LINKING MANAGEMENT PRACTICES TO PLANT SPECIES & GENETIC DIVERSITY IN AGROFORESTRY SYSTEMS

A Dissertation

by

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ABSTRACT

Agroforestry, a farming system where crops and trees co-exist, continues to rewrite rural landscapes as governmental and nongovernmental policies have globally endorsed it as a panacea to protect biodiversity while maintaining agricultural production. But we know little about its biogeographical outcomes. My study utilizes a quasi-experimental design to describe and measure the relationship between agroforestry farming practices and biodiversity outcomes at species and genetic levels by examining a coffee agroforestry program run by an NGO in Junin, Peru.

The main research question is: how do changes to agroforestry practices through participation with the NGO change biodiversity? In this study, I (1) describe how the NGO's agroforestry program alters farming practices and resource access; (2) measure biodiversity (plant species and genetic diversity of *Inga oerstediana* Benth.) on farms utilizing biogeographic methods paired with landscape genetic techniques; and (3) quantitatively test the impact of farming practices on biodiversity outcomes. I show that different agroforestry regimes between NGO participants and non-participants create divergent biotic landscapes, as seen by plant species and genetic diversity on farms.

Interviews and vegetation data show that NGO has mixed results when examining resource distribution, species diversity, and genetic diversity. I find that NGO technicians are working within the constraints of supervisors' decisions and distribute resources, including plants, seeds, and knowledge, differently across participating communities and farmers. Differences in biotic compositions can be seen in the plant

species found on farms and are related to specific farmers and their participation with the NGO, when considering the presence of plant taxonomic families and the *Inga* genus. The NGO has also changed the diversity and population structure of *I. oerstediana* on the farms that most recently received plants, indicating that individuals genetically different from the rest in the region were introduced.

This dissertation represents the beginning of understanding the link between an organization's work and biodiversity changes in an agroforestry system. Using the linkage framework detailed in this dissertation, we can continue to explore the relationships between policies, organizations, and biodiversity. In a world undergoing continued land cover change and climate change, building such an understanding should be a global priority.

DEDICATION

To the strongest and bravest women in my life who have never failed to support and inspire me.

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Contributors

Part 1, Faculty committee recognition

This work was supervised by a dissertation committee consisting of Professors Wendy Jepson (advisor), Christian Brannstrom, and David Cairns of the Department of Geography and Professor Konstantin Krutovsky of Department of Forest Genetics and Forest Tree Breeding at University of Göttingen.

Part 2, Student and collaborator contributions

An undergraduate student, Erin Mosier (Texas A&M University, Class of 2016), was trained in laboratory techniques to assist with DNA extractions and Kranti Konganti at Texas A&M Institute for Genome Sciences and Society assisted by running raw genetic data to prepare for data analyses. All other work for the dissertation was completed independently by the student, Swetha Peteru.

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NOMENCLATURE

ddRADSeq	Double digest Restriction Associated DNA sequencing
DNA	Deoxyribonucleic acid
GBS	Genotyping-by-Sequencing
LCS	Land change science
LULCC	Land use land cover change
NGO	Non-governmental organization
NGS	Next Generation Sequencing
SNP	Single nucleotide polymorphism

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CHAPTER I

INTRODUCTION

Globalization has pushed conservation to integrate with agriculture, livelihoods, and resource use (Zimmerer 2006), and to intensify conservation-development interventions in Latin America in recent decades (Zimmerer 2011). Agricultural land use occupies approximately 40% of the global land surface compared to only about 6% being protected areas (Tscharntke et al. 2015). Although seemingly contradictory, conservation and agriculture can occur side-by-side, creating “the matrix” (Perfecto et al. 2009), and agriculture can make contributions to conservation by allowing for sustainable management of biodiversity and ecosystem services (Daily et al. 2003, Tscharntke et al. 2005, Vandermeer et al. 2007). Agroforestry is one way to achieve the goals of development and conservation simultaneously. Since late 1970s, policies have endorsed agroforestry as a panacea to solve problems of maintaining agricultural production while reducing loss of forest cover.

Despite agroforestry’s continued importance in rewriting Latin American rural landscapes, we know little about its biogeographical outcomes (Robbins et al. 2015). As Robbins et al. (2015) state “there remains little theoretical or empirical evidence of strong causal linkages and outcomes, traced from commodity economies [such as coffee, rubber, cacao] through agroforestry practices, to diversity outcomes” (p. 77). Further, ecological and socioeconomic complexities are part of agroforestry systems (Sanchez 1995). The majority of agroforestry studies have centered only on biophysical aspects such as nitrogen fixation and soil conservation (Mercer & Miller 1997, Kant & Lehrer 2005, Kiptot and Franzel, 2011), and the existing socioeconomic studies have excessively depended on quantitative predictive models (Mercer & Miller 1997, Pollini 2009). Given the complexities of agroforestry systems, we need to understand the biophysical as it relates to the social aspects through a coupling of qualitative and quantitative methods at different spatial scales (Sanchez 1995, Pollini 2009, Robbins et al. 2015). To fill this gap, I offer a study that utilizes mixed methods to describe and measure the relationship of the social dimension, which is understood as agroforestry farming practices, to biodiversity outcomes at species and genetic levels. This will provide another way to measure and access biodiversity for conservation efforts.

The central research question of this study is: how do changes to agroforestry practices change biodiversity? Thusly, I investigate biodiversity changes through participation in a coffee agroforestry project in the montane forests of the Chanchamayo province in Junín, Peru, expanding the shade coffee literature beyond Central American countries. Biodiversity is broadly defined here as variation at the ecosystem, species, and genetic levels (Wilson 1988), which can also be divided into two categories: wild biodiversity and agricultural biodiversity (agrobiodiversity[1]; Zimmerer 2010). Further, agrobiodiversity can be understood to have two components: planned agrobiodiversity, where plants and animals deliberately incorporated and specifically managed; and associated agrobiodiversity, which is composed of "indirectly managed organisms,

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[1] Zimmerer (2010) defines agrobiodiversity as all plant, animal, and microorganisms existing and interacting in broadly defined cultivated environments.

including pollinators, weeds, soil organisms, pests, and disease pathogens as well as natural enemies" (Zimmerer 2010:139). This project examines changes in planned agricultural biodiversity through an integrated study of participation, biogeography, and landscape genetics (a field that combines molecular techniques with landscape ecology). I survey plant biodiversity present on coffee agroforestry farms, specifically tree species, and test how participation relates to biodiversity at the species and genetic levels using a quasi-experimental study design complemented with a mixed methods approach.

The agroforestry project I selected for this study is run by a national NGO[2] established in 1997. Through its coffee agroforestry project the NGO aims to improve quality of life, slow the rate of deforestation, reforest the landscape, and protect biodiversity in the region, indicating the use of a land sparing or intensification approach. The NGO recruits local farmers to participate in the program to receive farm resources (e.g. seeds, fertilizer) and technical knowledge, thereby changing the way the farmers have been working the farm (planting and harvesting coffee; managing shade and other trees). Thus, the working hypothesis of this research is that adoption of NGO proffered agroforestry "best practices" and resources result in different biotic landscapes than in non-participating farms as measured by species and genetic diversity.

[2] The NGO described and studied within this project will be referred to and named only as the "NGO." To protect the NGO and moreover the farmers from being identified and to reduce the risk of any funding loss due to findings of this research, I choose to leave the NGO unnamed. Further, this was listed as a technique on the approved IRB application as a way to protect the participants of this study.

1.1 Research Objectives

The research question is addressed through the following research objectives:

1. Describe how the agroforestry program alters practices and the regime of resources available to participating farmers.
2. Quantify and test biodiversity (woody tree species and genetic diversity) on the farms.
3. Quantitatively test the relationship between farming practices and biodiversity outcomes using statistical analyses.

This project is a novel integration of human-environment geography, biogeography, and landscape genetics to examine the relationship between agroforestry farming practices and landscape change. This research contributes to geography by showing how changes in practices alter and shape landscapes and agrobiodiversity, especially at the genetic level. This study builds on previous work (Dawson et al. 2008, Hollingsworth et al. 2005) that has examined population genetics in agroforestry systems by further stratifying the sampling scheme in the human-modified landscapes. The design provided here incorporates genetic techniques using the field of landscape genetics and next-generation sequencing (NGS) technology. Further, the research design in this study should be broadly transferable to other areas, whether considering agrobiodiversity or wild biodiversity. The methods utilized here also lend themselves to replicability given the use of NGS, which makes obtaining large amounts of genetic level information cheaper, easier, and does not require prior genomic knowledge or a reference genome of the species for analysis (Peterson et al. 2012).

1.2 Analytical Framework: A Quasi-Experimental Design

It is through the distribution of resources that the NGO in Chanchamayo is changing the landscape. Resources refer to not only material things that are distributed by the NGO but also the information and knowledge that the agronomists and the technicians bring to the farmers and communities. To track and document the efficiency of NGOs and conservation organizations in general, the amount of material resources distributed or money spent on items for a project are recorded and reported to funding agencies. However it is more difficult to track the impact of the resources distributed on the lives of the people that are meant to be helped or the change it has led to on the biotic landscape. In this study, I measure the resources distributed by the NGO and assess changes in tree and genetic diversity on associated farms.

Using a quasi-experimental design complemented with a mixed methods approach, this study associates an organization with changes in biodiversity at the species and genetic levels. The nonequivalent groups design within quasi-experimental designs allows for the comparison of groups in which the subjects have chosen their treatment groups; i.e., whether or not to participate with the NGO. The differences between the subjects and outcomes can then be compared. With this design, many variables are held constant so the effects of the treatment or variation can be used for generalized causal inference.

A chain of influences that contributes to explaining biodiversity in coffee landscapes is required if we are to document biotic outcomes. Expanding upon the general chain of explanation relating policy and economy to biodiversity through agroforestry practices and producer decisions provided by Robbins et al. (2015), I develop a more specific explanatory framework applicable to my study area[3] to increase our ability to trace changes by an organization to biodiversity. The explanatory framework with the links visualized between the actors and the landscape of this study is represented in Figure 1.1. In this figure, similar to Robbins et al (2015), I demonstrate the causal mechanisms that link NGO's work to biodiversity outcomes based on what we know of individual interactions between the components. One of the main concerns of the NGO in this region is the protection of wild biodiversity from expanding agriculture and illegal logging – both leading to deforestation. This protection partly occurs through the conservation concession obtained in 2005. More recently, the NGO has designated the area between the conservation concession and another patch of intact forest owned by a university as a biological corridor. It is within this biological corridor that most of the participating farmers live and own farms.

The agricultural "best practices" of coffee growing promoted by the NGO technicians and how the practices are framed are based in part on the instructions and training they receive from the NGO, which in turn depend on the NGO's commitments to international organizations and governments via funded proposals and contracts. The technicians meet with the farmers, encourage and incentivize them to follow the "best practices". The farmers' adoption of these practices is mediated by their knowledge and costs of inputs, crop yield, and other economic incentives. These new/changed farming

[3] The framework is also applicable to any future study measuring biodiversity outcomes due to organizations or policies.

practices lead to land use change, the extent of which depends on prior land uses. In turn, we can observe these changes in the biodiversity on participating farms, as documented by Valencia et al. (2015), where farmers' planting preferences were changing towards planting more *Inga spp.* by NGOs and government agents.

This expanded framework is based on previous studies that show policies and organizations as drivers of biotic land change (specifically deforestation; Meyfroidt and Lambin 2008, Meyfroidt et al. 2013, Zimmerer & Vanek 2016), operationalized mainly

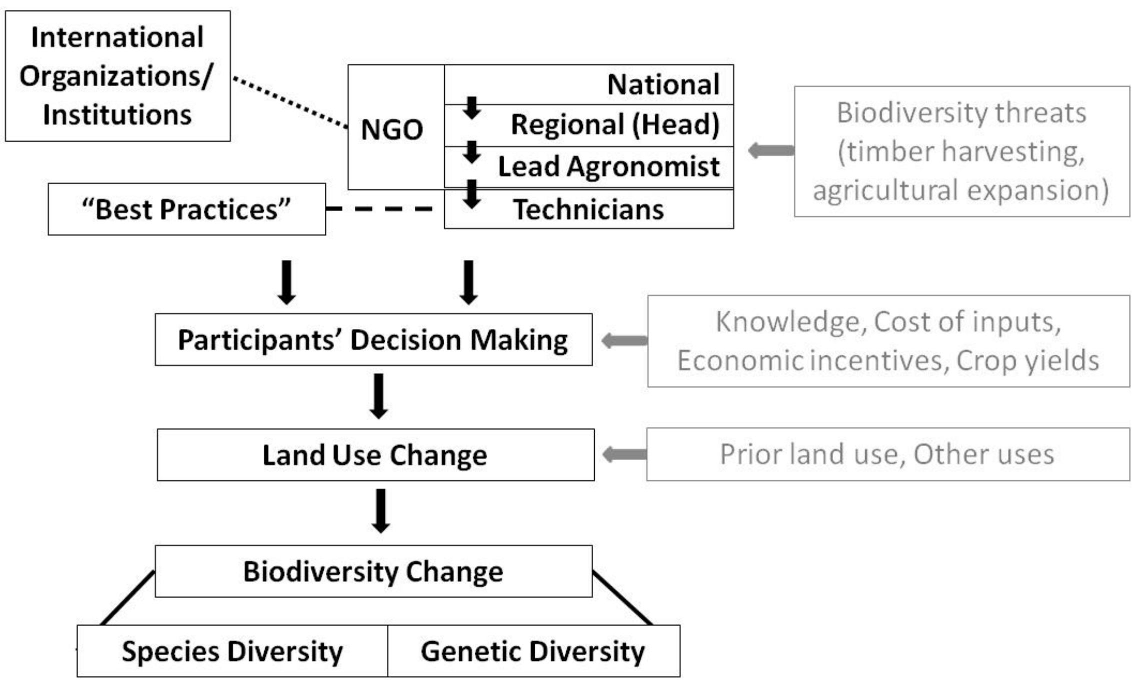

Figure 1.1. Explanatory framework and links between agents and actors of this dissertation. The boxes in grey represents other factors that can influence the actor's decision making.

Note: The biodiversity change in the explanatory framework for this study is agrobiodiversity, however, it could shifted to be applied to wild biodiversity for a study with a different focus (e.g., reforestation efforts).

from the global land use and land cover change (LULCC) and agroecological studies. Our understanding of causes and agents of deforestation has changed over time, moving from thinking of smallholders being the sole cause of deforestation to a broader understanding of the complex situation with multiple factors (Rudel et al. 2009). Geist and Lambin (2002) discuss underlying drivers of land use change, specifically in relation to deforestation. Two categories they discuss that are relevant to the work of the NGO are: technological change and cultural factors. Technological change encompasses agro-technical changes, such as intensification or extensification, and agricultural production factors. Cultural factors are public attitudes, values, and beliefs (i.e., concern about conservation) as well as the decisions of individuals and households. Further, Zimmerer and Vanek (2016), using a meta-analysis show the links between interactions of smallholder agrobiodiversity influenced by demographic and social factors and the political economy in turn influence above and below ground biodiversity and soil and water resources.

Existing studies that identify policies and organizations as drivers of land change limit their analysis to categories such as agriculture, pasture, urban, and forest and do not pay attention to variation within these categories – assuming homogeny within each (Angelsen and Kaimowitz 2001, Robbins et al. 2015). For example, in a dichotomous classification of a landscape into forest – non-forest, where agroforestry or secondary forests be placed is unclear, especially at a larger scale where agroforestry landscapes would not be detected by large scale surveys (Mendenhall et al 2011). In this dissertation, I argue that we need to go beyond *dichotomies* and study changing *compositions* that are a part of the land use and land cover change, much like the agroecological matrix suggests considering quality for landscapes. If the ultimate goal is to understand factors affecting biodiversity conservation and design policies to protect biodiversity, it is important to look deeply into the characteristics of existing land uses and changes due to technological and other interventions by governments and organizations. In the specific case of tree biodiversity on coffee producing landscapes, the focus of my dissertation, measuring species and genetic diversity helps understand the resilience of a farm and species to adverse environmental and economic shocks as well as the contribution of these farms to conservation as part of a biological corridor or a larger landscape (the matrix) that can contribute to conservation. Using this, I seek to further understand changes occurring due to organizations on the ground.

1.3 Dissertation Roadmap

The remainder of this dissertation is organized into chapters that I outline here. Chapter 2 places the study in the broader literature and debates regarding global land change, agroforestry, and biodiversity conservation. Chapter 3 covers the research design of this study. In this chapter I provide details about the study area, data collection, data analyses, and explore my positionality as a student researcher while conducting this research.

Chapter 4 is the first of the three empirical chapters; here I document the details of the NGO and its agroforestry project. I further explore the resources the NGO offers and how the NGO field technicians distribute them to the farmers. I also use interviews and surveys with farmers to investigate why the farmers choose to participate with the NGO and their expectations. With Chapters 5 and 6 I explore the patterns in species and genetic diversity present on the farms, respectively. In Chapter 7 I synthesize the patterns of biodiversity and NGO resources explored in the previous chapters. And lastly in Chapter 8, I draw conclusions and make recommendations for managers of agroforestry and biodiversity conservation projects.

CHAPTER II

LITERATURE REVIEW

Land transition is a major form of global environmental change (Turner et al. 2007). As such, understanding various aspects of land transition, notably into agricultural production, has been a major focus of land use land cover change (LULCC) studies/ land change science (LCS). LULCC views land dynamics as an “interactive process of the human and environmental subsystems” (Turner and Robbins 2008, 299). LULCC focuses on human-environment dynamics to uncover characteristics and processes of change in land uses and covers to address global environmental change and sustainability. Conceptualization of problems has come a long way in LULCC from single factor explanations to multiple factor explanations (VanWey et al. 2005). Current research in LULCC generally rejects single factor explanations and accepts a *drivers and causes* model (many have been proposed, e.g. Geist and Lambin 2002, 2004; Hersperger et al. 2010, Brown et al 2013, Bakker et al. 2015) in explaining cause to cover relationships. Among the drivers, the role of human activities has been closely studied (Zimmerer 2004, Carr 2008, Zimmerer and Vaca 2016). The explanations for land change depend on ecological, cultural, socio-economic, institutional, and political factors, requiring an interdisciplinary effort to fully understand (Turner et al. 1994, Lambin et al. 2001, VanWey et al. 2005, Hersperger et al. 2010).

As we try to understand our changing global environment, more emphasis has been placed on conservation to integrate with agriculture, livelihoods, and resource use

(Zimmerer 2006). This is in contrast to strict protection of landscapes and resources, banning them from any use, a conservation strategy that is criticized for being unable to meet local livelihood needs and often in conflict with them (Naughton-Treves et al. 2005, Zimmerer 2006, Redpath et al. 2013). The move to integrated conservation efforts fits with what has been articulated as the "third wave of conservation," which integrates sustainability into conservation's goals (Zimmerer 2006). While such integration can reduce conflict between conservation and livelihoods, we need a better understanding of factors that determine its ability to achieve both goals.

An important and noted feature of the third wave is the expansion in activities of global organizations and institutions that transcend national boundaries (Zimmerer 2006). For instance, Castro and Locker (2000) found that about 90 percent of funding for biodiversity conservation in Latin American came from international donors. However, we do not know the explicit link between the NGOs work/efforts and the resulting outcomes of biodiversity (Robbins et al. 2015)

In this chapter, I explore the literature informing my overall research question. Thus, I frame my question in terms of the previous conservation and agriculture focused studies in the land use and land cover change (LULCC) or LCS literature. I also include sections on what is known about agroforestry's impact to conservation and (agro)biodiversity. I also place the research objectives regarding species and genetic diversity into broader ecological literature that explores the importance of both species and genetic diversity.

2.1 Land Change Science and Agriculture

Land change science has closely studied the role of humans in changing the Earth's ecosystems. Deforestation, irrigation, and industrial production are some human activities that have been directly linked to environmental changes (Turner et al. 2007). LCS studies use various ways to measure and understand land use change, such as through Geographic Information System and remote sensing, understanding land change in the context of integrated human-environment systems, modeling of land change, and understanding outcomes such as resilience, vulnerability, and sustainability (Turner et al. 2007, VanWey et al. 2005). More recently, LCS studies have also documented the drivers or causes of land change that are not geographically connected, such as leakage effects (Meyfroidt et al. 2013).

Our understanding of drivers of land use change has been supported by case studies from all over the world. Most studies highlight agriculture as a primary driver of land use change (Mustard et al. 2012). With increasing global population and standards of living, land use change for food production is predicted to continue for some time (Mustard et al. 2012). Lambin et al. (2013) note that by "2030, an additional 81 to 147 million hectares (Mha) of cropland will be needed compared to the 2000 baseline" (p. 892), thus threatening biodiversity. Given this reality, finding ways to integrate agriculture with conservation seems not only desirable from a rural livelihood and food production point of view but also from a biological perspective.

Models of land change within global change research have identified the central role of environmental governance (Geist and Lambin 2002, Turner et al. 1994). This could take the form of institutions–sets of formal rules such as land tenure, legislation, contracts, and usufruct rights as well as informal rules such as traditional practices and socio-cultural norms (Tucker and Ostrom 2003). For example, property rights, a set of institutions that determines access, withdrawal, management and exclusion to land resources, have been used as an explanation for land change (Richards 1990, Brannstrom 2001, Deininger and Feder 2001, Fearnside 2001, Chowdhury 2010, Corbera & Brown 2010, Corbera et al. 2011). These institutions can be seen as mediating the societies' relationships with resources (Ostrom 1990, Robbins 1998, Geist & Lambin 2002, Vadjunec & Rocheleau 2009, Jepson et al. 2010). Gibson et al. (2000) state that local institutions act as filters for market, technological, demographic, and political factors.

More recently, work using New Institutional Economic approach, which considers the interactions between organizations and institutions, has illustrated the importance of considering access to resources rather than only the right to resources (Ribot and Peluso 2003, Jepson et al. 2010). Further, both Robbins et al. (2015) and Zimmerer and Vanek (2016) include political economy into their conceptualization framework for producers' decisions influencing (agro)biodiversity. And NGOs as organizations can deliver services and resources to its constituents, creating opportunities and access as well as institutions. With the involvement of transnational conservation NGOs in integrating conservation and agriculture, it is possible that they will create new or alter practices through their promotion of certain management practices. Valencia et al. (2015) document the shaping of a community's knowledge by workshops of NGOs and government agencies in Mexico, which translated into farmers' decisions regarding what species to plant on their farms. Similarly, the NGO in this study uses workshops and technicians to teach farmers the "best practices" and distributes material resources that are geared towards initiating land use and biodiversity-related changes on the farms, in an effort to integrate conservation and agriculture.

2.1.1 Integrating Conservation and Agriculture

Pittelkow et al. (2015) note that a "primary [challenge] of our time is to feed a growing and more demanding world population with reduced external inputs and minimal environmental impacts, all under more variable and extreme climate conditions in the future." To address this challenge, some have focused on studying and developing agricultural techniques that can improve yield with minimum impact on the environment (conservation agriculture; Glamann et al. 2015, Pittelkow et al. 2015). Likewise, the landscape approach attempts to create a people-centric conservation effort through addressing "the complex interactions between different spatial scales, and the need to embrace the full complexity of human institutions and behaviors" (Sayer et al. 2012: 8350). However, debates exist on the best methods for the integrating of conservation and agriculture. The fundamental disagreement is on the role of agricultural intensification (Green et al. 2005, Fisher et al. 2008), and has lead to two contrasting approaches.

Two broad ways have been proposed to manage agriculture and conservation. One such method, "land sparing" refers to the separation of lands for conservation and crops, with high-yield farming facilitating the protection of remaining natural habitats from agricultural expansion (Phalan et al. 2011). Others support the idea of “land sharing,” where biodiversity conservation and agriculture are integrated *on the same land* by using wildlife-friendly and sustainable farming practices, such as agroforestry and organic farming (Vandermeer and Perfecto 2010, Perfecto et al. 2009, Perfecto & Vandermeer 2015).

Phalan et al. (2011) compare land sharing and land sparing approaches to biodiversity conservation to examine which one would do the least amount of harm while producing more food. To compare the two, they use data on bird and tree densities in Ghana and India and see how they fare under each approach. They find that the optimal strategy for biodiversity is land sparing due to the loss of potential conservation areas in land sharing and populations (trees and birds) are also adversely affected by farming. Land sparing had higher populations at all production targets measured. The ratio of loses compared between land sharing and land sparing is the highest for species that have small ranges. They find that both countries can produce more food with little negative impacts on forest species if they implement sustainable forest management practices but they have to be in the form of land sparing as it will protect the most number of species.

More recently, Chandler et al. (2013) compared bird communities in integrated open canopy (IOC) coffee to heavy shade coffee landscapes in Mexico to test a small scale land sparking approach. IOC coffee is where coffee is grown in low shade landscapes, however land next to the production area is conserved (essentially becoming a secondary forest) to provide protection to the coffee crops. They find that IOC coffee farms are more similar in bird composition to forest areas than the heavily shade coffee farms while also yielding 2-5 times more coffee.

On the other hand, many studies have shown that land sparing approach does not always provide the desired outcomes (Vandermeer and Perfecto 2005, Vandermeer and Perfecto 2007, Matson and Vitousek 2006, Goulart et al. 2016). One criticism of land sparing, from the point of view of conservation, is that it focuses on the size of the natural habitat while ignoring the broader landscape which would also effect the survival of species (Perfecto and Vandermeer 2010, 2015). This also follows the thinking that animals (and species in general) will not follow or stay within the any boundaries drawn around areas (e.g., snow leopards studied in Mongolia by Johansson et al. (2016)). Thus, Perfecto and Vandermeer (2010) suggest a landscape perspective called the agroecological matrix whereby certain types of landscape elements modified by humans can support biodiversity and even broader ecological functions (Perfecto et al. 2009, Perfecto and Vandermeer 2010, Altieri and Toledo 2011). In this matrix quality approach, Perfecto an Vandermeer (2010) present us with a framework for analyzing the relationship between agriculture and conservation.

Rooted in metapopulation theory, this view recognizes that inter-fragment migration fosters metapopulation survival. Metapopulation dynamics considers patches of habitats that could be distinct from one another. Each patch has resources available to support the local population (Vandermeer & Carvajal 2001). The implication for land sharing is that certain types of agricultural landscapes can improve the quality of the matrix by facilitating (or at least not hindering) inter-fragment migration, where organisms can find refuge "for a long enough period of time to reproduce and send out propagules, thus contributing to the overall potential for the matrix to be "permeable"" (Perfecto & Vandermeer 2015:255). Further, given the matrix quality approach, small-scale sustainable agriculture is more likely to protect biodiversity in the long term in tropical landscapes. This places the smallholders, who use few or no external inputs and maintains a diverse agroecosystem, at the crux of a high quality matrix (Perfecto and Vandermeer 2010). Such a landscape can better protect biodiversity as there are no "sacrifice zones" unlike with land sparing, where only food production or conservation can occur (Hecht 2006, Perfecto and Vandermeer 2010).

Quandt (2016) documents the likelihood that under agricultural intensification in Barjomot, Tanzania, where the farmers would remove all the trees from their farms, the farmers would likely have to venture into the "spared" forest to collect tree products. Scherr and McNeeley (2008) and Perfecto & Vandermeer (2015:249) also argue that intensification of farming practices does not generally save land for nature, and conservationists are trying to adapt an "ecosystem approach" that would include creation of biological corridors. However, for this to work there needs to be resource management strategies for where farmers have to sustainably increase output and reduce costs using ways that would increase habitat quality and ecosystem services and farmers or conservation managers expand natural areas (Scherr and McNeely 2008). Furthermore, spatial configuration should allow for connecting of patches so to minimize habitant disturbance, an argument in favor of biological corridors.

Harvey et al. (2008) use the example of Mesoamerica to highlight conservation opportunities where land sharing exists; and conservation and production units exist together in an agricultural matrix. They outlined six strategies for managing the agricultural matrix: identify an overlapping hotspot of conservation and production; address threats to biodiversity; protect remaining native habitat; protect and further facilitate diversity of tree cover; promote and conserve traditional agricultural practices; and reforest less productive lands. Though they examine the Mesoamerican landscape, these suggestions can be applied to similar situations elsewhere. The six strategies outlined by Harvey et al. (2008), capture well the activities of the NGO in Chanchamayo. The NGO works in a region with unique biodiversity that comprises pockets of the Eastern Andes but also has fertile soil and the ideal elevation to produce coffee. They attempt to address threats of deforestation and agricultural expansion through their on-going projects to maintain and increase shade coffee production. They purchased the rights to manage a conservation concession to protect native habitat and they promote the planting of native trees to increase the quality of the matrix.

Some authors have begun to call to move beyond the land sharing-land sparing debate, highlighting that the approaches are not mutually exclusive and only offer two unappealing options for conservation (Fischer et al. 2008, Tscharntke et al. 2012, Fischer et al. 2014, Kremen 2015, Goulart et al. 2016). Goulart et al. (2016:1027) in revising land sharing and land sparing approaches both make assumptions regarding “complex causal chains that involve biophysical, ecological and cultural world,” where many issues still have to be addressed. Based on historical data, their theoretical model shows that increasing intensification on farmland increases natural habitat loss, leads to population declines of species, and decreases permeability of the natural habitat. With land sparing there is a risk of deeply impacting food production, biodiversity, and ecosystem services. They conclude by stating that land sharing is likely a safer strategy based on ecological and social aspects. However, as Fischer et al. (2014) and vonWehrden et al. (2014) warn us, the land sparing-land sharing framework can help us identify trade-offs but cannot tell you which is desirable; and it allows us to compare two hypothetical models of conservation but does not deal with scale issues or globalization effects. Fisher et al. (2014) recommend that when using either framework recognize the value but also its real world limitations. Both Kremen (2015) and Johansson et al. (2016) call for the need to have both land sharing and land sparing to promote biodiversity conservation.

Agroforestry is an important form of a wildlife-friendly land use that creates a high quality matrix. This approach of land sharing can be seen as transforming the perspective on agricultural landscapes from purely food production to having ecological potential provided appropriate methods are used. Farming practices are increasingly using farmland for multiple purposes, not only generating diverse livelihood products but also increasing biodiversity. For instance, in Mesoamerica, 98 percent of farms had more than 10% tree cover, 81% of farms had more than 30%, and 52% of farms had 50% woody cover (Zomer et al. 2009). Recently, agroforestry was identified as “low hanging fruit” to achieve carbon sequestration and provide other ecosystem services including being a refuge for biodiversity, further placing weight on these programs to produce multiple benefits (Nair 2012). However, limited research has looked into the process and outcomes of conservation and biodiversity through agroforestry programs and how they change landscapes (Robbins et al. 2015). And the extent to which such agricultural landscapes support biodiversity, particularly at the genetic level, remains an open question, especially for tropical plants (Manel & Holderegger 2013).

2.2 Agroforestry, Conservation, and Biodiversity

Agroforestry has been practiced for centuries in the realm of traditional land-use practices that were noted historically in Asia, Central America, Latin America, Europe, and Africa (Budowski 1987, King 1989, Miller & Nair 2006). The importance of crops and trees as parts of the system are clear but examples indicate that the focus of an agroforestry system was food not tree production (Conklin 1957, King 1989, Wilken 1976, Miller & Nair 2006). In Latin America, the association of crops and trees in fields and homegardens has been a widespread practice (Atangana et al. 2014, Wilken 1976). For example, indigenous communities in the Amazon use shifting cultivation or swidden-fallow agriculture (Brookfield and Padoch 1994, Porro et al. 2012), which later evolved into a shaded agroforestry system (Denavan 1971 in Atangana et al. 2014, Porro et al. 2012).

Geographers have studied agroforestry as an important farming regime in traditional societies and as a model for sustainable development (Hecht & Cockburn 1989, Anderson 1990, Anderson and Ioris 1992, Brookfield & Padoch 1994, Corlett 1995, Kleinman et al. 1995, Smith 1996, Voeks 1996, Montagnini and Mendelsohn

1997, Coomes et al. 2000, Schneider et al. 2002, Hecht et al. 2010). Studies conducted by geographers and others with observations of non-sustainable farming systems on tropical soils and forests entered agroforestry into the policy realm as a holistic land-use system for development and conservation (Kant & Lehrer 2005, King 1989, Mercer & Miller 1997). Today, agroforestry continues to be promoted as a strategy for food sovereignty, sustainable livelihoods, carbon sequestration, and biodiversity conservation, and much of it occurring simultaneously (Garrity 2004, Scherr & McNeely 2007, Nair 2012, Perfecto et al. 2009). One agroforestry system that has been highlighted and studied for its potential for simultaneous development and biodiversity conservation is shade coffee (Perfecto et al 1996, Philpott & Dietsch 2003, Rice & Ward 1996, Solis-Montero et al. 2005, Perfecto & Vandermeer 2015).

Dawson et al. (2013) state there are three ways in which agroforestry can assist in conservation. First, trees planted in agricultural landscape could provide habitat for biodiversity. Second, these trees provide an alternative source of wood and certain forest products, or act as biological corridors that connect fragmented lands. Third, the trees can themselves be sources of seed and gene banks that assist in further conservation. The authors do warn that planting new varieties of trees in the farmland may lead to undesirable biodiversity outcomes if the planted varieties differ substantially from the surrounding natural species. They advocate a need for further research to understand appropriate planting configurations and species mixture – making the understanding of genetics crucial in any planting and reforestation efforts. Further, agroforestry crops cover a much larger area in the tropics than do conservation areas, thus making their capacity to maintain or lose biodiversity an important conservation concern (Robbins et al. 2015).

Agroforestry is purported to offer a means to have production whilst protecting or even enhancing biodiversity. Though there is some debate about whether conservation is possible with agriculture (Clough et al. 2011, Phalan et al. 2011), many scholars believe that wildlife-friendly and sustainable farming practices, such as agroforestry and organic farming (Vandermeer & Perfecto 2007, Perfecto et al. 2009) can provide integration of biodiversity conservation and agriculture. By considering the type of agriculture and targeting sustainability and small scale farming, the landscape can better protect biodiversity and be a fully integrated approach that considers agriculture, conservation, ecosystem, and rural livelihoods – since the agricultural land provides food, habitat for species, and ecosystem services (Hecht et al. 2006, Scherr & McNeely 2008, Perfecto & Vandermeer 2010). However, for this to work there needs to be resource management strategies for farmers to sustainably increase output and reduce costs using ways that would increase habitat quality and ecosystem services (Harvey et al. 2008, Scherr & McNeely 2008).

NGOs along with government programs carry out agricultural extension programs to help farmers. Altieri (1999) states that NGOs can use traditional farming knowledge for a specific place as a starting point and incorporate both traditional and modern agricultural knowledge to produce resource conserving and high yielding systems. Geographers have studied NGOs and their ability to bring social and environmental policies and changes (Hecht and Cockburn 1989; Heiman 1996, Farrington & Bebbington 1993, Hulme and Edwards 1997, Bryant 2001, Mercer 2002, Sundberg 2003, Bebbington 2004, 2005). In Latin America during the 1980s and 1990s the number of environmental NGOs grew swiftly (Price 1994). Initially hailed as sources of development alternatives and advocates for the poor, NGOs were celebrate and viewed as having the ability to make a difference. As time passed on it became clearer that NGOs were not as adept at promoting participation and addressing the needs of the poor (Hulme & Edwards 1997, Banks et al. 2015). Today, they are critiques for their close association to donor agencies and mirroring the agencies' concerns in its activities (Bebbington 2004, Banks et al. 2015). However, they are also in a position to bring resources to populations that would not be able to access them otherwise, as well as carry out development projects.

Over the past decades various development projects have often changed agroforestry farming practices, resulting in changes to the amount of shade species used on the farms (Perfecto et al. 1996, Perfecto & Armbrecht 2003, Potvin et al. 2005, Perfecto et al. 2007, Mendez 2008). In Central America, recent programs have been attempting to encourage farmers to increase diversity on farms and transition away from sun coffee plantations (coffee varieties grown without shade). Further, certification programs created to incentivize farmers to maintain shade coffee despite economic pressures have shown no difference in biodiversity between the certified and non-certified farmers (Philpott et al. 2007).

Though we poorly understand the processes that influence and govern biodiversity in agroforestry, we do know about the components that link the political economy to biodiversity (Figure 1.1, Robbins et al. 2015). Evidence of the contributions of agroforests to biodiversity conservation has been reported from around the globe. Studies have documented the similarities between coffee and cacao agroforests and forests at the global level (De Beenhouwer et al. 2013), in Costa Rica (Valencia et al. 2014), in Mexico (Bandeira et al. 2005, Lopez-Gomez et al. 2008) and in Nepal (Sharma & Vetaas 2015). Others have also shown higher diversity in agroforests compared to traditionally managed farms or diversity across a production gradient (Lopez-Gomez et al. 2008, Mendez et al 2007, Philpott et al. 2007, Goodall et al. 2014, Worku et al. 2015, Karanth et al. 2016.) There are sufficient studies that have shown the contribution of agroforestry to biodiversity conservation and habitat creation, but as Robbins et al. (2015) point out this suggests the need to understand the specific influences that account for higher or lower diversity in the agroforestry systems. These influences can be ecological structures or it can be political and economic contests that create the conditions for this structure. In this dissertation, I specifically focus on the conditions created by an NGO and test what changes occur in biodiversity related to this influence.

2.3 From Forest Cover to Species/Genetic Diversity: Landscape Genetics

Forest cover is frequently used as a proxy to measure biodiversity and land change by many conservation programs to assess success of programs in achieving desired conservation outcomes. While forest cover can provide some information regarding land use and land cover of a region, it is subject to the researcher's decisions that may be masked within the generation of maps and limitations of technology

(Robbins 2001, Wong et al. 2007). The ability to gather information from forest cover beyond percent canopy cover is difficult and depends on availability of data, and its temporal, spatial, and spectral resolution (Liverman & Cuesta 2008). This challenge is exacerbated in tropical locations where persistent cloud cover limits use of available data archives. Vadjunec and Rocheleau (2009) also state forest cover does not measure species biodiversity in the tropics.

There is much literature on the importance of diversity. The diversity can range from varieties in landscapes to species to economic activities to land uses to production of strategies. Going back to MacArthur (1955), the understanding has been that a larger amount of diversity begets ecosystem stability; this has been further supported by more recent studies (Carvalho et al. 2013, Tilman et al. 2014, Isbell et al. 2015). This understanding has also been expanded and applied to plant species and explanations of social and livelihoods stability. In the latter, it is a similar idea that having diversity in markets, production strategies will allow households and people to have stability should one aspect or strategy not pan out or should one market collapse/fail.

In order to have a fuller understanding of the relationship between participation with NGO and changing practices and environmental change, a “look down” into the genetic structure of biota can allow for additional measurements to assess biodiversity composition and structure. Landscape genetics is a field that provides an approach integrating molecular techniques from population genetics (neutral molecular markers[4]) along with landscape ecology (spatial statistics; Holderegger et al. 2010, Manel et al. 2003). This field allows for direct measurement of diversity at the genetic level and offers a way to go beyond forest cover and “forest” and “not forest” land classifications. Further, in Geography, landscape genetics is being currently being applied to answer questions in Medical geography to enhance understandings of local-level disease environments (Carrel & Emch 2013, Young et al. 2016), and more relatedly to answer questions about the role of spatial factors and landscapes as geographic barriers and corridors to gene flow resulting in population genetic structure of plants (Johnson et al. 2014) and animals (Murphy et al. 2010, Ruiz-Lopez et al. 2016).

Diversity at the species level, for both wild and agro-biodiversity, is important for ecosystem functions, while genetic diversity is important to predict extinction vulnerability and survival of the species (Booy et al. 2000, Martin et al. 2012). Species level diversity has important implications for ecosystem functions and stability (Booy et al. 2000, Vellend 2003, Vellend & Gerber 2005). Species level variation is also important for agrobiodiversity, defined as “domesticated organisms and interacting biota in ongoing farmer- and land-user-based domestication and adaptation” including diversity of trees, crops, soil microbes, pollinators, etc. present on farms (Zimmerer 2010:139).

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[4] Neutral molecular markers are fragments of DNA in the genome that are not under selection. Examples of molecular markers include amplified fragment length polymorphisms (AFLPs), microsatellites (or simple sequence repeats, SSRs), and single nucleotide polymorphisms (SNPs).

The Convention on Biological Diversity in 1992 recognized that agrobiodiversity is important to conserve and manage for sustainable use as high levels of agrobiodiversity can protect the farmer against total loss from pests, diseases, and environmental changes. Research on agrobiodiversity, especially in coffee agroforests has found that farmers maintaining trees and complexity within the system provides ecosystem services such as pest control (Vandermeer et al. 2010), higher production yields (Bisseleua et al. 2013), soil nutrition, and pollination services (Abraham et al. 2013). Further, maintaining agrobiodiversity of crops for sustainable agroecosystems through crop rotations including cover crops (e.g., shade trees) sustains soil quality and productivity by enhancing soil carbon and nitrogen and microbial biomass (McDaniel et al. 2014). When considering agrobiodiversity, the role of the farmer as the manager cannot be over looked. Not only does the farmer decide what is planted or removed from the farm according to their knowledge and personal or cultural preferences (Cardinale et al. 2012, Valencia et al. 2015) but also decides and coordinates with other neighboring farmers on where to plant (Zimmerer and Vaca 2016). The same-crop spatial clustering observed by Zimmerer and Vaca (2016) in the Bolivian Andes is a global phenomenon especially in landscapes with smallholders and it provides resilience to the smallholders' land use.

Genetic diversity at the population level is the basis for species level diversity, and it maintains the population's ability to cope with environmental changes and persist over time (Booy et al. 2000, Frankham et al. 2010, Martin et al. 2012, Young et al. 2000). Genotypes of plants can have enormous impacts on the structure of the communities dependent on it. Studies show activities of arthropod, soil microbial, and plant communities can differ due to genetic variation of plants, as they modify soils and soil nutrients (Iason et al. 2005, Bailey et al. 2006, Schweitzer et al. 2008, Schweitzer et al. 2010, McDaniel et al. 2014, Zimmerer and Vanek 2016). Impacts of genotypic variation can also extend to ecosystem level processes and services by creating communities that vary in productivity, herbivory, and predation (Zak et al. 2003, Bailey et al. 2006, Hughes et al. 2008, Bailey et al. 2009, Schweitzer et al. 2008, Kotowska et al. 2010). This illustrates that sustaining genetic diversity maintains biodiversity at the species and ecosystem levels.

Landscape genetics allows for the study of gene flow (through use of neutral molecular markers) in relation to geographic barriers and habitat fragmentation showing the status of species genetic diversity in an area (Martin et al. 2012). However, only a limited number of landscape genetics studies focus on plants and even fewer on tropical plants (Storfer et al. 2010). Further, only few studies have systematically examined plant species diversity (Moguel & Toledo 1999, Perfecto et al. 1996, Perfecto & Armbrecht 2003, Schroth 2004, Tejeda-Cruz et al. 2010), or plant genetic diversity (Hollingsworth et al. 2005, Dawson et al. 2008) within agroforestry systems.

This study will advance the work of Dawson et al. (2008), Hollingsworth et al. (2005), and others by further stratifying sampling of the farms to go beyond “natural” and “planted” for a deeper consideration of differences in farming practices. The treatment of each farm as a distinct unit will allow for the ability to distinguish the effects of participation with the NGO on species and genetic diversity. Hollingsworth et al. (2005) and Dawson et al. (2008) examine the genetic diversity of *Inga edulis* Mart. in close geographic areas to examine the difference between natural and planted stands in five sites. Hollingsworth et al. (2005) find concerns about genetic erosion through domestication is valid but that the genetic diversity of the planted stands are still high when compared to the natural stands. Dawson et al. (2008) using the same data find that the *I. edulis* on farms is of non local origin making any conservation efforts between the local wild and farmed populations unsuitable.

Maintaining connectivity between species, whose populations have become increasingly fragmented due to habitat destruction, is an important conservation issue. Isolated groups will not be able to survive in the long term even when they are restricted to specific areas, prompting conservationists to study "corridors" that will allow these species to connect. For example, Epps et al (2007) and Etherington (2011) illustrate how landscape genetics and GIS technique can be combined to study connectivity between fragmented species populations. Landscape genetics provides tools to correlate landscape spatial heterogeneity with gene flow estimates; studies have utilized simple and partial Mantel tests (these relate genetic distances of individuals or populations to geographic or landscape distances), multiple regressions on distance matrices, clustering algorithms, assignment tests, ordination, and modeling (Sork and Smouse 2006, Storfer et al. 2007, Manel and Holderegger 2013) In terms of conservation management, landscape genetics can provide information on species movement, needs for management efforts or evaluate current management efforts (Bolliger et al. 2014).

2.4 For a Better Understanding…

As this chapter has illustrated LULCC/LCS is at the nexus of social and natural sciences and works to understand the factors and process in land change. We can see the difference types of information that are linked together to create a better understanding of our changing landscapes. However, there are many challenges that LULCC faces in terms of linking land cover change to actual decisions made by agents (Rindfuss et al. 2004). Inherent in LULCC is the understanding that factors originating from different scales will affect the local scale where the land use change actually occurs because of decisions being made by the household or individuals. This is an important point for this dissertation and research design, and as we will see, decisions made by the NGO and donor agencies do influence the household and ultimately the land use and land cover (and biodiversity) of the farms.

CHAPTER III

RESEARCH DESIGN

In this chapter, I describe the design and implementation of this study. Following a quasi-experimental design to allow for general causal inferences, this study focuses on a NGO agroforestry program that operates in an area of approximately 40x40km in Junín's Chanchamayo province (Figure 3.1). I describe the study area and the background of the region to provide a context for the dissertation. I first present a broad overview of the climate and vegetation found in the Chanchamayo province, which is

Figure 3.1. Map locating the Chanchamayo province in Junín, Peru.

part of the Eastern Andean slopes of Peru. Then I focus specifically on Chanchamayo to detail the region's past, ongoing economic activities, and threats to biodiversity faced by this specific area to show the context in which the NGO operates. In the second section, I describe the data collection methods and analysis I utilize to answer my research questions. And lastly, I discuss and reflect on my positionality in the field as a student and researcher.

3.1 Study Area and Context

Peru is a highly biodiverse country indicated by its inclusion in the Tropical Andean hotspot identified by Myers (2000). The hotspot is a "leading hotspot" in the world with 45,000 plant species (20,000 endemic) and 3,389 species of vertebrates (1,567 endemic; Myers 2000). Peru itself is home to 25,000 plant species with 5,500 species being endemic (CBD 2015). The country has shown a commitment to protect biodiversity by signing the Convention of Biological Diversity in 1992 and Kyoto Protocol in 1998.

The Eastern slopes of the Andes form one of the most physically and biologically diverse areas in Peru. This region falls under the ecoregion known as the Selva Alta or Yungas (Reynel et al. 2013, Reynel and Leon 1989). Also known as the *ceja de selva* (eyebrow of the jungle), this ecoregion refers to the forests found on the Eastern slopes of the Andes above the Amazonian plain (Reynel et al. 2013, Young 1992). These forests, according to the Holdridge classification, fall under the ecological formations of pre-montane, lower montane, montane, and sub-Andean forests (Reynel and Leon 1989).

3.1.1 Climate and Vegetation

Local climate on the Eastern slopes of the Peruvian Andes varies in temperature from 9-25 Celsius, though the ranges vary based on elevation (Young 1992); with most of the rainfall occurring from November to April when the ITCZ is located south of the equator. Elevation gradients are steep, reaching 3000-4000 m within 100 km of horizontal distance with acidic to neutral soils ranging from loam to clay (Reynel et al. 2013, Reynel and Leon 1989, Young 1992).

Forests are generally semi-dense reaching an average height of 9-25 m, though some can reach a height of 40-45 m (Reynel et al. 2013). The vegetation can be characterized as the humid tropics consisting of montane and premontane tropical forests found between the elevations of 800-3800 m (Reynel et al. 2013). Vegetation characteristics and typical species vary based on elevation. The diversity present in montane forests is thought to decrease with elevation and peak at ecotonal areas between 500-1500 m (Gentry 1995). In this ecotone, organisms from both forest types exist (Gentry 1995), and potentially represent areas where forests have persisted over climatic harshness and shifts (La Torre-Cuadros et al. 2007). This ecotone contains biogeographical units, one of which is the Chanchamayo valley eastern Andean cordillera within the Chanchamayo-Apurimac unit (La Torre-Cuadros et al. 2007).

In the higher elevation forests (2000-3500m) you encounter more epiphytes, mosses, and lichens on tree trucks due to the higher amount of precipitation and condensation. For tree species, the family of Lauraceae, and the Genera of *Podocarpus*, *Hedyosmum*, *Weinmannia*, and *Ceroxylon* (in some parts) are common (Reynel et al. 2013).

The lower elevation forests (600-2000m) receive less rainfall and thus have less tree ferns, epiphytes, mosses, and lichens. The plant families of Leguminosae (Fabaceae), Moraceae, Rubiaceae, Lauraceae, and Euphorbiaceae are prevalent. The species of *Juglans neotropica* Diels, locally known as *nogal*, is exclusively found in this Andean elevation belt and is characteristic of this region. *Nogal* is classified as endangered by the IUCN Red List due to declining habitat and timber exploitation (American Regional Workshop 1998). *J. neotropica* exemplifies the struggle of the forests in this region due to easy access and soil quality that lends itself to agriculture (Reynel et al. 2013). Further, nogal is a species that the NGO has distributed to the farmers as part of their efforts. The lower elevation forests have been significantly modified by the presence of humans and the expansion of human habitation in this region (La Torre-Cuadros et al. 2007, Reynel et al. 2013).

3.1.2 The Chanchamayo Context

The Chanchamayo province in Junín is part of the Peruvian *Selva Central* located in the center of Peru that spans four states: Junín, Pasco, Huánuco, and Ucayali. The province is 472,340 hectares (4 725 km^2), making it the largest province in the state after Satipo (INEI 2012). It is also the second most populous province in Junín and is home to approximately 169,000 people (43% rural) according to the 2007 census. The province was expected to reach 204,000 people by 2015, a 20% growth in population (INEI

2015). Most of the working-age population (67%) works within the agricultural sector (Municipalidad Provincial de Chanchamayo 2013). The average farm size in the province is 6 hectares (PRONAC 1990).

The focus of this research is on the work of the NGO in the rural part of a district within this province. As of 2005, there were approximately 490 households (~1700 residents) within the communities where the NGO works. These 490 households are about 19% of the rural population and 7% of the total population in this district. The NGO works with about 300 (60%) households of these in the agroforestry projects.

3.1.3 Economic Activities and Threats

Historical and recent migration into this region for economic opportunities along with illegal logging and expanding agriculture has fragmented the forest cover and contributed to the loss of 85% of primary forest (La Torre-Cuadros et al. 2007, Reynel & Leon 1989). Currently, 90% of existing forest within the region is considered secondary or disturbed forest.

This region is well connected to Lima through roads, which contributes to the agricultural expansion in this region. For example, migrants arriving from the higher Andean regions seeking better economic opportunities have caused an increase in deforestation because of agricultural expansion. Agricultural land in Junín has expanded from around 300,000 Ha in 1975 to over 750,000 Ha in 2000 (INEI 2011). This trend continues today. The Chanchamayo province is known for its citrus and coffee production for national and international markets. Economically, this region is highly important for coffee farming, producing approximately 20% of Peru's coffee in 2012 (41% in the 1980s; OAS 1987, Santos-Granero and Barclay 1998, Andina 2012). Farmers that migrated from the Andes often described the harsh climate and the difficulty of farming in the Andes during the interviews in addition to the economic opportunities of farming coffee as reasons for moving to the region.

3.1.3.1 Coffee

The commercial cultivation of coffee in Chanchamayo began in the mid-1800s with coffee exports starting in 1887 (Junta Nacional del Café (JNC) 2016). The amount of land under coffee cultivation fluctuated initially, varying with market prices, with most of the farms dedicating agricultural efforts towards coffee production by 1919 in this region due to the increase in prices (Ortiz 1969). Today, Junín is Peru's top most coffee producing regions, producing about 25% of Peru's coffee. Approximately 107,900 Ha of land in Junín is utilized for coffee, with 32,761 farmers averaging 3.29 Ha (see Table 3.1 for a comparison to other top producing states in Peru; INEI 2012).

In Peru, about 62.5% of the farmers producing coffee own less than 10 hectares, while 30% own between 10 and 30 hectares and about 7.5% own more than 30 hectares (MINAGRI 2014).Approximately 42 thousand coffee producing families are organized into 730 organizations (cooperatives, associations, etc.), while the remaining 72% of coffee farmers (108 thousand) are not in Peru (JNC 2016). Some of the farmers in organizations have been able to mobilize and develop programs to improve production – these organizations correspond to the coffee cooperatives that were formed after the agrarian reform in 1969 that were able to generate and invest surpluses to improve production. These farmers have been able to create partnerships with medium-sized roasters in consuming countries, mainly Europe and Japan (JNC 2016). However, the rest of the farmers (and all the smallholder farmers in the study area) sell their product to intermediaries, who then sell it to the exporters.

Table 3.1. Coffee producing units across Peru.

State	Total land (Ha)	% of total land	Number of farms	% of total farms	Average farm size (Ha)
Junín	107,903.85	25.36432	32,761	14.64257	3.29
San Martin	93,687.77	22.02263	41,195	18.41216	2.27
Cajamarca	73,098.11	17.18274	58,379	26.09257	1.25
Cusco	52,222.57	12.27565	25,354	11.332	2.06
Amazonas	42,744.24	10.04764	26,356	11.77985	1.62
Huánuco	16,819.22	3.953594	10,317	4.611197	1.63
Pasco	11,429.03	2.686554	4,104	1.834288	2.78
Ayacucho	8,782.08	2.064352	6,338	2.832778	1.39
Puno	8,213.07	1.930597	7,184	3.210898	1.14
Piura	4,678.19	1.099675	7,499	3.351688	0.62
TOTAL (Peru)	**425,415.85**	**100**	**223,738**	**100**	**1.9**

Source: INEI 2012 Agricultural Census

At the national level, in addition to the state, two organizations, Junta Nacional del Café and Camara Peruana de Café, exist that are dedicated to designing and executing strategies to increase the competitiveness of Peruvian coffee (MINAGRI 2014). Peru has 75 coffee exporting companies, of which 28 export gourmet coffee.

About 90% of the coffee exporting is concentrated to 20 of these 75 companies and the top 10 export 75% (JNC 2016). Most of the coffee produced in Peru is exported. Top six importing countries of Peruvian coffee include Germany (34%), United States (18%), Belgium (13%), Columbia (8%), Sweden (4%), and Canada (4%; JNC 2016)

3.1.4 Region's Past

Prior to the arrival of the Spanish, the *Selva Central* region was cultivated up to 1500 m elevation by indigenous groups (Campas, Amuesha, Ashaninka; OAS 1987). The native communities initially participated in trade with the Spanish; they traded items such as vanilla, achiote, and cascarilla, which were in demand in the colonial and European cities (OAS 1987). Historically, the region has seen the settlement of immigrants from France, Germany, Austria, Italy, and China; however the Italians, Germans, and Chinese are the main groups to settle in the Chanchamayo province (OAS 1987, Santos-Granero and Barclay 1998).

Land legislation and colonization policies intended to incorporate the Amazonian region into existing governed land attracted European migrants to the Selva Central in waves starting in 1857 and continuing into the early 1900s (Santos-Granero and Barclay 1998). As part of the agreement, the migrants received large portions of land, of which they had legal ownership (OAS 1987, Santos-Granero and Barclay 1998). The European footprint can still be seen today, especially in towns such as Oxapampa in Pasco where houses are built using European-style wooden architecture. It is important to note that as European migration into the region increased, land became scarce, and the indigenous peoples were driven off the land, often violently especially since they did not work for the colonists (Santos-Granero and Barclay 1998).

The colonists in this region planted coffee under an agroforestry system (OAS 1987). Chanchamayo is one of the first places in Peru to cultivate coffee at a larger scale. Though coffee had been cultivated in small amounts for local consumption prior to 1850, it was after this point when the colonists consolidated areas and began a constant rate of coffee production (Cuadras 2001, Camcafe 2016, Junta Nacional del Café 2016). By the end of the 1800s and beginning of 1900s, coffee was being produced commercially and the area was divided into *haciendas* that produced coffee, cotton, sugarcane, citrus, and timber (Cuadras 2001, Santos-Granero and Barclay 1998). These large land holdings in the Chanchamayo province concentrated power to a few: wealthy families from Tarma (a nearby highland town), some Italians immigrants who were able to accumulate capital and acquire haciendas, and the rest of the European immigrants (based on land holding size; Santos-Granero and Barclay 1998). However, the lack of labor forced the hacienda owners to bring laborers from Tarma and other highland towns to work seasonally during harvest or allow them to live on uncultivated portions of the hacienda (OAS 1987, Santos-Granero and Barclay 1998). A few large farms contracted Chinese workers but most hired long-term contracted workers (*mejora* system) from the mountains, who were entrusted with 1-10 hectares of farm land that they were expected to clear, plant coffee, and care for the plants until they started production. These long-term workers were allowed to plant crops in the fields alongside the coffee crops for household consumption (OAS 1987). As coffee prices continued to increase, more people were attracted to the area for work and set up individual (small) farms, and owners of haciendas in Chanchamayo took the opportunity to modernize and increase efficiency (Ortiz 1969, Santos-Granero and Barclay 1998).

In the 1960s, when Juan Velasco Alvarado came to power, he restricted individual land holdings to a maximum of 80 hectares, which affected all of the haciendas and a large number of modern farms (Santos-Granero and Barclay 1998). Unlike the coastal and highland regions, labor movements were not considered a reason for reform in Chanchamayo; however the government intervened due to a desire to break up the monopoly of the coffee producing groups for the benefit of the public treasury, and the disparity in the distribution of land (Santos-Granero and Barclay 1998). This land was first converted into cooperatives, and when the cooperative structure did not work for the farmers, the land was divided among the peasants that worked on these farms (OAS 1987, Santos-Granero and Barclay 1998, Sheanan 2001). Though this occurred to most of the haciendas, some families divided the land among themselves to avoid the reform (Farmer interview 2014). The current land holdings (mostly) are a direct result of the agrarian reform on these haciendas, though many of the farms since have been subdivided within families or sold to others, when the farmers were unable to work the land.

After some success, the agrarian reform had disastrous effects. Despite facing price drops of primary export commodities, an increase in interest on external debt, and a decline in production, the subsequent governments supported cooperatives between 1970 and 1980, mostly through agrarian bank loans with low interests. Cooperatives exported

80% of Peru's coffee production in the 1970s (OAS 1987, Tulet 2010). Profits from export quotas were put back into cooperatives according to the International Coffee Agreement. However, cooperatives did not make efforts to improve operations and continued to be small and were characterized as inflexible, nepotistic and corrupt (Tulet 2010). The cooperatives had many institutional structure problems, where work and benefits were not rightly divided.

In addition to these conditions, the abandoning of the International Coffee Agreement after 1989 and the structural adjustment policies of Alberto Fujimori's administration (where the government backed away from intervening with production and trade networks lead to the proliferation of private intermediaries which has contributed to the disorganization of the coffee commodity chain. Further, the terrorist activities of the Shining Path created insecurities resulting in the decline of institutional operations after 1980 and contributed to the destruction of harvests/plantations, the decline of agricultural production, interruption of trade networks, decline of support services, and the disappearance of credit and coffee growers' organizations. With the violence and terrorism in the 1980s due to the Shining Path and difficulties of potato farming, higher elevation Andean farmers and families have migrated to areas where they hoped for an improved quality of life (Interviews 2013). During this period of terror, some of the coffee farmers already in the region left their land, having a negative impact on the maintenance of cultivated areas (Santos-Granero and Barclay 1998). With the weakening of state institutions, NGOs started to emerge to fill the gaps in rural development (Tulet 2010).

Today, the region continues to experience population growth as a result of downward migration from higher elevation locations in the Andes due to an increase in the ease of access to this area and better economic opportunities (OAS 1987, Santos-Granero and Barclay 1998). Roads were constructed and expanded in the region during the 20th century to improve and facilitate trade from the Amazon to the highland cities and the coast, specifically Lima (Santos-Granero and Barclay 1998).

3.1.5 Communities

The communities as referred to in this study are a relatively small collection of households (generally 20-50, although one community consisted of 220 households in 2005; INDECI 2007). The availability of resources and infrastructure varies from community to community. Some communities have a designated space where the families live in a centralized off-farm location; while in other communities families live directly on their farms lacking a designated area. This directly impacts the amenities that are available to the families in these communities, such as electricity and water. Communities that have a central living place, generally have electricity and easier access to water, including communal water taps. On the other hand, the non-centralized communities might not have electricity or cell phone service (partially due to the distance from town).

Some of the families in these communities are multi-sited households, living part-time in the nearby town. This is especially true of families that have farms a great distance from the town and younger children that need to attend school. Some of the communities have schools, which are generally decreasing in size, as more and more families decide to send their children to schools in town. Further, the schools located in the communities tend to only be primary schools. Communities located closer to town are able to use *micros* to transport their children to and from schools in town. The frequency of the micros drops-off significantly to the communities that are further away from town. For example, two of the furthest communities have service only once a week or once every two weeks to enable the community members to purchase anything they might need (such as oil and sugar) from the weekly market or town.

Figure 3.2 maps the location of the communities where the NGO operates. Farms are generally located away from the immediate villages in which people live. Farmers walk anywhere from 10 minutes to 1.5 hours from their house to reach their farms.

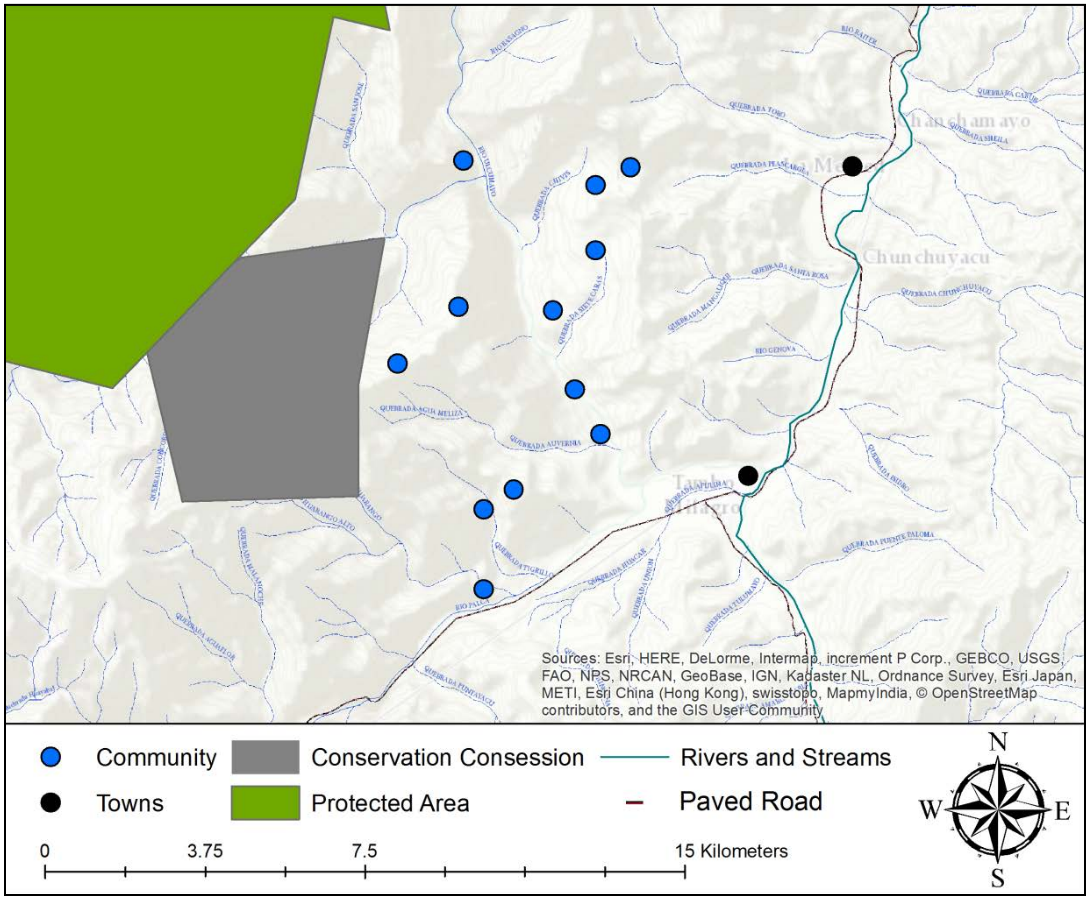


Figure 3.2. Location of the communities where the NGO works along with the NGO owned conservation concession (in gray).
Note: The shapes of the protected areas have been modified slightly to protect the studied communities and the NGO from being identified.

3.2 Data Collection and Analysis

As mentioned in the earlier chapters, this study employs various forms of data and data collection methods to address the objectives. I use participant observation and semi-structured interviews to collect qualitative data to understand the work of the NGO, the resources it disseminates, and the participation of the farmers with the NGO. This was supplemented with quantitative data from surveys. I also use vegetation plot census and cambium tissue sampling to measure diversity between and within farms.

Following Perfecto and Vandermeer (2010), I sample in the agroecological matrix. Here the NGO views and uses its relationship with the farmers to achieve biodiversity conservation outside of protected areas. Agriculture (especially of high quality) is an intricate part of the means to achieve biodiversity conservation, thus, I approach the coffee farms as not only land that generates income for the farmers but also makes contribution to the conservation.

3.2.1 Research Compliance

I obtained appropriate approval from the Institutional Review Board (IRB) at Texas A&M University prior to the start of field work to conduct interviews and surveys of the farmers at the study site and NGO employees.

I also obtained a permit to bring in to the US dried plant cambium and leaf tissue from the United States Department of Agriculture (USDA). Also, with the guidance and collaboration of Dr. Carlos Reynel and Mr. Aniceto Daza at the School of Forest Sciences at UNALM, I obtained a permit from the Peruvian government (MINAG) to collect dried plant material at my research site. Herbarium voucher samples were deposited at the UNALM herbarium as per the permit. The cambium samples were brought into the US on my return trips after field work.

3.2.2 Participant Observation, Surveys, and Interviews

The semi-structured interviews and surveys were carried out with NGO employees and farmers (Table 3.2) in accordance to the approved IRB protocol after obtaining consent. I used an information sheet that was given to the participants to provide and review the details of the project and my contact information, as well as to explain that all information shared will be kept confidential and that the participants' names will not be associated in any writings and reports.

Table 3.2. Number of people surveyed and interviewed.

Role	**Number**
NGO supervisors/ agronomists	4 interviews
NGO technicians	2 interviews
Farmer – Participating	61 surveys
	18 interviews
Farmer – Not Participating	38 (9 former participants) surveys
	2 interviews

3.2.2.1 NGO Employees

The interviews with NGO employees (supervisors, agronomists, and technicians; n=6) varied from 45 minutes to a couple of hours in length over multiple days. The interviews were semi-structured in that they were guided discussions around the following themes: personal education and training, what they (the NGO) hope to accomplish with the farmers, farmer recruitment, work with farmers, requirements for participation, and why they (the NGO) do what they do. Interviews were audio recorded when the interviewees consented (n=4), otherwise detailed notes were taken by hand during the conversation.

Prior to interviewing the NGO employees, permission to work with the NGO staff in Chanchamayo was obtained from a supervisor in Lima as well as the supervisor at the regional office. The permission of these supervisors also allowed me access to the various secondary documents, reports, and surveys produced by the NGO. Further, I was able to accompany the NGO employees during their activities and workshops in addition to spending time at the NGO office (Table 3.3).

Table 3.3. Workshops and activities I partook in with the NGO.

Date	Event
Sept. – Oct. 2013	Various days of technicians visiting farmers
Oct. 23, 2013	Workshop/practical on applying fertilizer to coffee crops
Oct. 31, 2013	Agronomist and technician helping farmer with building a composter
Nov. 5, 2013	Agronomist and technicians creating a nursery of native species at the conservation concession
Nov. 6, 2013	Supervisor from Lima visiting (NGO and farms) to check on project status
Nov. 8, 2013	Technician visiting farmers
Sept. 19, 2014	Technician visiting farmers
Oct. 21, 2014	Technicians visit local school (only my conversations with the technicians are documented and referred to in this study)

3.2.2.2 Farmers

Table 3.4. Survey questions.

Theme	Questions
Background	Profession and education Farm size and division for crops Household size
Output intensity	Harvested products Yield data
Technology: Labor and intensity	Labor (household, hired) Assistance (form, hours, topics)
Technology: Subsidies to productive processes	Use of soil nutrients/fertilizer Seed sources Pest control methods
Production type	Subsistence versus for market

The interviews and surveys of farmers that participate and do not participate with the NGO were conducted during the 2013 and 2014 field seasons. I started an interview or a survey only after I presented and reviewed the IRB consent informational sheet with the farmer, answered any questions, and obtained consent. I initially started with interviews of the NGO participating farmers gathering as much information as possible regarding the project, farmer views, and farm details. The semi-structured interviews were in-depth discussions regarding the problems the famers encounter on their farms, their willingness (and reasons) to participate with the NGO, and the type resources they receive, including time with technicians, knowledge sharing with neighbors, relationships with neighbors, farm work/labor allocation within the household, and hired help amount and duration. Semi-structured interviews usually lasted between 45 and 90 minutes and were recorded.

The survey consisted of structured questions summarized in Table 3.4 (see Appendix 1 for survey) that I asked farmers. The interviews aided in developing the survey questions. I designed the survey to gather information regarding the farm, crops and yield, management practices, participation, and technical assistance received by the farmer. As part of the survey, farmers were also asked to draw a map of the farm to help them explain the crops planted on the farm to me. The intention of the survey to was to be able to collect information directly regarding these topics quickly. On average the survey took approximately 15-20 minutes.

To recruit participants in this study, I used two techniques: snowball sampling and technique as well as approaching households. This sampling technique is like a chain referral, where after speaking to a farmer, they are asked to suggest other farmers I could speak with. This technique allowed me to efficiently identify and learn the names of other farmers I could interview or survey next, especially when farmers in the community were spread out. The major disadvantage of this technique is my selection could be biased, since farmers might have referred me to others they know well – someone within their own social network, possibly limiting me to only a specific sub-population. Thus, in addition to the use of snowball sampling to recruit participants, I also approached households of farmers not referred by a previous farmer.

More specifically, towards the beginning of my field work, I was introduced to some of the farmers during a workshop by the NGO and also by the NGO technicians when I accompanied them to visit farmers. Many of the initial farmers I spoke with in the villages were participants with the NGO, who referred me to other farmers. Often, the first-interviewed farmers also communicated about my visit to other farmers in their community, making my presence in the community known. This made introducing myself to subsequent farmers easier and probably also made farmers more likely to speak with me. Many of my surveys/interviews also consisted of opportunistically approaching a household, checking whether the famers were home, and asking whether they would be willing to speak with me regarding their experiences as a coffee farmer. Random sampling of farmers is not possible as there was no accessible list of farmers in this region to systematically select which farmers will be interviewed or surveyed. Further, identifying households using satellite images (Google maps/Earth) would result in more households being identified in communities with a centralized location compared to non-centralized communities. This sort of identification would also miss households due to forest cover, not allowing for all households to be identified and subjected to random sampling. Though the opportunistic sampling is not random, it allowed me to potentially access more than one social network, which would have been a limitation of only using snowball sampling.

Though it did not occur too often, some farmers did not agree to speak with me as they were busy at that moment and would often suggest another time for me to return. In most of these situations I was able to return and speak to the farmer, but there were times when the farmer was not present or the household was not interested in participating due to unavailability of time.

3.2.3 Interview and Survey Analysis

I entered the data from the surveys directly into Excel and transcribed the interviews for further analysis. For the survey data, each farmer/household was represented by a row in an Excel file. The columns represented the various questions from the surveys, such as age, community of residence, farm size, crops planted, seed sources, coffee yield, pesticide and fertilizer use, participation (and length) with the NGO, and distance to farm from homestead. Table 3.5 below provides descriptive statistics on farmers divided into two groups, those who participate with the NGO and those who do not. As we can see in both groups the farmers are comparable in age and land holding (farm size).

Table 3.5. Descriptive statistics of farmers and their farms.

	Participants	**Non-Participants**
No. of Individuals	61	38
Age	19-77	20-76
Avg. Farm size (Ha)	7.795	7.047
Median Farm size (Ha)	4	4

The interviews of the NGO employees were transcribed completely, while the interviews of the farmers were only partially transcribed and coded. The interviews of the NGO employees were used to gather information about the NGO's practices, mission, and work with the farmers, which are detailed in Chapter 4. The targeted transcriptions of the farmers' interviews were of the parts focusing on why they participate with the NGO and the NGO's resources/help, in addition to information on household characteristics.

All analyses were carried out using Excel and various packages/libraries of R (Version 3.2.2). These include base library functions and the RQDA package (Version 0.2-7) in R. The RQDA package was used to code the interviews for farm size, length of participation, and reasons for participation. After the initial coding of the farmers' semi-structured interviews, each coded response was reviewed and evaluated for patterns in opinions, problems, reasons, and help received and desired from the NGO.

Analysis of the survey data included conducting non-parametric statistical tests (Wilcoxson test) to check for any significant associations between farmer characteristics and participation with the NGO. Analysis also included conducting linear regressions to test for significant relationships between participants characterizes (education, farm size, distance from town, distance to farm) and the distribution of NGO resources (as measured by the amount of time a technician spent with a given farmer each month).

3.3 Measuring Biodiversity

3.3.1 Data collection: Vegetation Plots and Cambium Collection

This study employs two main techniques to analyze biodiversity: vegetation plots for species-level analysis and cambium collection for genetic-level analysis. I conducted vegetation census plots on the farms to gather data regarding the tree species diversity present. Plots of approximately 40m x 40m (1600m^2 in area) were set up on 40 farms after I obtained permission from individual farmers. All trees and saplings with diameter greater than 5 cm were identified, and the associated diameter at breast height (DBH; at 1.5 m height) was recorded. Environmental data of each plot such as elevation, slope, canopy cover (approximate percentage shade present), and GPS coordinates were recorded.

This study uses *Inga oerstediana* Benth. (Leguminosae: Mimosoideae) for genetic analysis; from the farms selected for vegetation plots, a subset were selected for genetic sampling. At each of these farms, approximately 25 individual specimens of *I. oerstediana* were collected along with GPS location points for landscape genetic analysis. Following Dawson et al. (2008), sampling occurred in the “natural” (non-farm) areas nearby the farms for comparison. Sampling resulted in a total of 344 collected specimens for genetic analysis.

Cambium has previously been shown as a viable way to obtain genetic material when leaves are difficult to acquire from trees, especially large trees (Gemeinholzer et al. 2010). Building on the cambium collection methods described by Colpaert et al. (2005) using a leather hole punch, my field assistant and I utilized a sterilized knife to remove a small portion of the bark from the tree trunk and then proceed to remove a very thin strip of the cambium (see Figure 3.3). The cambium was placed into already prepared ‘O’-ring sealed 2 ml screw cap plastic tubes that were filled 2/3 of the way with silica gel and labeled accordingly to dry the collected samples. Cambium specimens (completely desiccated samples can be seen in Figure 3.4) were stored at room temperature until DNA was extracted using a modified CTAB protocol customized specifically for this species. A Nanodrop machine and a fragment analyzer were used to quantify the DNA. Extracted DNA of each individual was subject to next generation sequencing (NGS) using the Illumina Hiseq 2500 v4 at the TAMU AgriLife Genomics and Bioinformatics lab following their protocols.

Figure 3.3. A small opening created in the bark to expose and collect a thin layer of cambium.

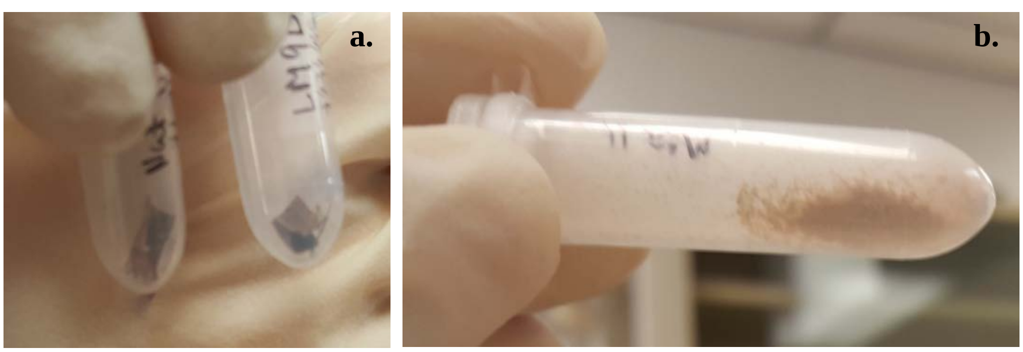


Figure 3.4. (a) Completely desiccated cambium being prepared to be ground into a fine powder using a bead mill. (b) Ground dried cambium ready for the modified CTAB DNA extraction.

Figure 3.5 below shows a summary of the questions that I seek to answer regarding changes in biodiversity with the data I collected and the associated analysis techniques I use.

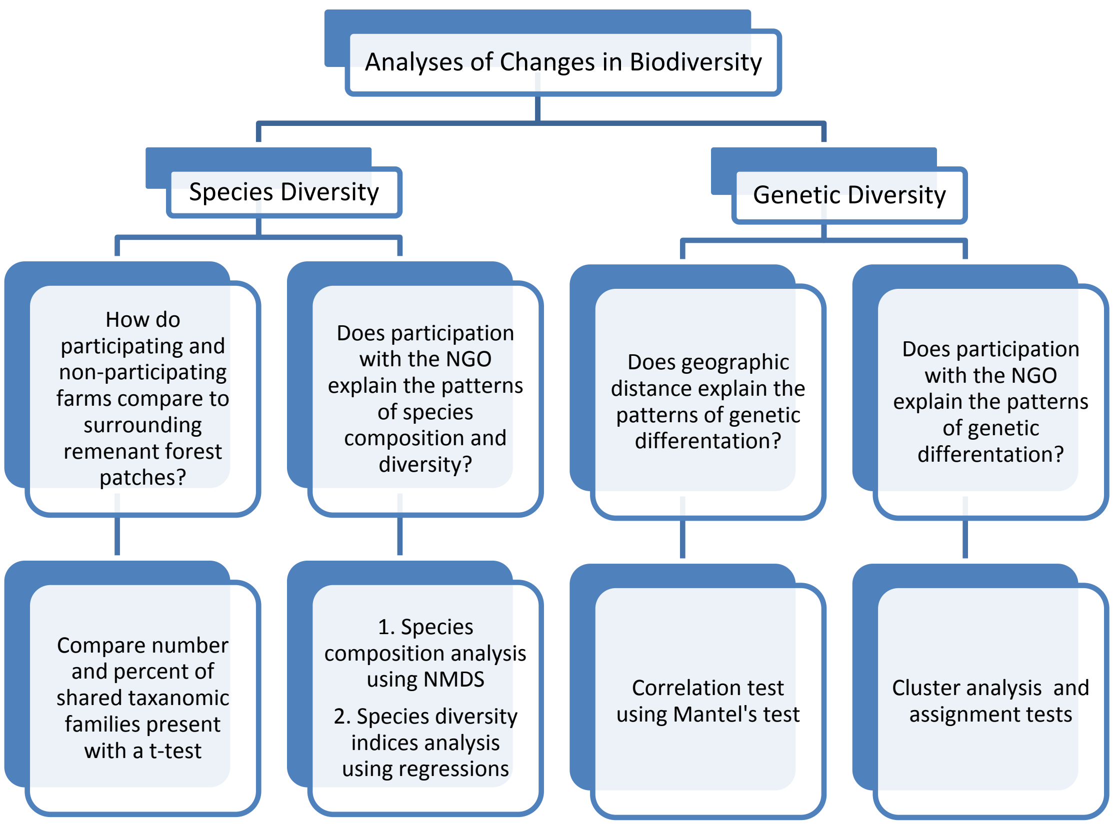


Figure 3.5. Figure summarizing my (sub)research questions and methods I use to answer them.

3.3.2 Species Diversity

To be able to assess species composition and species diversity of the agroforestry systems, a tree plot census was conducted. For each farm I recorded the following information for each tree above a DBH of 5 cm: tree species, DBH, elevation, average slope, number of trees measured, distance from town, number of unique species, and soil type. Elevation was measured using a GPS before carrying out the vegetation census. The average slope was calculated using multiple clinometer readings in each plot. The distance recorded for each plot is the distance from town to the community obtained using Google maps. Soil type, both the WRB and USDA classification taxonomies were identified for each plot using its coordinates and querying the SoilGrids1km database (http://rest.soilgrids.org/), which provides global soil information at the 1km resolution.

Vegetation and environmental data was analyzed using Excel and the statistical software R (Version 3.2.2) to determine any patterns that are present between and within the different management practices. First, I compared the plant taxonomic families present on the farms to the families present in surrounding forest patches (in La Torre-Cuadros 2007) using a t-test to examine the amount of difference between the two areas. An ordination (Non-metric Multidimensional Scaling (NMDS) paired with Analysis of similarities (ANOSIM)) was conducted to determine whether species composition (using abundance data) was different in the participating farms compared to the non-participating farms. This method has been utilized by previous diversity studies in coffee production landscapes to test for differences between farms and forest (Tejeda-Cruz & Sutherland 2004, Valencia et al. 2014) as well as compare epiphyte diversity across different types of landscapes (Moorhead et al. 2010). In addition to base library functions, the community ecology package, *Vegan*, version 2.3-4 was utilized. Lastly, diversity indices, such as Shannon's and Simpson's index and associated evenness, were calculated for each plot using the formulas detailed below and compared across the participating and non-participating farmers using regressions (ANCOVA and linear regressions).

I compute measures of species diversity through the following indices. First is the Shannon index and the second is the Simpson index, which are commonly used measures of diversity that goes beyond species richness (Nagendra 2002, Valencia et al. 2014). For each plot i, the Shannon diversity index (H) is computed as:

$$H_i = -\sum_{j=1}^{S} p_{ij} \ln(p_{ij})$$

where $j = 1, 2, \ldots, S$ denotes each species and p_{ij} is the proportion of species j found in the plot i. Values for this index range between 0 and 5, with a higher value of H represents greater species diversity. A corresponding index, called the Shannon's equitability (E_i^h) index can be calculated as:

$$E_i^h = \frac{H_i}{\ln S_i},$$

where S_i is the total number of plants found in farm i. This index allows us to understand how evenly species are distributed in each farm.

The Simpson's Diversity index also relies on relative abundance of each species. It is calculated as:

$$D_i = \frac{1}{\sum_{j=1}^{S} p_{ij}^2}$$

where p_{ij} is defined as above. Values for this index start at 1 and higher values indicate higher species diversity. A corresponding equitability (evenness) index is calculated as:

$$E_i^d = \frac{D_i}{S_i}.$$

3.3.3 Genetic Diversity

The goal of the genetic diversity analysis is to use information from SNPs to estimate genetic diversity using the heterozygosity present within and across population as well as to estimate genetic differentiation and infer gene flow, using a measure of differentiation due to population structure (F_{ST}[5], Weir and Hill 2002). Overall, this information allows for the quantification of gene flow between populations (participating/non-participating farms and non-farm areas) which can possibly provide evidence for whether or not these farms can act as corridors in a fragmented landscape and thus increase and preserve biodiversity. This also will indicate whether there is a genetic difference in the populations of *I. oerstediana* between participating and non-participating farms.

[5] FST is a measure that allows us to infer how different one population is from another. Values range from 0 to 1, with values close to 1 indicating a high amount of differentiation between the populations, meaning that there is limited to no gene flow between the populations (no mixing between the populations).

I specifically utilized the double digest RADseq protocol (ddRADseq; Peterson et al. 2012) to discover single nucleotide polymorphisms (SNPs; a type of molecular marker) in the specimens of *Inga oerstediana* with the Illumina HiSeq. SNPs are increasingly being used in genetic diversity studies because they are ubiquitous in most genomes, cost-effective, and easy to genotype (most have only two alternative nucleotides at a single SNP; Brumfield et al. 2003). I followed standard protocol for preparing and filtering the SNP dataset and analysis as suggest by Peterson et al. (2014).

The sequencing of samples was run by Texas A&M AgriLife Genomics and Bioinformatics Services using an Illumina HiSeq2500. The ddRADseq is a method that builds on RADseq and is used widely in wildlife and fisheries studies when there is limited or no genomic information known for the species (Peterson et al. 2012). Unlike the random cutting of the DNA strands in RADseq, ddRADseq uses specific restriction enzymes to cut only at specific locations along the genome, allowing for the same location in the genome to be sequenced for all the specimens. Each fragment is then ligated to adapters with unique identifying sequences (molecular identifiers or MIDs), replicated, and then sequenced. The adapter ligation step allows for multiple specimens to be pooled together for sequencing in a single lane. Specimens can be then separated using the MID through bioinformatics and relevant SNPs can be identified (Hohenlohe et al. 2011, Peterson et al. 2012). Such an approach allows for skipping of the previously necessary steps of marker development and is known as genotyping-by-sequencing (GBS). The DNA from all the collected specimens were digested with MluCI and PstI restriction enzymes and fragments ranging from 250 – 500 base pairs were selected for paired-end sequencing. All DNA from specimens were pooled and run on two HiSeq2500 lanes.

The resulting sequences were aligned based on MIDs and the adaptor sequences were subsequently removed. The alignments were created and subjected to variant calling using a dDocent pipeline (calling was by FreeBayes; Puritz et al. 2014) by the Texas A&M Institute for Genome Sciences and Society. Variant calling identifies potential SNPs, insertions, deletions, and among other types of variations in DNA.

One file was created with all the sequenced samples with the variant calls. This file was then subjected to filtering for SNPs. Poor quality reads (ambiguous 'N' nucleotides and sequencing errors; *phred* score >30) within the identified SNPs were removed. I use different bioinformatics tools such as VCFtools (Danecek et al., 2011) and BCFtools (Li et al. 2009) for filtering and detecting the quality of SNPs. Further filtering was also done based on the criteria of higher than 3X coverage with minor allele frequency (MAF) > 0.05 (similar to recent genetic studies on plants; Deulvot et al. 2010, Mandaliya et al. 2010, Van Inghelandt et al. 2010, Elshire et al. 2011, Trebbi et al. 2011, Blair et al. 2013, Matthews et al. 2013, Micheletti et al. 2015, Lu et al. 2013, Ganal et al. 2014) to remove SNPs that might be a result of errors.

Various programs and techniques were used to analyze the SNP data, as suggested and used by recent plant genetic studies (Soler et al. 2013, Peterson et al.2014, Wallace et al. 2015, Filippi et al. 2015, Owens et al. 2016). For genetic analysis, I use mantel tests and cluster analysis and assignment tests. Mantel tests allow testing of whether geographic distance is acting as a barrier for gene flow for the populations. Cluster analysis and assignment tests allow for clustering of individuals based on the sampled populations or based on individual genotypes, which can be examined along with environmental patterns (and NGO program participation) to explain population structuring. I employ DAPC (discriminant analysis of principal components), *k*-means Bayesian clustering algorithm, and fastStructure (version 1.0; a Bayesian clustering analyses; Raj et al. 2014) to identify similar clustering individuals or (sub)populations (Foster et al. 2010, Pritchard et al. 2000). This program allows for identifying populations and testing population genetic structure. This provides information about whether genetic drift has been acting on the (sub)populations and if there are any migrants. Genetic parameters, Mantel tests, DAPC, and the *k*-means Bayesian clustering algorithm is calculated and checked using R's *vegan, poppr, adegenet,* and *diveRsity* packages.

Further, to examine and assess the observed population structure, I utilize DAPC. Lastly, I use a *k*-means Bayesian clustering algorithm and the fastStructure software to infer populations/groups given the genetic variation of the individual specimens.

3.4 Linking Analysis

To understand the explicit relationship between practices and landscape outcomes, I analyze the data collected from surveys and vegetation plots/genetic analysis for correlations and general causal links. I conduct statistical analyses to test for relationships between variation in farming practices and biodiversity outcomes (with the null hypothesis that there is no biodiversity difference between landscapes under different management practices).

Such methods have been employed in previous studies that have linked practices and environmental change. Robbins (1998) used a general linear hypothesis test to see if the increase in explanatory power with the addition of institutional variations as independent variables was significant. Vadjunec & Rocheleau (2009) used broken-stick and log-normal goodness of fit tests to compare across the different management types. Following the precedence set in the literature, I use linear regressions and ANCOVAs to examine and test for significant relationships with the variables and biodiversity outcomes.

3.5 Positionality

When carrying out fieldwork, there are multiple things that can shape your research as well as how you are perceived by your researched communities (which could be reflected in your findings). As Sultana (2007:376) states, "being reflexive about one's own positionality is to […] reflect on how one is inserted in grids of power relations and how that influences methods, interpretations, and knowledge production (cf. Kobayashi 2003)". Here I reflect on my time in the field and what factors influenced my interactions with the farmers and the NGO.

Entering Peru I knew I carried privileges of being a foreigner that could afford to travel as well as being an advanced student. For the duration of the fieldwork, I introduced myself and clarified before an interview that I was a student conducting my thesis and was not employed by the NGO, a bank, or the government. I explained my position and the purpose of the interview/survey to be only for my dissertation research and stressed that any information they shared would be confidential and would not be shared with the NGO (for the NGO participants). This to me seemed especially important in the communities closer to town, where bank representatives had passed through wanting to collect information and give out agricultural loans after the coffee leaf rust protests of 2013 (detailed below), leaving the farmers skeptical of anyone they did not recognize approaching them regarding their farms.

Despite my attempts to be seen only as a student due to the nature of my interview and survey questions regarding crops, the use of pesticides, and problems the farmers encountered on their farms, I was often mistook for an agricultural expert. Some farmers asked me for advice on how to deal with pests or how they could improve their farms, prompting me to explain the limitations of my knowledge regarding agricultural practices. I would normally follow up by elaborating on Geography and what I study.

Further, having received permission from the NGO office in Lima to speak with the staff and technicians in Chanchamayo and the willingness of the NGO supervisor in Lima to share information with me, helped to build trust with the NGO employees in Chanchamayo. I believe in addition to this, the hours I spent at the NGO office observing conversations and activities, helped me build a rapport with the employees This allowed me to gain the trust of the NGO employees, visibility among the NGO employees and farmers, and reciprocate to the NGO by helping with tasks, especially related to GPS and GIS mapping.

In addition, upon further reflection of my time in the field, I believe there were three other things that shaped and re-shaped my research and interactions with the farmers: *La roya amarilla* (coffee leaf rust); the road and the layout of the communities; and being accompanied by a local assistant.

3.5.1 La Roya Amarilla

It was at the beginning of my field season in 2013 that I started to hear about the coffee farmers being unhappy regarding their coffee harvest. The harvest season of 2013 was a particularly difficult one, where coffee plants of many farmers were damaged by the coffee leaf rust fungus, leaving very little or nothing to harvest. The coffee farmers started to petition the government to help them with their plight, calling the event a natural disaster. When initial requests were unheard, the farmers banded together in protest and blocked roads, so that even the coffee that was harvested could not be transported out of the region. After a week of the blockade, the government agreed to assist the farmers.

Though the farmers I interviewed were not directly involved with the protest, they supported the movement. I believe these events influenced my time and research in two ways. The first, the farmers were open and willing to talk to me about their problems and farms because they wanted people to know about how their livelihoods have been impacted by the fungus. On one occasion, one farmer that I was interviewing introduced me to another farmer passing by and stated to him that he was participating and wanted to talk about his problems so that more people can know how difficult things are.

Second, I think perhaps the farmers appreciated receiving seeds and consulting with the NGO technicians more than before.

3.5.2 Roads and Communities' Layout

The communities I worked in were located on hills on either side of a river. On each side, the major road ran either through the communities or many farmers' households were located right along the road. Figure 3.6, captured from Google Earth Pro, shows one of the communities that follows a very linear household by the road structure. This allowed me to be visible to community members and farmers not only during my visit to the specific community but also when my assistant and I were only passing through to the next community. This also led to many informal hellos and conversations, allowing me to build relationships and increase credibility with the farmers.

3.5.3 Local Assistant

Hiring a local assistant to transport me and accompany me resolved difficulties with accessing the communities as well as ensured my safety. It further had an unanticipated effect as well. When an interviewer was wary or was unsure of me, my assistant would explain that he and his family are farmers from a nearby community and that I was only a student and needed to ask a few questions for my thesis. I believe that knowing he was local and that they could find his family if need be provided extra reassurance regarding me and my purpose. Sometimes the farmers would recognize his name and knew his father, which also made them warm up to both of us.

Figure 3.6. Satellite image obtained from Google Earth Pro showing an example of one community where most of the households are along the main road. Image © 2016 DigitalGlobe. Map Data: Google Earth Pro 2012

CHAPTER IV

THE NGO, FARMERS, AND RESOURCES

As discussed in Chapter 2, Non-governmental organizations (NGOs) can play a role in decisions made about the landscape and also affect land use. Further, by changing land use and related decisions, NGOs and organizations, as part of the broader political economy, can change biodiversity on the farms (Robbins et al. 2015). Organizations commonly use the approach to work with farmers to distribute technologies and knowledge to alter practices, especially agroforestry projects (e.g., Valencia et al. 2015). Thus, we need to understand better and document what changes occur on the landscape due to this participation. This is especially true of conservation-development organizations[6] that seek to attain a "win-win" situation for both the people and the environment. In order to be able to relate the NGO in Chanchamayo and changes associated with participation on the farms, we have to first understand the NGO's operations and how it is altering farming practices and resources available to the farmers.

NGOs can vary in goals and scale of operation. Most often, we are most familiar with the big international NGOs (BINGOs), such as Conservation International, World Wildlife Fund, The Nature Conservancy, Oxfam International, and CARE international. However, NGOs operate at many different scales, from working with major policy issues

[6] A conservation-development organization is defined here as one that aspires to accomplish both conservation/environmental goals along with development goals to benefit their beneficiaries. The particulars of these goals for the NGO in focus here are detailed in the vision and mission subsection (4.2.1) below.

at the international and national levels to carrying out projects at the village and household levels. BINGOs often collaborate with local NGOs to accomplish or meet their project goals, while possibly working with foreign governments to bring services to a location otherwise not accessible. This places these smaller, local or national NGOs in an integral role to provide services, whether they are acting as an agent for another organization/government or carrying out an independent project.

Within the literature on NGOs, there is skepticism in the ability of the NGOs to bring about development and change. This literature has so far focused on development NGOs that tackle poverty and with a few exceptions there has been a lack of study of conservation NGOs (Brockington & Scholfield 2010).

In this chapter, I analyze the work of one NGO and assess the extent to which it has been able to meet its goals by studying how it distributes resources. In the process, I bring to bear the theory of access and uneven development to frame my analysis. After briefly reviewing the literature on the role of NGOs in development and access to resources, I delve into the internal structure and workings of the NGO. I provide background information on the NGO by describing the goals of the organization, supervision, and the process by which the organization obtains funds.

The aim of the chapter is to focus on the NGO's role as an organizer and disseminator of resources and how the NGO is circulating the "best practices" and knowledge to the farmers. The focus and goal of this chapter is not what "best practices" should be implemented nor who is deciding what are the best practices; rather, it is covered only briefly here to indicate what types of changes in farming practices the

NGO aims to implement on the farms. Further, the adoption rate of these practices is beyond the scope of this dissertation, rather it is to understand why famers elect to participate with the NGO despite the demands on their time and restrictions to their land use. Revisiting Figure 1.1 from Chapter 1, we see that the NGO is composed of people/employees in different positions of power. And it is the technicians that are the link between the NGO and the farmers to distribute the "best practices" and cause the participants' decisions to change, leading to change in biodiversity. Ultimately, the goal is to trace the relationship and flow of resources between the farmers and the NGO.

I frame my argument and analysis in the broader discussion of NGOs and their capabilities to bring about development and change. Further, I link this with the theory of access (where access is defined by more than just legal rights; Ribot and Peluso 2003) to guide my analysis and interpret my findings. I use information on why the farmers decide to participate with the NGO and how the NGO resources are distributed across participating farmers to argue that the NGO is modifying access to resources and ultimately influencing in what ways and how the farmers utilize their property, in this case specifically their farm land. I use data from the semi-structured interviews and surveys to support my argument. Then I test what socio-economic variables and trends are associated with participants. The last part of the chapter focuses on the distribution of NGO resources across the farmers based on data from surveys. I use the time technicians spent with each individual farmer as the metric to measure knowledge distribution by the NGO. The technicians represent the NGO and interact with the farmers on a daily basis.

Thus, the time the farmers spend with the technicians represents the knowledge that is shared or transferred from the NGO to the farmer.

I find that the farmers participate with the NGO to gain access to material resources and the knowledge distributed through the various projects. At the same time, through the use of contracts and the technicians' knowledge of "best practices" the NGO is setting new norms and creating informal rules of use for the farmers and modifying access to resources. I also find that the distribution of resources by the NGO is constrained by limited time and geographic realities of working in mountainous regions. However, it is through the distribution of these resources and the access to them that is leading to land use change, and changes in biodiversity, on the farm.

4.1 NGO Geographies, Development, and Access

Recognizing the important and large role NGOs play in society and development, scholars have studied NGOs as organizations. As Bassett and Zimmerer (2004) stated, research on indigenous organizations, NGOs, and social capital shows the role of rural development institutions on resource management and technological change. Further, much has been written on the impact of foreign donors on NGOs, and NGOs filling the role of service providers within the confines of political and economic neoliberalism mediated by financial institutions, states and donors as opposed to serving public interests (Farrington and Bebbington 1993, Hulme and Edwards 1997, Zaidi 1999, Mercer 2002, Kamat 2004, Schuller 2009, Banks et al. 2015). Within this literature, several generalizations exist regarding the ineffectiveness of NGOs in tackling poverty, including statements that NGOs with their dependency on donors and alignment to donor agendas are stopped from being transformative (Edwards and Hulme 1996, Bebbington 2004, Banks et al. 2015). Hulme and Edwards (1997) and Banks et al. (2015) use the phrase “too close for comfort” to describe the close relationship between the operations of the NGO and the donor agencies.

Building on earlier work documenting presence of NGOs in urban areas over rural areas (e.g., Gray 1999, Campbell 2000) and in ‘development hotspots’ over neglected areas (Mercer 1999, Mercer 2002), Tony Bebbington in the early 2000s coined the subfield of “geography of development interventions” highlighting the unevenness present with and within NGOs (Bebbington 2000, Bebbington 2004). Following the work of Cowen and Shenton (1996), he distinguishes between imminent and intentional development as a way to discuss the pathways for development. Imminent development is structural and political economic change due to the expansion of generally capitalist systems of production, exchange, and regulation. While intentional development is the work of organizations that carry out interventions for the purposes of development. Bebbington claims that NGOs are not well placed to even out the unevenness of imminent development, stating that NGOs do not necessarily work in the poorest regions and have a tendency to cluster geographically. Other scholars have also found the claims by NGOs that they reach the poorest people to be inaccurate, when examining credit schemes, other economic interventions, and NGOs in Ghana (Riddell and Robinson 1992, Hulme and Mosley 1995, Koch et al. 2008, Opoku 2015). Further, Fruttero and Gauri (2005) show through analyses of NGO location decisions in Bangladesh that changes in NGO programs in a community were not related to indicators of community need, rather they were influenced by concern for obtaining donor funding.

Studies have mapped the geographic distribution of NGOs with varying foci at the country or state level in Peru (Hurtado et al. 1997), Ecuador (Raberg and Rudel 2007), Bolivia (Galway et. al. 2012), and Cambodia (Biddulph 2011) illustrating the uneven distribution across regions (clustering) and an urban bias (Chambers 2008). Bebbington (2004: 732) goes further to suggest that the spatial unevenness of NGO interventions can be seen across "different scales - among countries; among regions within a country; among microregions within a region; among communities within a microregion; and among households within a village."

Though NGO interventions can be uneven, they create a connection between people, places, and flows that would otherwise not be present. NGOs place specific locations of their work into types of global network (Massey 1991, cited in Bebbington 2004), and among other things, they bring meanings, forms of exercising power, and resources (Bebbington et al. 2008). The flows associated with the presence of an NGO can also change patterns and ideas of resource use, thereby changing human-environment relationships (Keese 1998, Durand and Lazos 2008, Gray et al. 2008, Wright and Andersson 2012, Sharma et al. 2016). Thus, NGOs can be poised to bring and give access to resources to the people and communities they work with through aid/capital, especially to marginalized locations. An analytical framework that examines how land managers (farmers) access different resources of an organization(s) can provide insights into the processes that cause land use change (Jepson et al. 2010).

Ribot and Peluso's discussion of theory of access provides such a framework and allows us to think about access to resources as "all possible means by which a person is able to benefit from [resources]" (2003: 156), rather than only considering the right to do so. "Mechanisms" is a key term in their theory of access, as it allows for more attention to means, processes, and relations rather than static boundaries of ownership in explicit focuses on property rights. More specifically, building on Blaike's (1985) "access qualifications," Ribot and Peluso (2003) explore how technology, capital, markets, labor, knowledge, authority, identities, and social relations can mediate and shape how benefits from a resource are gained, controlled, and maintained. Locher and Müller-Böker (2014) using the theory of access documented the role that access to authority, legitimizing discourses, and knowledge played in the local population's power (and their position) and ability to negotiate and benefit from large-scale transactions with forestry companies in Tanzania. Further, they show that the local population cannot be treated as a homogenous unit in the decision making process, rather social identity, education, and financial resources differentiate groups in this process.

Corbera and Brown (2010) analyze benefits of carbon offsets using theory of access, finding that farmers and rural communities are limited in their ability to benefit from carbon sequestration due to a lack of key structural and relational factors such as capital, labor, expertise and technology. In other words, even though farmers may own the forested land, they may not have the financial potential and capability to organize access to the technical assistance and expertise needed to manage and sell carbon credits. Employing the access regimes approach and considering the interactions between farmers, organizations, and institutions, Jepson et al. (2010), examine the resulting land cover change decisions and patterns in the Brazilian Cerrado. They find that farmers worked within the arrangements of government contracts and organization-based credit and incentive programs, facilitated by agricultural cooperatives, to collect resources, such as technology and inputs, to achieve agricultural intensification.

Drawing upon this framework to understand access, we can see that NGOs would be situated to change resource (property – or land) use by being the conduit through which other resources can flow into a specific location and ultimately lead to land use change. To provide a context for the work of the NGO and their relations with the farmers and communities, I provide in the next section details on the NGO's vision and mission statements, locations where they work, organizational structure, and funding sources.

4.2 The Case Study: The NGO

Peru, in addition to being recognized as home to rich biodiversity, has also been called the "kingdom of NGOs" to highlight the large role NGOs in the country (FRIDE 2008). The NGO in Chanchamayo is part of a national organization that works throughout many regions of Peru on social, economic, and environmental issues for sustainable development started in 1996. It began its first project, a reforestation project, in Chanchamayo in 1997. Broadly, the organization is concerned with the livelihoods of the smaller producers' families. They seek to improve the quality of life of these producers, thus their mission is to work with both the men and women of the households.

More specifically in this region, the NGO works to tackle low income, under-nutrition/food security, environmental contamination/degradation, deforestation, and biodiversity conservation.

Most frequently the NGO partners with municipal governments, and other branches of the local and foreign government, such as the Ministry of Agriculture, Ministry of Education, Ministry of Health, and universities. They also have alliances with the private sector. Within Chanchamayo, the NGO works with the local municipal governments and researchers from abroad and from Universidad Nacional Agraria La Molina. For the NGO, achieving sustainable development (social, environmental, and economic) to improve the quality of life of the farmers is the main goal along with biodiversity conservation through the protection of the conservation concession and surrounding areas, which they have recently termed as a biological corridor.

4.2.1 Vision and Mission

The vision of the NGO is to improve the quality of life of disadvantaged or impoverished people with social, economic and environmental responsibilities based on the principles of justice and equality. Their mission is to execute programs that facilitate sustainable development in the communities. Prior to mid-2014, though biodiversity conservation is not directly stated as a goal aside from the mention of the environment in the vision for sustainable development (2009 and 2011 NGO annual reports), the NGO employees in Chanchamayo stated during interviews the benefits of agroforestry for biodiversity (Oct. 2013). Further, the most recent project undertaken by the NGO is to create and improve an ecological corridor between two intact forest fragments. The NGO has also produced pamphlets on the importance of corridors for animals, which have been distributed to school children during presentations by the technicians across local schools in the communities (Oct. 2014). And it is within this ecological corridor that the communities with which the NGO works are located. Based on my conversations with the NGO regional head (Jul. 2012, Sept. 2013) and evaluation of annual reports (2009, 2011) produced by the NGO, the most likely reason biodiversity conservation was omitted from the larger vision and mission despite the projects of the Chanchamayo office is due to the lack of a similar foci and activities across all the regional offices of the NGO. However, in the most recent strategic plan (2014-2021), the NGO included a revised description of goals for the environment under sustainable development that includes protection and conservation of biodiversity.

The Chanchamayo regional office works with the communities to improve their quality of life through increasing income using coffee agroforestry, raising awareness about nutrition and health, and environmental contamination. This office also runs a reforestation program in the area in the conservation concession the NGO owns since 2005. Though during the interview the regional head (Sept. 2013) stated that the NGO conducts a survey before the start of a project and at the end, however I did not observe this. Instead, I noted that surveys were carried out in 2009 and then in 2011. I was able to help the NGO by digitizing the 2011 survey; however, without access to the 2009 survey data I am unable to quantify the impact of the NGO on the farmers. In its reports, the NGO generally reports the numbers of farmers that participated in a project (350 in

2011; ~300 in 2013 based on interview in Oct. 2013 for current ongoing project) the amount of coffee seeds or plants distributed to each family (5000 coffee plants in 2011; 4200 seeds based on interview in Oct. 2013 for current ongoing project) or the amount of hectares of coffee that were planted, renovated, or received assistance in total (350 Ha. in 2009; 1,750,000 coffee plants in 2011; goal of 780,000 coffee plants for current project).

4.2.2 Locations Where They Work and the Farmers They Work with

The NGO is a national not-for-profit organization that works in six states of Peru: Cusco, Junín, Lambayeque, Lima, Pasco, and Piura. The projects carried out in each of these states and associated provinces are varied and dependent on the needs of region. For example, the foci of the projects in Lima tend to be centered on working with small shops and women on issues of violence, under nutrition, and micro-credit financing. Another example is there are projects in Cusco and Piura that focus on livestock production and improvement, which would not be helpful to farmers the NGO works with in Chanchamayo, as they do not tend to have much livestock. During my time in the communities, I noted many families having a few chickens around their households while only a handful of farmers had pigs and I noted only two households with cows.

Farmers at the study site mainly plant coffee, which is a major source of income. However, many of the farmers also plant avocados and bananas to sell in the market to supplement their income (see Table 4.1). Some farmers (64%) also plant crops for household consumption on their farms. Other crops planted on the farms include: achiote, papaya, flowers, star apple, passion fruit, mango and yuca.

The average farm size for the surveyed farmer is 7.5 Ha with a median farm size of 4 Ha. Figure 4.1 shows the distribution of farm size across the farmers in the province (Agricultural Census 2012) and those that I surveyed. We can see that my sample captured more of the smaller farmers, especially in the 3-4.9 Ha range, and less of the larger farms (6-9.9 Ha) compared to the farmers of the province. Generally, surveyed farmers with large farm holdings cultivated only portions of the farm. For example, one surveyed farmer owned 102 Ha but cultivated only 10 Ha. The largest cultivated area was of a farmer who owned 40 Ha and cultivated 25 Ha. The average amount of land cultivated across the surveyed farmers was 3.5 Ha with a median of 2.5 Ha.

There are no coffee cooperatives in the immediate region that the farmers participate with. There are a couple of concurrent efforts in some communities to form associations. A few farmers (10%) indicated recent participation with an association not from with the immediate area.

Table 4.1. Crops other than coffee planted by farmers for the market (n=99).

Crop	Percent of farmers
Banana	75.76
Avocado	60.61
Citrus	16.16
Cacao	9.09
Corn	9.09
Beans	5.05
Other	13.13
No other	2.02

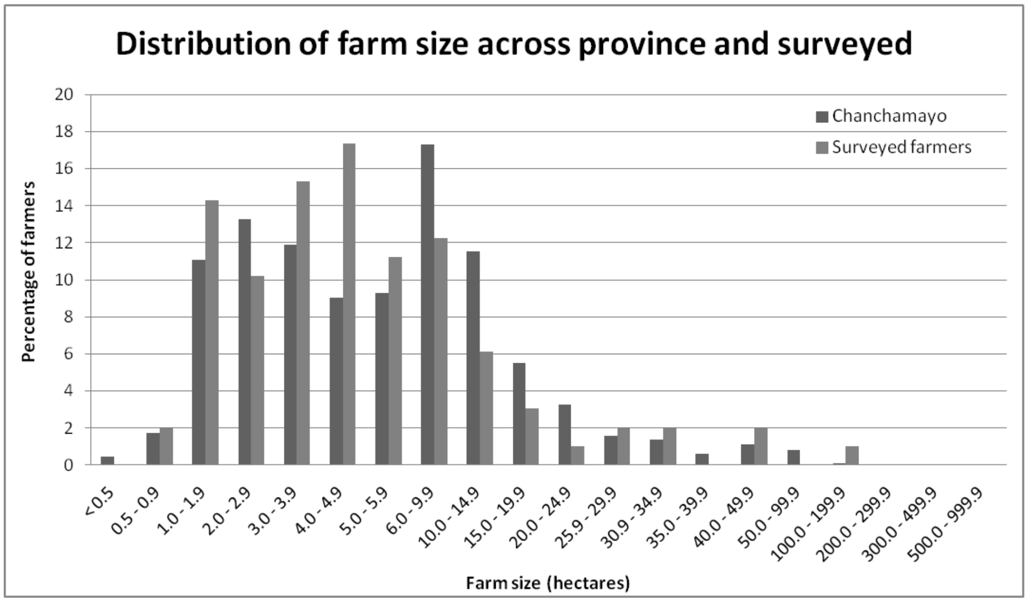


Figure 4.1. Distribution of farm size (in hectares) across the farmers in the Chanchamayo province and farmers surveyed.

4.2.3 Funding

The funds for operating the NGO's projects are generally from the local, national and foreign governments. European governments, such as the United Kingdom, Spain, Germany, and Holland, have been a major source of funds to run the projects and work with the communities (Interviews with NGO supervisor and regional head, Aug. 2013, Sept. 2013). The specific projects follow the funding cycles, thus each project recruits farmers to participate. For each project during recruitment, the NGO explains to the farmers the purpose of the specific initiative, rationale, and the resources that will be provided to the farmer if they choose to participate. All funding goes to support projects that work towards the mission and vision.

The money for the daily operation of the NGO, such as the employment of staff and care takers/workers, comes directly from the produce they sell. In addition to helping the communities, the NGO has land where they grow ornamental plants and flowers for the local and Lima markets; they also grow and sell produce such as tomatoes, bell peppers, eggplants, cucumbers, coffee (Field notes, July 2012), and more recently chia seeds (Field notes, Sept. 2014). The NGO also grows coffee that they use to harvest seeds and distribute to the farmers starting a nursery (to renovate the crops). This avoids the additional cost of the NGO having to purchase seeds that are expensive, especially certain varieties of coffee. However, the organization will sometimes purchase seeds from towns such as Villa Rica, as determined by the needs of the project.

Though the regional and national offices work collectively to put together the ideas for funding proposals, most of the proposal writing is done by the national office. Collection of data for proposals or for progress/completion reports are carried out by the regional offices and partly during visits to the regional office and project locations by the supervisors. However, similar to the grants, the majority of the writing and putting together of the documents occur within the national office. There is a constant flow of information between the national and regional offices. Though the NGO functions independently, it will sometimes also partner with local and regional governments to create the critical amount of funds to initiate projects.

4.2.4 Organizational Structure

The national office of the NGO is in Lima, where most of the "big picture" activities occur. Regional offices of the NGO in rural areas tend to be more focused on the programs and projects with majority of the time devoted to carrying out the proposed work and working with the farmers. The regional office is organized hierarchically with the manager at the highest local position. Below his direction are *ingeniero*s for the agricultural/agronomy and nutrition portions of the programs the NGO undertakes. The nutritionist generally works alone visiting families in the communities that have agreed to participate and receive guidance on how to grow and prepare nutritionally balanced foods. However, coordination between the different employees of the NGO occurs especially during workshops and talks with the communities. The agriculture engineer/agronomist has several technicians (technical specialists), who have also specialized in agronomy. The *ingeniero* coordinates with the technicians daily on their specific tasks in regards to the work with farmers in the communities (Interview Oct. 2013, Observations Sept. and Oct. 2013).

The NGO employs people from the nearby community, mostly women that might have small children or people that do not have much land to plant crops of their own, to tend to the plant nursery and the crops. The office staff, *ingeniero*s, and technicians are also from the surrounding towns. Further, most of the employees have been educated in the nearby schools and colleges.

4.2.4.1 Supervision

Multiple times (2-3) during a year, a “supervisor” from the national office visits the regional offices. This visit usually lasts 2-3 days, during which the supervisor gets updates on the projects from the regional office director, *ingeniero*, and technicians. Discussions during the meetings revolve around what the regional office, particularly the *ingeniero* and technicians, needs to function better in their work with the farmers. There are in depth discussion of things that have been working well, what has not been working, and the difficulties/challenges encountered with the specific project. During the visit, the supervisor will also visit some of the participating families. The supervisor attempts to understand the on-the-ground work, difficulties, and challenges. Thus, one of the major goals of the visit is to examine cases of farmers where the NGO was able to execute its plan with varying success; so the supervisor visits a “excellent,” “good,” and “bad” farm in regards to the goals of the project. The supervisor then attempts to figure out why the farm fell in that category with the help of the *ingeniero* and technicians and how to improve and more effectively help all the farmers have “excellent” farms.

4.3 “Best Practices”

The “best practices” circulated to the farmers by the NGO revolve around two main topics: shade and coffee. The information summarized here is largely based on interviews with NGO employees (2013) and participant observations of a workshop (focus was on fertilization but also touched on other topics of maintaining production; Oct. 2013) and technician-farmer interactions (in 2013 and 2014). Practices regarding shade relate to the various species that are suitable with coffee, such as the species to plant for shade (e.g., *Inga* genus is good while avocados are not), the ideal distance for planting *Inga spp.*, practices of pruning or removal of trees to maintain the desired amount of shade.

The remaining “best practices” are related to directly to the management and growth of coffee plants. These include instruction on the up keep of the coffee crops, proper harvesting techniques, planting coffee in rows along an elevation, how much and how to apply fertilizer, and how to prepare a nursery to renovate coffee crops. Up keep of the coffee plants is with the goal of maintaining production as the coffee plants age. Through a pruning process, *poda*, production can be maintained as the plant is cut to divert energy to developing fruits instead of branches and ensure that it does not grow too tall. Understanding and implementing correct harvesting techniques to reduce the chances of disease and pests on the farm is crucial. The technicians also recommend to the farmers that when harvesting the coffee berries they should not only pick ones that are mature but rather to remove all the berries from the plant. This will decrease the opportunities for pests, such as the coffee berry borer. The advice to plant coffee in rows along one elevation rather than along an elevation gradiant is to not only make harvesting easier but also to reduce erosion and nutrient loss (after the application of fertilizers). And lastly the perparation of a nursery for coffee has been a major component of the the NGO’s work with the farmers. This includes advice on contructing and maintaining the nursery until coffee reaches the stage where it can be planted in the farm, replacing old or dead coffee plants (coffee renovation).

4.4 To Participate, or Not?

Farmers participate with the NGO because of various factors but also because they are trying to balance risk and associated costs. The farmers have a desire to improve their production on farm, however might lack the means to do so. This is the case especially when the coffee leaf rust started to decimate the coffee crop, the farmers were perhaps more likely to be open to receiving resources and knowledge from the NGO. The reason many farmers choose to participate with the NGO is to be advised on what to do and how to farm.

During the interviews, farmers were asked why they decided to participate with the NGO. Here I explore the two main reasons they provide - gaining access to resources and a need to improve or modernize their farming practices. Gaining access to resources included recieveing seeds/plants of coffee and vegetables, plastic bags (to grow coffee plants in), some fertilizer for young coffee plants, help with building better stoves and laterines from the NGO. Farmers indicated the desire to participate to gain knowledge so they would be able to carry out activities such as planting and maintaining nurseries and modernizing their farms. In response to our conversation regarding why the NGO and technical assistance are important to him, a farmer stated:

> *Well it is good that we always have technical assistance. Because agriculture will constantly innovate and it can go unknown to the farmer; in our case we are not updated. There are always things to improve and with the lack of knowledge we have to make the time to train and enable ourselves… it is always good to have the technical assistance of this NGO or another organization, right? It is possible that I can know more by the internet than them but they are here and have the ability to let you know more.* (Farmer, Age 37, November 2013)

Another farmer also expressed similar benefits to participating with the NGO, stating that the NGO:

> *…teaches us how to grow vegetables, gives us technical help or how to plant, how to grow coffee, and [they also give us] social help. For example, they help us a little with pesticides, [giving] an improved solution. They teach us to have composter, live healthy in the home, that has our kitchen…, the dining room, or whatever else, they support and teach you what you do not know....* (Farmer, Age 46, November 2013)

Some farmers also said that since the technicians were so frequently in the communities they would be able to find them on days even when they were not the intended farmer for the visit. This access to technicians allows them to ask questions not only about coffee but also any other problems they might be having on the farms, for example with pests on avocado trees. This sentiment was mainly expressed in the communities that were centralized, which would facilitate this access. Based on my observations and time spent in the communities, this could be because information would travel faster between the farmers regarding the presence of the technician at a particular household within a centralized community. The arrival and presence of technicians in the centralized community is also more visible compared to communtities where the farmers live at greater distances from each other, because the technician or their motorcycle is on the main road outside of the household of intended farmer. This allows the farmers to access the technicians and their knowledge even when it is not time for visit. They can consult with the technicians on any problems they might have encountered on the farm or clarify the instructions that were provided during the last visit.

Embedded within this desire to have access to the technicians and their knowledge is a wish to modernize the production of coffee, recognized as “technification” in Latin American settings (Rice 1999), some local farmers referred to it as the need to “tecnificar” (Oct. 2013, Nov. 2013). To modernize a farm, it would generally require a transition to higher yield coffee varieties (of Arabica) and the optimization of the farm. This sort of renovation is expensive and would be hard for the farmer to accomplish with their limited finances. Thus, most farmers take out bank loans to help with the expenses of buying seeds, fertilizers, and other materials. During several interviews and conversations with farmers and technicians, they would often state that production of coffee in countries like Colombia is centralized and modernized, which is why they have higher yield per hectare.

One farmer from the farthest communtity from town (and closest to the NGO conservation concession) stated during an interview that since the NGO is interested in their region for conservation (and owns the concession), they have an obligation to help the surrounding farmers to modernize their farming practices. The farmer went on to state that the NGO should also help his community fix up and restart the school that once existed (Field Notes, Nov. 2013).

Another (older) farmer recalled the time before the government stopped supporting cooperatives, which caused the coffee cooperatives in this region to collapse. He said that when the cooperatives functioned they had better coffee production and this was mainly due to the technicans that would come and work with the farmers on every aspect of coffee farming (Field notes, Oct. 2014). This sentiment of wanting technical help on various aspects of coffee farming but also just farming in general was echoed throughout many interviews and surveys. The desire to have help on all aspects of farming will have to be fullfiled by the NGO for the moment, as assistance programs run by the various Ministiers of the government tend to focus on one single issue. For example, during the latter part of my field work, agents from SENASA (Servicio Nacional de Sanidad Agraria), a national government institutions that works with issues of agricultural health were sent out to the coffee growing regions with only the task of helping farmers understand and fight coffee leaf rust. The work of the NGO is distinct from these sorts of government projects which respond to immediate needs and do not address the coffee growing process as a whole. SENASA also only supplied fertilizer and information through a few workshops over 2013 and 2014, but did not supply the farmers with any plants or seedlings. And farmers that needed seeds for coffee renovation, would have to take out loans and obtain the seeds themselves. Also, any farmer interested in supplementing their income by planting trees for timber, would have to find the seeds, germinate them, and then plant them on their farms.

There are also many farmers that do not participate or decide to stop participating with the NGO. When asked why they do not participate with the NGO, some stated they had not been asked by the NGO to enroll but had a desire to pariticpate. Though none of the non-participating farmers stated this explicitly, four of the participating farmers stated that some did not want to participate because they did not want to be told what to do and how to farm, indicating that the farmers thought they were already doing well. I would speculate that they fear to a degree that they would lose control of their ability to make decisions regarding the farm based on my observations of the technicians and their interactions with the farmers. In addition, the contract that is required to be agreed upon and signed by the farmer is based on the fact that the farmer will do what is asked of them.

In addition, some farmers do not trust the NGO, and do not want the knowledge from the technicians. One farmer (Oct. 2013) stated that some farmers in her community do not want to participate because they believe that the organization says the help and materials are free now but they will ask for something at a later date. Another farmer (Nov. 2013) from the same community stated that in the past she had stopped working with the NGO because they asked for money after distributing resources initially stated as free. She said she had been hesitant to work again with the NGO but the technicians had convinced her to enroll by promising that no payment would be asked of her.

4.4.1 Relating Participation with Socio-Economic Charateristics

In this section, I want test whether any of the socio-economic characteristics of the participating farmers are significantly different compared to non-participating farmers. Using a Wilcoxon rank-sum test (due to the non-parametric, skewed, distribution of the data) or Chi-square test, I examine age, total farm size, amount of farm cultivated, education, distance to town, distance to farm, and amount of coffee harvested in 2011 as possible determinants of participation. The results of the Wilcoxon tests are summarized in Table 4.2. The results indicate that there are no statistically siginificant differences between the participants and non-participants across these socio-economic variables, except for amount of coffee harvested in 2011.

Table 4.2. Summary table of the Wilcoxon reank-sum test results.

Variable	Median (Mean)		W-statistic	p-value
	Participants	**Non-participants**		
Age	49.5 (50.03)	54 (49.24)	1062.5	0. 7269
Distance (Km) to town	4.8 (6.809)	3.75 (5.123)	935.5	0.1195
Time to farm (hours)	0.415 (0.5586)	0.5 (0.8206)	1075	0.2824
Farm size (Ha)	4 (7.795)	4 (7.047)	1008	0.3776
Cultivated area (Ha)	3 (3.75)	2.5 (3.135)	927.5	0.1391
Number of children	4 (4.517)	3 (3.486)	858.5	0.0604*
Coffee Harvest in 2011 (number of bags)	10 (10.886)	6.667 (7.358)	649.5	0.0241**

$^{*}p < .1$, $^{**}p < .05$, $^{***}p < .01$

During data collection using the survey, I recorded the amount of coffee harvested by the farmers during each year between 2011 and 2014. However, since some areas of the region began experiencing coffee leaf rust as early as 2012, the amount harvested in 2011 was utilized in the tests as the reliable amount of coffee being produced by the farmer. The results show us that farmers that participate with the NGO produce significantly higher amounts of coffee per hectare compared to farmers that do not participate.

Though the difference is not statistically significant (at p<0.05), farmers with larger families appear to be participating with the NGO more than farmers with smaller families. The relationship between participation and time to farm is also not significant but the participants on average lived closer to their farm than their non-participanting counterparts. In addition, we did not see a significant difference in participation according to distance between farm and household, unlike findings reported by agroforetry adoption studies. For example, Mercer and Pattanayak (2003) find that the greater the distance between the household and the farm the less likely the farmer is to adopt agroforestry in Mexico and Phillipines.

Further, the Chi-square tests were conducted with the variables of level of education (high or low based on whether primary schooling was completed), use of fertilizer, and use of pesticides. The tests show that participation with the NGO is independent of the level of education (χ^2= 4.8722e-06, p-value = 0.9982) and use of pesticides (χ^2=8.1161e-31, p-value = 1), but the use of fertiliizer (χ^2=5.7135, p-value = 0.01683) by the farmer is siginificantly related to participation.

Taken together, the results of the 2011 coffee harvest and the use of fertilizer by the farmer being significantly correlated to participation indicate that farmers participating with the NGO are not likely to be the poorest farmers. These are likley to be farmers that are slightly better off and have a higher income, indicating a pulling away of the NGO from the poor and the prioritization of being a service provider at the cost of carrying out civil society functions, which has been seen elsewhere (Banks et al. 2015, Porter and Wallace 2013). Similar findings have been reported for farmer participation with agricultural and environmental programs in Northern Italy (Defrancesco et al. 2008) and for farmer trailling with agroforestry in Zambia (Kabwe 2010).

4.5 Resource Access and Flows

Through its many conservation and sustainable development projects, the NGO distributes various resources to its participants. The lengths of the projects vary, but generally range from one to five years. The focus of the research is mainly on the agroforestry related projects that seek to work with the local farmers to achieve the dual goal of increasing quality of life and protecting biodiversity. I document the activities of the NGO using data collected from interviews of its employees, participant observations, and reports produced by the NGO. The views of the farmers presented in this section are drawn from the interviews.

To receive any resources distributed by the NGO, a farmer has to enroll as a participant. Farmers often find out about the projects through neighbors that currently participate, through talking with the technicians during visits to the community, or through informational sessions held by the NGO. Prior to enrollment, details of the project, its goals, and resources to be provided during the course of the project are explained to the farmer. Formal enrollment involves the farmer or an adult member of the household signing (or thumb printing) an agreement and providing identifying information, including their DNI (document of national identity). Upon agreement to the terms, the participant becomes a *beneficiario* of the project. The NGO does not stipulate any pre-conditions for participation, such as a title to the land, except to have land where distributed resources can be utilized.

Here I seek to go beyond the previous studies about the uneven distribution of NGO resources. I argue that the NGO is in a position to bring resources to farmers (allowing them a different access to the specific resources than before) and that the NGO is ultimately changing the capacity of and the extent to which the farmer can benefit from their land. This happens in two ways; first, the farmers can use the knowledge from the NGO to plant the new varieties of coffee and use other material resources given by the NGO (fertilizers, seedlings, etc.), and farmers could potentially obtain a higher yield of coffee on their land. Resources to renovate a coffee plantation are cost prohibitive to many of the farmers that struggle to make ends meet. This is true especially if farmers are dependent solely on agricultural income. Even more important than the monetary resources required are they technical resources that are required, the knowledge for planting and growing for planting a nursery, appropriately taking care of the coffee seedlings until they are ready to be planted in the farm, and the correct use of fertilizers. So the farmers might initially agree to participate to receive the seeds, which can be expensive depending on the variety that the farmer desires to purchase and also sometimes hard to obtain. Some of the varieties are not found or sold in the nearby town; rather the farmer would have to purchase these seeds from a town 2-3 hours away.

Second, in addition to changing the relationship between the farmer and how their land is used, the NGO asks farmers to sign documents that serve as a contract that states that certain portions of the farmers' land is under "conservation" and will not be deforested. The lands of interest to be placed under conservation are forest patches ranging from primary to secondary forests (includes abandoned agricultural lands). The contract outlines that the NGO agrees to provide help through the technicians and workshops for coffee agroforestry if the farmer agrees to not slash and burn the forested land under conservation, plant native trees, and allow the NGO to monitor and surveillance the forests. The contract formalizes the obligations of both the NGO and the farmer; summarized in Table 4.3. The contract is subject to renewal and also states that either party can terminate the contract if there is non-compliance by notifying the other through written communication with a 15 day notice.

Table 4.3. Obligations outlined in the contract between the NGO and the farmer.

Actor	Commitments
NGO	• Survey the primary or secondary forest that is part of the farmer's property • Collect seeds from the conservation concession • Install nurseries of native trees and distribute to farmers • Provide individual technical assistance and trainings to raise awareness of conservation and management of forests and promote sustainable development in the area through coffee agroforestry systems. • Create a plan of management and monitoring for forest conservation • Help with surveillance of forests to prevent incursions by foreign entities for extractive activities.
Beneficiario	• Avoid deforestation and burning of primary and secondary forests • Plant native species distributed by the NGO in the empty spaces on the farm • Allow for monitoring and care of the forest (that is owned by the farmer)

The NGO provides to farmers access to knowledge, which is in the form of technicians' visits and workshops held. The "experts" or the technicians that have been trained (via education) in agro-economic practices and essentially hold this knowledge, which is a reason many farmers decide to participate with the NGO, to gain access to this knowledge. Technicians go through trainings as well as part of some projects and interact with the scientific community beyond their schooling for the technicians'' degree. For example, learning about the *Inga* plant genus and running small experiments on it to determine certain "best" qualities was part of a scientific study carried out by professors from universities in Lima and abroad. They also interact with researchers that come to visit and conduct their investigations in the surrounding farms and forests. The technicians often get involved and participate to a certain extent in the researchers' projects and can also become experts. For example, one of the three agroforestry technicians is held as the local *Inga spp.* expert within the organization due to this participation and training during a project carried out in the mid- to late- 2000s.

4.5.1 Resource Flows

Farmers participating with the NGO are enrolled as a *beneficiario* to receive specific benefits that will improve the crops and management on the farms. This is different compared to government programs that work with farmers, and more specifically farmer cooperatives in the region and in Central America (NGO supervisor interview 2013). There are two main ways that the NGO distinguishes itself from the government programs and cooperatives in this region (Field notes, Sept. – Nov. 2014). The first is through its constant presence in the communities carrying out one project after another, while government agencies programs do not have a continued presence (government technicians and resources are present only when there is funding for specific programs). Second, the NGO is concerned with various aspects of the household (summarized in the background section above), as in they do not tackle only one issue unlike the government programs and cooperatives; thus they provide varied resources ranging from advice on food preparation to advice on fertilization of crops beyond coffee to helping build latrines and better stoves.

Table 4.4 summaries the flow of knowledge and the role of each of the actors in the flow of resources. I classify the resources of the NGO into two main categories: the first being any plant and seed materials and the second are any technical knowledge that is shared by the NGO. We are able to see that the NGO, as an entity is the provider and enabler of the resources that are being distributed to the farmers. The NGO is able to use funds to obtain the material resources (purchased, grown, or collected) and hire the staff, such as the technicians that have the knowledge of best practices. These resources are transmitter or transferred by the technicians, whereby they become an integral and important part in this flow (as indicated in Figure 1.1). Lastly, the farmers are the receivers of these resources. However, they are also possible transmitters of knowledge to their families and neighbors.

Here, we see that the NGO is constructing an "access regime" through the process of farmer enrollment as a *beneficiario* in which the NGO is creating mechanisms and pathways by which farmers can access resources that were not present before, while operating under the constraints of agreement (the signed contract) proposed by the NGO. As a receiver of these resources, the farmers have the potential to benefit more from their land, with the possibility for a higher yield due to new varieties of coffee and coffee (crop) renovation and new knowledge. On the other hand, the NGO is also able to benefit from providing these resources (both material and knowledge) to the farmers, they indirectly gain some control of how the land is being used. Further, the NGO is not only controlling the farm by deciding what to crops and plants to distribute but it also gains authority (due to the contract and status as an "expert") over land use. This authority legitimizes any action the NGO decides to take against the farmer, whether it is giving a warning for future use or removal from the program, barring the farmer from receiving any further resources. Though the farmers stand to benefit from the resources distributed by the NGO, the access to knowledge and authority channeled by the NGO, enabled by external sources of capital, ultimately gives the NGO control over the resource (land and land use).

Table 4.4. Defining the role of the actors in the resource flow.

Actor	Materials (seeds, plants, etc.)	Knowledge
NGO	Provider	Provider
Technicians	Transferor/transmitter	Transmitter
Farmers	Receiver	Receiver and possible transmitter

4.5.1.1 Seed and Plant Materials

The NGO distributes seeds and plants to the participating farmers. However, the origins of the materials vary for coffee and trees. With coffee, the NGO distributes their own seeds that they grow and maintain on their own farm, sometimes supplementing with seeds purchased in the market. For the trees, the NGO technicians will mostly collect the seeds they want to distribute to the farmers from surrounding areas when the trees are producing fruit and seeds. Figure 4.2 shows the *ingeniero* displaying seeds with labels that collected of native trees during a visit from a supervisor from Lima. They often use the help and knowledge of the farmers to locate the trees to collect. The seeds were to be used for both creating a native tree nursery for distribution to farmers as well as reforestation efforts in areas of the NGO owned conservation concession. The regional manager from the NGO stated that “the seeds come from here, the same forest, the same watershed,” indicating that the source of the seeds was not necessarily one nursery or one specific forest patch but rather the area in general where the NGO work and anywhere they could encounter a tree producing seeds that they desired.

Figure 4.2. Seeds of native trees that have been collected from around the area on display in preparation for the supervisor's visit.

During my time in the field, I worked alongside NGO employees to search for and collect seeds from native trees. On several occasions during drives or visits to farmers, technicians would make a mental note of specific trees they saw flowering or fruiting to remember to return to collect the seeds. If a farmer happened to have a tree on their farm that the NGO was interested in, the technicians would ask about the source of the tree, as well as permission to see it (Field Notes Sept. & Oct. 2013). By collecting and distributing the seeds, the NGO is able to distribute a wide variety of species, even ones that might not be readily available in the market. Further, by recruiting farmers to share seeds and sources of seeds, the NGO is creating a new social norm to share seeds with the NGO and other families. The sharing of seeds would have a direct impact on species present on the farms as well as the genetic diversity of the plants.

4.5.1.2 Technical Knowledge/Information

Knowledge is disbursed by the NGO through the communities using mainly two different methods: group workshops and personal visits to the farmers. The knowledge here refers specifically to technical information regarding farming and coffee growing described earlier. The information that is transferred revolves around the best practices for growing coffee under an agroforestry system.

The knowledge of the *ingeniero*s and technicians are based upon their trainings as agronomists and technicians, their local knowledge, and in-field observations. The employees, specifically the technicians that interact with the farmers on a daily basis, are mainly locals, meaning they have first hand experiential knowledge with the system they are operating in. Further, it can be argued that since most of them are from local areas, they either directly have a farm they manage nearby or have family members that have farms in the surrounding area. This might influence how the *ingeniero*s and technicians approach the farmers in the area, as well as how the farmers perceive them. The NGO uses the standard “training and visit” structure in respect to their interactions with the farmers. This method of achieving agroforestry has been critiqued (Kiptot et al. 2006) but appears to work effectively in this area, at least superficially. This method involves initially disbursing information and training the farmers in a group workshop setting and then the *ingeniero*s and technicians visit the farmers’ households on occasion (see images in Figures 4.3 and 4.4).

Based on interviews, the reason the “training and visit” method seems to have performed decently in the region is most likely the frequency of the visit to the communities. Farmers during interviews stated that even if the *ingeniero*s and technicians were not visiting a particular family on a day, the family would be able to find out where they are and if they were in the community; this is an artifact of the size of the community. It is also possible that this works in these areas due to the small size of the communities, whereby making the visits clearly visible. By being present in the communities very often, the *ingeniero*s and technicians make themselves available to all the farmers of that community. Thus, if a farmer has a question but is not the target of the visitation on a particular day, they can still locate the *ingeniero*s and technicians and receive answers/advise and resolve problems.

(a) (b)

Figure 4.3. Farmers learning to fertilize a young coffee plant after a brief lecture (shown in (a)) and a short demonstration by the *ingeniero* (b).

Figure 4.4. An NGO technician visiting a farmer's household to check on the progress of the coffee nursery set up.

Figure 4.5. The NGO's nursery of native trees with labels for species.

In addition, my analysis of observations at the NGO's office and at one of the plant nurseries indicate that the NGO is trying to educate the people about the plants themselves in addition to the best practices (Field notes, Sept. 2014). This can be seen in the fact that they try to put signs up at the nursery of native hardwoods with both the scientific and local name (Figure 4.5). However, despite this, during the interviews and surveys, some farmers were unclear on the names of the trees they had received from the NGO and even of the varieties of coffee they received. For example, in one community during an interview (Nov. 2013) and a survey (Sept. 2014), the farmers could not recall the names of the trees, They looked towards my assistant describing the tree (it grows straight), who started to list the trees we knew the NGO distributed (bolina, pino chuncho, etc.), waiting to see if the farmers would find the names familiar, they often did. Another farmer during an interview (Oct. 2013) listed trees that she "believed" were on her farm. However, it would be important to note that this occurred mostly when speaking with female farmers.

In regards to the lack of information regarding coffee varieties, my assessment suggests that the farmers might not recall the varieties as the NGO usually does not distribute only one variety of coffee seeds, it is usually a mix of a couple of different varieties and different varities have been distributed over the years. The distribution of seeds in a mixed package rather than as one pure variety seems to be a sensitive point with some of the farmers. Another possibility is that the technicians did not transmit this information well to the farmers. They might have just offered the seeds as a whole stating they were coffee seeds or stating that it is one variety while it was mixed

(Interview Nov. 2013). Having witnessed some of these transfers (Oct. 2013, Sept. 2014) – where seeds in an bag were handed over to the farmer or the seedlings of native tree species were mixed together and loaded for transport after the initial selection of trees by the farmer –I noted the fast speed at which the transactions were completed and signed. Further, not all farmers were satisfied with the technicians. A few farmers were dismissive of the help they recieved from the technicians. They (across different communities) stated that the technician would just visit and ask if everything was ok, get a paper signed and then leave - indicating they there was no detailed coversation about the farm and that the visit was usually extremely short and unhelpful. During the part of the conversation regarding receiveing assistance from the NGO, one farmer (Age 60, Oct. 2014) laughed and said: "Right, [Mr. X] does come to visit sometimes and apparently he is a "technician" and supposed to help me."

Though my data shows there was transmission of information, my evaluation of the transactions and the dismissiveness of the farmers suggests that speed could have hindered proper transfer of information and also not have been a conducive opportunity for the farmer to ask questions.

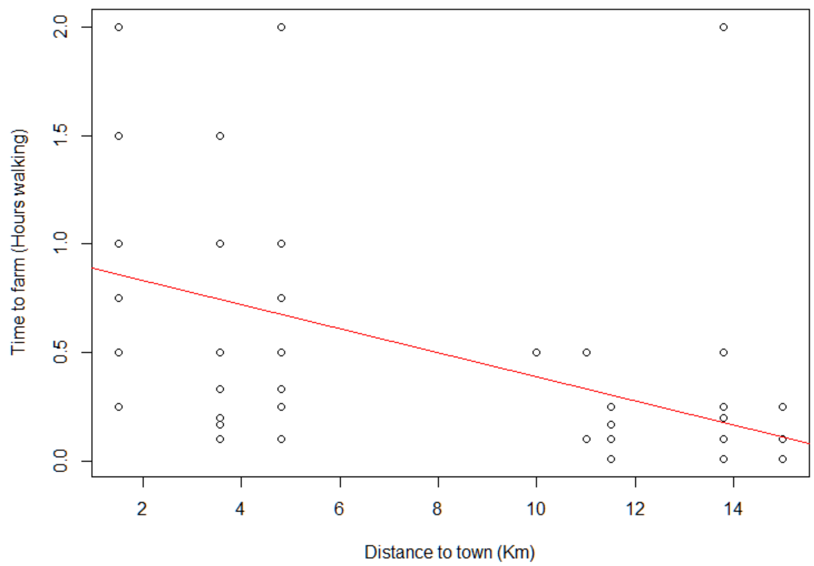
4.5.1.3 Resources Mismatched to Immediate Needs

Reflecting on my time in the field, it sometimes seemed that the NGO was not truly interested in helping the farmers but rather sticking to the project that has been proposed and funded. This observation fits with the critiques in the literature of NGOs not being effective exactly for this reason, that pleasing the donors and continuing the funding is more important than helping the actual farmers that the organization set out to help (Bebbington 2004, Banks et al. 2015). An example of this would be that during the duration of the last project, La Roya Amarillo (coffee leaf rust) hit this region hard, as it did for other parts of Latin America. Though the project started after the fungus started to infect the coffee plants, its full effects on the harvest were not yet felt by the majority of the farmers in the region. As I was carrying out my field work in 2013, I asked the regional head whether they were distributing varieties of coffee as part of the project that were resistant to the fungus. The response was not one I was prepared for, but he said that it is not the specific goals of the project to explicitly help with the fungus problem. I received a similar explanation during the interview with the lead agronomist. They were indeed distributing resistant coffee varieties (and had been for some time) but that was to increase yield per hectare. It was a coincidence that the farmers that had been participating with the NGO did not lose all of their crops and were still able to harvest some coffee when impacted by the fungus. So, even though the NGO is facilitating resources to the region and farmers, the resources do not entirely address the immediate needs of the farmers. For example, the NGO could have held workshops on how to control the fungus on the farms to limit its spread.

4.6 Patterns of Resource Distribution by the NGO

How are the NGO's resources spread on the ground? This section focuses on the farmers that have elected to participate with the NGO to examine how the NGO is distributing its time across the farmers and communities. We know from the literature that NGOs have a tendency to cluster and have biases in their locations, working in regions that are easier to access (Bebbington 2004, Biddulph 2011). Here, I show that we see a similar pattern in the case of this NGO but at the community and farmer level.

Before we examine the distribution of NGO resources, specifically knowledge/information, I want to illustrate the farmer community and farm location relationship by testing for a pattern between a community's (in which the farmer's household resides) distance from town and the time from farmer household to the farm. This relationship is plotted in Figure 4.6 along with the results from a linear regression showing a significant negative relationship between the two variables. We are able to see that there is a significant difference between communtities that are closer to town and ones that are further away. The figure below shows the decreasing relationship between walking time to farm from the house as the distance from town increases. Generally, time to farm decreases as the community's distance from town increases, as more of the farmers reside in households on their farms. This means that farmers in communities farther away will tend to live closer to their farms compared to their farmer counterparts that live closer to town. Further, the farther communties are decentralized, unlike the communities closer to town. It is important to consider this information in terms of the likeihood of the technicians being able to locate the farmers during their visit to the household.



	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	**0.94208**	**0.10935**	**8.616**	5.02e-12***
Distance	**0.05546**	**0.01307**	**4.243**	**7.89e-05*** **

Adjusted R-squared: 0.2208

* $p < .1$, ** $p < .05$, *** $p < .01$

Figure 4.6. Relationship between time to farm and distance to town.

As stated earlier, I use technician time as a measure of the amount of knowledge transferred between the NGO and the farmer. Knowledge and the ability to transfer information from the managers to the farmers is a critical part to the functioning of agroforestry systems. Though information on management practices might be present, it has been shown that little of this information reaches the desired recipients and local knowledge might take the place of institution-based knowledge (Boahene et al. 1999). In this light, we can think about the NGO and its technicians as bringing knowledge that would not be accessible (sourced from education and trainings as agronomists and technicians) to the farmers in the small communities.

I use linear regressions to examine the relationship between technicians' time and frequency of visits to the farmer with a meaure of remotness of the farm (time to farm from household) and other variables, such as length of participation.

4.6.1 Time to Farm

I examine whether the time spent with the farmers is related to the distance of the time to reach the farm. Each observation point in Figure 4.7 is colored in the graph to reflect distance to town. The blacks and blues represent farmers residing in communities closer to town while the greens and reds are farmers that reside in communities farther away. Though there is no clear grouping of time spent according the farmers' community distance from town, we can see a statistically significant decreasing trend (as seen in the linear regression) of time spent with the farmer as the distance between the house and the farm increases.

The results are reported in Table 4.5 below. The results show that techicians are likely to visit a farm less frequently if they are located further away, unsurprisingly. The farmers with remote farms (farms with large amount of time required to travel from the farmer's homestead) also reported that the tecnicians spent less time with them. Both these factors potentially lead to less transfer of knowledge to farmers who have farms are located further away from their home possibly due to the required travel time both on the part of the farmer as well as the technician.

Table 4.5. Regression results for relationship between visits by technicians and remoteness of farms

	(1) No. visits/month	(2) Hrs spent per visit	(3) Total time spent
Time (hrs) to farm	-0.272*	-0.341**	-33.38**
	(0.145)	(0.140)	(13.22)
Constant	1.345***	0.748***	62.81***
	(0.176)	(0.127)	(13.90)
R-squared	0.0239	0.110	0.0809
Std. err	Robust	Robust	Robust

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

There are differences between farmers based on what community they reside in, especially in relation to their distance from town or the NGO office. Farmers in some communities repoted less frequent visits from the technicians, as shown in Table 4.6 below.

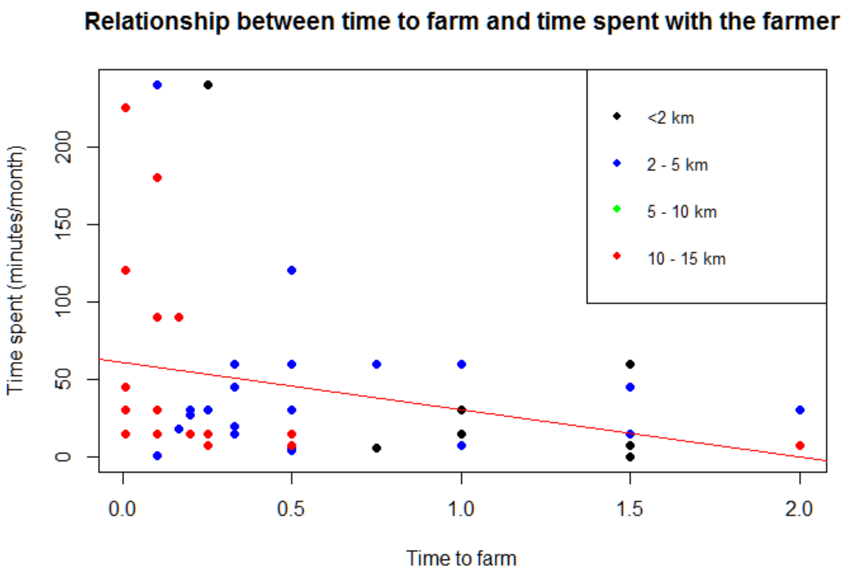
Table 4.6. Frequency of visits to the communities as reported by the farmers.

Community	No. farmers (N=61)	Avg. visits/month
1	8	1.69
2	15	1.10
3	2	0.75
4	8	0.83
5	1	0.50
6	2	1.00
7	14	1.05
8	10	1.30
9	1	2.00

This indicates increasing transaction costs as distance increases in the workings of the NGO. It indicates the mismatch occurring between when the farmer is present at their houses versus when the technicians are present within the communities to work with the farmers. What the trend is also reflecting is the reality of farmers that walk a great distance, sometimes over 1.5 hours to reach their farm. Based on my time in the communities and the interviews with the technicians, I can infer this to be the difficulty of finding farmers between the hours of 9 am and 5 pm, when the technicians typically work. In the case of farmers that have farms close to their residence, it is easier to encounter them at home or get their attention by calling out their names.

Further, a test using linear regressions of time spent with the farmer with the amount of years the farmer has been participating with the NGO and total farm size, did not show statistically significant relationships. This indicates that the technicians are not spending statistically significant more time with newly enrolled participants compared to participants that have been enrolled for many years, nor with participants with larger or smaller farm sizes. Similar results were obtained with linear regressions of time spent and total cultivated area. Lastly, examining whether the level of education or the amount of coffee harvested (per hectare in 2011) is related to the technician time spent (Figure 4.8), we see that there is no significant relationship. We do not see indications that the technicians spend more time with people with lower amounts of education. And we also do not find that technician time spent is related to the amount harvested. Given these results and the results from earlier analysis of participating and non participating farmers in regards to the statistically significant difference in amount of coffee harvested (section

4.4.1), we can state that most likely either farmers that are well-off are self-selecting to participate with the NGO or the NGO is specifically targeting and recruiting these farmers.



	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	60.55	10.56	5.734	4.54e07***
Time to farm	30.43	13.79	2.206	0.0316*

Adjusted R-squared: 0. 06571

$^{*}\ p < .1$, $^{**}\ p < .05$, $^{***}\ p < .01$

Figure 4.7. Relationship between time to farm and time spent with the farmer.

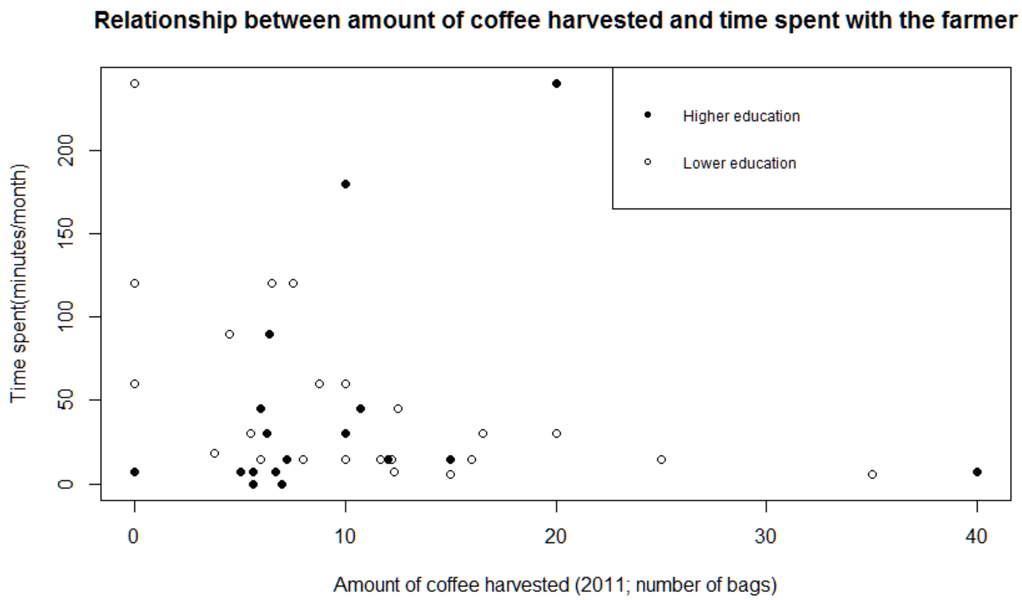


Figure 4.8. Relationship between amount of coffee harvested per hectare, education level of the farmer, and time spent by the technician with the farmer.

4.7 Discussion

4.7.1 "Best Practices"

The NGO through the use of "best practices" is trying to manage and set farming norms or rules for the farmers. These rules range from how coffee should be planted to how it should be harvested and what should be used for shade. We know that oganizations have been documented to change environmental perceptions as well as environmental use through the use of institutions, they can use institutions to mediate the relationship between the farmer and their land (Jepson et al. 2010, Robbins 1998, Vadjunec & Rocheleau 2009, Ostrom 1990, Geist & Lambin 2002). Here the NGO is creating informal rules and norms of farming by employing the techinicans to teach “best practices,” which the farmers are to follow after entering into the agreement (contract) with the NGO.

As summed up by Robbins (2012) under the conservation and control theme, conservation and sustainability programs are often seen as benign but could be taking control and power and having harmful effects. Unlike many cases of resource control and conflicts where the people may be vocal about their land being taken away or the effects are visibly detrimental, the subtle resource access and control changes taking place here via the contract and “best practices” between the farmers and the NGO in Chanchamayo is being largely unnoticed or unchallenged. May be it should be of even a greater concern to us that people are willing to acknowledge that they are giving up some control over a resource they own and have a right to for being given access to other resources that might be of hardship.

4.7.2 Knowledge

The consideration of knowledge within agroforestry systems is crucial for the system to work as envisioned and planned. There are two major aspects of knowledge considered here. The first is the access to knowledge to place agroforestry into practice. The second is the implementation and transfer of knowledge to farmers.

Historically, government extension programs have taken up the role of providing farmers with information about technology and other innovations in agriculture, through "Training and Visit (T&V)" system (Benor and Harrison 1977). This approach has drawn much criticism due to its ineffectiveness. Currently, more emphasis is being placed on the role of facilitation. However, studies have found that, even with these changes, there is much lacking. For example, Kiptot et al. (2006) found that extension programs in Kenya have lacked impact among small-scale farmers. Most of the problems arise in lack of adequate staffing and limited resources, as well as high level of corruption and mismanagement. Lack of continuity and uniformity in implementation has also been a major problem (Kiptot et al. 2006). In this case, the NGO has maintained a continous presence in this area with different on-going projects over the past two decades, unlike government initatives. However, the efforts of the NGO also have similar problems that Kiptot et al. (2006) found in Kenya. Though I did not document corruption (which was beyond the aims of this dissertation), the limited resources, especially in terms of the number and time of the technicians became apparent. The NGO and its technicians had to manage multiple projects with differing goals and switch from one task to another at the direction of the regional supervisor. This disrupts the continuity of the technicians work in the communities as well as increases the time between visits to each farmer.

In addition, attempts to help with the dissemination of technical knowledge and materials are met with difficulties of working in mountainous regions, transportation time and the difficult terrian especially during the months of heavy rain. The ability of the NGO to help the farmers is also restricted by limitation of funding mechanisms. And the meaning of “help” as seen by the NGO versus the people is different. Though the farmers want the seeds and other resources the NGO provides, they stated an interest in having more trainings and wanting more knowledge. NGO is helping the uneven development – reinforcing the statements and findings of Bebbington (2004) and others. There seems to be unevenness in the work of the NGO. However, these are to be related to the realities of working with the limitations of time and terrain. They are also realities of working on "projects" and deadlines set forth by funding agencies and being part of the endless funding cycles. It is not just the policies of the organization that are effecting development but the actual physical geographies itself that matters and is creating differences and uneven development.

Through its position (and the position of the technicians) and the signed contract, the NGO has in a way commoditized technical knowledge/information. It uses this commodified knowledge to attain its goal of changing land use in the area. This is done through three steps facilitated by the contract: deploying the knowledge or information through the trainings; providing the materials (seeds, plastic bags, etc.) to implement techniques (which are part of the information package); and lastly the reinforcement of techniques or information based on receiving instructions through the daily work of the technicians. The NGO is just able to situate itself as the best that knows what should be occurring/planted on the farms. One of the reasons the NGO is able to gain high participation despite the demands of the contract, is the lack of other organizations or programs that yield similar benefits to the farmers in these communities in terms of coffee plants, native trees that can act as a source of income, and trainings/workshops on various topics of coffee planting and farming (including practices and planting of *Inga* shade trees).

4.7.3 Changing Relationships

Are the farmers making decisions regarding participation and potential loss of ability to control decisions regarding the farm for some benefits that they hope to gain to compensate for the loss? The most apparent way this "invisible" tension is visible is among the farmers that do not wish to participate with the NGO. These farmers do not have the desire to be told or directed on how to use their land or what actions to perform on it – a sentiment that was confirmed by neighboring farmers that participate as a rationale for why some might not want to participate. These tensions are worsened by the fact that some farmers, including some of the participating farmers, are under the impression that the NGO does not maintain its presence in the region to help them, but rather to take advantage of them. Some participating farmers expressed to me that during the visits from the technicians the advice/knowledge they received was next to nothing or not valuable (also reflected in the short duration of the visit to the farmer). They thought of the visit more as a way of being checked on and a way that the NGO collected signatures so the NGO can continue to get money.

Within communities there is an uneven distribution of resources and they are correlated to farmer characteristics and connections. The NGO could be seen here as the exacerbator of uneven development across different communities and within communities as well, as seen in from analysis of the survey data. Whether the farmers are self-selecting to participate with the NGO or if the NGO is specifically targetting middle-income farmers, the NGO is not reaching the poorest farmers and is not accomplishing goals set in its mission and vision statements. This finding is similar to previous studies of NGO target groups that exclude the poorest (Rahman and Razzaque 2000, Fruttero and Gauri 2005). For example, in Bangladesh Islam and Sharmin (2011) document how two micro-credit NGOs work with groups that are able to return the money back to the organization and exclude the "ultra poor," displaying a rent seeking attitude and a lack to accountability to the beneficiaries. Bebbington (2004) and Banks et al. (2014) note that NGOs with their relations to donor agencies have had to show results in their work, and often the way to do this would be to work with farmers where results would be produced.

Certain communities and farmers have been the focus of the NGO efforts. Based on the analyses, preference for certain communities appears to be due to distance but could also by a result of the NGO's needs to test out the distribution and planting efforts in one community or before expanding to other commuinities. Furthermore, certain farmers have been the focus of many of the efforts, creating imbalance in the distribution of resources within communities. For example, two of farmers that reported the highest amounts of time spent with the technician, have been participating with the NGO for over 10 years, yet continue to receive resouces; however, the resources they receive could be reflective of the relationship and trust they have built with the NGO.

4.8 Conclusions

This chapter has illustrated the relationship and resource flows between the NGO and the farmers. We have seen evidence of the NGO using contracts and the distribution of resources to change the farmers' decisions in regards to coffee and by placing lands forested parts of their farm under conservation.

Though the time and recources of the NGO are not evenly distributed across the communities due to transaction costs, the norms (or rules) being set by the NGO are untimately indicating to the farmer what should be present on their farms along with coffee, native trees and *Inga* genus for shade. In this way, the NGO has situated its actions to influence (agro)biodiversity on the farms.

Looking beyond the unevenness of the distribution of resources, the NGO is changing the relationship between the farmer and their land through their distribution of resources. The theory of access framework allowed for the conceptualization of the resource flows between the NGO and the farmers with the technicians acting as meditaors and facilitators. However, as we have seen the distributed resources are not accessible to all farmers evenly. If an NGO's goals are both livelihood development and to benefit biodiversity, then knowledge distribution and resource distribution must be even. This would apply especially when thinking about biological corridors that are meant to connect patches of forest. If the NGO biases (distance or the preference to work with not the poorest farmers), play out on this landscape, rather than evening out the imminent development, they could create (and become the cause of) another layer of unevenness with the potential to influence biodiversity in the various parts of the corridor.

In the next chapter, I examine whether participation with the NGO has resulted in changes in biodiversity, as compared to farmers that do not participate with the NGO.

CHAPTER V

SPECIES DIVERSITY

Species diversity within agroforestry systems has been and is of interest to various groups (farmers, forestry officials, colonists, conservationists, ecologists, etc.). Studies have examined how traditional and converted agroforestry systems contribute to biodiversity conservation and to the livelihoods of rural communities (Atta-Krah et al. 2004, Perfecto et al. 2003, Molla & Kewessa 2015). It is known that agroforestry can help in creating biological corridors or increasing the landscape matrix quality between two protected areas or intact forests (Schroth 2004). Having trees as a part of this landscape can provide connections for animals foraging, facilitate in gene flow and minimize inbreeding as it decreases isolation. It can also help in connecting species populations that are less mobile by connecting them as one population for reproduction purposes. We can think of the farms as patches that connect the metapopulations that are part of the protected areas.

Within coffee and other agroforestry systems, scholars have measured the amount of different tree species present alongside crops, their uses and value, their contribution to ecosystem services, and what other types of biodiversity they supported (ex.: Rice 2008, Rice 2011, Perfecto et al. 1996, Perfecto et al. 2003). Studies focusing on coffee have found that these farms can be a refuge to many species, provide ecosystem services, and increase resilience to climate change (Perfecto et al. 1996, Jha et al. 2011). A study by Jha et al. (2014) has found that diverse shade coffee production areas have decreased between 1996 and 2012. This suggests that globally we are seeing patterns of intensification on the shade coffee farms.

Due to the benefits from agroforestry, especially of coffee agroforestry on the quality of the coffee that is produced, governments and organizations seek to help farmers keep or switch to shade coffee farming by providing subsidies or aid often channeled through cooperatives. Thus, many studies have focused on cooperatives; previous studies on management types and the variation in biodiversity have also focused on diversity as varied by cooperatives (Mas and Dietsch 2004, Mendez et al. 2007, Mendez et al. 2009) or certification programs (Tscharntke et al. 2015). However, there are other farms that form a big part of the landscape matrix and contribute to coffee production are not part of cooperatives. For various reasons farmers might not be able to or have the desire to participate in cooperatives or certification programs yet they are part of the landscape and do contribute the overall quality of the matrix. Thus if we limit our understanding of biotic changes only through the narrowed lens of cooperatives, then we might risk not understanding the entire picture or accounting fully for the quality of the matrix. The study carried out by Goodall et al. (2014) in Costa Rica shows that individually managed farms had a higher density of shade trees than farms that were collectively managed. However, they found mixed results in terms of the species diversity, where the individually managed farms had lower species diversity one year and higher another year compared to the collectively managed farms.

In addition to the variation that might exist between collective versus individually managed farms, there are many organizations that work directly with individual farmers to influence their management practices. However, little is known about how species assembly is determined by management practices in tropical agroforestry systems (Chazdon et al. 2009, Livingston et al. 2013). These changes can significantly modify the ecosystem function of the specific farm and can even have regional effects. Further, upon reflecting on their global assessment of the presence of trees on farms, Zomer et al. (2009) state that there is a need to understand “the factors which lead to different patterns of tree cover within relatively short distances with similar population and climate" (p. 45).

Thus in this and the following chapter, I address the question of what are the changes in biodiversity are as a result of changing agroforestry farming practices due to the NGO’s projects. As stated earlier, I answer this question at two different levels, at the tree species level on the farms and at the genetic level (of *Inga oerstediana*; Chapter VI). More specifically, in this chapter I concentrate on the former by analyzing vegetation plot census data to examine what variables explain the differences and diversity between the farms. Further, I also compare the species present on the farms to the species present in surrounding areas to document the contribution of the coffee farms to the species diversity of the biological corridor between conserved/protected areas.

5.1 Species Diversity in Chanchamayo’s Coffee Systems

Interviews from 2013 of NGO supervisors reveal there are generally three temporal categories of plants on a farm: short-, medium-, and long- term. Short-term plants are the coffee crops that provide income annually, typically from the months of

April to June. Medium-term plants are plantains/bananas or other small legumes, which can provide temporary shade for coffee. The long-term plants are woody tree species such as *cedro* (*Cedrela fissilis* Vell. or *Cedrela odorata* L.) or *ulcumano* (*Retrophyllum rospigliosii* (Pilger) C. Page), which can be harvested at 8, 12, 25 or 35 years depending on the species. Also present on the farms and nearby forests are the coffee associated species of *pacae* (*Inga spp.*) utilized for shade and nitrogen fixing. Six species of *Inga* are used in the coffee agroforestry system in this region: *I. edulis* C. Martius, *I. adenophylla* Pittier, *I. oerstediana* Benth. ex Seem., *I. punctata* Willd., *I. saltensis* Burkart, and *I. marginata* Willd. However, only *I. adenophylla*, *I. oerstediana*, *I. punctata*, and *I. marginata* are used across the altitudes of 950m-1800m, ideal coffee growing elevations. And *I. edulis and I. oerstediana* are the two species most commonly used by farmers with coffee in this region. The use and preference for these specific two *Inga* species was confirmed with the data collected during farmer interviews. Farmers (and supervisors) also stated that the NGO advises them to use the latter *Inga* because of the amount of nutrients that are returned to the soil through leaf litter as well as its nitrogen fixing capabilities and its ability to last on the farm longer than *I. edulis*.

Interviews also revealed that the NGO has demarcated a biological corridor between the two patches of forests surrounding the farms within one of their recent project. They plan to plant trees along approximately a 100 km area to form or improve the existing corridor between the two forest patches. Within this demarcated land reside the coffee farmers and their farms, thus the trees planted for the purpose of the corridor will have to be planted on the farms by the farmers. And to observe the changes in species within the corridor, I collect and analyze data using vegetation plots on the farms of participating and non-participating farmers. In the following sections, I, first briefly give a data overview and then explore and analyze the data to answer three questions:

1. What is the contribution of the farms to the biodiversity/conservation element of the corridor when compared to surrounding forested areas? Is there a difference between participating and non participating farms?

2. Is the species composition of farms being altered due to participation with the NGO?

3. Can differences of species diversity among the farms (measured by diversity indices) be explained by participation with the NGO?

5.2 Data Overview

I collected data on 40 farms, out of which 31 belonged to participating farmers and 9 to non-participating farmers. For each farm, I measured a 40 m by 40 m plot to study the vegetation. Stems with DBH (diameter at breast height) greater than 5 cm were identified and recorded. Across the 40 farms, I recorded 3682 individual stems (some trees had multiple stems) with an average of 92.7 stems per plot. A total of 2164 unique trees were measured and recorded across all of the plots, with the distribution breakdown summarized in Table 5.1. The total number of unique species is 92, including 12 unknown species. Figure 5.1 shows positions of the vegetation plots on the farms relative to the town center.

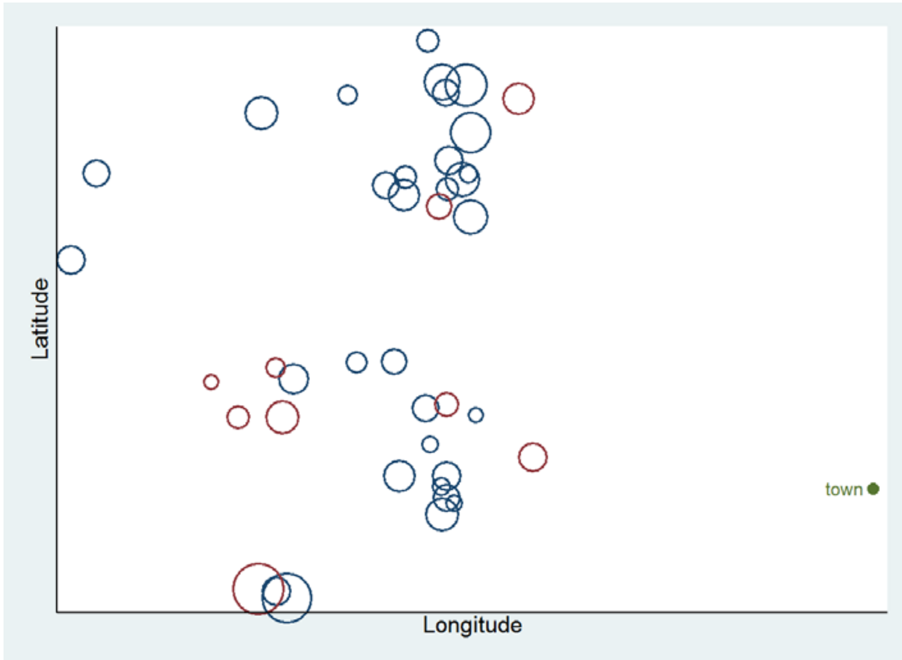


Figure 5.1. Location of the vegetation plots. Positions of farms relative to the town. Size of the circles represents the number of unique species found in each farm. The color of the circles indicates participation; blue circle are participating farms, and red circles are non-participating farms.

Table 5.1. Distribution of measured individuals and number of species recorded in participating and non-participating farms.

	Participating	Non-Participating
Number of trees	1566	598
Number of trees per Ha.	315.7258065	415.2777778
Total number of species	77 (+9 unknown)	46 (+1 unknown)
Number of species per Ha.	17.33870968	32.63888889

For each farm I also recorded the following characteristics for analysis: elevation, average slope, spatial coordinates (GPS location), distance to town (continuous), community of farmer (categorical), participation with NGO (categorical - binary), time (years) participating with NGO (continuous variable), and soil type (categorical).

All the data, except for soil type, were collected either through direct observation or by interviewing the farmers. The summary statistics (mean, standard deviation, minimum value, and maximum value) of these variables are provided in Table 5.2.

Table 5.2. Summary statistics of continuous variables for participating and non participating farms that were selected for vegetation plot census.

N=40	Mean	Std. Dev.	Min	Max
Elevation (m)	1266.50	238.88	883.00	1850.00
Average slope (%)	25.60	12.73	4.00	51.33
Distance (km)	8.18	4.58	1.50	15.00
Participated years	3.38	4.12	0.00	16.00
Species Richness	11.00	4.01	3	19

5.3 Comparing Farms to Surrounding Areas

In order to understand the contribution of the participating and non-participating coffee farms to biodiversity conservation (acting as part of the agroecological matrix and the biological corridor), it is essential to compare the coffee farms to surrounding forested areas. Previous studies in Chanchamayo have documented the diversity found in different forest patches. One particular study by La Torre-Cuadros et al. (2007) documented diversity in one hectare vegetation plots ranging from primary to secondary forests in Chanchamayo province of Peru with the goal to examine the relationship to the environmental gradient in this area. They identified all the trees within the plots to the family level. They collected data from seven forest fragments: Cedros de Pampa Hermosa (CPH), Pichita Slope (PS), Pichita Riverside (PR), Genova Slope (GS), Genova Late Secondary (GLS), Genova Hill (GH), and San Ramon Slope (SRS). The forest stand CPH is a primary forest within a nearby protected area, while the rest are secondary forests with varying amount of years left undisturbed.

Here, I compare the families reported by La Torre-Cuadros et al. (2007) in each of the seven locations and to the one I collected. My collected dataset is separated into the families found on the participants' farm and the non-participants' farm. Table B.1 (Appendix 2) lists the families and their presence in either of the studies, with green highlighted families appearing in both studies. There are altogether 86 known families that are recorded by me or La Torre-Cuadros et al. (2007). Among them, 20 (23.5%) are common in across farms I sampled and the forest stands sampled for the paper. Further, out of the 84 families listed by Torre et al. (2007) across the various forest remnants, 36% are also found in participating farms and 23% are found in non-participating farms. This distinction indicates that collectively the farms of the participants are more diverse at the family level and more similar to the primary and secondary forest stands compared to the non-participants. This pattern is similar to those observed by Bhagwat et al. (2008), where they noted that generally similarities between plant species in agroforests and natural areas are lower than compared to animals. This is in part due to farmers making the decision regarding planting and removal of individual trees. Further, studies by Hager et al (2015) and Pinard et al. (2014) have found that agroforests can share about 20% of the tree species from the surrounding forests.

Participating farms have a higher number of families present (30) compared to the non-participating farms (19). However, there are some families (10), such as Calophyllaceae and Cupressaceae, recorded on the farms but not present in any of the nearby forest stands, potentially indicating that these families might have been introduced to the farm from a different region by the farmer. Surprisingly, the number of families recorded on the participating farms is higher than two of the forest remnants studied by La Torre-Cuadros et al. (2007), though it would be important to remember that types of families present would be different. These sites are secondary forests that were once part of a coffee *hacienda*.

The number of families on the participating farms (30) is also not that different compared to the primary forest site (CPH; 35). There are 21 families that occur on the farms and overlap with families in the various forest patched; 19 overlapping families from participating farms and 14 families from non-participating farms. Further, a *t*-test (two sample, assuming equal variances) comparing the number of families occurring on the (participating and not participating) farms and the number of families in the forest patches shows that there is no significant difference between the two groups (*t* statistic: -1.7815; p-value (two tail): 0.1180)[7]. This shows that the farms are contributing to some degree of connectivity (acting as a biological corridor) between the remnant forest patches, even if not all the families are the same from one patch to another. However,

[7] The two groups tested here include the number of families counted on the participating farms and non participating farms in one group (2 data points), while all the other forest patches were placed together into a second group (7 data points).

since the comparison is at the taxonomic family level, this generalization about possible contribution is applicable to more generalist species of fauna.

5.4 Changes in Biodiversity

To document changes in biodiversity as a result of participation, the data collected from the vegetation plots were analyzed using NMDS and multiple linear regressions. The analysis was carried out to test whether the NGO is effective and achieving its goals of sustainable development and biodiversity conservation in this biological corridor they have demarcated. If yes, then we should expect to see a difference in composition and diversity on farms that participate versus that do not participate. Further, the NGO has demarcated this area, which exists between two intact forests patches, as a biological corridor and has been seeking to increase its contribution to conservation. As a participant with the NGO you receive knowledge and advice to change farming practices as well as seeds and seedlings of native trees to plant on the farm to increase both biodiversity and act as an additional source of income (which aids in meeting the goals of the project as well as the achieving the missions of the organization). Thus, we would expect to see a difference in the farms of the NGO participants when compared to the farmers that do not participate in both the analysis with NMDS and species diversity indices.

5.5 Species Composition

5.5.1 Analysis with NMDS

In order to analyze the species composition in the vegetation plots, I first perform an ordination using the non-metric multidimensional scaling (NMDS) method. NMDS is a gradient analysis technique that demonstrates relative similarities or differences among the farms in terms of their species composition on synthesized axes that are created to illustrate the relatedness of the plots to each other. This means that farms that are located closer together are more similar in species composition than ones that are farther apart.

For analysis here, I utilize the absolute and the relative abundance of each tree species found on the farm to create the dissimilarity/distance matrix. Since the two are slightly different ways of conceptualizing diversity (counts versus proportions of a species), I apply the both methods to the examining species composition on the farms.

Furthermore, I also conduct analysis separately with divisions of the vegetation plot census dataset: all species recorded and with only the genus *Inga* species. The genus *Inga* has a very wide species range across Central and South America. It is a species often utilized as a shade tree for coffee. Though the farmers themselves have *Inga* species on their farms as shade, the NGO promotes specific species of *Inga* because of the increased amount of nitrogen fixing as well as the amount of leaves the trees shed that act as a natural fertilizer. This is an important genus because it accomplishes two of the NGO’s goals: helping increase the coffee yield, which would improve quality of life but it also attracts and sustains insects, birds, and other wildlife due to its flowers and fruits. Thus, I run four different NMDS ordinations and analysis (Table 5.3).

Table 5.3. Four NMDS analyses.

Dataset	Abundance	Relative Abundance
All Species	NMDS A	NMDS B
Inga only	NMDS C	NMDS D

The relevant species-plot matrix is input into R using the vegan package to compute the relative distance between each pair of farms based on their species composition by minimizing the "loss" or the difference between actual pair-wise distance and two-dimensional distance. Then, based on the desired number of dimensions or axes[8], an ordination is performed. The ordination can then be fit with environmental data (linear regression) associated with the farms to test if any of the synthesized axes correlate significantly to the environmental variables. Categorical variables were omitted from the environmental data linear regressions; rather, they were used to plot the farms on the generated axes so we can see the grouping of farms based on categorical environmental factors. I further tested if the grouping pattern is significant by using ANOSIM (analysis of similarities).

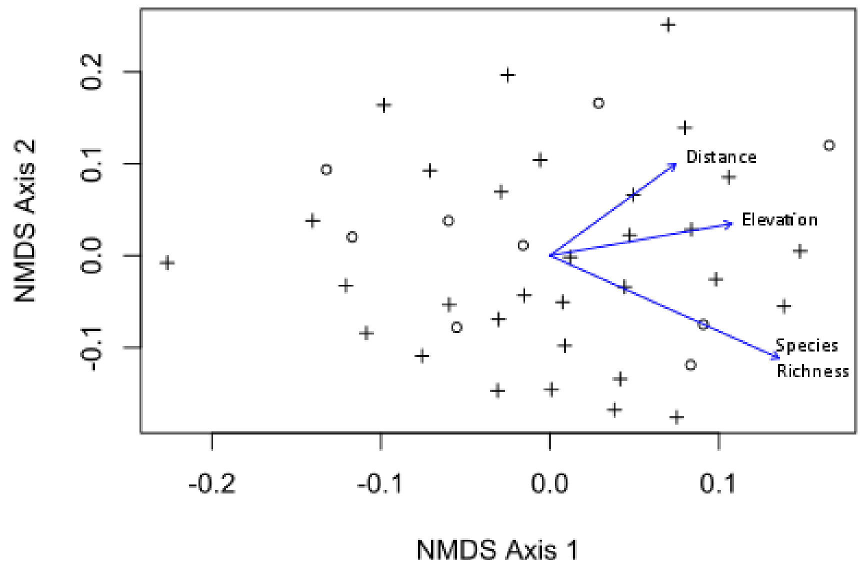
5.5.2 Correlates of Species Composition

What variables explain the diversity in species composition across the coffee farms in Chanchamayo? Does species composition of the farms vary on participation due

[8] The dimensions (axes) can vary but the goal is to reduce the total number of dimensions so that we can visualize the differences among the farms. Here two dimensions were selected for all four of the NMDS analyses based on the minimal stress with the least amount of dimensions across a stressplot ranging from 1 to 5 dimensions.

to the NGO? To test whether over the past 18 years the NGO has changed the species composition on the participating farms, I analyze the results of the NMDS procedure with four datasets (Figures 5.2 to 5.5) as the plot-species input matrix: (a) all species with absolute abundance, (b) all species with relative abundance, (c) *Inga* species with absolute abundance, and (d) *Inga* species with relative abundance. These NMDS ordinations were run with a Bray-Curtis distance matrix with 40 iterations before the best solution was fit with the environmental variables with 10,000 permutations.

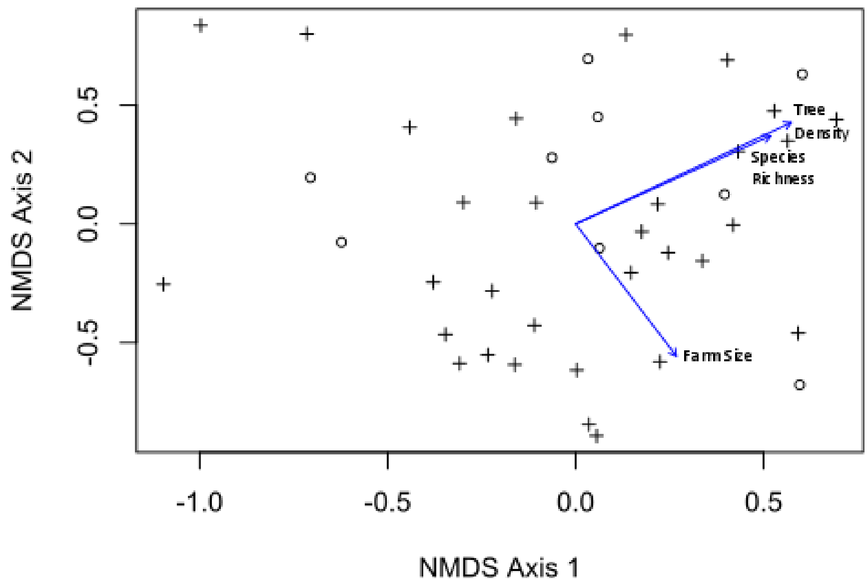
By fitting environmental variables to the NMDS axes, we see the variables as vectors as shown in Figures 5.2 to 5.5. These vectors show the relationship of the significantly correlated continuous variables to the two NMDS axes. They help us understand the correlation of the variables to the synthetic axes that have been generated, thereby helping us understand the relationship of the farms to each other in this space. The direction of the arrow allows us to see if there is a positive or negative relationship and the length of the arrows show the strength of the relationship. The longest arrows or the strongest relationship are environmental variables.



Variable	*Elevation*	*Distance*	*Species Richness*
NMDS1	0.9271	0.5697	0.9720
NMDS2	0.3748	0.8218	-0.2349
r^2	0.1868	0.2394	0.3355
p-value	0.0245**	0.0074***	0.0005***

Figure 5.2. NMDS A (All species – abundance) results along with the significantly correlated variables. The arrows on the plots are only of significantly correlated continuous variables. Circles indicate non participating farms while plus signs indicate participating farms.

* $p < .1$, ** $p < .05$, *** $p < .01$



Variable	Species Richness	Tree Density	Farm Size
NMDS1	*0.8132*	*0.8021*	*0.43385*
NMDS2	*0.5820*	*0.5972*	*-0.9010*
r2	*0.1934*	*0.2433*	*0.1819*
p-value	*0.0198*****	*0.0049******	*0.0212*****

Figure 5.3. NMDS B (All species – relative abundance) results along with the significantly correlated variables. The arrows on the plots are only of significantly correlated continuous variables. Circles indicate non participating farms while plus signs indicate participating farms.
* $p < .1$, ** $p < .05$, *** $p < .01$

With NMDS A (Figure 5.2), we see that elevation is significantly and positively correlated to axis NMDS 1 and only somewhat correlated to axis NMDS 2 at the p-value <0.05 level. We also see similar relationships with distance from town (measured in kilometers) and species richness. All of these are environmental or geographical variables that are significantly correlating with the axes. It appears that elevation and species richness on NMDS axis 1 are distinguishing the farms. The significant correlation with species richness indicated that some of the difference (~33%) between the species composition of the farms is explained by increasing number of species (on the x axis of the biplot). However, we do not see any grouping of the farms based on participation with the NGO, rather participating and non participating farms are mixed together in the species composition space. This analysis through NMDS shows that there is no correlation between participation and the axes and the distribution of the plots across the axes. Further, the lack of significant separation or grouping based on participation was verified using ANOSIM (analysis of similarities with 999 permutations), which returned an ANOSIM statistic R of 0.02326 and a significance of 0.369 that indicates no separation.

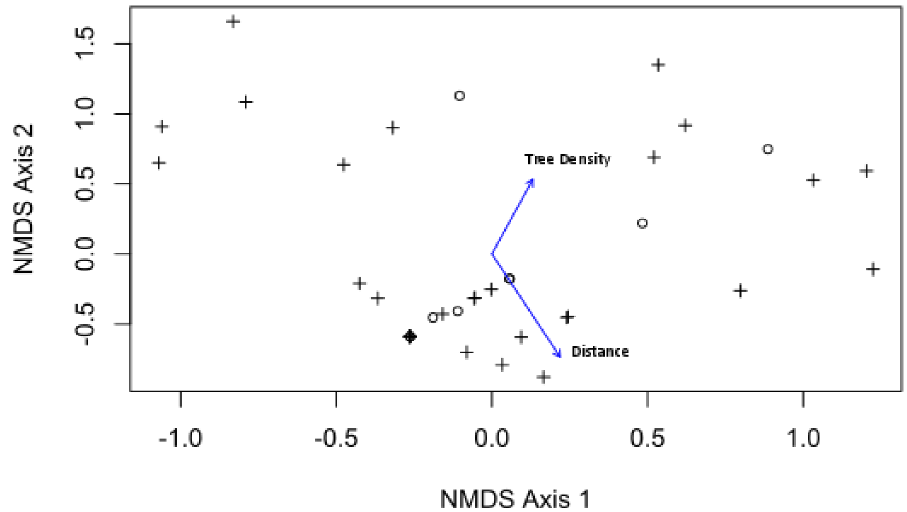
Performing the NMDS with relative abundance of all the species across the plots (NMDS B; Figure 5.3), we see that the tree density, species richness, and farm size are correlated with the NMDS axes. However, we do not see elevation or distance having significant correlations with species compositions based on relative abundance, as they were in the previous analysis. Also, I tested the grouping based on participation using ANOSIM and obtained similar results as the previous analysis (ANOSIM statistic R of 0.003663 and a significance of 0.462). Further, farm size has a strong negative correlation while species richness and tree density have a positive correlation with NMDS axis 2, suggesting that species richness and tree density are higher on farms where the farmers own less land.

5.5.3 Inga Species Only

Does the composition of the species in the genus *Inga* depend on participation with the NGO? As noted earlier, this genus is important as part of the coffee landscape and due to the operation of this NGO over the past 18 years in the region and the specific goal of multiple projects to improve the yield and production of coffee through the planting of a variety of *Inga spp*. as a shade trees, the farms that participate with the NGO would be expected to contain more *Inga spp*. than farms that do not participate.

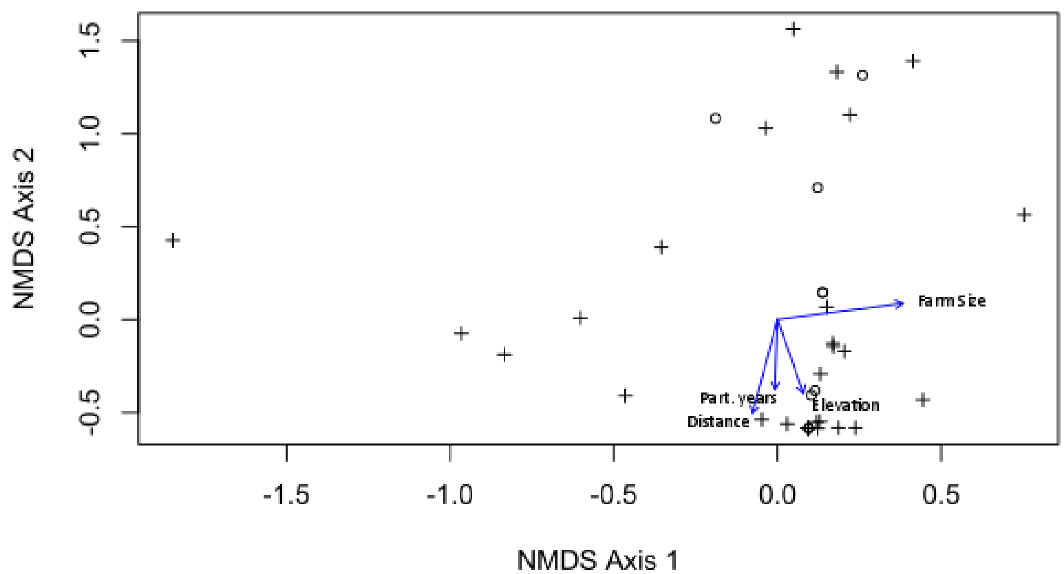
The third and fourth NMDS analyses (NMDS C and D) were with a partial dataset, where only the observations of the species in the genus *Inga* were present. Running the NMDS with the *Inga spp.* only dataset, a new pattern of relationships and correlations emerge between the variables and the axes. NDMS C (Figure 5.4) performed with the abundance of *Inga* only species has only tree density and distance variables correlated to its axes. This shows that along the NMDS axis 2, tree density is positively correlated while distance is negatively correlated.

However, NMDS with the *Inga* only relative abundance dataset (NMDS D; Figure 5.5) shows different relationships. We again, similar to the NMDS A, see that elevation and distance again has a strong relationship with the axes, however, they are negatively correlated with NMDS2 axis in this case. What we also note is that similar to NMDS B, farm size is also significantly correlated with the NMDS axis 1 but with a p-value of 0.057. We can also see, though significant only at a higher p-value (0.07), the number of years participating with the NGO explains about 13% of the variance present in the *Inga* genus species composition based on relative abundance. The relationship is negative, so as the number of years participating increases, NMDS axis 2 goes down. The number of years participating with the NGO is a quantitative representation of participation. Unlike the first NMDS with all of the species, when considering only the genus *Inga*, which the NGO has been promoting heavily, we see that participation time with the NGO is influencing species composition. This shows us that though the species composition measured by abundance is not changing much, the relative abundance of one species of the genus *Inga* to another has changed over the course of time when participating with the NGO. Neither NMDS C (ANOSIM statistic R: 0.0401, Significance: 0.291) or D (ANOSIM statistic R: 0.0661, Significance: 0.174) has a significant grouping according to the participation variable when tested by ANOSIM.



Variable	*Tree Density*	*Distance*
NMDS 1	0.2400	0.28541
NMDS 2	0.9708	-0.95841
r2	0.1494	0.2937
p-value	0.0516	0.00160

Figure 5.4. NMDS C (*Inga* only– abundance) results along with the significantly correlated environmental variables. The arrows on the plots are only of significantly correlated continuous variables. Circles indicate non participating farms while plus signs indicate participating farms.
* $p < .1$, ** $p < .05$, *** $p < .01$



Variable	*Elevation*	*Distance*	*Farm Size*	*Participating years*
NMDS 1	0.19530	-0.15052	0.97537	-0.0197
NMDS 2	-0.98074	-0.98861	0.22059	-0.9998
r2	0.1559	0.2498	0.1478	0.1357
p-value	0.04400 **	0.00350***	0.05779*	0.0707*

Figure 5.5. NMDS D (*Inga* only – relative abundance) results along with the significantly correlated environmental variables. The arrows on the plots are only of significantly correlated continuous variables. Circles indicate non participating farms while plus signs indicate participating farms.
* $p < .1$, ** $p < .05$, *** $p < .01$

5.6 Species Diversity: Shannon's and Simpson's Index

Does participation with the NGO explain the species diversity patterns present across the plots? I compute alternative measures of species diversity that does not rely on relative compositions in farms to answer this question. Figure 5.6 shows that distribution of the Shannon and Simpson diversity indices and their associated evenness measure across the farms.

5.6.1 ANCOVA Analysis with Species Diversity Indices

Here I use the calculated diversity indices to examine what variables explain (predict) species diversity on the farms – testing whether there is a relationship between the social (participation) or environmental variables and species diversity. I use Analysis of Covariance or ANCOVA to study the effect of the categorical variable by using it along with the predictor variable and while controlling for other moderating influences. The categorical variable here is participation and the dependent variable is species diversity indices.

I use the calculated Shannon and Simpson indices and their corresponding equitability indices (measuring evenness) as dependent variables in this analysis. For covariates (variables I want to control for), I chose the variables indicated as having a significant relationship with the species composition on the farms from the NMDS analysis. These include: elevation, average slope, distance to town, distance to farm from household, and tree density. I report the results of in Table 5.4 A-D for all the diversity measures. We can see that with all of the dependent variables that participation is not a significant variable. This indicates that participation with the NGO is not able to explain the variability that we see in the species diversity indices

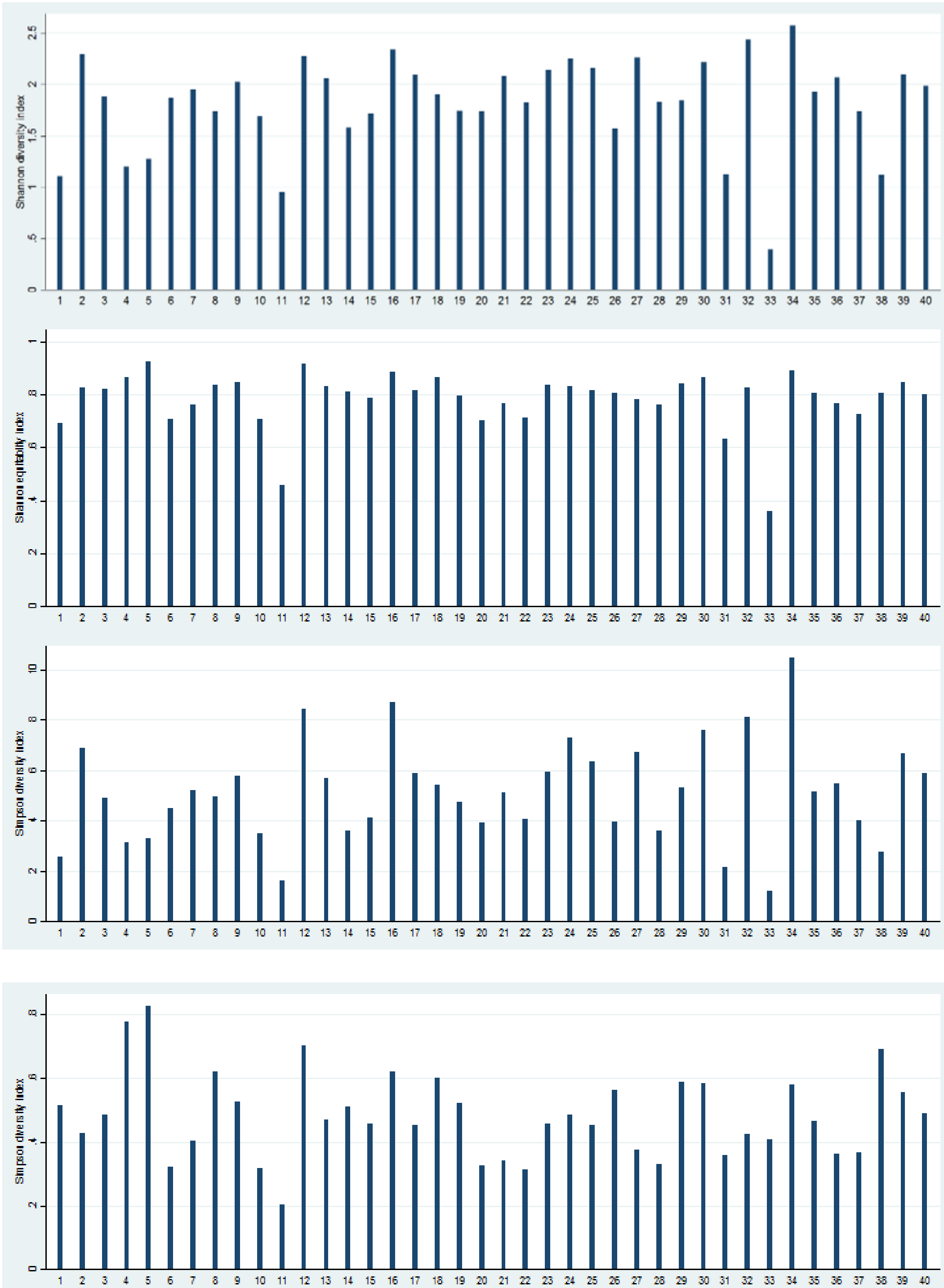


Figure 5.6. Graphs showing the calculated diversity indices for each farm. The farms show considerable variation across each index. Graph 1 is the Shannon's diversity index, graph 2 is the Shannon equability index, graph 3 is the Simpson's diversity index, and graph 4 is the Simpson's diversity index.

Table 5.4. A-D. ANCOVA analysis with species diversity and evenness indices.

A. Shannon's diversity	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Tree Density (Ha^{-1})	1	1.48E+00	1.47502	7.8706	0.00836 **
Elevation (m)	1	1.52E-01	0.15222	0.8122	0.37399
Distance to town (km)	1	0.1303	0.13033	0.6954	0.41032
Time to farm (mins)	1	0.0001	0.0001	0.0005	0.98201
Average slope	1	0.0084	0.00844	0.0451	0.8332
Participation (Yes/No)	1	0.0004	0.00044	0.0024	0.96156
Residuals	33	6.1845	0.18741		
Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1					

B. Shannon's eq.	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Tree Density (Ha^{-1})	1	0.00182	0.001818	0.1378	0.7129
Elevation (m)	1	0.00037	0.000366	0.0277	0.8688
Distance to town (km)	1	0.00256	0.002558	0.1938	0.6626
Time to farm (mins)	1	0.00523	0.005226	0.396	0.5335
Average slope	1	0.00863	0.008629	0.6539	0.4245
Participation (Yes/No)	1	0.00366	0.003664	0.2776	0.6018
Residuals	33	0.43549	0.013197		
Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1					

C. Simpson's diversity	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Tree Density (Ha^{-1})	1	17.265	17.2652	4.2296	0.0477 *
Elevation (m)	1	0.2	0.2002	0.049	0.8261
Distance to town (km)	1	1.355	1.355	0.3319	0.5684
Time to farm(mins)	1	0.097	0.0973	0.0238	0.8782
Average slope	1	0.206	0.2062	0.0505	0.8236
Participation (Yes/No)	1	0.002	0.0016	0.0004	0.9843
Residuals	33	134.706	4.082		
Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1					

D. Simpson's eq.	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Tree Density (Ha^{-1})	1	0.06352	0.063521	3.7669	0.06086
Elevation (m)	1	0.05524	0.055241	3.2759	0.07942
Distance to town (km)	1	0.00015	0.000152	0.009	0.92503
Time to farm (mins)	1	0.00687	0.006872	0.4075	0.52763
Average slope	1	0.00891	0.008909	0.5283	0.47244
Participation (Yes/No)	1	0.01151	0.011511	0.6826	0.41461
Residuals	33	0.55648	0.016863		
Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1					

Table 5.5. A-B. Summary of the linear regression analysis of the two species diversity indices.

A. Shannon's Diversity	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1.261041	0.431901	2.92	0.00627***
Tree Density (Ha^{-1})	0.001115	0.000353	3.164	0.00334***
Participation in years	0.026091	0.019106	1.366	0.18131
Elevation (m)	-0.00015	0.000469	-0.324	0.74782
Distance to town (km)	0.023174	0.02593	0.894	0.37794
Time to farm (mins)	0.002588	0.005642	0.459	0.64953
Average slope	0.002362	0.005982	0.395	0.69545
--- Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1				
Residual standard error: 0.4212 on 33 degrees of freedom				
Multiple R-squared: 0.2637, Adjusted R-squared: 0.1299				
F-statistic: 1.97 on 6 and 33 DF, p-value: 0.0985				

B. Simpson's Diversity	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	4.763322	1.966219	2.423	0.0211**
Tree Density (Ha^{-1})	0.004001	0.001605	2.493	0.0179**
Participation in years	0.165931	0.08698	1.908	0.0652*
Elevation (m)	-0.00225	0.002137	-1.054	0.2997
Distance to town (km)	0.087247	0.118045	0.739	0.4651
Time to farm (mins)	0.013632	0.025687	0.531	0.5992
Average slope	0.013187	0.027231	0.484	0.6314
--- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 1.917 on 33 degrees of freedom				
Multiple R-squared: 0.2113, Adjusted R-squared: 0.0679				
F-statistic: 1.473 on 6 and 33 DF, p-value: 0.2177				

Conducting a linear regression with the two diversity indices and using the number of years a farmer has participated with the NGO rather than the participation (categorical), we see different results. The results show that the number of participation years does have a positive and statistically significant impact on Simpson's diversity index (Table 5.5 A and B). The coefficient of this variable is 1.908 and it is statistically significant at p<0.1. However, this variable does not appear to be statistically significant in the other regression model with Shannon's diversity index, but this could be reflective of the different ways the two indices are calculated.

5.7 Summary

Changes in biodiversity are occurring on the farms due to participation with the NGO. These changes have implications for conservation work and show the potential for contribution of biological corridors as part of an agroecological matrix. However, this depends on the measures of biodiversity. Comparing the presence of families on farms, we saw a greater amount of families (an increase of 50% from non-participating farms) in participating farms. Looking at the farms as a whole in terms of species composition, participation does not seem to be making a difference. However, if we focus on the relative abundance of the genus that the NGO has identified as part of their "best practices," the genus *Inga*, we are able to see the composition on the farms is correlated to the number of years a farmer has been participating with the NGO. Further, the number of years participating with the NGO was also significant when testing the Simpson's Diversity index as a dependent variable in a linear regression. This shows that perhaps the changes in biodiversity due to participation are subtle and take a long time to accumulate to be detected and measured.

Further limited changes that are observed in the species composition of the farms could mean the following:

1. The NGO is not being effective in getting the farmers to plant the trees to the degree that they would like. Relatedly, the NGO could be successful in having the farmers plant the trees on the farms but the practices of the farmers themselves in this region are diverse enough that the additional plant saplings distributed by the NGO are not making a difference in the species composition.

2. The plants are being planted by the farmers but are not going beyond the sapling stage for various reasons. It is possible that not enough knowledge is being transmitted to the farms to help to keep them alive (as observed in the previous chapter that interaction time between the farmer and the technicians tend to be short) or that they are being destroyed by an external mechanism. While speaking with two farmers (Sept. 2014, Oct. 2014), they mentioned planting the seedlings given to them by the NGO. However, they expressed distress over finding their trees indiscriminately slashed by other farmers passing through while swinging their machetes.

Overall, we see some mixed evidence of participation with the NGO making a difference in regards to species composition and diversity. However, the finding that it is the amount of years participating with the NGO that are correlating to the diversity variables indicates that the changes desired by the NGO to create a corridor between remnant forest patches will take a long time. It is interesting to note the variables that were identified during the analyses (farm size, species richness, tree density) have been documented as factors for variation in agroforestry systems (Dhakal et al. 2012).

In the next chapter, I focus on genetic diversity of *Inga oerstediana* across the participating and non participating farms. This is the second type of biodiversity measure that was indicated as being influenced and changed by the NGO in my explanatory framework (Figure 1.1). Further, we have already noted the importance of the Inga genus to the NGO in achieving its vision (sustainable development and decrease pressure on forested areas) in Chanchamayo.

CHAPTER VI

GENETIC DIVERSITY AND VARIATION

Genetic diversity of wild and managed populations contributes to ecosystem stability and needs to be considered carefully, especially as we face global environmental change. This makes understanding the processes that mediate diversity patterns in human-modified landscapes essential for conservation outside protected areas. Similar to knowing little about how species assembly is determined by management practices in tropical agroforestry systems (Chazdon et al. 2009; Livingston et al. 2013), limited studies have dealt with genetic diversity patterns of tropical plants and the contribution of agricultural landscapes towards genetic diversity (Storfer et al. 2010; Manel and Holderegger 2013). Given agroforestry is a significant feature of agricultural landscapes across the globe (Zomer et al. 2009), understanding the diversity present across these areas become important especially for conservation.

As discussed in Chapter 4, the NGO distributes plants and seeds to the farmers as part of their continued agroforestry project. The seeds for the trees are generally sourced from the surrounding areas and shared between farmers, both of which have implications for genetic diversity. We know that farmers make decisions about their land and the planned agrobiodiversity present on the farm. Thus, I seek to answer whether the trees the NGO distributed to the farmers for planting are genetically different from those of other farmers.

In the previous chapter, analysis showed that there was significant difference in the plots for the examined species of the Genus *Inga*. Further, like previously stated the

NGO heavily promotes the use of *Inga* species on the farms as shade as they serve the dual purpose of increasing yield (including restoring soil) and fostering biodiversity (of birds, ants, etc.) in a fragmented landscape. In the mid to late 2000s the NGO in conjunction with scientists from universities in Lima and the UK conducted a study, on which *Inga* species was the best for alley cropping[9] and on coffee farms in terms of the leaf litter. The brief test indicated that *Inga oerstediana* is better in the amount of shade, leaf litter, and length of viability on the farms (especially at the elevation of this area), especially compared to *Inga edulis* (often used as a shade tree in coffee and cacao farms in other locations).

In this chapter, I present the genetic characteristics of tree samples sourced from a subset of the farms selected for species level analysis (Figure 6.1). I compared the genetic patterns of samples collected from participating farms, non-participating farms, and non-farm areas to assess whether participation in the NGO's program has impacted the patterns of genetic diversity of *I. oerstediana* in a fragmented landscape. The NGO is likely changing the population structure of this species in the farms by changing the way the seeds and seedlings have been shared between the farmers. Though a few studies have examined the genetic diversity patterns resulting from reforestation efforts and compared planted and "natural" stands (Dawson et al. 2008, do Cruz Neto et al. 2014), however, studies have yet to consider differences due to management practices (and the role of organizations).

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[9] A method where trees are planted in widely spaced rows, allowing for a reduction in soil erosion and restoring of degraded soils while also possibly leaving room for crops to be planted in between rows.

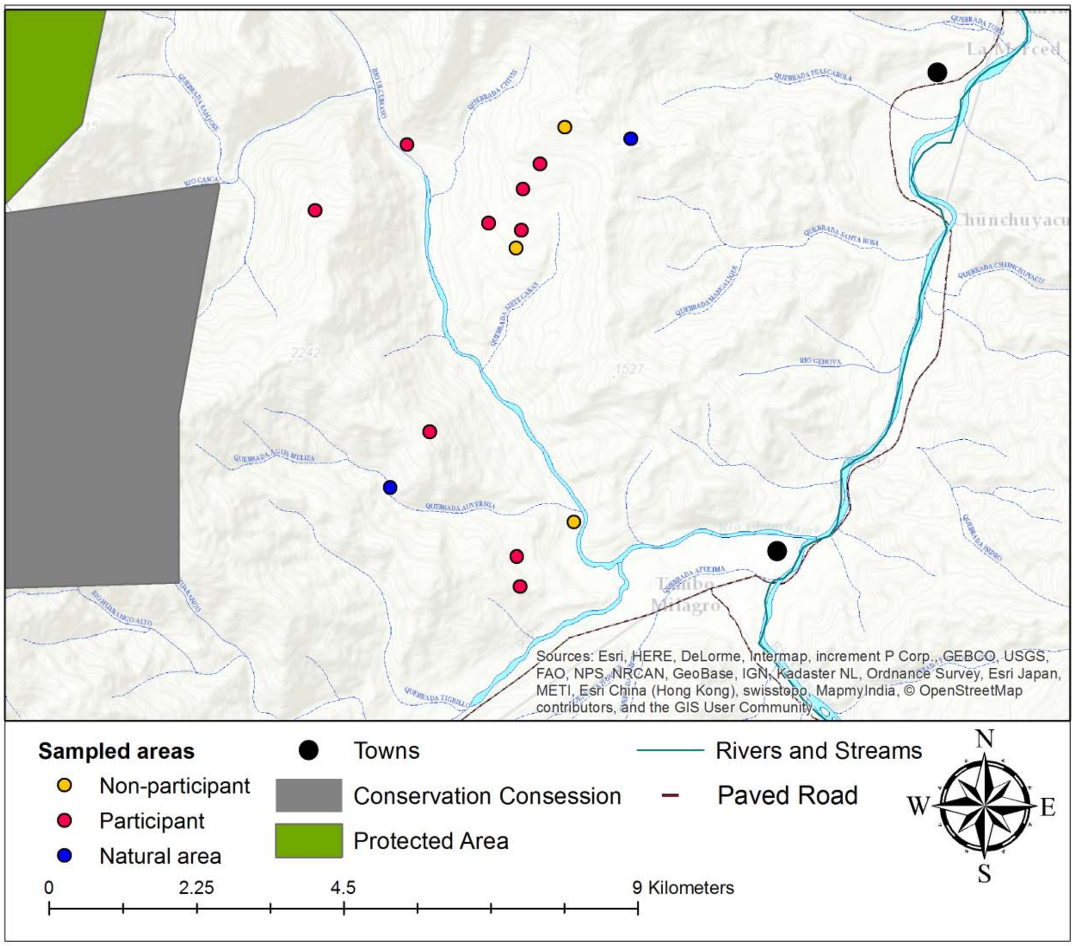

Figure 6.1. Map of sampled populations (farms). The colors of the points indicate the type of area (participating - red, not participating - yellow, and non-farm area - blue).

6.1 A Geographical Approach to Genetic Analysis

In a paper in 2003, Manel et al. described Landscape genetics as a subfield that combines Landscape Ecology and Genetics. Since then, the field has rapidly evolved especially with the help of advances in geo-computational abilities, modeling, GIS, and Next-Generation Sequencing. Over the past decade these advances have made it possible for us to understand and associate environmental and landscape features to the process and patterns of gene flow and local adaptation (Manel and Holderegger 2013). As Storfer et al. (2010) stated, many landscape features/variables have been studied, but there are only a few generalities, and effects of landscape variables vary among species. Landscape variables that have been examined and documented to influence gene flow includes elevation, ridgelines, topographic relief, rivers, regenerated habitats, deforestation, agricultural development and damming (e.g., Goldizen et al. 2009; Murphy et al. 2010; Castilla et al. 2016). Storfer et al. (2010) also highlighted the need for species-specific studies. In addition, there have also been limited studies of tropical trees within landscape genetics (Storfer et al. 2010; Manel & Holderegger 2013).

In terms of conservation, landscape genetics offers the potential to support management decisions by providing understanding of dispersal, fragmentation, functional connectivity and the effectiveness of connectivity measures (Holderegger et al. 2008, Segelbacher et al, 2010, do Cruz Neto et al. 2014).

6.2 Inga Oerstediana

Inga oerstediana is a member of the species rich Leguminosae (Facaceae) family that represents about 16% of woody species in Neotropical forests (Burnham and Johnson 2004). *Inga* is a large genus that diversified within the last 2-10 million years and consists of approximately 300 species (Richardson et al. 2001). Many of the species have multiple uses on local farms, with at least 33 that are used as shade trees for perennials in agroforestry systems (Lawrence et al. 1995). *Inga* is able to withstand acidic soils (Hands 1998). The *Inga* genus has a widespread distribution across South America and has been semi-domesticated over a long period of time for its edible pods (Pennington 1997, Dawson et al. 2008). *I. oerstediana* is mainly used as a shade tree, for its edible fruits, fertilizing effect via leaf litter, and sometimes for its soil rehabilitation abilities.

Previous studies examining genetic diversity in an agroforestry system in lowland Peruvian forests utilized *Inga edulis* present on cacao farms as the focus species (Hollingsworth et al. 2005, Dawson et al. 2008, Dawson et al. 2009). There have been no genetic studies specifically on *I. oerstediana* thus far. However, Hanson (1995) carried out a brief study of 17 *Inga* species and their associated chromosome counts. Hanson (1995) found that *I. oerstediana* is a diploid organism with a total of 26 chromosomes, like most of the 17 species she tested.

The main pollinators for this species include bees, butterflies, other insects, and hummingbirds. *I. oerstediana* is a hermaphroditic flowering species, producing both male and females parts on the same flower (Koptus 1984, Bawa et al. 1985). Fruits of this tree are approximately 20 cm in length and 1cm in diameter, in which seeds are surrounded by a sweet, white pulp. *Inga* trees produce many flowers to attract pollinators but due to self-incompatability, fruit set will occur only when pollinated by pollen from another individual to prevent inbreeding (Koptur 1984). Dispersal of seeds usually occurs by animals that eat the pulp (Koptur 1984, Pennington 1997).

6.3 Sample Collection

For genetic analysis, I collected samples of *Inga oerstediana* from 12 of the 40 farms selected for vegetation plots. Nine of them participated in the NGOs agroforestry program, and three did not. In addition, I also collected samples from two non-farm areas, where I was sure that the trees would not have been planted, thus brining my sampled areas to 14 (Table 6.1). I followed a sampling approach similar to Dawson et al. (2008), who carried out their study with another *Inga* species in the lower Peruvian Amazon area.

Table 6.1. Summary of sampled areas.

Sampled area	Average elevation (m)	Side of river	Type of area
1	1219	East	Participating
2	1323	East	Participating
3	1349	East	Participating
4	1564	West	Participating
5	883	West	Non participating
6	1251	East	Non participating
7	1850	West	Participating
8	1066	West	Participating
9	1389	East	Non-farm
10	1453	West	Non-farm
11	1277	East	Participating
12	1524	East	Non participating
13	1108	East	Participating
14	1172	West	Participating

I collected a total of 344 cambium samples with ~25 individuals from each farm except for one farm, where I was able to collect only 21 samples, and I collected 31 and 27 samples from each of the non-farm areas. Given the location of the farms in a humid area and quick changing weather, I lost 20 of the collected samples due to mold growth on the cambium. This was most likely the result of the high humidity conditions, which were difficult to avoid, especially at higher elevations. Thus, I had a total of 323 cambium samples for DNA extraction and sequencing.

In Table 6.2 below, I report summary statistics of the diversity indices and some variables of farms from where I collected the genetic data. One can see that the farms that were sampled for genetic materials are similar to the remaining 28 farms sampled for vegetation census (Chapter 5) in terms of the environmental variables.

Table 6.2. Summary statistics for the subset of farms that were selected for genetic sample and the remaining farms

	Sampled for genetic analysis					
	Non-participants (N=3)		Participants (N=9)		Remaining (N=28)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Shannon div. index	1.96	0.22	1.87	0.43	1.80	0.48
Shannon eq. index	0.80	0.08	0.75	0.13	0.79	0.10
Simpson div index	5.65	1.78	5.15	2.16	5.04	2.01
Simpson eq. index	0.50	0.16	0.42	0.14	0.50	0.13
Elevation	1219.33	321.67	1325.33	246.08	1252.64	234.99
Average slope	15.46	3.92	16.14	8.70	29.73	12.31
Distance	10.03	4.68	9.45	4.59	7.58	4.60
Minutes to town	55.00	35.00	57.78	23.47	47.86	26.23
Participated years	0.00	0.00	5.89	6.11	2.93	3.15

6.4 Genetic Marker Development

After sending the extracted DNA from the 323 cambium samples to the TAMU AgriLife Genomics and Bioinformatics lab for sequencing, I received raw sequence files for each of my samples. The sequence alignment and variant calling were performed by Texas A&M Institute for Genome Sciences and Society (TIGGS) following standard GBS protocol. TIGGS used a dDocent pipeline (Puritz et al. 2014) to align reads, and then, SNPs were called using the FreeBayes software in the pipeline to generate a VCF file with raw annotated sequences ready for filtering. From the sequencing and alignments, there were a total of 441,844 assembled sequences with 411,331 SNPs. I excluded all other types of variant called in the sequence (insertions, deletions, multi-nucleotide polymorphisms.), resulting in a SNP only dataset. I removed one individual after my initial filtering based on *phred* score (>30), as it was not sequenced for 95% of the identified SNPs, leaving a dataset with 322 individuals and 306,698 SNPs. The SNPs were further filtered for biallelic SNPs with a coverage of 3X and a minor allele frequency of greater than 0.05.

Table 6.3. Record and SNP counts before and after filtering.

Count type	Raw Dataset	Filtered dataset
Samples	323	308
SNPs	411331	5059
MNPs[*]	51875	0
Insertions/deletions	30262	0
Others	10181	0

* Multi-nucleotide polymorphisms

In filtering the SNPs further, I removed SNPs that failed to be sequenced in more than 5% of the individuals. I also filtered out individuals (N=15) that were missing more than 15% of the SNPs. This left a dataset with 6,191 SNPs and 308 individuals for genetic analysis (Table 6.3). Filtering of the SNPs is an essential step for downstream genetic analysis, as it seeks to remove inaccurately called SNPs/sequences, and the allele frequency filtering removes any rare alleles from the dataset. Using Bayescan 2.1, I filtered out 1,132 SNPs found to be under selection based on an outlier F_{ST} analysis (Foll and Gaggiotti 2008).

6.5 Statistical Analysis and Results

To examine and test the genetic characteristics of the *Inga oerstediana* across the farms and non-farm areas, I compare genetic measures of the different sampled locations. I first calculate various measures of genetic diversity (Shannon's and Simpson's diversity indices), treating each sampled area as a population to check for differences and test whether the population structure observed is significant. Then I test whether the population structure measured by genetic distance can be due to isolation by distance (Euclidian) using a Mantel test. Further, to examine and assess the observed population structure, I utilize discriminant analysis of principal components (DAPC). Lastly, I use a *k*-means Bayesian clustering algorithm and the fastStructure software to infer populations/groups given the genetic variation of the individual specimens.

6.5.1 Measuring Genetic Diversity

Genetic diversity was measured in the different sampled areas. The results are reported in Table 6.4 for each of the sampled areas. We can see small amounts of variation in the Shannon-Weiner and Simpson's Diversity indices across the different sampled areas. We also see variation in expected heterozygosity (H_e) across the sampled areas and the types of sampled areas (Table 6.5). Moreover, we see that the observed heterozygosity is greater than the expected heterozygosity for each sampled area and type of sampled area, indicating the possibility of mixing populations that were previously isolated. In this case, it would be indicative of individuals on farms mixing with other individuals from other farms and the non-farm areas. The expected and observed heterozygosity values from the types of sampled areas shows us that participating farms have slightly higher values compared to non-participating farms but non-farmed areas have the highest values. This indicates that there is higher genetic variability in the non-farm areas and participating farms compared to the non-participating farms.

We see little difference in the two calculated genotypic diversity indices from one population to another. We also observed low F_{ST} values; this is because most of the genetic variation is present within populations (for life traits such as height) rather than between populations (Petit and Hampe 2006). However, tropical trees do tend to have more genetic differentiation than temperate or boreal trees (Krutovsky et al. 2012). Though it is only a small portion of overall genetic variation, genetic differences between populations are indicative of population structure[10] and possible restrictions to gene flow. I calculated an unbiased F_{ST} between sampled areas (F_{ST} = 0.095, p-value=0.001), which indicates some structuring between the areas. Further, calculating F_{ST} values for each type of sampled area separately (Table 6.5), we can see that the genetic differentiation varies from 0.089 (participating) to 0.154 (non-participating), with natural non-farm areas having an F_{ST} value closer to participating farms (0.091). This indicates that there is higher population structure among the non-participating farms compared to the participating farms and non-farms areas; meaning that there is less gene flow between non-participating farms. The higher Fst and the lower observed heterozygosity in a self-incompatible species can indicate that in the non-participating farms, there has been genetic drift that has been acting on the species

[10] Subdivisions among the individuals which can allow them to evolve apart, independently

Table 6.4. The genetic diversity for each of the sampled areas for the filtered dataset.

Pop	N	Shannon-Weiner Diversity index	Simpson's Diversity index	H_e (expected heterozygosity)	H_o (observed heterozygosity)
1	25	3.2189	0.9600	0.2322	0.2917
2	25	3.2189	0.9600	0.2223	0.2758
3	20	2.9957	0.9500	0.2179	0.2449
4	25	3.2189	0.9600	0.1716	0.2248
5	25	3.2189	0.9600	0.1987	0.2471
6	15	2.7081	0.9333	0.2046	0.2648
7	21	3.0445	0.9524	0.2048	0.2340
8	25	3.2189	0.9600	0.2178	0.2830
9	21	3.0445	0.9524	0.2115	0.2731
10	18	2.8904	0.9444	0.2273	0.2770
11	25	3.2189	0.9600	0.2264	0.2692
12	18	2.8904	0.9444	0.2127	0.2659
13	20	2.9957	0.9500	0.2329	0.2919
14	25	3.2189	0.9600	0.2016	0.2383
Total	308	5.7301	0.9968	0.2170	0.2630

Table 6.5. Expected and observed heterozygozity and FST for each type of sampled area.

Type of area	He	Ho	Fst (p-value)
Participating	0.214167	0.261499	0.089 (0.001)
Non-participating	0.205333	0.259253	0.154 (0.001)
Non-farm	0.2194	0.275081	0.091 (0.001)

6.5.2 Genetic Diversity and Distance

In order to examine whether the genetic differentiation observed across the sampled areas is a result of the geographical isolation between the areas, I performed a Mantel test using a pairwise F_{ST} calculated for each pair of sampled area. F_{ST} is a measure of differentiation between populations due to different allele frequencies in these populations (genetic structure). It can be calculated for any number of populations. In this test it is calculated for each pair of populations and used as a genetic distance between these populations. A pairwise matrix of geographical distances in kilometers between the areas was also created based on recorded GPS coordinates. GenAlEx was used to estimate pairwise F_{ST} values between populations, and the *vegan* R package (version 2.3-4) was used to run the Mantel test. The Mantel test statistic, *r*, can range from -1 to +1, where values close to -1 indicate strong negative correlation and +1 indicate strong positive correlation. An *r* value of 0 indicates no correlation.

This test allows for testing the hypothesis that population differentiation is due to isolation by distance. If genetic drift in combination with partial isolation is a main factor driving population differentiation, then a positive significant correlation is expect between genetic (F_{ST}) geographic (km) distances. For example, the connectedness or the limited distance of pollen dispersal from one sampled area to another of *Inga oerstediana* could explain why one area differs genetically from another. This would indicate spatial patterns in genetic variability due to factors such as genetic drift and isolation by distance.

The correlation statistics, Pearson's and Spearman's, correlation coefficients were calculated in this Mantel test. Both correlation methods were used as they test for different relationships in the correlation; Pearson's tests for a linear trend while Spearman's tests for a monotonic trend. For my samples, the computed Mantel statistics for both correlation methods were not statistically significant (Table 6.6). Further, examining the Mantel statistic *r* for both correlation methods, we see that the values (0.1231 and 0.2153) are close to zero indicating a weak but not significant correlation. The test showed us that genetic distance did not correlate with geographical distance; the genetic differentiation between sampled areas did not follow geographical distances between them. This indicates that samples closer together were not significantly more similar than those farther away. The results of this test indicated that the population structure or the genetic variation is not due to the linear spatial processes.

Table 6.6. Results of Mantel test.

Correlation method	Mantel statistic *r*	p-value	Permutations
Pearson's	0.1231	0.2165	10000
Spearman's	0.2153	0.1076	10000

6.5.3 Determining Number of Populations

To test the number of distinct clusters or groups contained in the 14 areas sampled for genetic analysis and thus infer population structure, two different approaches were used, and their results were compared. First, I used a multivariate method, discriminant analysis of principal component (DAPC; Jombart et al. 2010, Grünwald & Goss 2011) with the sampled areas as the identifiers of populations, and second I use a *k*-means clustering algorithm and a Bayesian clustering approach (fastStructure) to examine inferred populations from the sampled individuals (Pritchard et al. 2000, Raj et al. 2014).

6.5.3.1 Discriminant Analysis of Principal Component (DAPC)

DAPC was first used by Jombart et al. (2010) to infer the number of clusters of genetically related individuals. Similar to using NMDS with species level data in Chapter 5, using multivariate approaches, such as DAPC, to examine genetic diversity depends on constructing synthetic variables as combinations of alleles. This approach allowed us to analyze individual data to describe and identify populations or large genetic clusters. The DAPC approach optimizes variance between clusters and minimizes variance within clusters by seeking synthetic variables that would infer differences between clusters as best as possible while minimizing variation within clusters. DAPC first uses principal component analysis (PCA) to transform the data and then uses discriminant analysis to identify clusters. I utilized the *adegenet* R package (version 2.0.1) to perform the DAPC.

DAPC was run with the filtered SNPs with the sampled areas denoted as populations. The first step of DAPC transformed and retained 50 principal components into uncorrelated axes with 13 (total number of sample areas - 1) discriminant functions. The number of principal components was selected based on cross validation. A scatter plot of the results shows that many of the denoted populations cluster together (Figure 6.2). We are able to see that one area (population 4) is very distinct from the rest. The remaining areas group into 2 major clusters, with populations 3, 7, and 10 falling outside their respective clusters. The cluster to the bottom right of the graph consists of populations 14 and 5 overlapping; however population 7 overlaps only slightly. Thus, I would say there are a total of 6 identified clusters by DAPC. None of the clusters we see are directly explained by variation in elevation, soil type, or aspect.

The clustering we see can be partially explained by participation in the NGO program. The farmers of the two populations that cluster out, 3 and 4, are both recently (about 2 years at the time of the interview) enrolled in the NGO program. Upon enrollment, both received plants of *I. oerstediana*. Of the other participants, the farmer of population 11 also received *I. oerstediana* from the NGO program; however he received them in the late 2000s, where the seeds were most likely sourced locally. The farmer of population 7 is also a participant in the NGO program, but he has not received any *Inga* plants from the NGO program at the time when specimens were collected. Rather he stated that he was able to get them from an area at a slightly lower elevation[11]. Farmers of populations 1, 2, 8, 13 & 14 are also participants but had not received any *Inga* by the time the samples were collected (populations 1, 2, & 8 received them within a year of the interview). The rest of the populations belong either to the non-participating farmers (5, 6 & 12) or represented non-farm areas (9 & 10).

Sampled populations 1, 2, 6, 8, 11, 12, & 13 along with 9 (non-farm area) clustered together towards the top of the graph. These populations (except 11) are either non-participating or have not received *I. oerstediana* seedlings from the NGO. Further,

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[11] Even if the farmer obtained the plants for a slightly lower elevation, it would be still the highest among all the sampled areas, except for some individuals from population 10 (a natural area).

many of the farms belong to the farmers residing in the same or close by villages, with the exception of population 8. So the resulting structure is most likely due to the historical background that all of the individual farms were once part of a large hacienda, because the farmers share seeds, or there is gene flow between these areas without any resistance. It seems like individuals from the non-farm area, population 9, are similar to these farm populations, while the other non-farm area, population 10, is different, as there is no overlap.

Populations 5 and 14 that overlap significantly are that of a non participant and participant farmer, respectively. However, the most likely reason for the similarities between the two populations is due to either the shared historical background or they sourced the seeds from the same place.

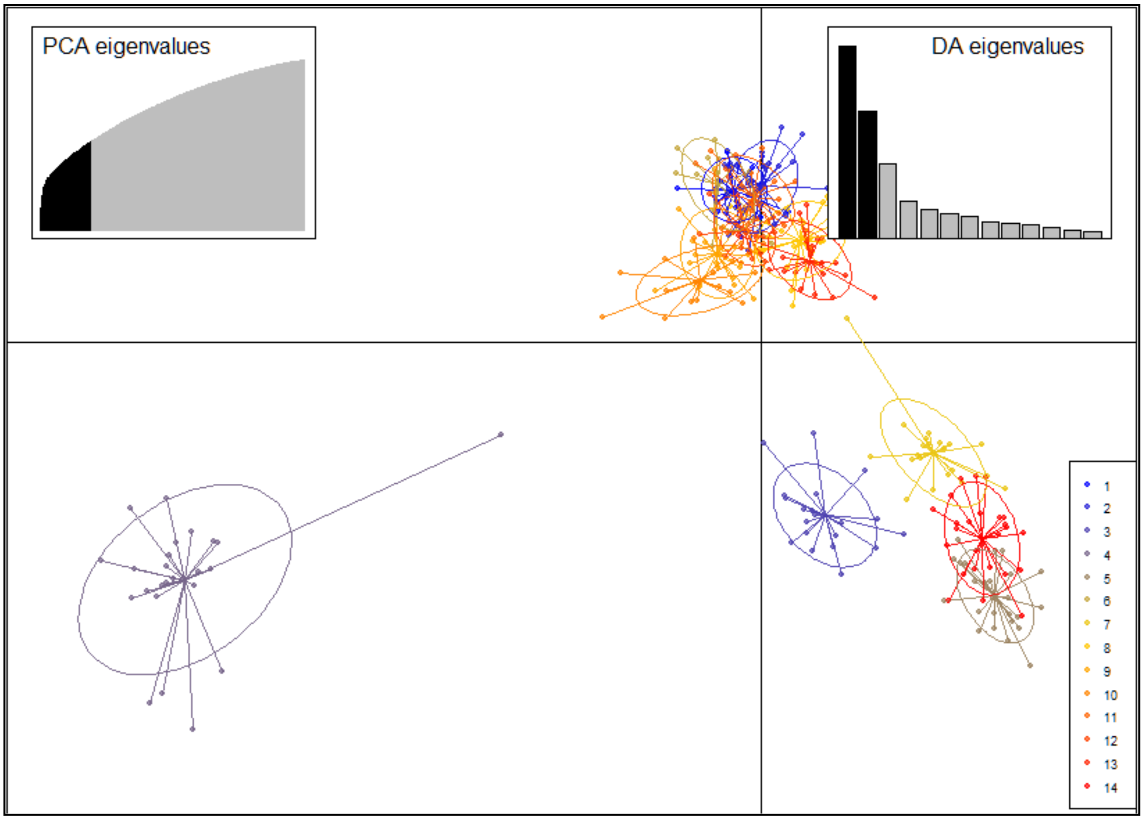

Figure 6.2. Scatterplot of individuals on the first two principal components of DAPC. In the graph, dots represent individuals and the ellipses encircle populations. The insets show PCA and DA eigenvalues.

Overall, the DAPC analysis shows that through recent participation in the NGO program, the genetics of *Inga oerstediana* has changed on certain farms. It is likely that the NGO sourced at least some of its seeds or seedlings from other locations outside of this immediate area. The other possibility for the divergence we see with population 4 is that the seed(lings) were obtained from fruits of the small area of *Inga oerstediana* planted by the NGO approximately at a 10 km distance from the sampled farms. Most likely these seedlings from this more distant area could be the result of the planted trees having mixed (outcrossed) with the local population.

6.5.3.2 Inferred Clusters

To identify clusters or groups of more closely related individuals without giving any prior information, I utilized a *k*-means clustering algorithm using the *find.clusters* script in the *adegenet* R package (Jombart et al. 2010) and the fastStructure software (Raj et al. 2014). Both methods group together individuals that are genetically similar into the clusters. These two methods allowed me to find the optimal number of clusters/groups in the samples. Both these approaches work similarly, where the number of tested clusters *K* is set and run sequentially with increasing number of potential *K*. The associated score (Bayesian Information Criterion (BIC) for *k*-means clustering and log-marginal likelihood scores for fastStructure) for each *K* is compared and the optimal clustering solution, ideally corresponding to the lowest score (indicated by an "elbow" in the curve of the scores as a function of *k*), should be picked as the optimal number of clusters.

The algorithm in the *find.clusters* script is similar to the DAPC but without the populations (sampled areas) being flagged (indicated) a priory. The run was completed with 75 principal components retained, and the lowest BIC value was for *K*=6 (six clusters). By plotting the individuals in the inferred groups ("Inf 1," "Inf 2," etc. in Figure. 6.3) against their original populations ("ori 1," "ori 2," etc.) we can compare their genetic assignments with their origin (locations). One can see that the majority of individuals from population 4 remained together and were assigned to the inferred cluster 3, with no other sampled populations contributing to this cluster. This indicates that this group is genetically distinct from the others. Individuals from population 3, which had also stood out as distinct in the earlier analysis, were assigned to all different inferred clusters except inferred clusters 1 and 4. Original populations 7 and 10 also had clustered out in the previous analysis. Here we see that each of these populations is split into various clusters. Examining inferred cluster 4 and the individuals from populations 3, 7, 10 and 12 grouped into this cluster, one can conclude that this group most likely correlated with elevation based on populations that composed this inferred group. Further, populations 5 and 14 also grouped together with a few individuals from populations 3 and 7 into inferred cluster 5.

Further, upon examining the individual assignments into inferred clusters 2 and 6, one can see that many individuals from populations from the East side of the river grouped into cluster 6, while many individuals from populations from the West side of the river grouped into cluster 2. However, it is also important to note that individuals from these populations are being assigned to these two groups, though not at the same ratio. This indicates that there is a small amount of differentiation caused by the river, but there is also gene flow between the two areas. Even the non-farm areas were grouped into inferred clusters 6 (all individuals of sampled population 9) and 2 (about 2/3 of the individuals from sampled population 10), respectively based on the side of the river.

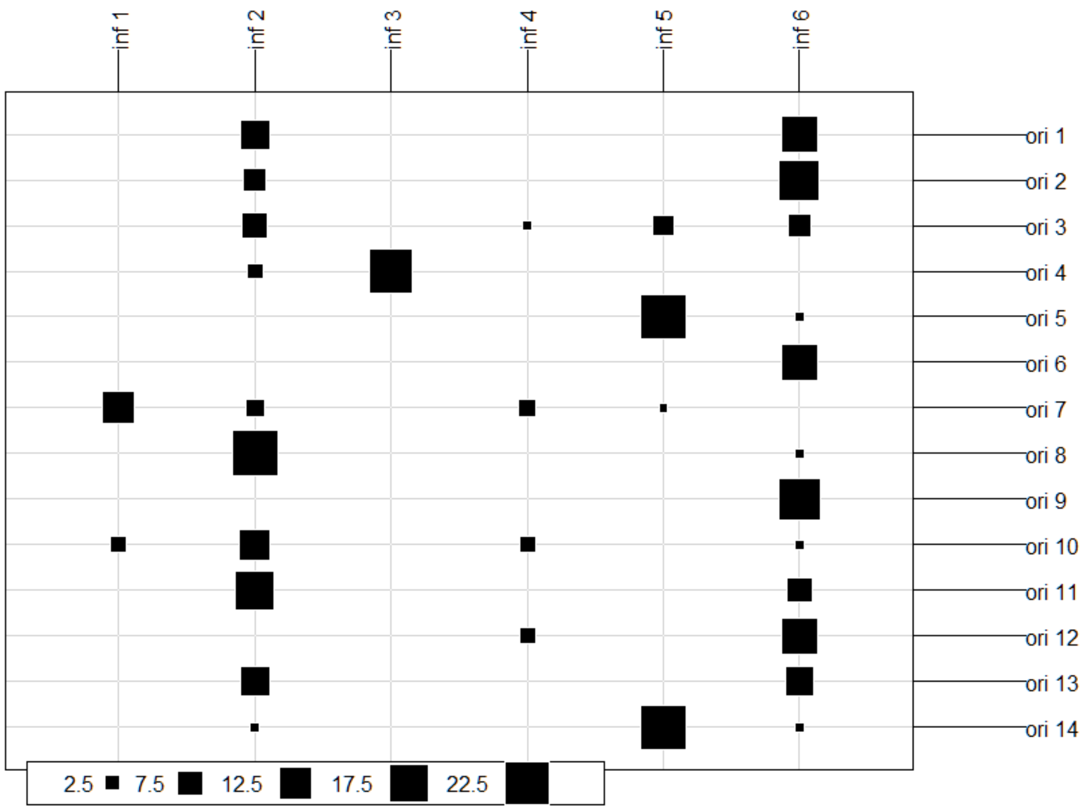

Figure 6.3. Plot showing the origin of individuals from original sampled populations (ori 1, ori 2, etc. on the *y*-axis) assigned to the new inferred clusters (inf 1, inf 2, etc. on the *x*-axis).

Running a DAPC (keeping 75 principal components) and creating a scatter plot of the individuals based on their new cluster designations, one can further see which of the inferred populations are more closely related than the others (Figure 6.4). Inferred clusters 3 and 4 were very distant from the remaining 4 clusters. Inferred cluster 1 is also a little distinct from the other clusters – 2, 5 and 6, which overlap together. From the inferred clusters based on genetically similarities, we see that there is some evidence of genetic variability due to geographic and landscape variables.

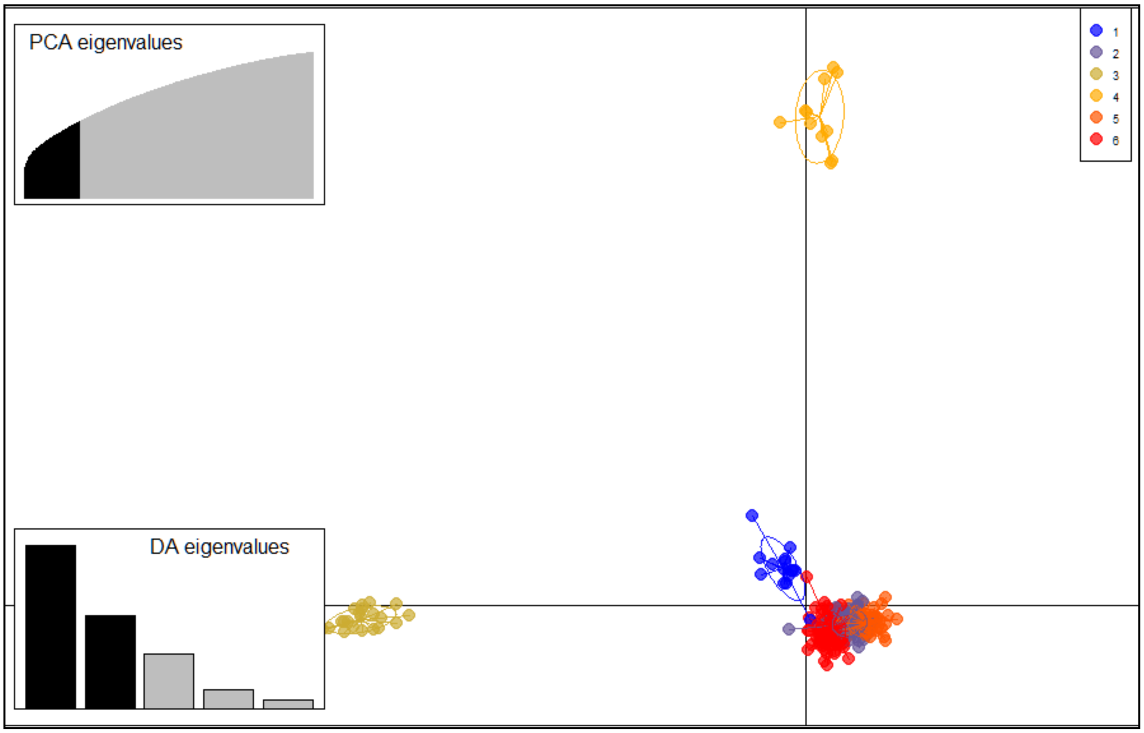

Figure 6.4. Scatter plot of individuals on the first two principal components of DAPC assigned to the six clusters inferred using *find.clusters* script in the *adegenet* R package. In the graph, dots represent individuals and the ellipses represent groups. The insets show PCA and DA eigen values.

Lastly, I analyzed the genetic dataset using the fastStructure software with the Bayesian clustering approach to determine population structure. By testing for the possibilities of 1 to 14 clusters (*K*=1, 2, … 14) within my data using the standard model with a simple prior[12]. The fastStructure software performs iterations for each *K* automatically. I then used the chooseK.py function of the software to determine which range of clusters (*K*) works best for this dataset (chooseK.py outputs a range of possibilities for the optimal *K*, the decision is then made based on looking at bar plots for the suggested number of clusters and species history). The algorithm determined that four, five, or six clusters (*K*=4, 5, or 6) would be the most likely number of clusters to explain the structure in the dataset based on maximized log-marginal likelihood.

The individual assignments for *K*=4, *K*=5 and *K*=6 are presented in Figure 6.5, where each color representing a cluster (four colors for *K*=4, five colors for *K*=5 and six for *K*=6, respectively) and assigned as genetic admixtures for each individual by the software, and the while dotted lines are demarking the original populations based on areas that were sampled. One can see that the population 4 was also identified by fastStructure as a distinct cluster regardless of the number of clusters. The original populations 1, 2, 11, 12, and 13 were very similar, and all of them are present on the East side of the river. Further, the original population 3 is a very much admixed population, containing individuals with admixtures from multiple different clusters within each individual.

[12] fastStructure has the option for two prior distributions over allele frequencies: simple and logistic prior. A simple prior has a “flat beta-prior over population-specific allele frequencies at each locus.” While at a given locus with the logistic prior “the population-specific allele frequency is generated by a logistic normal distribution, with the normal distribution having a locus-specific mean and a population-specific variance” (Raj et al. 2014).

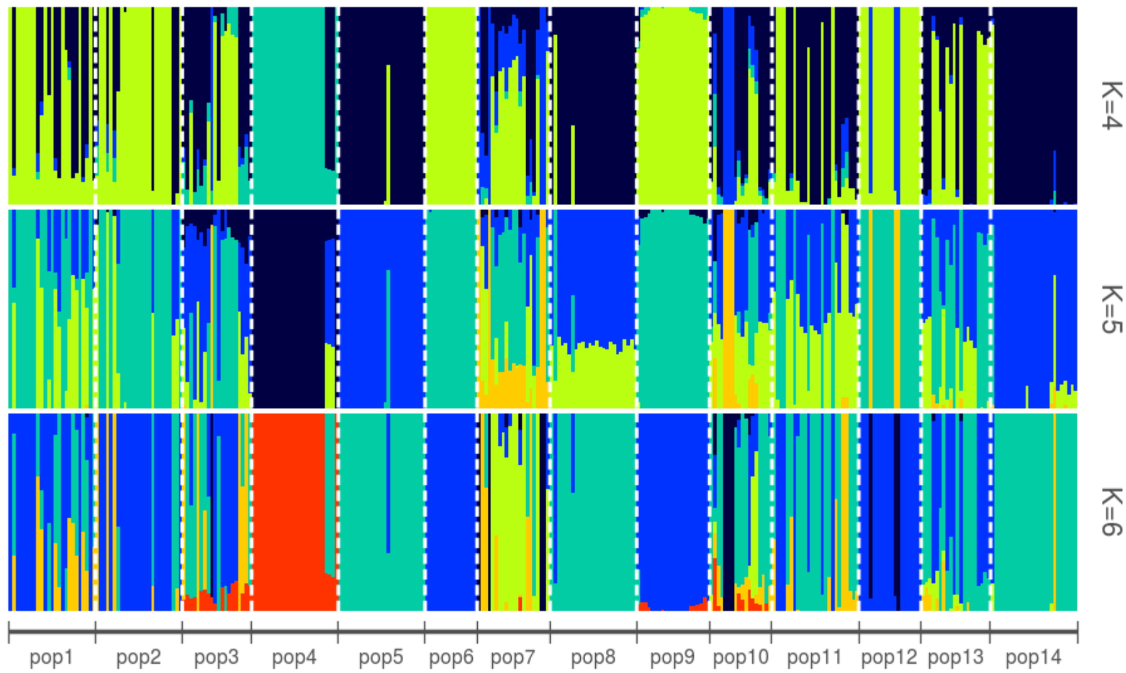

Figure 6.5. Bar plot showing genetically inferred clusters by fastStructure and their distribution across the sampled areas.

6.6 Isolation by Distance and by Resistance

Isolation by distance and isolation by resistance are two commonly used landscape genetics approaches. Generally, geographical distance is used to determine if population structure is due to isolation by distance. In case of *I. oerstediana* in this region, the Mantel statistic showed that geographical distance did not correlate with the genetic differentiation observed between the sampled areas. Further, analysis using DAPC showed that the clustering of sampled populations was not in consensus with distance between populations because one can see overlap between distant areas. In addition, the clustering pattern of the sampled populations cannot be easily explained by soil type, elevation, or aspect.

However, when the geographic information regarding the location of sampled populations was not used in cluster analysis, and the grouping of genetically similar individuals into the clusters was allowed without considering their original population assignment, a different pattern emerged. We saw that most of the individuals that were sampled from closer locations were clustering together, and that most of the individuals sampled on each side of the river tended to cluster together (especially for individuals from the East of the river). Moreover, some individuals collected from farms at the high elevation also formed a cluster on their own. This indicates that there is gene flow among the sampled areas, whether it is through pollination or seed exchange between the farmers.

The genetic variability that we see on the farms can be explained by the actions of the farmers and the NGO program. Farmers, as managers of their farms, monitor and regulate what is allowed to go on the farm. We know that farmers are selective and have preferences as to what species they will allow to grow, and they maintain those preferred species (Albertin and Nair 2004, Soto-Pinto et al. 2007, Souza et al. 2010, Anglaaere et al. 2011, Valencia et al. 2015). Regarding shade species farmers have a clear preference for *Inga*. However, timing and need play large roles in whether a new individual tree will be allowed to stay on the farm. If there is no opening on the farm that requires shade, or no an older tree that requires to be replaced, the seedling that arrived by chance (on to an area that is suitable for its growth) will be eliminated from the farm. Also, when a farmer requires an *Inga* seedling but none are present on the farm (that have come up naturally from existing trees or if the trees are not fruiting), then the farmer must look outside the farm - borrowing or purchasing seeds from neighbors or nurseries. Also, the calculated F_{ST} values for each of the sampled areas indicate that there is less connectedness or sharing of genetic material among the non-participating farms (which show higher F_{ST} value) compared to the participating farms (which have lower F_{ST} value).

These decisions and management practices of farmers can be viewed in terms of resistance for genetic isolation on the farms. Whereas in a traditional landscape genetics approach of isolation by resistance, you would consider habitat suitability of the species, here we need to consider the farmer as being the basis for resistance of gene flow on the farms, especially given the scale of the study. Based on need and timing the farmers would be considered as a resistance to the establishment of any new plants of *Inga* on their farms (and thus potential new genetic material). However, should there be a tree that is dying, or if they would like to replace the existing individual with another, then there would be ease of gene flow due to the fact that individuals or seeds from other locations are being planted on the farms. Thus, genetic diversity and gene flow in a landscape with farms would depend on the farmers.

In case of the NGO program and participating farms, we see *I. oerstediana* individuals that are distinct from those present in the region being planted. The individuals most likely originated from outside this immediate zone of gene flow. Though the NGO claims to obtain their seeds from around this area, they do often bring materials from other places. For example, Villa Rica, Pasco is a nearby town (approximate travel time of 2-3 hours) with a large amount of coffee production. The NGO employees often visit the area for other projects they carry out but also to purchase coffee seeds and other materials. It is possible that they obtained some seeds or seedlings of *I. oerstediana* and brought them back to Chanchamayo for planting. Or the NGO has distributed seeds that are a result of outcrossing. The sampled areas 3 and 4 are perhaps a good indicator of two scenarios in regards to the genetic diversity shifts due to farmers choosing to participate with the NGO. In the first case with sampled area 3, we see that there is a greater diversity among individuals when it is divided into the 5 of the 6 inferred populations. This is perhaps an indicator that the NGO obtained seeds from various locations and then distributed them to the farmers, making each farm more diverse than before, at least initially. In the second case with sampled area 4, most of the individuals here are similar to each other and cluster together, with a few individuals being assigned to another inferred population. Not many of the individuals sampled in this study resemble the ones found here, indicating that perhaps they were not from the local area.

Considering farmers as playing a role in isolation by resistance and shaping the genetic diversity and the landscape is important. The role of farmers in determining genetic diversity and gene flow is present in the literature. A study examining genetic structure in goats showed that the farmers' connectivity via their ethnicity, spatial distribution and husbandry practices significantly correlated to genetic differentiation (Berthouly et al. 2009). Moreover, the role that farmers' networks play in seed exchanges that ultimately determine the diversity present on farm, and on farm conservation has been recognized as important (Thomas et al. 2011, Pautasso et al. 2013).

Ultimately, this analysis shows that the distinction between “natural” (non-farm) and “planted” for species such as *Inga* is not sufficient to understand genetic differentiation observed in the present farms. Understanding farmer practices, exchange networks, and the presence of outside factors, such as organizations, is crucial to understanding how conservation and development efforts can manipulate and change genetic diversity patterns.

CHAPTER VII

TYING IT ALL TOGETHER

So far, the previous chapters in this dissertation have examined participation with NGO in terms of resources, species diversity, and genetic diversity individually. Here, the main goal of this chapter is to synthesize the findings of chapters 4, 5, and 6. In this chapter, I test whether there is any relationship between the trends we see across the different chapters of the work of the NGO in Chanchamayo. There is specifically one question that I would like to return to and focus on in this chapter: what are the changes in biodiversity as a result of changing agroforestry farming practices? Thus, ultimately, I want to answer the question: is there any relationship or correlations that we can see between participation, time spent with farmers (knowledge distribution patterns), species diversity on the farms, and genetic diversity on the farms of the participating farmers.

Building on previous chapters, the premise here is that for farming practices to be changed, the knowledge of the practices has to be distributed to the desired audience before it can be expected to be implemented. Thus, time spent with farmers would be indicative of changes in management practices and biodiversity if they are participants.

7.1 Species Diversity and Technician Time Spent

In order to answer the question about the relationship between changing practices and biodiversity, I explore the relationship between species diversity and time spent with the farmer by the technicians using multiple linear regressions. I use measures of species diversity (diversity indices) as the dependent variable to test for any effects of the NGO on biodiversity. I also add total time spent as an additional variable into the NMDS analyses from Chapter 5, to examine the relationship in another way.

Table 7.1 reports the result of a regression with the Shannon-Wiener diversity index and the number of technician visits per month, hours spent per visit, and total time spent on the farm by the technician in columns 1, 2, and 3 respectively. The coefficient on each of the explanatory variable is statistically not different from zero, so I do not find any evidence that knowledge transferred by the NGO technician (as measured by visit time and frequency) had a statistically significant impact on the farms' species diversity. Regressions using other measures of species diversity, Shannon's equality, Simpson's diversity index, and Simpson's equality, also yield similar results (Tables 7.2-7.4). However, there is a negative relationship (which is significant only at the higher $p<0.1$ value) between total time spent and the Simpson's equitability index. This indicates a weak correlation, between increasing total time spent with the technician and the decreasing evenness of the species on the farms. As the NGO distributes species that were not likely to be found on the farms prior to participation and also distributed in limited numbers, the evenness of the species present could be expected to decrease with participation due to the increase of rare species[13].

[13] Species that are uncommon and have low frequency in the vegetation plots

Table 7.1. Regression results for relationship between visits by technicians and Shannon's diversity index.

	(1) **Shannon div. index**	(2) **Shannon div. index**	(3) **Shannon div. index**
No. visits/month	0.0402		
	(0.0846)		
Hrs spent per visit		0.152	
		(0.115)	
Total time spent			0.00106
			(0.000953)
Constant	1.782***	1.768***	1.795***
	(0.125)	(0.104)	(0.0898)
Observations	40	40	40
R-squared	0.00811	0.0237	0.0109
Std. error	Robust	robust	Robust

Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$

Table 7.2. Regression results for relationship between visits by technicians and Shannon's equitability index

	(1) **Shannon eq. index**	(2) **Shannon eq. index**	(3) **Shannon eq. index**
No. visits/month	0.0209		
	(0.0160)		
Hrs spent per visit		0.0159	
		(0.0369)	
Total time spent			-0.0000465
			(0.000252)
Constant	0.759***	0.776***	0.784***
	(0.0298)	(0.0258)	(0.0226)
Observations	40	40	40
R-squared	0.0381	0.00454	0.000361
Std. err	Robust	robust	Robust

Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$

Table 7.3. Regression results for relationship between visits by technicians and Simpson's diversity index.

	(1) **Simpson div index**	(2) **Simpson div index**	(3) **Simpson div index**
No. visits/month	0.233		
	(0.358)		
Hrs spent per visit		0.440	
		(0.609)	
Total time spent			0.000989
			(0.00458)
Constant	4.847***	4.936***	5.079***
	(0.461)	(0.418)	(0.364)
Observations	40	40	40
R-squared	0.0140	0.0103	0.000486
Std. err	Robust	robust	Robust

Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$

Table 7.4. Regression results for relationship between visits by technicians and Simpson's equitability index.

	(1) **Simpson eq. index**	(2) **Simpson eq. index**	(3) **Simpson eq. index**
No. visits/month	0.0228		
	(0.0263)		
Hrs spent per visit		-0.0182	
		(0.0535)	
Total time spent			-0.000560*
			(0.000318)
Constant	0.456***	0.489***	0.499***
	(0.0331)	(0.0284)	(0.0247)
Observations	40	40	40
R-squared	0.0294	0.00386	0.0341
Std. err	Robust	Robust	Robust

Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$

The lack of statistically significant results does not necessarily mean that there does not, in fact, exist an effect. Though sampling 40 farms was not a quick task, a future study working with a larger team in the field should aim to conduct more widespread farms. The small sample could have precluded me from reaching conclusive results. A larger sample of farms may reveal a more conclusively whether the NGOs involvement, specifically through the flow of knowledge resources, is making any difference at the species level.

7.1.1 NMDS

I also analyze whether the time spent by the technicians is associated with the species composition across the farms as described by the NMDS axes. I tested the relationship with the complete and *Inga* only vegetation dataset (datasets used for the NMDS A and NMDS D from Chapter 5). Adding the variables on technician visit frequency, duration, and total visit time to the NMDS analyses show that these variables are not significantly correlated with synthetic axes of species composition differences on the farms. With both the datasets, we see that technician time is not associated with changes in the species composition.

For the NDMS analysis with the complete dataset (all species with abundance data), this indicates that the changes in species composition are more related to the environmental factors as indicated in the earlier chapter. It is also possible that the changes in species composition are minor and subtle between the participating and the non participating farmers and therefore are undetected. This could occur if the farms are already diverse and varied in species composition then planting additional trees received from the NGO do not change the existing variation much.

The NMDS analysis with the *Inga* only dataset (species of genus *Inga* with relative abundance data) in Chapter 5 indicated a relationship between changes in *Inga* relative abundance to the length of participation in addition to elevation and distance from town. With the addition of the technician time variables, we see that they are not correlated to the axes. This indicates that though the number of years a farmer has been participating with the NGO is altering the abundances at which specific species of *Inga* are present on the farms, the amount of time (and knowledge transferred) is not a significant explanatory factor in this change. Thus, the change in relative abundance correlated to the number of years participating is most likely a suggestion of accumulation and slow change over time on the farms.

7.2 Genetic Variation and Technician Time Spent

In order to answer questions about practices and biodiversity, I explore the relationship between genetic variation, participation and technician time spent. In the previous chapter on genetic diversity and variation we saw that the farms that received seedlings from the NGO differed from other (nearby) farms. The farms that received the seedlings (# 3, 4, and 11) during the time of sample collection are not the same farms with the highest amount of technician time; rather they indicate a spread in the amount of time. Sampled area 11 had one of the highest technician time reported by the farm (225 minutes/month). This farm was selected as one of the first to receive seedlings; further, the NGO also uses it as a demonstration farm. The other two sampled areas, 3 and 4 respectively had 120 and 60 minutes of technician time per month. Sampled areas 1 and 8 did receive plants after the specimen collection for this study was complete, each with 45 and 15 minutes of technician time respectively. Though the sample size here is small to make an overarching generalization, it seems that farmers that are favored in terms of technician time are also ones likely to receive seedlings first.

The NGO distributing seedlings in batches to the farmers shows the difficulties of seed storage and flowering/fruiting time of various trees and introduces potential biases for characteristics. Seed storage within this genus is difficult, where the seeds can be stored only up to approximately 2 weeks before they need to be planted. The inability to store seeds long term makes accumulation of seeds difficult, thus decreasing the possibility to collect seeds from different populations, mix, and then redistribute to the farmers. This is further compounded by the fact that trees flower and fruit at different times. Further, it is possible that the NGO technicians could be unintentionally biased about seeds they harvest, creating unintended selection for certain characteristics. For example, the size of the fruit they pick to harvest the seeds - larger fruits would facilitate easier removal of the seeds, while smaller fruits would take more time to work with. All of these difficulties have consequences for genetic variation, especially if the *I. oerstediana* in the small NGO area approximately 10 km away is truly outcrossing with the local population.

Further, the genetic diversity and variation present on farms is important to consider when putting it in the context of an agroecological matrix. Any new genetic material that is planted on to a farm, can and will influence the non-farm/wild populations of that species, the metapopulation theory can be applied here as detailed in the literature review. This can lead to changing allele frequencies and outbreeding within the populations of the species when there is crossing between the wild and planted populations. Depending on the conservation goals, decisions for such plantings have to be fully considered. If the goal is to keep two populations as distinct to maintain diversity across populations, then planting trees from one population into another would lead to eventual homogenization.

7.3 Putting it in Perspective

Returning to explanatory framework present in Figure 1.1 that we started out with in beginning, I want to discuss the chain of influences based on my findings. Figure 7.1 is a revised explanatory framework with my findings added. At the start of the dissertation, I hypothesized that there was a link between the NGO, global conservation agencies and its donors due to funding flows. Based on my interactions with the NGO and the need to stick to funded projects stated by the NGO employees, I believe that this relationship is best captured by an arrow to show a direct and immediate effect in the NGO's activities, where we can know that the NGO is expected to fulfill its obligations to the donors especially if it is to be funded again.

We also saw evidence of the NGO using contracts and "best practices" to set new norms and rules for how coffee should be grown and more broadly how land should be farmed and conserved. In a way the NGO has commoditized technical knowledge and leveraged their position as an expert to indirectly control land use. Though the contract is not binding, if the farmer wishes to receive any technical assistance and coffee seeds (which can be extremely expensive, especially varieties that are resistant to coffee leaf rust) they have to meet the demands of the NGO (plant native trees, grant permission for forest monitoring on their land, etc.). Thus in this way the NGO is changing the participants' decision making.

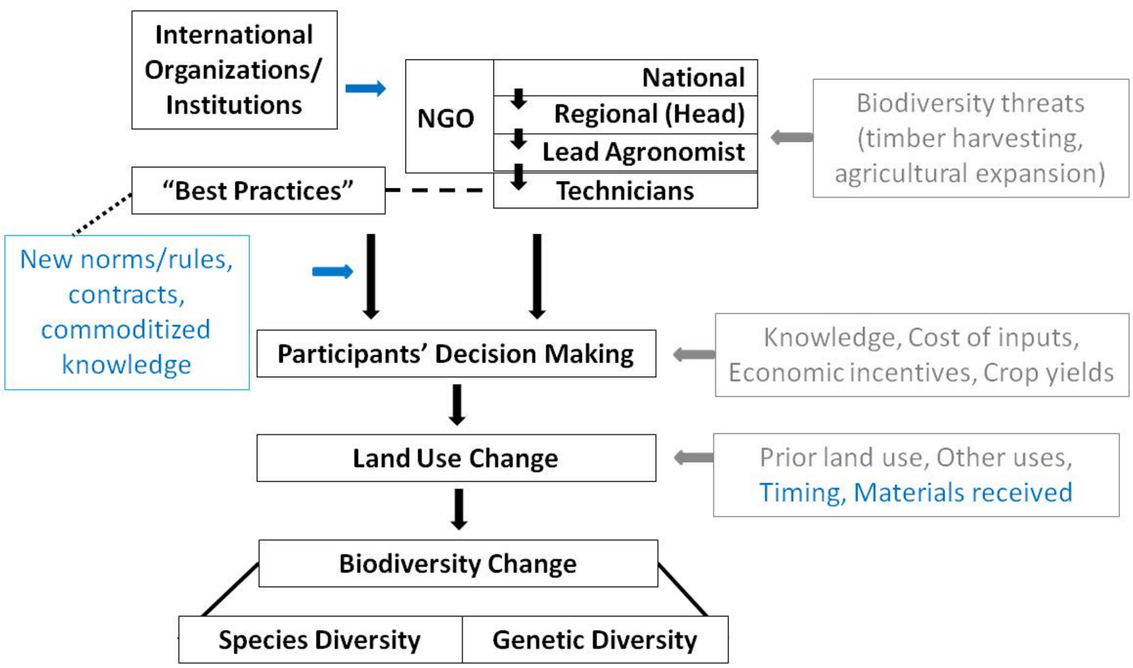

Figure 7.1. Revised explanatory framework with my findings added in blue.

In addition to the knowledge/information component delivered by the technicians and the lead agronomists, the NGO also provides materials to the farmers to facilitate the desired land change on the farms. For example this includes, the distribution of coffee seeds to renovate old coffee crops to increase yield and decrease pressure on forests and the distribution of native plants to plant on the farms that serve to create connectivity between forest patches and be an additional source of income to the farmers. It is also through these distribution practices that the NGO is changing what might be considered "typical" agrobiodiversity species in this coffee agrosystem. By intentionally planting native tree species on the farms, the NGO has placed trees like *nogal* and *cedro* as part of agrobiodiversity. Before the NGO, it was possible that the farmers could have these species on their farms as part of the remnant forest trees or by naturally dropped seeds germinating fortuitously, with the NGO, intentional and active planting of these species is common practice.

Also, the timing of the materials received is important – for example, the case of many farmers signing up to work with the NGO due to the coffee leaf rust. Further, though I did not find evidence of technician time being correlated to receiving material resources (plants measured via species diversity), they are still the means the farmers have to interact with the NGO on a daily basis, and thus their role as a facilitator or transmitter for the resources is still important.

Agroforestry case studies indicate the presence of tens to hundreds of tree species on tropical farms (Dawson et al. 2013). Agroforestry practices have long received attention for their potential to provide livelihoods and ecosystem services (Garrity 2004).

The land under agroforestry can act as a corridor and the species part of this system can be of benefit to production systems and support ecological and social resilience. The land sharing land sparing debate started out a dichotomy but evidence (e.g., Kremen 2015, Johansson et al. 2016) has shown that these two approaches do not have to be mutually exclusive; rather the approaches can work in synergy to protect a more variety of flora and fauna than either approach alone. In the case of the NGO, it is employing both strategies in its work. Through the maintenance and protection of the conservation concession it is protecting wild biodiversity using a land sparing approach. And through its work with the farmers to plant shade trees and native trees and protect forested parts of the farm land, the NGO is using a land sharing approach to improve the quality of the matrix and increase agrobiodiversity. However, if we examine the actions of the farmers protecting the forested parts of their land, at a smaller scale this can also be considered land sparing.

Work by Perfecto and Vandermeer (2010, 2015) shows us that coffee agroforestry systems are an ideal system in thinking about the blending of agriculture (food sovereignty) and conservation. Building on their claims, I sample within the matrix that exists between forest remnants and coffee farms in Chanchamayo to test the work of the NGO in improving the quality of the matrix and create biological corridors. The work of the NGO speaks to the sociopolitical-ecological conditions where biodiversity can persist and even thrive in productive agricultural systems. Perfecto and Vandermeer (2010) present diversified small-scale agriculture (and thus smallholders) as benefiting biodiversity and giving us a way (and hope) for the persistence of biodiversity in our increasingly fragmented agricultural landscape.

This study adds to the evidence that landscapes of high quality can exist and contribute to biodiversity conservation. In some ways the NGO could be seen as trying to create a sociopolitical-ecological condition with the farmers that facilitates the creation and maintenance of a high quality matrix in Chanchamayo. By not only promoting intensification through the distribution of coffee seeds and the workshops/trainings but also adding native trees (*Inga* and others) to the farms, the NGO creates a high quality matrix that can support both food (income) security while decreasing the need to deforest more land and also create a landscape where biodiversity can find refuge and potentially reproduce. Further, by combining both goals of food production and biodiversity conservation on the coffee farms, the NGO is decreasing the "sacrifice zones" that exist in the study area.

The success of conservation depends on many factors such as genetic diversity in the tree population, which in turn depends upon the type of management practices employed by the farmers. For instance, Dawson et al. (2013) note that "promoting connectivity [through agroforestry]… may not necessarily support tree populations in situ if farmland trees are of the 'wrong' source, chosen as such either inadvertently or because they are the most productive trees for farmers to plant" (pg. 312). Conservation NGOs can play an important role in coordinating activities of farmers to maximize the conservation potential of agroforestry programs but the consequences of the activities must also be considered. Whether it is in terms of the genetic diversity of *I. oerstediana* or the interest in increasing the presence of native tree species on the farms, the potentials of what can occur genetically to the surrounding (wild) populations has to be taken into account. If we do not, we can risk creating an outbreeding depression, whereby we reduce the survival of the offspring in their parents' environments.

Often, there is an understanding that populations that are managed by humans have significantly lower amount of genetic diversity despite some studies having demonstrated otherwise (Hollingsworth et al. 2005). Studies have thus far examined the difference between planted and non-farm/wild populations and reforestation efforts of tree species, concluding that genetic diversity is reduced or similar in planted populations compared to the non-farm/wild populations. However, this dissertation demonstrates similar genetic diversity between planted and non-farm populations and that considering the nuances of planted populations is important. We see through an examination of genetic variation that there are differences in between the populations planted by individual famers and those planted by farmers with the NGO. Thus, programs that change farming practices are not only changing the species present on farms but can also change seed and plant-material sharing practices that ultimately effect genetic patterns and diversity.

CHAPTER VIII

CONCLUSION

With this dissertation I set out to combine various approach to answer the question of whether the national NGO in Chanchamayo was leading to changes in biodiversity. Over the course of conducting fieldwork and data analyses, I have found that the NGO has mixed results and effects when examining resource distribution, species diversity, and genetic diversity. In attempting to create the biological corridor, the NGO is increasing some awareness of the farmers to the broader benefits of agroforestry and the importance of native trees through its workshops and distribution of native tree seedlings. The actual effect on trying to increase the quality of the matrix is occurring at least in part (for example when considering the presence of plant taxonomic families and the *Inga* genus), and significant differences can be seen only at certain scales of analyses. Given this, the NGO should consider more effective ways to have farmers plant more trees to increase biodiversity, if the goal remains to increase the connectedness between the forest patches to ultimately create refuges for biodiversity.

In terms of the changes in genetic diversity and patterns due to participation, we see evidence that in addition to existing genetic differentiation between the farms, the NGO has changed the diversity and population structure of *I. oerstediana* on the farms that most recently received plants. This indicates that the NGO (unknowingly) introduced individuals that were genetically different from the ones present in the region. This newly introduced genetic diversity can lead to changes in genetic variability and population structure of the new offspring in surrounding farms and the non-farm areas. Since genetic diversity can support unique communities and species diversity of arthropods, soil communities, etc., it would be important to monitor the genetic mixing that occurs with the newly planted *I. oerstediana* individuals.

I think more effectively, the NGO has demarcated a zone where it can control certain actions of the farmers through the use of the contract and farming practices packaged as "best practices," whereby expanding the control they have from the purchased conservation concession into private property (the farms). In fact, these kind of power dynamics can be subtler and under the radar in the third wave of conservation. As conservation NGOs with large amounts of resources negotiate with farmers about their use of their land, the unevenness in power will undoubtedly influence the ultimate decisions about on and about the farm. This is in contrast to the era of fortress conservation, where any detrimental impacts on the livelihoods of local farmers was apparent and therefore had greater likelihood of collective political resistance. As a result, the subtle resource access and control changes taking place here between the farmers and the NGO in Chanchamayo is perhaps being largely unnoticed.

Working with the NGO over the past four years, I have documented and realized that the organization uses different rhetoric and causes as rent seeking mechanisms, similar to the findings of Islam and Sharmin (2011). The discourse it has used has evolved as the political, policy, and grant/aid landscape has changed. We can see this when we look at the projects that have been taken on by the NGO. It shows the major concerns of what the granting agencies or governments were seeking to fund. We see a trend moving from reforestation projects to sustainable development projects to (most recently) climate change projects; we observe a similar trend of focus in conservation policy and funding realms. Though what the farmers have received has changed very little as part of the various projects, the titles and descriptions of the goals of the projects have changed. At the most basic level, however, the resources and work with the farmers has been very similar over the past 15 years, especially since the focus turned to helping farmers with their coffee crops. The underlying work of the NGO in many ways has been around the idea of agroforestry. Reflecting on the work of the NGO and the literature, I would go as far as to say the work and rhetoric of the NGO matches the latest discussions in the literature and the policy realm. This resonates strongly with the NGO critiques of Bebbington (2004) and Banks et al. (2015), where the NGO is committed to the agendas presented in the policy and donor realms rather than work from the concerns of the marginalized peoples they seek to help.

8.1 (Re)Thinking Biodiversity in Agroforestry Landscapes

I began this dissertation with an explanatory framework aiming to link together the work of an NGO with farmers to biodiversity changes. Reflecting on the process of creating this link and my findings, I think it is important to re-visit the framework presented by Robbins et al. (2015). Many aspects of their framework are useful in conceptualizing the links moving from the very large scale political economy to the changes that can occur on the farms of the smallholders via producer decisions and agroecology. However, while we still attempt to concretely understand the links and generalities in these relationships, this framework will need to be adjusted to specific instances, locations, and projects. We must remain cautious of rolling out this framework to understand the links, much like we do with agroforestry initiatives rolled out all over the world to accomplish multiple goals. Agroforestry can take many different forms, and (as this study shows) can vary greatly between farmers of the same region. This framework will need to be modified to be suited to the time (temporal factor considering what else is occurring) of research and to each area or project under consideration. This will allow for nuances in the political economy of that area (e.g., emerging farmer organizations, access to rather than availability of credit), other influential factors affecting producer decisions (e.g., knowledge, crop growing conditions- plagues, diseases, pests), as well as unique conditions of biodiversity (and associated threats) to be recognized and accounted for within the framework.

Further, as my findings show NGOs or organizations can be important factors in the decisions made by farmers. In the current framing by Robbins et al. (2015), non-state actors were only mentioned in passing. However, organizations can play a major role; they can be a part of the structural and operational conditions in the form of associations and cooperatives but they can also act as a mediator or modifier of these conditions for a group of farmers or a region. The NGO in this study mediated the relationship between the farmers and the land with specific goals of increased production and conservation in mind. Despite operating individually, the farmers, through the NGO, were able to obtain knowledge through trainings and workshops, as well as coffee seeds that would be cost prohibitive. And the NGO also facilitated the movement of seeds from one part of the study area to others (native trees' seeds were harvested in the conservation concession as well as select farmers), and in between farmers. The modification of access to resources by organization should be explicitly considered within this framework, especially within the link between the political economy and the producer decisions.

Further, Robbins et al. (2015) broadly include "levels of biodiversity" within their framework, however, explicitly consideration of genetic diversity remains elusive in their framework as well as political ecology, land change science, and agroforestry literatures. As important as it is to consider the species level biodiversity, it is also vital to examine the changes occurring at the genetic level. Genetic diversity ultimately supports species level biodiversity and ensures the adaptability of a species, especially given rapid changes occurring with climate change. Recognizing that humans modify and alter genetic diversity of a species and examining how intentional interventions (via planting, removal, and reforestation) change genetic diversity patterns will allows us to protect and conserve biodiversity from a different level and perspective.

8.1.1 Potentials of Landscape Genetics

Landscape genetics can make important contributions to political ecology and studies of conservation efforts. This sub-field has some distinct advantages that allows for us to apply it. First, landscape genetics does not require us to pre-define a genetically distinct population of a species. Rather, it allows us to sample in the areas and then through analyses determines what falls under one population or another. This is advantageous because it allows us the flexibility to sample across the study area without the worrying about mixing populations, which can result in misleading conclusions.

With the cost of genetic analysis constantly decreasing, the types of analysis presented in this dissertation can be carried out to check the genetic diversity/differentiation status of crops and trees not only across coffee and other agro ecosystems but also expand the analysis to reforestation projects carried out by many organizations. Further, collaboration with ecologists and geneticists, will permit access to funds for interdisciplinary projects that can facilitate this explicit measurement of genetic diversity. Ultimately, incorporation of this field will allow us to also better document seed sharing and farmer networks, which still remain difficult to track. Landscape genetics provides a way to examine the crops or seeds that are being shared and can complement and support social-network type analyses. In degraded or deforested landscapes where reforestation efforts are common by NGOs and governments, landscape genetics facilitates an examination of the genetic diversity that has been introduced/re-planted and can provide an understanding of future dynamics between the new populations and the existing populations (both on farmed and non-farm areas).

Overall, landscape genetics stands to contribute to our understanding of human, institutional, and organizational impacts on the environment at a new scale, which is growing ever more important to understand in our increasingly fragmented and changing landscapes. It allows for a consideration of biodiversity as something that is changing (gene flow) rather than something that is static, though as evidenced by the changes on the participating versus non-participating farms, we can see that even species level biodiversity is dynamic and highly subject to resources (seedlings) and desires of the farmer.

8.2 An Agenda for Future Research

Development and conservation agendas have pushed agroforestry as the solution to many of the problems faced by the changing world. In slightly different ways, but similarly both these agendas tend to be crisis driven without time for in depth studies or analyses before implementation of projects or policies. By using the framework detailed in this dissertation and in Robbins et al. (2015), we have a means to examine one of the most prevalent global land uses and its relationship with biodiversity. Though this study shows positive impacts on the biodiversity levels on the farm associated with participation with an organization, every agroforestry area will have its own nuances (both relating to the farmers but also temporal). What has worked in the years of 2012-2015 with the farmers in Chanchamayo might not work with cooperative-organized farmers in Costa Rica despite facing similar challenges of falling coffee prices.

This dissertation was limited in scope due to my own resource constraints and I was able to only survey a limited number of farms for species and genetic diversity. A more ambitious project which collects more detailed information on a larger number of farming households, their interaction with conservation NGOs, and biodiversity outcomes on a much larger scale is needed to better understand the effectiveness and outcomes of attempts to integrate conservation and agriculture. With the need to think about the landscape as a matrix in which different land uses can be improved to meet the needs of humans and biodiversity, an understanding of the role organizations and other actors play in changing land use is crucial. Such a project will no doubt require an interdisciplinary team of biogeographers, political ecologists, geneticists, and social scientists to uncover all facets of modern conservation practices. Given the urgency of slowing down climate change while maintaining agricultural production, such a research project would help us better understand and adapt to a changing future.

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APPENDIX 1

SURVEY

Name: ____

Community: ____________________ Profession: ____________________

Birth year: __________ Education: ____________________ No. people in household: ______

Sex: (____) M (____) F Marital status: ____________________ # Children _____M _____V

The farm

Total area	Cultivated area	Primary forest	Secondary forest
Obs:	Obs:	Obs:	Obs:

Can you draw a map of your farm with where your crops are located? *[on a separate paper]*

Do you have a title to your property: (___) Yes (___) No (__) Other: ____________________

Where is your farm?____________________ Distance from house ____________________

What crops do you grow for the market? ______________________________

What crops do you grow for your house? ______________________________

What plant do you use shade for coffee? ______________________________

Do you use fertilizer? Which one? How much? ______________________________

Do you use chemicals? Which one? How much? ______________________________

Where do you get your fertilizers and chemicals? ______________________________

How do you manage diseases and pests on your farm? ______________________________

How do you manage weeds? ______________________________

Product	**Variety**	**Amount harvested** last/this year		**Price per unit**		**Income**	**Age of crop**
Coffee							
Banana							
Other							

Where are the seeds and plants from of:

Coffee? ____

Inga. spp.? ____

Other? ____

What soil type do you have? ____________________ Organic matter? ______________________

Work/Labor

How many hours do you work on the farm? ________________ For how many days? ____________

Who helps you? ____

Do you hire others to work on your farm? ____

Technical assistance

Do you receive technical assistance? _______ In what manner? _____________________________

Do technicians visit your farm or house? ____

How often? _____________________ For how many hours each time? _____________________

Social data

Do you participate in an association? _____ Why?____

Name of association: ____

Who do you sell your products to? ____

How do you transport your products?____

Other Problems

____

APPENDIX 2

PLANT FAMILIES COMPARED

Comparison of plant taxonomic families between my sampled areas (farms) and forest patches from La Torre-Cuadros et al. (2007). Families highlighted in green are common to both the farms and one of the forest patches.

Taxonomic Family	Participation		Regions in La Torre-Cuadros et al. (2007)						
	Yes	No	CPH	PS	PRS	GS	GLS	GH	SRS
Acanthaceae			X						
Anacardiaceae	X	X	X			X	X	X	X
Annonaceae	X	X	X	X	X	X		X	X
Apocynaceae				X		X		X	X
Aquifoliaceae					X				
Araliaceae			X	X	X	X		X	X
Arecaceae						X		X	X
Bixaceae	X								X
Bombacaceae			X			X	X	X	X
Boraginaceae				X					
Brunelliaceae					X				
Burseraceae				X	X				
Calophyllaceae	X								
Caprifoliaceae				X	X				
Caricaceae	X	X	X						
Cecropiaceae			X	X	X	X	X	X	X
Celastraceae			X					X	
Chloranthaceae					X				
Chrysobalanaceae				X					X
Clethraceae				X					
Clusiaceae			X	X	X	X	X	X	X
Combretaceae			X					X	X
Cunoniaceae				X	X				
Cupressaceae	X								
Elaeocarpaceae									X
Ericaceae					X				
Euforbiaceae	X	X							
Euphorbiaceae	X	X	X	X	X	X	X	X	X
Fabaceae	X	X	X	X	X	X	X	X	X
Flacourtiaceae			X	X	X	X	X	X	X
Hydrangeaceae				X					
Icacinaceae									
Juglandaceae	X	X	X				X		
Lacistemataceae					X				X
Lamiaceae	X								
Lauraceae	X	X	X	X	X	X	X	X	X
Lecythidaceae								X	X
Magnoliaceae				X	X				
Malpighiaceae								X	

Malvaceae	X	X							
Melastomataceae		X	X	X	X		X	X	X
Meliaceae	X	X	X	X	X	X	X	X	X
Monimiaceae				X	X				
Moraceae	X	X	X	X	X	X	X	X	X
Musaceae	X	X							
Myristicaceae			X			X		X	X
Myrsinaceae			X	X	X			X	X
Myrtaceae	X		X	X	X		X	X	X
Nyctaginaceae							X	X	X
Ochnaceae									X
Olacaceae								X	X
Opiliaceae				X				X	
Oxalidaceae	X	X							
Palmae	X								
Papaveraceae			X		X				
Pinaceae	X	X							
Piperaceae		X	X	X	X	X	X		
Podocarpaceae	X			X					
Polygonaceae			X			X	X	X	X
Proteaceae	X								
Pteridophyta				X	X			X	X
Rhamnaceae						X		X	X
Rosaceae	X		X	X	X			X	
Rubiaceae	X		X	X	X	X	X	X	X
Rutaceae	X	X					X		
Sabiaceae			X	X	X			X	
Sapindaceae			X	X	X	X	X	X	X
Sapotaceae	X	X	X	X		X		X	
Solanaceae	X		X	X	X	X	X		
Staphyleaceae			X	X	X	X		X	
Sterculiaceae	X	X				X	X	X	X
Styracaceae			X	X	X			X	
Symplocaceae				X	X				
Tapisciaceae	X								
Theaceae				X	X				
Theophrastaceae								X	
Tiliaceae			X	X		X	X	X	X
Ulmaceae	X		X		X	X		X	X
Urticaceae			X	X	X	X		X	X
Verbenaceae							X		X
Violaceae									X
Vochysiaceae								X	X
No. of Families (Total=82)	**30**	**19**	**35**	**39**	**37**	**27**	**23**	**41**	**39**
Percentage of Total Families	**36.59**	**23.17**	**42.68**	**47.56**	**45.12**	**32.93**	**28.05**	**50.00**	**47.56**