., 2, 249– 257.

Déjeant-Pons M (2006) The European landscape convention. Landsacpe Res. 31, 363–384.

DeWalt SJ, Maliakal SK, Denslow JS (2003) Changes in vegetation structure and composition along a tropical forest chronosequence: implications for wildlife. For. Ecol. Manage. 182, 139–151.

Díaz S, Demissew S, Carabias J et al (2015) The IPBES Conceptual Framework - connecting nature and people. Curr. Opin. Environ. Sustain. 14, 1–16.

Díaz S, Fargione J, Chapin III FS, Tilman D (2006) Biodiversity loss threatens human well-being. PLoS Biol. 4 (8), e277.

Díaz S, Pascual U, Stenseke M et al (2018) Assessing nature's contributions to people. Science 359, 270–272.

Díaz S, Symstad AJ, Chapin III FS, Wardle DA, Huenneke LF (2003) Functional diversity revealed by removal experiments. Trends Ecol. Evol. 18, 140–146.

Didham RK, Lawton JH (1999) Edge structure determines the magnitude of changes in microclimate and vegetation structure in tropical forest fragments. Biotropica 31, 17–30.

Dirzo R, Raven PH (2003) Global state of biodiversity and loss. Annu. Rev. Environ. Resour. 28, 137–167.

Dorresteijn I (2015) Biodiversity conservation in traditional farming landscapes: the future of birds and large carnivores in Transylvania. Dissertation, Leuphana University, Lüneburg.

Dorresteijn I, Hartel T, Hanspach J, von Wehrden H, Fischer J (2013) The conservation value of traditional rural landscapes: the case of woodpeckers in Transylvania, Romania. PLoS One 8(6), e65236.

Dorresteijn I, Loos J, Hanspach J, Fischer J (2015) Socioecological drivers facilitating biodiversity conservation in traditional farming landscapes. Ecosyst. Heal. Sustain. 1, 1–9.

Dorresteijn I, Schultner J, Collier NF, Hylander K, Senbeta F, Fischer J (2017) Disaggregating ecosystem services and disservices in the cultural landscapes of southwestern Ethiopia: a study of rural perceptions. Landsc. Ecol. 32, 2151–2165.

Doughty CE (2013) Preindustrial human impacts on global and regional environment. Annu. Rev. Environ. Resour. 38, 503–527.

Edwards DP (2016) Conservation: the rainforest's "do not disturb" signs. Nature 535, 44–45.

Edwards FA, Edwards DP, Larsen TH et al (2014) Does logging and forest conversion to oil palm agriculture alter functional diversity in a biodiversity hotspot? Anim. Conserv. 17, 163–173.

Eigenbrod F (2016) Redefining landscape structure for ecosystem services. Curr. Landsc. Ecol. Reports 1, 80–86.

Ellis EC, Goldewijk KK, Siebert S, Lightman D, Ramankutty N (2010) Anthropogenic transformation of the biomes, 1700 to 2000. Glob. Ecol. Biogeogr. 19, 589–606.

Ellis EC, Kaplan JO, Fuller DQ, Vavrus S, Goldewijk KK, Verburg PH (2013) Used planet: a global history. Proc. Natl. Acad. Sci. USA 110, 7978–7985.

Ellis EC, Ramankutty N (2008) Putting people in the map: anthropogenic biomes of the world. Front. Ecol. Environ. 6, 439–447.

Engelen D, Lemessa D, Şekercioğlu ÇH, Hylander K (2017) Similar bird communities in homegardens at different distances from Afromontane forests. Bird Conserv. Int. 27, 83–95.

Essl F, Dullinger S, Rabitsch W, Hulme PE, Pyšek P, Wilson JRU, Richardson DM (2015) Historical legacies accumulate to shape future biodiversity in an era of rapid global change. Divers. Distrib. 21, 534–547.

Ewel JJ (1999) Natural systems as models for the design of sustainable systems of land use.

Agroforestry Systems 45, 1–21.

Ewel JJ, Putz FE (2004) A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment 2, 354–360.

Ewers RM, Didham RK (2006) Confounding factors in the detection of species responses to habitat fragmentation. Biol. Rev. 81, 117–142.

FAO (2014) State of the world's forests. Enhancing the socioeconomic benefits from forests. FAO, Rome.

Farina A (2000) The cultural landscape as a model for the integration of ecology and economics. Bioscience 50, 313–320.

Faure N, Ichou B, Venisnik T (2019) Communities at the heart of forest management: how can the law make a difference? Sharing lessons from Nepal, the Philippines and Tanzania. ClientEarth, London.

Faye MD, Weber JC, Abasse TA et al (2011) Farmers' preferences for tree functions and species in the west African Sahel. For Tree Livelihoods 20, 113–136.

FDRE (1995) Constitution of the federal democratic republic of Ethiopia. Federal democratic republic of Ethiopia, Addis Ababa.

FDRE (2011) Ethiopia's climate-resilient green economy. Green economy strategy. Federal democratic republic of Ethiopia, Addis Ababa.

FDRE (2018) Forest development, conservation and utilization proclamation no. 1065/2018. Federal Negarit Gazette, Addis Ababa.

Feyera S, Beck E, Lüttge U (2002) Exotic trees as nurse-trees for the regeneration of natural tropical forests. Trees 16, 245–249.

Fischer J, Gardner TA, Bennett EM et al (2015) Advancing sustainability through mainstreaming a social-ecological systems perspective. Curr. Opin. Environ. Sustain. 14, 144–149.

Fischer J, Hartel T, Kuemmerle T (2012) Conservation policy in traditional farming landscapes. Conserv. Lett. 5, 167–175.

Fischer J, Lindenmayer DB (2007) Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265–280.

Fischer J, Meacham M, Queiroz C (2017) A plea for multifunctional landscapes. Front. Ecol. Environ. 15, 59.

Fischer J, Sherren K, Stott J, Zerger A, Warren G, Stein J (2010) Toward landscape-wide conservation outcomes in Australia's temperate grazing region. Front Ecol Environ 8, 69–74.

Fischer J, Stott J, Zerger A, Warren G, Sherren K, Forrester RI (2009) Reversing a tree regeneration crisis in an endangered ecoregion. Proc. Natl. Acad. Sci. USA 106, 10386–10391.

Fisher JA, Patenaude G, Giri K et al M (2014) Understanding the relationships between ecosystem services and poverty alleviation : A conceptual framework. Ecosyst. Serv. 7, 34–45.

Flinn KM, Marks PL (2007) Agricultural legacies in forest environments: Tree communities, soil properties, and light availability. Ecological Applications 17, 452–463.

Flora of Ethiopia and Eritrea (1989-2006) Flora of Ethiopia and Eritrea. Addis Ababa, Ethiopia: The National Herbarium and Uppsala, Sweden: The Department of Systematic Botany, Uppsala University.

Foley JA, DeFries R, Asner GP et al (2005) Global consequences of land use. Science 309, 570–574.

Foley JA, Ramankutty N, Brauman KA et al (2011) Solutions for a cultivated planet. Nature 478, 337–342.

Folke C (2006) Resilience: the emergence of a perspective for social-ecological systems analyses. Glob. Environ. Chang. 16, 253–267.

Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, Holling CS (2004) Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Evol. Syst. 35, 557–581.

Forman RTT (1990) Ecologically sustainable landscapes: the role of spatial configuration. In: Zonneveld IS, Forman RTT (Eds.) Changing landscapes: an ecological perspective. Springer-Verlag, New York, pp. 261 – 278.

Foster D, Swanson F, Aber J, Burke I, Brokaw N, Tilman D, Knapp A (2003) The importance of land-use legacies to ecology and conservation. Bioscience 53, 77–88.

Franklin JF, Spies TA, Pelt RV et al (2002) Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For. Ecol. Manage. 155, 399–423.

Friis I, Demissew S, van Breugel P (2010) Atlas of the potential vegetation of Ethiopia. Royal Danish Academy of Science and Letters, Copenhagen.

Gamfeldt L, Hillebrand H, Jonsson PR (2008) Multiple functions increase the importance of biodiversity for overall ecosystem functioning. Ecology 89, 1223–1231.

Gamfeldt L, Roger F (2017) Revisiting the biodiversity-ecosystem multifunctionality relationship. Nat. Ecol. Evol. 1, 1–7.

Gamfeldt L, Snäll T, Bagchi R et al (2013) Higher levels of multiple ecosystem services are found in forests with more tree species. Nat. Commun. 4:1340.

Gardner TA, Barlow J, Chazdon R, Ewers RM, Harvey CA, Peres CA, Sodhi NS (2009) Prospects for tropical forest biodiversity in a human-modified world. Ecol. Lett. 12, 561–582.

Gascon C, Williamson GB, da Fonseca GAB (2000) Receding forest edges and vanishing reserves. Science 288, 1356–1358.

Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52, 143–150.

Getahun JM (2016) Oromo indigenous knowledge and practices in natural resources management: land, forest, and water in focus. J. Ecosyst. Ecography 6(2), 181.

Getahun K, Poesen J, Van Rompaey A (2017) Impacts of resettlement programs on deforestation of moist evergreen Afromontane forests in southwest Ethiopia. Mt. Res. Dev. 37, 474–486.

Ghazoul J, Sheil D (2010) Tropical rain forest ecology, diversity, and conservation. Oxford University Press, New York, USA.

Gibson L, Lee TM, Koh LP et al (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478, 378–381.

Gobeze T, Bekele M, Lemenih M, Kassa H (2009) Participatory forest management and its impacts on livelihoods and forest status: the case of Bonga forest in Ethiopia. Int For Rev 11, 346–358.

Godfray CHJ, Garnett T (2014) Food security and sustainable intensification. Philos. Trans. R. Soc. 369, 20120273.

Gole TW (2003) Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for in situ conservation of wild Coffea arabica L. populations. Cuvillier Verlag, Göttingen.

Gole TW, Borsch T, Denich M, Teketay D (2008) Floristic composition and environmental factors characterizing coffee forests in southwest Ethiopia. For. Ecol. Manage. 255, 2138–2150.

Gove AD, Hylander K, Nemomisa S, Shimelis A (2008) Ethiopian coffee cultivation—implications for bird conservation and environmental certification. Conserv. Lett. 1, 208–216.

Häger A, Fernández Otárola M, Stuhlmacher MF, Acuña Castillo R, Contreras Arias A (2015) Effects of management and landscape composition on the diversity and structure of tree species assemblages in coffee agroforests. Agric. Ecosyst. Environ. 199, 43–51.

Hanski I (2000) Extinction debt and species credit in boreal forests: modelling the consequences of different approaches to biodiversity conservation. Ann. Zool. Fennici 37, 271–280.

Hanski I, Ovaskainen O (2002) Extinction debt at extinction threshold. Conserv. Biol. 16, 666–673.

Hanspach J, Hartel T, Milcu AI et al (2014) A holistic approach to studying social-ecological systems and its application to Southern Transylvania. Ecol. Soc. 19(4): 32.

Harper KA, Macdonald SE, Burton PJ et al (2005) Edge Influence on Forest Structure and Composition in Fragmented Landscapes. Conserv. Biol. 19, 768–782.

Hartel T, Dorresteijn I, Klein C et al (2013) Wood-pastures in a traditional rural region of Eastern Europe: characteristics, management and status. Biol. Conserv. 166, 267–275.

Hartig F (2016) DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. Available at: https://cran.r-project.org/package=DHARMa.

Hector A, Bagchi R (2007) Biodiversity and ecosystem multifunctionality. Nature 448, 188–190.

Helm A, Hanski I, Pärtel M (2006) Slow response of plant species richness to habitat loss and

fragmentation. Ecol. Lett. 9, 72–77.

Hernández-Martínez G, Manson RH, Hernández AC (2009) Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico. Agric. Ecosyst. Environ. 134, 89–98.

Hill MO, Gauch HG (1980) Detrended correspondence analysis : an improved ordination technique. Vegetatio 42, 47–58.

Hisano M, Searle EB, Chen HYH (2018) Biodiversity as a solution to mitigate climate change impacts on the functioning of forest ecosystems. Biol. Rev. 93, 439–456.

Hobbs RJ, Arico S, Aronson J et al (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Glob. Ecol. Biogeogr. 15, 1–7.

Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. Trends Ecol. Evol. 24, 599–605.

Hosonuma N, Herold M, De Sy V et al (2012) An assessment of deforestation and forest degradation drivers in developing countries. Environ. Res. Lett. 7, 044009.

Hundera K, Aerts R, Fontaine A, Van Mechelen M, Gijbels P, Honnay O, Muys B (2013) Effects of coffee management intensity on composition, structure, and regeneration status of Ethiopian moist evergreen Afromontane forests. Environ. Manage. 51, 801–809.

Hurni H (2007) Challenges for sustainable rural development in Ethiopia. Addis Ababa University, Faculty of Technology, Addis Ababa.

Hylander K, Ehrlén J (2013) The mechanisms causing extinction debts. Trends Ecol. Evol. 28, 341–346.

Hylander K, Nemomissa S (2008) Home garden coffee as a repository of epiphyte biodiversity in Ethiopia. Front. Ecol. Environ. 6, 524–528.

Hylander K, Nemomissa S (2009) Complementary roles of home gardens and exotic tree plantations as alternative habitats for plants of the Ethiopian montane rainforest. Conserv. Biol. 23, 400–409.

Hylander K, Nemomissa S (2017) Waiving the extinction debt: Can shade from coffee prevent extinctions of epiphytic plants from isolated trees? Divers. Distrib. 23, 888–897.

Hylander K, Nemomissa S, Delrue J, Enkosa W (2013a) Effects of coffee management on deforestation rates and forest integrity. Conserv. Biol. 27, 1031–1040.

Hylander K, Nemomissa S, Enkosa W (2013b) Edge effects on understory epiphytic ferns and epiphyllous bryophytes in moist Afromontane forests of Ethiopia. Polish Bot. J. 58, 555–563.

Iiyama M, Neufeldt H, Dobie P, Njenga M, Ndegwa G, Jamnadass R (2014) The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Curr. Opin. Environ. Sustain. 6, 138–147.

IPBES (2018) Biodiversity and nature's contributions continue dangerous decline, scientists warn human well-being at risk. Landmark reports highlight options to protect and restore nature and its vital contributions to people. IPBES media release. Accessed 27 March 2018.

Isbell F, Adler PR, Eisenhauer N et al (2017a) Benefits of increasing plant diversity in sustainable agroecosystems. J. Ecol. 105, 871–879.

Isbell F, Calcagno V, Hector A et al (2011) High plant diversity is needed to maintain ecosystem services. Nature 477, 199–202.

Isbell F, Craven D, Connolly J et al (2015) Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature, 526, 574–577.

Isbell F, Gonzalez A, Loreau M et al (2017b) Linking the influence and dependence of people on biodiversity across scales. Nature 546, 65–72.

Ives AR, Klug JL, Gross K (2000) Stability in complex communities. Ecol. Lett. 3, 399–411.

Jackson ST, Sax DF (2010) Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover. Trends Ecol. Evol. 25, 153–160.

Jalata A, Schaffer H (2013) The Oromo gadaa/siqqee democracy and the liberation of Ethiopian colonial subjects. Alternative: An International Journal of Indigenous Peoples 9, 277-295.

Jara T, Hylander K, Nemomissa S (2017) Tree diversity across different tropical agricultural land use types. Agric. Ecosyst. Environ. 240, 92–100.

Jha S, Bacon CM, Philpott SM, Méndez VE, Läderach P, Rice RA (2014) Shade coffee: update on a disappearing refuge for biodiversity. Bioscience 64, 416–428.

Jiren TS, Dorresteijn I, Schultner J, Fischer J (2017) The governance of land use strategies: Institutional and social dimensions of land sparing and land sharing. Conserv. Lett.

e12429.

Johann F, Schaich H (2016) Land ownership affects diversity and abundance of tree microhabitats in deciduous temperate forests. For. Ecol. Manage. 380, 70–81.

Kaimowitz D, Sheil D (2007) Conserving what and for whom ? Why conservation should help meet basic human needs in the tropics. Biotropica 39, 567–574.

Kassa H, Bekele M, Campbell B (2011) Reading the landscape past: explaining the lack of on-farm tree planting in Ethiopia. Environ. Hist. 17, 461–479.

Kassa H, Dondeyne S, Poesen J, Frankl A, Nyssen J (2016) Transition from forest- to cereal-based agricultural systems : a review of the drivers of land-use change and degradation in southwest Ethiopia. L. Degrad. Dev. 28, 431–449.

Keenan RJ, Reams GA, Achard F, de Freitas JV, Grainger A, Lindquist E (2015) Dynamics of global forest area: results from the FAO Global Forest Resources Assessment 2015. For. Ecol. Manage. 352, 9–20.

Kennedy CM, Lonsdorf E, Neel MC et al (2013) A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecol. Lett. 16, 584–599.

Krauss J, Bommarco R, Guardiola M et al (2010) Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. Ecol. Lett. 13, 597–605.

Kremen C, Merenlender AM (2018) Landscapes that work for biodiversity and people. Science 362, eaau6020.

Kremen C, Miles A (2012) Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol. Soc. 17(4): 40.

Kuhlman T, Farrington J (2010) What is sustainability? Sustainability 2, 3436–3448.

Kumsa L, Hylander K, Gurmessa D, Nemomissa S (2016) Patch area and current coffee management determine woody plant diversity in patches of semi-forest coffee embedded in an agricultural matrix. Glob. Ecol. Conserv. 8, 230–240.

Kuussaari M, Bommarco R, Heikkinen RK et al (2009) Extinction debt: a challenge for biodiversity conservation. Trends Ecol. Evol. 24, 564–571.

Lambin EF, Turner BL, Geist HJ et al (2001) The causes of land use and land cover change: moving beyond the myths. Glob. Environ. Chang. 11, 261–269.

Lande R (1996) Statistics and partitioning of species diversity, and similarity among multiple communities. Oikos 76, 5–13.

Laurance WF (1991) Edge effects in tropical forest fragments: application of a model for the design of nature reserves. Biol. Conserv. 57, 205–219.

Laurance WF (2006) Have we overstated the tropical biodiversity crisis? Trends Ecol. Evol. 22.

Laurance WF, Ferreira LV, Rankin-de Merona JM, Laurance SG (1998) Rain forest fragmentation and the dynamics of Amazonian tree Communities. Ecology 79, 2032–2040.

Laurance WF, Nascimento HEM, Laurance SG et al (2006) Rapid decay of tree-community composition in Amazonian forest fragments. Proc. Natl. Acad. Sci. USA 103, 19010–19014.

Laurance WF, Useche DC, Rendeiro J et al (2012) Averting biodiversity collapse in tropical forest protected areas. Nature 489, 290–294.

Lefcheck JS, Byrnes JEK, Isbell F et al (2015) Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats. Nat. Commun. 6, 1–7.

Lemenih M, Kassa H (2014) Re-greening Ethiopia: History, challenges and lessons. Forests 5, 1896–1909.

Letourneau, DK, Armbrecht I, Rivera BS et al (2011) Does plant diversity benefit agroecosystems? A synthetic review. Ecol. Appl. 21, 9–21.

Lewis SL, Edwards DP, Galbraith D (2015) Increasing human dominance of tropical forests. Science 349, 827–832.

Liang J, Crowther TW, Picard N et at (2016) Positive biodiversity-productivity relationship predominant in global forests. Science 354, aaf8957.

Lindborg R, Eriksson O (2004) Historical landscape connectivity affects present plant species diversity. Ecology 85, 1840–1845.

Lindenmayer DB, Fischer J, Felton A et al (2008) Novel ecosystems resulting from landscape transformation create dilemmas for modern conservation practice. Conserv. Lett. 1, 129–135.

Lira PK, Ewers RM, Banks-Leite C, Pardini R, Metzger JP (2012) Evaluating the legacy of

landscape history: Extinction debt and species credit in bird and small mammal assemblages in the Brazilian Atlantic Forest. J Appl Ecol 49, 1325–1333.

Loos J, Abson DJ, Chappell MJ, Hanspach J, Mikulcak F, Tichit M, Fischer J (2014) Putting meaning back into "sustainable intensification." Front. Ecol. Environ. 12, 356–361.

Loreau M, Mouquet N, Gonzalez A (2003) Biodiversity as spatial insurance in heterogeneous landscapes. Proc. Natl. Acad. Sci. USA 100, 12765–12770.

Lugo AE, Helmer E (2004) Emerging forests on abandoned land: Puerto Rico's new forests. For. Ecol. Manage. 190, 145–161.

MA (2003) Ecosystems and human well-being: a framework for assessment. Millennium ecosystem assessment. Island Press, Washington, DC.

MA (2005a) Ecosystems and human well-being: biodiversity synthesis. Millennium ecosystem assessment. World Resources Institute, Washington, DC.

MA (2005b) Ecosystems and human well-being: synthesis. Millennium ecosystem assessment. Island Press, Washington, DC.

Maestre FT, Quero JL, Gotelli NJ et al (2012) Plant species richness and ecosystem multifunctionality in global drylands. Science 335, 214–218.

Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures - implications for conservation. Biol. Conserv. 132, 311–321.

Manning P, van der Plas F, Soliveres S et al (2018) Redefining ecosystem multifunctionality. Nat. Ecol. Evol. 2, 427–436.

Marin-Spiotta E, Ostertag R, Silver W (2007) Long-term patterns in tropical reforestation: plant community composition and aboveground biomass accumulation. Ecol. Appl. 17, 828–839.

Maron JL, Connors PG (1996) A native nitrogen-fixing shrub facilitates weed invasion. Oecologia 105, 302–312.

Mayfield MM, Daily GC (2005) Countryside biogeography of Neotropical herbaceous and shrubby plants. Ecol. Appl. 15, 423–439.

McCann JC (1995) People of the Plow: an agricultural history of Ethiopia, 1800–1990. The University of Wisconsin Press, London.

McClellan M, Montgomery R, Nelson K, Becknell J (2018) Comparing forest structure and biodiversity on private and public land: secondary tropical dry forests in Costa Rica. Biotropica 50, 510–519.

McNeely JA, Schroth G (2006) Agroforestry and biodiversity conservation - traditional practices, present dynamics, and lessons for the future. Biodivers. Conserv. 15, 549–554.

Mekonnen A (2009) Tenure security, resource endowments, and tree growing: Evidence from the Amhara region of Ethiopia. Land Econ 85, 292–307.

Melo FPL, Arroyo-Rodríguez V, Fahrig L, Martínez-Ramos M, Tabarelli M (2013) On the hope for biodiversity-friendly tropical landscapes. Trends Ecol. Evol. 28, 462–468.

Mendenhall CD, Shields-Estrada A, Krishnaswami AJ, Daily GC (2016) Quantifying and sustaining biodiversity in tropical agricultural landscapes. Proc. Natl. Acad. Sci. USA 113, 14544–14551.

Mercer B (2015) Tropical forests: a review. The Prince's Charities, International Sustainability Unit. London.

Meshesha DT, Tsunekawa A, Tsubo M (2012) Continuing land degradation: cause-effect in Ethiopia's Central Rift Valley. L. Degrad. Dev. 23, 130–143.

Metzger JP, Martensen AC, Dixo M, Bernacci LC, Ribeiro MC, Teixeira AMG, Pardini R (2009) Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. Biol. Conserv. 142, 1166–1177.

Milton SJ (2003) "Emerging ecosystems" – a washing-stone for ecologists, economists and sociologists? South African Journal of Science 99, 404–406.

Mitchell MGE, Suarez-Castro AF, Martinez-Harms M et al (2015) Reframing landscape fragmentation's effects on ecosystem services. Trends Ecol. Evol. 30, 190–198.

Mitiku F, Nyssen J, Maertens M (2018) Certification of semi-forest coffee as a land-sharing strategy in Ethiopia. Ecol. Econ. 145, 194–204.

Mittermeier RA, Turner WR, Larsen FW, Brooks TM, Gascon C (2011) Global biodiversity conservation: the critical role of hotspots, in: Zachos FE, Habel JC (Eds.) Biodiversity hotspots: distribution and protection of conservation priority areas. Springer, Heidelberg.

Moat J, Williams J, Baena S et al (2017) Resilience potential of the Ethiopian coffee sector under climate change. Nat. Plants 3, 17081.

Monastersky R (2014) Life – a status report. Nature 516, 159–161.

Mortelliti A, Fagiani S, Battisti C, Capizzi D, Boitani L (2010) Independent effects of habitat loss, habitat fragmentation and structural connectivity on forest-dependent birds. Divers. Distrib. 16, 941–951.

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012) Closing yield gaps through nutrient and water management. Nature 490, 254–257.

Muller-landau HC (2007) Predicting the long-term effects of hunting on plant species composition and diversity in tropical forests. Biotropica 39, 372–384.

Murcia C (1995) Edge effects in fragmented forests- implications for conservation. Trends Ecol. Evol. 10, 58–62.

Mwavu EN, Witkowski ETF (2009) Population structure and regeneration of multiple-use tree species in a semi-deciduous African tropical rainforest: Implications for primate conservation. For. Ecol. Manage. 258, 840–849.

Naeem S, Li S (1997) Biodiversity enhances ecosystem reliability. Nature 390, 507–509.

Naeem S, Loreau M, Inchausti P (2002) Biodiversity and ecosystem functioning: the emergence of a synthetic ecological framework. In: Loreau M, Naeem S, Inchausti P (Eds.) Biodiversity and ecosystem functioning. Oxford University Press, Oxford. pp. 3–11.

O'Farrell PJ, Anderson PML (2010) Sustainable multifunctional landscapes: a review to implementation. Curr. Opin. Environ. Sustain. 2, 59–65.

Oksanen AJ, Blanchet FG, Kindt R et al (2017) vegan: Community Ecology Package. Available at: https://cran.r-project.org/package=vegan.

Oksanen J, Blanchet FG, Friendly M et al (2018) vegan: community ecology package. R package version 2.5-2. https://CRAN.R-project.org/package=vegan.

Olden JD, Rooney TP (2006) On defining and quantifying biotic homogenization. Glob. Ecol. Biogeogr. 15, 113–120.

Olsson PA, Mårtensson LM, Bruun HH (2009) Acidification of sandy grasslands – consequences for plant diversity. Appl. Veg. Sci. 12, 350–361.

Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422.

Ostrom E, Nagendra H (2006) Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory. Proc. Natl. Acad. Sci. USA 103, 19224–19231.

Padilla FM, Pugnaire FI (2006) The role of nurse plants in the restoration of degraded environments. Front. Ecol. Environ. 4, 196–202.

Pardini R, Bueno AdA, Gardner TA, Prado PI, Metzger JP (2010) Beyond the fragmentation threshold hypothesis: regime shifts in biodiversity across fragmented landscapes. PLoS One 5(10), e13666.

Pereira HM, Leadley PW, Proenca V et al (2010) Scenarios for global biodiversity in the 21st century. Science 330, 1496–1501.

Perfecto I, Rice RA, Greenberg R, van der Voort ME (1996) Shade coffee: a disappearing refuge for biodiversity. Bioscience 46, 598–608.

Perfecto I, Vandermeer J (2008) Biodiversity conservation in tropical agroecosystems: a new conservation paradigm. Ann. N. Y. Acad. Sci. 1134, 173–200.

Perfecto I, Vandermeer J, Mas A, Pinto LS (2005) Biodiversity, yield, and shade coffee certification. Ecol. Econ. 54, 435–446.

Peterson G, Allen CR, Holling CS (1998) Ecological resilience, biodiversity, and scale. Ecosystems 1, 6–18.

Petit N (2007) Ethiopia's coffee sector: a bitter or better future? J. Agrar. Chang. 7, 225–263.

Phillips A (1998) The nature of cultural landscapes — a nature conservation perspective. Landsc. Res. 23, 21–38.

Philpott SM, Dietsch T (2003) Coffee and conservation: a global context and the value of farmer involvement. Conserv. Biol. 17, 1844–1849.

Pimm SL, Russell GJ, Gittleman JL, Brooks TM (1995) The future of biodiversity. Science 269, 347–350.

Plieninger T, Dijks S, Oteros-Rozas E, Bieling C (2013) Assessing, mapping, and quantifying cultural ecosystem services at community level. Land use policy 33, 118–129.

Plieninger T, Höchtl F, Spek T (2006) Traditional land-use and nature conservation in European rural landscapes. Environ. Sci. Policy 9, 317–321.

Plieninger T, van der Horst D, Schleyer C, Bieling C (2014) Sustaining ecosystem services in

cultural landscapes. Ecol. Soc. 19(2): 59.

Poulsen JR, Clark CJ, Palmer TM (2013) Ecological erosion of an Afrotropical forest and potential consequences for tree recruitment and forest biomass. Biol. Conserv. 163, 122–130.

Primack RB, Lee HS (1991) Population dynamics of pioneer (Macaranga) trees and understorey (Mallotus) trees (Euphorbiaceae) in primary and selectively logged Bornean rain forests. J. Trop. Ecol. 7, 439–457.

Quandt A (2016) Farmers and forest conservation: how might land sparing work in practice? Soc. Nat. Resour. 29, 418–431.

R core Team (2018) R: A language and environment for statistical computing. R foundation for Statistical Computing, Vienna, Austria. URL http"//www.R.project.org/.

Ramankutty N, Foley JA (1999) Estimating historical changes in global land cover. Global Biogeochem. Cycles 13, 997–1027.

Rasmussen LV, Watkins C, Agrawal A (2017) Forest contributions to livelihoods in changing agriculture-forest landscapes. For. Policy Econ. 84, 1–8.

Reed J, van Vianen J, Foli S et al (2017) Trees for life: the ecosystem service contribution of trees to food production and livelihoods in the tropics. For. Policy Econ. 84, 62–71.

Reusing M (2000) Change detection of natural high forests in Ethiopia using remote sensing and GIS techniques. Int. Arch. Photogramm. Remote Sens. 33, 1253–1258.

Reyers B, Biggs R, Cumming GS, Elmqvist T, Hejnowicz AP, Polasky S (2013) Getting the measure of ecosystem services: a social-ecological approach. Front. Ecol. Environ. 11, 268–273.

Rockström J, Steffen W, Noone K et al (2009) A safe operating space for humanity. Nature 461, 472–475.

Rodrigues P, Shumi G, Dorresteijn I et al (2018) Coffee management and the conservation of forest bird diversity in southwestern Ethiopia. Biol. Conserv. 217, 131–139.

Rozendaal DMA, Bongers F, Aide TM et al (2019) Biodiversity recovery of Neotropical secondary forests. Sci. Adv. 5, eaau3114.

RRI (2017) Securing community land rights: priorities and opportunities to advance climate and sustainable development goals. Rights and Resources Initiative, Washington, DC.

Sabates-Wheeler R, Devereux S (2010) Cash transfers and high food prices: explaining outcomes on Ethiopia's Productive Safety Net Programme. Food Policy 35, 274–285.

Sakai AK, Allendorf FW, Holt JS et al (2001) The population biology of invasive species. Annu. Rev. Ecol. Syst. 32, 305–332.

Sala OE, Chapin II FS, Armesto JJ et al (2000) Global biodiversity scenarios for the year 2100. Science 287, 1770–1774.

Sax DF, Brown JH (2000) The paradox of invasion. Global Ecol. Biogeog. 9, 363–371.

Schlager E, Ostrom E (1992) Property rights regimes and natural resources: a conceptual analysis. Land Econ. 68, 249–262.

Schmitt CB (2006) Montane rainforest with wild Coffea arabica in the Bonga region (SW Ethiopia): plant diversity, wild coffee management and implications for conservation. Cuvillier Verlag, Göttingen.

Schmitt CB, Senbeta F, Denich M, Preisinger H, Boehmer HJ (2010) Wild coffee management and plant diversity in the montane rainforest of southwestern Ethiopia. Afr. J. Ecol. 48, 78–86.

Schmitt CB, Senbeta F, Woldemariam T, Rudner M, Denich M (2013) Importance of regional climates for plant species distribution patterns in moist Afromontane forest. J. Veg. Sci. 24, 553–568.

Schulze CH, Waltert M, Kessler PJA et al (2004) Biodiversity indicator groups of tropical land-use systems: comparing plants, birds, and insects. Ecol. Appl. 14, 1321–1333.

Schwartz MW, Brigham CA, Hoeksema JD, Lyons KG, Mills MH, van Mantgem PJ (2000) Linking biodiversity to ecosystem function. Oecologia 122, 297–305.

Senbeta F, Denich M (2006) Effects of wild coffee management on species diversity in the Afromontane rainforests of Ethiopia. For. Ecol. Manage. 232, 68–74.

Senbeta F, Schmitt C, Woldemariam T, Boehmer HJ, Denich M (2014) Plant diversity, vegetation structure and relationship between plant communities and environmental variables in the Afromontane forests of Ethiopia. SINET Ethiop. J. Sci. 37, 113–130.

Sheil D, Van Heist M (2000) Ecology for tropical forest management. Int. For. Rev. 2, 261-270.

Shumi G, Rodrigues P, Schultner J et al (2019) Conservation value of moist evergreen

Afromontane forest sites with different management and history in southwestern Ethiopia. Biol. Conserv. 232, 117–126.

Shumi G, Schultner J, Dorresteijn I et al (2018) Land use legacy effects on woody vegetation in agricultural landscapes of south-western Ethiopia. Divers. Distrib. 24, 1136–1148.

Slik JWF, Arroyo-Rodríguez V, Aiba SI et al (2015) An estimate of the number of tropical tree species. Proc. Natl. Acad. Sci. USA 112, 7472–7477.

Smith BD (2007) The ultimate ecosystem engineers. Science 315, 1797–1798.

Spellerberg IF, Fedor PJ (2003) A tribute to Claude Shannon (1916-2001) and a plea for more rigorous use of species richness and species diversity and the 'Shannon–Wiener' Index. Glob. Ecol. Biogeogr. 12, 177–179.

Steffen W (2010) Observed trends in Earth system behavior. WIREs Clim. Change 1, 428–449.

Steffen W, Broadgate W, Deutsch L, Gaffney O, Ludwig C (2015) The trajectory of the Anthropocene: the great acceleration. Anthr. Rev. 2, 81–98.

Steffen W, Persson Å, Deutsch L et al (2011) The Anthropocene: from global change to planetary stewardship. Ambio 40, 739–761.

Steffen W, Sanderson A, Tyson PD et at (2004) Global change and the Earth system: a planet under pressure. The IGBP book series, Berlin, Heidelberg, New York: Springer-Verlag, 336 pp.

Tadesse G, Zavaleta E, Shennan C (2014a) Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia. Biol. Conserv. 169, 384–391.

Tadesse G, Zavaleta E, Shennan C, FitzSimmons M (2014b) Policy and demographic factors shape deforestation patterns and socio-ecological processes in southwest Ethiopian coffee agroecosystems. Appl. Geogr. 54, 149–159.

Takahashi R, Todo Y (2017) Coffee certification and forest quality: evidence from a wild coffee forest in Ethiopia. World Dev. 92, 158–166.

Teketay D (1997) Seedling populations and regeneration of woody species in dry Afromontane forests of Ethiopia. For. Ecol. Manage. 98, 149–165.

Teketay D (1999) History, botany and ecological requirements of coffee. Walia 20, 28–50.

Telila H, Hylander K, Nemomissa S (2015) The potential of small Eucalyptus plantations in farmscapes to foster native woody plant diversity: Local and landscape constraints. Restor Ecol 23, 918–926.

Tesfaye G, Teketay D, Fetene M (2002) Regeneration of fourteen tree species in Harenna forest, southeastern Ethiopia. Flora 197, 461–474.

Thompson ID, Guariguata MR, Okabe K, Bahamondez C, Nasi R, Heymell V, Sabogal C (2013) An operational framework for defining and monitoring forest degradation. Ecol. Soc. 18(2): 20.

Thompson J, Brokaw N, Zimmerman JK et al (2002) Land use history, environment, and tree composition in a tropical forest. Ecol. Appl. 12, 1344–1363.

Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. USA 108, 20260–20264.

Tilman D, May RM, Lehman CL, Nowak MA (1994) Habitat destruction and the extinction debt. Nature 371, 65–66.

Tilman D, Reich PB, Knops JMH (2006) Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441, 629–632.

Tolera M, Asfaw Z, Lemenih M, Karltun E (2008) Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. Agri Eco Envir 128, 52–58.

Trogisch S, Schuldt A, Bauhus J et al (2017) Toward a methodical framework for comprehensively assessing forest multifunctionality. Ecol. Evol. 7, 10652–10674.

Tscharntke T, Clough Y, Wanger TC et al (2012) Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151, 53–59.

Tura HA (2018) Land rights and land grabbing in Oromia, Ethiopia. Land use policy 70, 247–255.

UNDP (2015) National human development deport 2014 Ethiopia. UNDP, Addis Ababa.

Vellend M, Verheyen K, Jacquemyn H, Kolb A, Van Calster H, Peterken G, Hermy M (2006) Extinction debt of forest plants persists for more than a century following habitat fragmentation. Ecology 87, 542–548.

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277, 494–499.

Vos W, Meekes H (1999) Trends in European cultural landscape development: perspectives for a sustainable future. Landsc. Urban Plan. 46, 3–14.

Wakjira FS (2006) Biodiversity and ecology of Afromontane rainforests with wild Coffea arabica L. population in Ethiopia. Cuvillier Verlag, Göttingen.

Wakjira TD, Gole WT (2007) Customary forest tenure in southwest Ethiopia. For. Trees Livelihoods 17, 325–338.

Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social-ecological systems. Ecol. Soc. 9(2): 5.

Watson JEM, Evans T, Venter O et al (2018) The exceptional value of intact forest ecosystems. Nat. Ecol. Evol. 2, 599–610.

Wiens JA (2002) Central concepts and issues of landscape ecology, in: Gutzwiller KJ (Ed.) Applying landscape ecology in biological conservation. New York, Springer-Verlag, pp. 3–21.

Wiersum KF, Gole TW, Gatzweiler F, Volkmann J, Bognetteau E, Wirtu O (2008) Certification of wild coffee in Ethiopia: experiences and challenges. For. Trees Livelihoods 18, 9–21.

Wilkinson DM (2004) The parable of Green Mountain: Ascension island, ecosystem construction and ecological fitting. J. Biogeogr. 31, 1–4.

Wittemyer G, Elsen P, Bean WT, Burton ACO, Brashares JS (2008) Accelerated human population growth at protected area edges. Science 321, 123–126.

Wright HL, Lake IR, Dolman PM (2012) Agriculture: a key element for conservation in the developing world. Conserv. Lett. 5, 11–19.

Wright SJ (2005) Tropical forests in a changing environment. Trends Ecol. Evol. 20, 553–560.

Wright SJ (2010) The future of tropical forests. Ann. N. Y. Acad. Sci. 1195, 1–27.

Wu J (2013) Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landsc. Ecol. 28, 999–1023.

Yachi S, Loreau M (1999) Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. Proc. Natl. Acad. Sci. USA 96, 1–6.

Yami M, Snyder KA (2015) After all, land belongs to the state: examining the benefits of land

registration for smallholders in Ethiopia. L. Degrad. Dev. 27, 465–478.

Yietagesu AA (2013) Conservation and livelihood impacts of decentralized forest governance in Ethiopia. Dissertation, University of Copenhagen, Denmark.

Zanini KJ, Bergamin RS, Machado RE, Pillar VD, Müller SC (2014) Atlantic rain forest recovery: successional drivers of floristic and structural patterns of secondary forest in southern Brazil. J. Veg. Sci. 25, 1056–1068.

Declaration

I hereby certify that the submitted dissertation entitled "Woody plant biodiversity conservation and ecosystem services in forest-agriculture mosaic of southwestern Ethiopia" has been written by me without using unauthorized aids. I did not use any aids and writings other than those indicated. All passages taken from other writings either verbatim or in substance have been marked by me accordingly.

I hereby confirm that in carrying out my dissertation project I have not employed the services of a professional broker of dissertation projects, nor will I do so in the future.

This dissertation, in its present or any other version, has not yet been submitted to any other university for review. I have not taken or registered to take another doctoral examination.

Lüneburg, 29.05.2019 _____

Girma Shumi Dugo