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Assessing Landscape Change in Highland Peru with an Emphasis on Tree Cover Change, 1948-2012

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ASSESSING LANDSCAPE CHANGE IN HIGHLAND PERU WITH AN

EMPHASIS ON TREE COVER CHANGE, 1948–2012

by

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ABSTRACT

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Tree cover change was examined around three cities in the central Andes of Peru, 1948-2012, using repeat photography, remote sensing, and ethnographic methods. Forest transition theory provided a framework to study the causes of the changes observed. The repeat photography results show that there were more trees on the landscape in 2012 than there were in 1948. There were increases in smaller groupings of trees visible in the photography that were associated with smallholder intensification in the form of new woodlots, field borders and dooryard trees. The remote sensing results show there was a significant increase in larger patches of trees beyond the view of the photographs. Many of these new large patches were associated with government sponsored afforestation programs.

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LIST OF ABBREVIATIONS

CAPS………………………………………………...……Agrarian Production Cooperatives

FAO……………….……..…....Food and Agriculture Organization of the United Nations

INEI……………….…………….Peruvian National Institute of Information and Statistics

NGO…………………………………………………...…Non-Governmental Organization

ONEC…………………………………………….National Office of Statistics and Census

PRONOMACH...........................Peruvian National Soil and Water Conservation Agency

SAIS…………………………………………….…..Social Interest Agricultural Societies

TOF……………………………………………………..……………Trees Outside Forests

CHAPTER I

INTRODUCTION

Despite significant and widely publicized deforestation in developing countries, particularly in the lowland topical forests in Central America and South America, observations of local and regional tree cover increases are becoming increasingly commonplace (Aide et al. 2013, Hecht 2010, Sanchez-Cuervo et al. 2012). Recent research of contemporary landscape change using repeat photography suggests several outcomes for the proposed project. In Honduras (Bass 2004, Bass 2006, McGregor 2011), Argentina (Veblen and Lorenz 1988), and Pakistan (Nusser 2000, Nusser 2001), areas of stable or increasing vegetation and tree cover were found. Using Food and Agricultural Organization (FAO) data, Rudel et al. (2005) found that during the 1990s, 38% of countries in the world experienced increases in forest cover.

The highland Andes of Peru, which form the focus area of this project, are not as extensively forested as they once were. Natural patches of native species such as queñual (*Polylepis*) are relics of once much more extensive forests. The noted Andeanist geographer Daniel Gade believes that the sierra below 4,000 meters was once heavily forested (Gade 1988). Though they were not perfect stewards of their environment, during the time of the Incas, forests covered much of the highlands below the tree line and were considered royal property. Forests were carefully managed to produce firewood and wooden tools such as the *chaquitaclla*, a human-powered foot plow (Chepstow-Lusty and Winfield 2000). A sharp decrease in forest cover followed during the colonial period, likely caused by the increased use of tree products as pit props, construction materials, and intensified use as firewood (Gade 1999). Remaining native highland forests are estimated to be about 280,000 hectares, or about 0.22% of Peru's total land area of 129 million hectares (Direccion General Forestal Y De Fauna 2013). Today, the most common tree seen in the highland landscape is the eucalyptus, or gum tree, originally imported from Australia in the 1860s (Doughty 2000). Its presence is ubiquitous on highland slopes and in valleys (Dickinson 1969).

Changes in the distribution of forests can be caused by a variety of factors, biophysical and anthropogenic. Biophysical factors include short and long-term variations in climatic variables such as changes in temperature and precipitation regimes. In the highland Andes of Peru, lake sediment analysis indicates that historic distributions of native species were affected by climatic fluctuations as well as human influences (Johannessen and Hastorf 1990, Chepstow-Lusty and Winfield 2000). Past human activities included the purposeful planting of trees, as well as the use of fire to clear forested areas so they might be used for agriculture. Landscapes of highland Peru have been shaped by these forces of human occupation for at least several thousand years during pre-Columbian, colonial, and modern eras (Brush 1982, Gade 1992). Contemporary highland landscapes in Peru are strongly influenced by the people that live in them. Most highland trees in the study area, whether in large government sponsored afforestation schemes or planted in smaller groupings as dooryard trees, are planted and managed by local people. Trees play an important role in the livelihoods of many highland people. They are actively planted as windbreaks, to stop erosion on riverbanks and hillsides, and sometimes to be sold for lumber. Perhaps most importantly, they are planted for their eventual use as firewood, which remains a common fuel for cooking. In many highland districts of Peru, more than 90% of households use firewood for cooking (INEI 2007).

This project uses repeat photography to analyze contemporary changes in tree cover seen in repeat photo pairs dated 1948 and 2012 taken in an area in the central highlands of Peru. This project relies upon recent forest transition theory as a framework to help understand the changes in tree cover seen in repeat photography and remote sensing data. Changes in tree cover are categorized according to one or more of the explanatory *pathways* outlined in the forest transition theory of Lambin and Meyfroidt (2010). Additionally, remote sensing methods are used to supplement and support the changes seen in the repeat photography. Finally, ethnographic methods provide context for the changes observed.

This research project contributes to our collective understanding of contemporary landscapes and environmental conditions in the world and complex ways people and the environment interact by documenting long-term landscape change in highland Peru.

CHAPTER II

RESEARCH CONTEXT

Human-Environment Interactions

Geography has a long tradition of examining human-environment interactions and how landscapes change over time. This tradition seeks to investigate how cultural and political factors influence how culture groups use resources and interact with the environment (Domosh et al. 2010). Reading the cultural landscape was a defining feature of the *Berkeley School*, established by Carl Sauer. Sauer characterized the cultural landscape as "the geographic area . . . fashioned out of a natural landscape by a culture group. Culture is the agent, the natural area is the medium, the cultural landscape is the result" (Sauer 1925, 46). Virtually every landscape on earth can be considered cultural, modified at least in some way by humans in the past (Denevan 1992).

In geography, the fields of cultural and political ecology developed from this tradition to further knowledge of the complex relationship humans have with their environment and how humans modify their landscape over time. Culture groups create cultural landscapes as they adapt to specific biophysical situations. Cultural ecology studied the resulting relationships. Political ecology is an extension of cultural ecology in that it attempts to add larger socioeconomic and political dimensions to the study of human-environment interaction (Zimmerer 1994, Zimmerer 2003, Zimmerer 2010). It recognizes the fact that external political forces outside a culture, region, or nation can influence local habits and actions (Robbins 2012).

There are many socio-cultural, political-economic, and biophysical reasons for changes in vegetation over time. A variety of methods has been used to examine changes in tree cover over time in the central Andes of Peru. Gade (1992) characterized the contemporary landscapes of highland Peru as the products of the mixing and filtering of Old and New World elements since the time of first European contact. Zimmerer's work shows that human dominated highland landscapes are not static and homogeneous within a given altitudinal zone as was once thought (Zimmerer 1999). Landscapes are more typically characterized by diversity in terms of pattern and change over time in response to extra-regional and global influences since at least the 1700s (ibid). The tree line and patterns of spatial and species distributions near forest edges have been studied extensively in the eastern Andean cloud forests (Young 1993a, Young 1993b, Young and Leon 2007). These studies found that biophysical factors such as temperature and precipitation were found to limit tree line, while climatic fluctuations and human disturbances contributed more to variations of species distribution within the tree line. In other studies of pollen records of lake sediment cores, historic distributions of native trees in highland Peru were found to be much more extensive than in the recent era (Johannessen and Hastorf 1990, Chepstow-Lusty and Winfield 2000). Dickenson studied the distribution and political economy of the eucalyptus, the most widely distributed tree of highland Peru (1969).

Forest Transition Theory

Forest transition theory was initially formulated by A.S. Mather (1992) to explain the general increases in forest cover observed in the twentieth century in developed countries following centuries of forest cover decrease. The theory proposed that the transition from an era of net forest decrease to one of net forest increase was caused mainly by land-use changes as countries experienced economic development. Two mechanisms were involved. First, agricultural intensification allowed more food to be grown on less land. Marginal agricultural land increasingly fell into disuse and reverted to forest. Second, rural areas experienced population declines as people moved to urban areas for work. Fewer people working the land meant more of it was available to revert to forest. These mechanisms seemed to apply well to developed countries such as Denmark, Britain, France, and the United States, which all experienced industrial development in the nineteenth century.

The economic development path cannot explain, however, many recent cases of forest increase occurring in developing countries of the tropics. The list of developing countries experiencing at least local or regional forest increase is long and the reasons for these increases appear to be many. In Honduras, an expansion of an agricultural crop — shade grown coffee — was associated with increases in forest cover (Bass 2006). In this case, agricultural land was not abandoned, but in fact expanded, and yet forested area increased. Korea experienced large increases in forest cover from 1956 to 1980, almost all of which can be explained by large-scale government sponsored reforestation programs (Bae, Joo, and Kim 2012). Reforestation of abandoned agricultural lands was explicitly rejected by researchers as a likely cause of the increases (ibid). Many areas in Vietnam experienced forest increases as formerly collectivized forestry land was allocated to households (Meyfroidt and Lambin 2008). Many of the new landowners planted trees substantially increasing tree cover in many areas of the country. Other recent increases have been observed in El Salvador (Hecht and Saatchi 2007), Ecuador (Farley 2010), Mexico (Klooster 2003), Costa Rica (Kull et al. 2007), as other countries in Latin America and Asia.

Additional explanatory *pathways* have been added to the original conception of forest transition theory to account for new processes thought to be at work in many of the above-mentioned cases of forest cover increase in tropical developing countries. The *forest scarcity* hypothesis suggests increases can be driven by anticipated or existing scarcity of forest products (Satake and Rudel 2007).

Lambin and Meyfroidt (2010) added three additional pathways (for a total of five) to better accommodate these new situations and better account for regional variation in explanations: state forest policy, globalization, and smallholder based intensification. *State forest policy*, as a driver of tree cover increase, occurs when governments actively encourage tree planting, most often in the form of large-scale plantation forestry (ibid). In Peru, these often involve community/government partnerships where the government supplies tree seedlings and technical expertise while local communities supply labor and land.

The *globalization* pathway recognizes the increased interconnectedness of places without regard to national borders, which can drive forest increases through a number of mechanisms (Lambin 2001). Globalization and its connection to forest-cover change has been extensively studied (Grau and Aide 2008, Kull et al. 2007, Bebbington 2001), especially in terms of rural to urban migration and the effects remittances have on rural landscapes (Hecht 2010). For El Salvador, remittances from the United States to the rural poor, and foreign markets for products, were found to be a driver of forest recovery as pressure from existing forests was reduced (Hecht and Saatchi 2007). Globalization is likely increasing in importance as a driver of landscape change in general and appears to be a cause of forest loss in many tropical countries such as Brazil. Many forests in the

Amazon basin are cleared and replaced with pasture for cattle or land for soy that is then exported to other countries (Oliveira et al. 2013).

Smallholder based intensification happens as small-scale landowners plant more trees around house compounds and in woodlots, orchards, and agroforestry plots (Meyfroidt and Lambin 2011). Because they are usually small in scale, tree cover increases associated with this pathway are difficult to detect with remote sensing methods but easier to see using the repeat photography method used in this study.

CHAPTER III

STUDY AREA

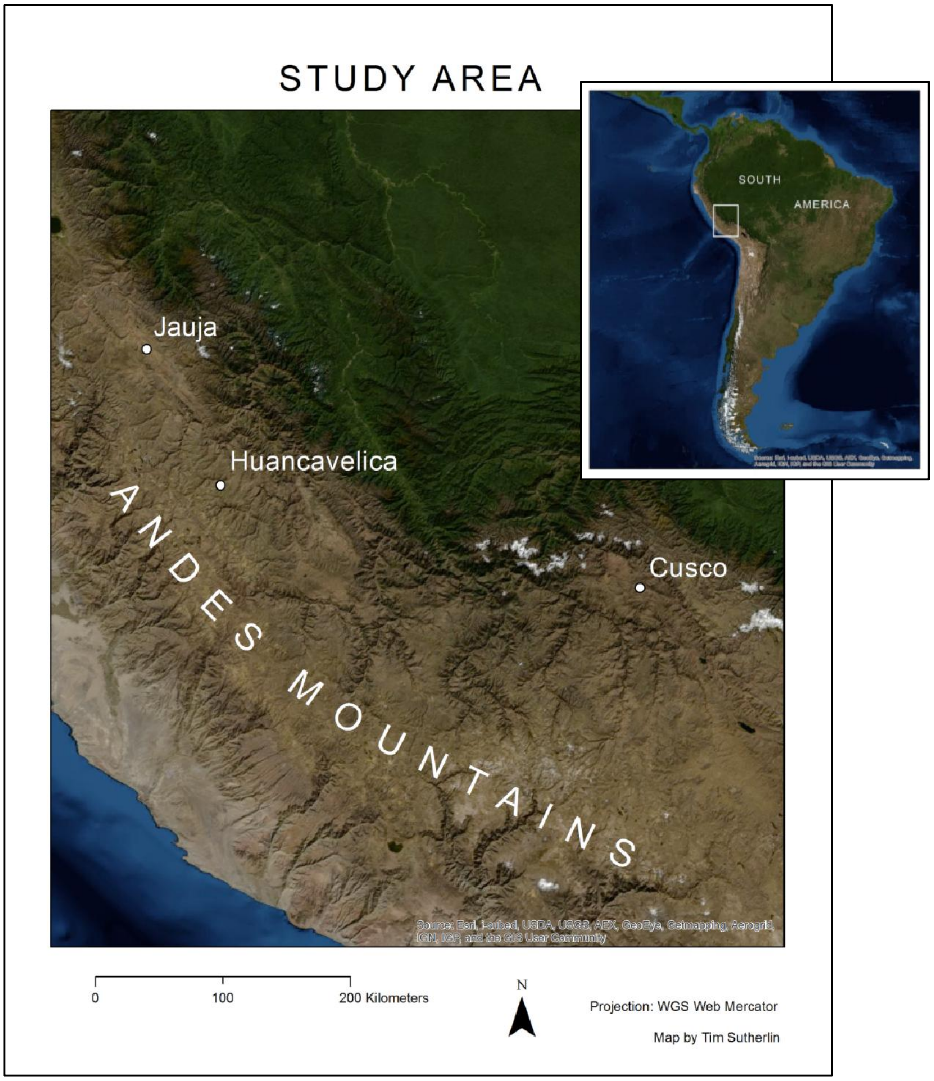

Figure 1. Study area, Peru.

The original 1948 photographs of the Berkeley-trained Latin Americanist geographer, Robert West, were originally taken in and around the three central Andean cities of Jauja, Huancavelica, and Cusco, Peru (Figure 1). The central Andes of Peru run generally northwest to southeast in two ranges (the oriental and occidental) separated by a central plateau (Caviedes and Knapp 1995). Annual average precipitation is around 700 mm and falls mostly in the rainy summer from November to April.

Jauja is located in the western end of the Mantaro valley in Jauja Province, Department of Junín at an elevation of 3,400 meters. Foothills surrounding the relatively flat valley floor rise to about 4,600 meters. Jauja was the capital of Peru for less than a year after it was founded as Peru's first capital by Francisco Pizarro in 1534. Jauja district, which more or less contains the current urban area of the city, had a 1961 population 14,294 and had grown only to 16,434 in 2007 (INEI 2007). The surrounding landscape is a patchwork of communal and individual agricultural fields often bordered by trees with some forested slopes on the surrounding hillsides. Land tenure in the Mantaro valley has long been divided among smallholders and small communities. This tenure arrangement was possibly compensation for local Huanca allegiance with Pizzaro against the Incas during the conquest of Peru (Hunefeldt 2010). The surrounding valley has been a major agricultural center since before the Incan period. The potato is the most important local crop, followed by maize, choclo (sweet corn), barley, quinoa, and traditional Andean tuber crops — oca, olluca and mashua (World Bank 2009). Open range pastures for sheep and goats cover the slopes above the city where nightly frosts make agriculture unsuitable, except for the cultivation of native trees such as the *queñual*. Jauja has long had good transport connections to the coast with a railroad connection to Lima established in 1908 and the Mantaro valley's only commercial airport.

Huancavelica is the capital city of the Province and Department of the same name. The city is located in a narrow valley with steep rocky walls and lies at an elevation of 3,600 meters. Huancavelica was founded in 1572 to serve the needs of the mercury mines in Peru and Bolivia during the colonial era. Huancavelica district had a 1961 population of 23,695 that grew to 37,255 by 2007 (INEI 2007). With the decline of mining activities in the nineteenth century, Huancavelica is now one of the poorest cities in Peru. Huancavelica has a small tourist industry as it is connected by narrow-gauge railroad from the Mantaro Valley with a daily tourist train.

Cusco is the capital city of the Province and Department of Cuzco and is the southernmost of the three study cities. Cusco is located in a valley at an elevation of 3,300 meters and is surrounded by low, undulating hills. The historical capital city of the Inca Empire, Cusco has experienced rapid growth in the last fifty years, the province growing from a 1961 population of 95,088 to 367,791 in 2007, an increase of almost 300% (INEI 2007). Tourism is by far the most important economic activity in Cusco with many of the almost 1 million annual visitors to nearby Machu Picchu passing through the area (Ministerio de Cultura 2011).

Eucalyptus were well established on the landscape by the time West travelled through the Sierra in 1948. Eucalyptus can be observed in almost every photo West took of the area. Most of the trees observed in his photos of highland landscape are eucalyptus as West notes on the photos. First introduced to Peru in the 1860's from Australia, they are now ubiquitous to highland Peru. Since World War II, eucalyptus have been promoted and received by forestry officials and locals as a tree with advantages over native species such as the queñual (*Polylepis*) (Doughty 2000). They grow rapidly and straight, which gives them great value as timber and makes them ideal as roof beams and fence posts. They grow in less than ideal soil and their leaves are not generally eaten by pasture animals (Dickinson 1969). Figure 2 shows sheep grazing on the grasses on a hill above Huancavelica. The leaves of the trees, even on the lowest branches well within reach of the sheep in the photograph, did not appear affected by them.

Figure 2. Sheep among eucalyptus planted on slope above Huancavelica, Peru. Large domestic herbivores such as sheep and goats do not eat eucalyptus trees as they do those of domestic species such as *queñual*. (Photo taken by author)

Eucalpytus are shade intolerant and therefore must be planted in areas without taller tree species. After they are established, however, they may suppress or eliminate other species. The leaves of bluegum eucalyptus release a number of terpenes and phenolic acids, which may surpress the growth of accompanying vegetation (Esser 1993).

Eucalypts are often planted in groups on hillsides as a means to control erosion and recharge groundwater. Figure 3 shows a group of young trees planted on a hillside above Huancavelica. The area was planted with labor supplied by members of the local community and seedlings and technical expertise supplied by the local government forestry department.

Figure 3. Eucalyptus on hillside above Huancavelica. More established trees are in the background. (Photo taken by author)

CHAPTER IV

METHODS

This thesis relies on a mixed-methods approach, combining repeat photography, remote sensing, and ethnographic data collection techniques.

Repeat Photography

A variety of research methods have been used to examine changes in vegetation, including repeat photography (Bass 2006, Bass 2004, Hastings and Turner 1969, Hendrick and Copenheaver 2009, Kull 2005, Nusser 2000, Nusser 2001, Nyssen, et al. 2010, Zier and Baker 2006). Repeat photography is simply repeating an earlier photograph from the same location (Griffin, Stahle, and Therrell 2005). In geography, repeat photography has been used to examine changes in various cultural and biophysical elements of landscape. It has been used to examine changes in the position and extent of glaciers (Molina 2010), to investigate changes in overall vegetation patterns (Hastings and Turner 1969, Veblen and Lorenz 1988, Bass 2004, Zier and Baker 2006), to examine both cultural and biophysical landscape changes (Byers 2000, Kull 2005), and explore changes in cultural elements of the landscape (Bass 2010, Moore 2010).

Using repeat photography has many positives as a tool to examine landscape change. Perhaps its greatest advantage compared to current satellite or aerial imagery is that it offers greater detail and resolution of a given area. Repeat photography also allows for the examination of landscapes from periods before satellite remote sensing existed. The first Landsat satellite was not launched until 1972 while ground-level images of the landscape date to as early as the mid-1800s. Repeat photography presents a scene as a whole with individual elements in a holistic context. Another strength of repeat photography is that it encourages the researcher to interact with locals during fieldwork, thereby allowing for a better sense of the forces and conditions seen in the photo pairs (Bass 2010, Bass 2013). Repeat photography, of course, has several limitations. Generally the original photographic location and view angle are not randomly chosen but subject to the selection bias of the original photographer. There is also the issue of scale. Ground-level photographs generally only show a small portion of the Earth's surface. A single photograph cannot say much, if anything, about conditions outside its frame of reference. This limitation can be mitigated somewhat by repeating a large number of photographs in an area, in effect producing a larger sample more likely to yield results indicative of general conditions. Another problem is that of scale within photographs: foreground objects are automatically emphasized and appear larger than background ones.

For this project, original photographs for the repeat pairs were drawn from the Boyd Professor Emeritus Robert C. West Latin American Photograph Collection at the Cartographic Information Center of Louisiana State University in Baton Rouge. The entire collection holds approximately 6,000 black-and-white 5 x 7 inch prints, approximately 350 of which are from the 1948 and 1975 trips that Dr. West made to Peru. Location and description information drawn from Dr. West's field notes are on the back of most prints. I selected approximately 50 photographs for re-photography based on their description that indicated that they were taken in or near the three cities of interest in the study area. I attempted to re-photograph the originals as close to the original camera positions as possible during a summer field trip (June-July 2012) to Peru using a Canon S100 digital camera with a 12 mega-pixel resolution.

Paired photographs were examined for changes in tree cover. Changes noted include location, density, and distribution, as well as detectable changes in species composition, age, and health. Changes in other elements of the photo pairs, such as changes in transportation infrastructure and land-use, were also noted, as they were helpful when assessing the reasons why tree cover changed.

Remote Sensing

This thesis uses remotely sensed methods to supplement and verify the findings of the ground-level data and to obtain a broader picture of contemporary tree cover change in the study area. Remote sensing is often used to obtain a synoptic view of an area of the earth's surface at various spatial and temporal scales. Using remote sensing to detect changes in vegetation, including tree cover, has been used extensively in recent decades as the number of available satellite and airborne sensors has multiplied (Echavarria 1999, Sader, Bertrand, and Wilson 2003, Hecht and Saatchi 2007). I selected Landsat imagery as it has been recorded at 30-meter resolution in visible and near-infrared wavelengths since 1981 (Jensen 2004). The near-infrared bands of Landsat sensors are particular helpful to detect variations in the distributions and type of vegetative cover.

I obtained six Landsat 5 Thematic Mapper (TM) images from the United States Geological Survey's (USGS) online image server at earthexplorer.usgs.gov. Images were acquired for Jauja, Huancavelica and Cusco for 1984 and 2004. All images were from the Southern hemisphere winter (May to August) with less than 10% cloud cover for the entire scene and virtually no cloud cover in the portion of each scene that made up an approximately 10 kilometer by 10 kilometer square surrounding the study cities.

I generated tree cover maps for each study city for the beginning and end of the twenty-year period, 1984-2004. I calculated total forest cover in hectares for each area for 1984 and 2004. I then used these tree cover maps to calculate a map of tree cover change — that is, a single map that simultaneously shows areas of tree cover increase and tree cover decrease from 1984 to 2004 — for each study site.

Ethnography

I also used ethnographic methods to gather additional data about tree cover change observed in the repeat photo pairs. I conducted informal, unstructured interviews as I encountered people during my repeat photography fieldwork. Other researchers have found this practice a useful method to gather information about landscapes and possibly make new discoveries about them (Bass 2010). During fieldwork, I showed approximately six people the 1948 West photographs and asked what they thought caused the changes in tree cover that they could see. No identifying information was asked or recorded about the people I encountered during fieldwork. I also completed short semi-structured informal interviews with two officials in the national forestry departments of Jauja and Huancavelica Provinces and asked about general patterns of tree cover change and what might be causing it.

While I interacted with people in the course of my fieldwork, the research I conducted did not require the review of the Institutional Review Board at the University of Southern Mississippi. People were not the subject of the research, and no personal or identifiable data was asked or recorded about them. In the course of my fieldwork, I identified myself as a student-researcher and did not ask questions that required the revelation of any personal information.

Other Data Sources

Several other secondary data sources were used to aid in the characterization of tree cover change documented in the repeat photo pairs. The 1961 and 2007 Population Censuses of Peru were used along with the 1961 and 2012 Agricultural Censuses of Peru. The 1961 Population Census was used rather than the 1940 Census because it coincided with Peru's first agricultural census. The two main census measures gathered were population by province and district and proportion of households that use firewood as a fuel for cooking.

It should be noted that comparisons of absolute census measures, such as population change between 1961 and 2007, have to be used with caution as Peru's internal political boundaries changed during this time. The boundaries of all three provinces in this study changed during this period as districts were consolidated (ONEC 1966, INEI 2007). Cusco and Huancavelica provinces increased in total area while Jauja province decreased considerably in area from over 23,000 square kilometers to under 4,000 square kilometers when the new province of Satipo was separated from Jauja in 1965. Complicating matters, the number of districts within each province changed during the same period, as many rural districts with low population were consolidated into adjacent districts.

Government documents from the Peruvian Ministry of Agriculture and other departments were consulted to gather information about the locations and characteristics of recent government plantation forestry programs. This information was mainly helpful to categorize particular tree cover increases near the study cities as those belonging to the state forest policy pathway of forest transition theory.

CHAPTER V

RESULTS

Repeat Photography

In June and July 2012, during a summer field trip to Peru, I repeated 14 photographs from the Dr. Robert C West collection of photographs. All 14 were taken of landscapes in and around Jauja, Huancavelica, and Cusco, the three central Andean cities in the study area. Photographic pairs were placed side-by-side on a computer monitor and visually analyzed for changes in tree cover. Photographic pairs will be presented below side by side and followed by a narrative description of the changes in tree cover observed. The photo pairs are grouped and presented by city: Jauja, Huancavelica and Cusco.

While rediscovering the positions from which the original 1948 photographs were taken, I realized the locations Dr. West chose were the same or similar ones anyone would use to gain a good vantage point for comprehensive landscape photographs of an area. From hillside positions over the study cities, Dr. West usually took a series of three or four photographs from each location that, if placed side-by-side, would cover an approximately 180-degree view of the area below.

Following Kull (2005), I describe tree cover changes seen in the repeat photography using simple descriptive phrases to indicate areas of tree cover change such as *increased*, *decreased,* or *no change*. In some cases, I have added modifiers to indicate a large change, such as *greatly increased*. References to right, center, and left of the photos are from the viewer's perspective. References to foreground, middle ground, and background are used in the common everyday usage to refer to the respective areas of the landscape portrayed in the photos.

I use the term *tree cover* to refer to trees that may occur in *forests*, *dooryard gardens*, *and settlement trees* and as *scattered trees*. The Food and Agricultural Organization (FAO) defines forests as any grouping of trees with more than 0.5 hectares in area and more than 10% canopy cover. While some areas of trees seen in the photo pairs are large enough to be thought of as forests according to this definition, many smaller areas are not. In 2010, the FAO in an attempt to recognize the cultural, economic and ecological value of smaller groupings of trees established a new official category of tree cover called *Trees Outside Forests* (TOF) (Foresta, et al. 2013). The minimum area to be counted as TOF is 0.05 hectares, with at least 5% canopy cover. Many of the trees seen in the repeat photography would fit this category of tree cover. In this study, this type of tree often makes up a significant percentage of total tree cover seen in the photographs as planted as windbreaks, property boundaries, and scattered trees, particularly for the area around Jauja.

No matter what they are called, these smaller groupings of trees play a significant role in the landscapes and livelihoods of the people of highland Peru. Cultural geographers call these small groupings *settlement, dooryard, or scattered* trees. *Settlement* trees are often found in and around the places where people live, such as along city streets, in parks, or along the borders of agricultural plots. *Dooryard* trees are often planted as a single tree, or in small groups of two or three, placed next to or near a house to provide shade, kindling, or tender for fires, or for aesthetic reasons. *Scattered* trees are just that, broadly dispersed trees in an area otherwise clear of trees. All of these types can be seen in many of the photo pairs presented below.

A. B.

Figure 4. Jauja, Peru.
A. (1948) View over central Jauja, facing northeast. White arrow indicates location of the central plaza in both photographs. (West 1948, SA1 [7A]-4)
B. (2012) Decreased tree cover in mid-ground, increase in background, expansion of urban area. (Photo taken by author)

Figure 4 shows a decrease in tree cover in the middle ground along with an increase in background areas. Many trees in mid-ground areas have displaced with urban structures such as houses and roads as Jauja's urban area expanded. The trees in the flat valley in front of the background slopes appear to be unbroken contiguous patches, but they are not. This is an illusion caused by the oblique perspective of the photograph. They are in fact linear plantings along field edges that function as windbreaks and field boundaries. Some of the larger patches of trees visible in the distant background of the 2012 photograph, but not the 1948 one, are likely part of the government/community cooperative afforestation programs that have operated in some form since the 1960s. Remote sensing shows these patches to be 8 to 15 acres of contiguous planting (discussed below). These larger patches are almost exclusively on south facing slopes and ravines not too rocky or shady for agriculture. There is also some increase in tree cover in the flat valley in the upper left of the photos, likely the result of smallholder intensification. The trees in the central plaza visible in the 1948 photograph (as indicated by the white arrow in both photos) are not present in 2012.

A. B.

Figure 5. Jauja, Peru.
A. (1948) View of northern end of Mantaro valley looking southeast. The braided Mantaro River is in the background. The valley has been used for agriculture for more than a millennium. (West 1948, SA1 [7]-14)
B. (2012) The slope has changed little since 1948. Urban features of Jauja have reached an area in the left center of the photograph, and there are more trees in the flat valley bottom and the slopes in the background. (Photo taken by author)

The view in Figure 5 looks south over the wide Mantaro valley from a hill overlooking Jauja, which is to the left out of view. The Mantaro River runs the length of the valley, in wide-braided shifting channels. Overall the scene is surprisingly stable, with tree cover somewhat increased in the background and middle ground in 2012 compared to the 1948 photo. Scattered trees have slightly increased in number in the foreground. Some agricultural fields have been replaced with urban features such as houses and commercial buildings as Jauja develops and its urban area expands. Just out of frame to the left of the 2012 photograph, there is an airport with daily scheduled airline service to Lima. This airport is the only one serving the cities of the Mantaro valley, including the much larger regional capital Huancayo at the valley's southern end.

A. B.

Figure 6. Jauja, Peru.
A. (1948) View over Jauja looking northeast. Laguna de Paca is in the background. (West 1948, SA1 [7]-9)
B. (2012) The urban area of Jauja has expanded noticeably toward the hills and lake in the background. Some areas of trees in the mid-ground have been replaced with urban features, and there are many more trees on the slopes near the city in the background. The number of dooryard trees in the city appears to be approximately the same. (Photo taken by author)

This photo pair in Figure 6 was taken from the slopes west of Jauja looking almost directly north at the northern end of the Mantaro valley. Laguna de Paca is in the background of the scene at the northern limits of the relatively flat valley. Jauja's urban area has obviously expanded during the 64 years between photographs with more houses and roads spreading further from the city center. Urban features are closer to the hill in the foreground as well as toward Laguna de Paca. In the middle ground, urban features have displaced some agricultural fields as well as small areas of forest, but there remain a substantial number of scattered trees, some as dooryard trees, and some in small parks. Tree cover has increased substantially in the background especially on the south-facing slopes of the low hills immediately behind the city and lake. The taller slopes in the background have many new trees in the form of scattered trees and small patches, especially in ravines. Trees planted in ravines help to stabilize slopes that are not otherwise used for agriculture.

A. B.

Figure 7. Jauja, Peru.
A. (1948) View over northern edge of Jauja with Laguna de Paca in the background. (West 1948, SA1 [7]-16)
B. (2012) There are many new trees on the landscape in gullies and along pathways on the slope above Jauja. (Photo taken by author)

This photo pair in Figure 7 was taken from the same slope as the previous pair but from a position about a kilometer to the north, closer to Laguna de Paca. There is a large increase in trees in gullies in the foreground between 1948 and 2012. Most are planted as individuals or in small groupings of 2 to 10. Other new trees are planted along roads and pathways, some as borders of agricultural fields, and some are planted on and above the steep bare slopes of the visible ravines of the background probably as a method of erosion control. Trees along paths are planted for shade. As community property, the area along paths is not used for agriculture. The extent and character of the ravines looks similar between the two photos, suggesting the rate of erosion is relatively slow.

A. B.

Figure 8. Jauja, Peru.
A. (1948) Location of photograph is about 1 kilometer south of Jauja, facing southwest, as the Mantaro River enters a gorge on its way to Oroya. (West 1948, SA1 [7]-29)
B. (2012) Tree cover has increased in the mid ground along with an increase in shrubs in the foreground. (Photo taken by author)

Figure 8 shows the Mantaro River as it leaves the Mantaro Valley just a few kilometers south of Jauja. There is an increase in trees in the mid ground across the scene as well as an increase in scattered trees in the background on the hillsides. There are also new woody shrubs in the foreground. The mid ground trees near the river appear to be almost exclusively eucalyptus in 1948, replaced with a mixture of eucalyptus and other species by 2012. Several of the tallest eucalyptus trees in the center mid-ground are no longer present, perhaps harvested for firewood or lumber. There appears to be less use of the agricultural fields on the middle slopes in the background with a distinct increase in scattered trees and shrubs on the same slope, especially on the rocky area to the right. Both photos show the landscape in June so both show approximately the same point in the annual agrarian cycle. Today there is an entrance to an irrigation canal on the left-hand bank just beyond sight from this position. It is unknown whether it existed in 1948 — West made no mention of it in the notes on the original photo. The river has shifted from right to left due to bar movement and bank accretion, but the water volume appears to be the nearly same as in 1948.

A. B.

Figure 9. Cusco, Peru.
A. (1948) Incan site of Sacsayhuaman, above Cusco, Peru. (West 1948, SA1 [8]-17)
B. (2012) New urban infrastructure of Cusco, roads, houses, and larger buildings, can be seen on the hills in the background. Large contiguous and scattered smaller groups of trees can be seen in the background. The central plaza of Cusco is in the valley behind the foreground hill on the left. (Photo taken by author)

Figure 9 is a view over steps carved in stone and constructed zigzag walls of the Incan fortress site of Sacsayhuaman, above Cusco, Peru. The site is on a hill about 120 meters above the valley of Cusco. The most dramatic change observed in the photo pair is the expansion of urban area up the slopes of the foothills in the background. New barrios complete with roads, houses, and other infrastructure cover the lower half of every slope by 2012. This expansion of urban area is not surprising given the fact that Cusco's population increased from 54,631 in 1940 to 95,088 in 1961 and from 208,040 in 1981 to 367,791 by 2007. Much of the increase occurred during the Sendero Luminoso period of the 1980s and early 1990s when many campesinos migrated to cities to escape the violence of the conflict between government forces and the terrorists. There are many new trees on the landscape. Two large patches of approximately six to ten hectares can be seen in the background center and right of the 2012 photo. An area with terraced rows of young trees can be seen near the top of the hill, background left. All three of these areas are likely the result of government/community cooperative planting programs designed both as a method to control soil erosion and as a means of economic development. Mature trees can be harvested for income. Both motivations can be traced to a larger and longstanding program of smallholder afforestation that began in the 1930s (Dickinson 1969). There are many other smaller patches of scattered trees visible on the background slopes and hilltops associated with smallholder intensification as well as some trees planted as dooryard garden trees.

A. B.

Figure 10. Cusco, Peru.
A. (1948) Incan site of Sacsayhuaman, above Cusco, Peru. (West 1948 SA1 [8]-20)
B. (2012) Many more trees on the landscape behind the smooth rock surface at Sacsayhuaman. (Photo taken by author)

In Figure 10, many more trees appear on the landscape in the 2012 photograph than there were in 1948. The land in the background is not part of the park but a patchwork mix of houses, roads, walkways, and small agricultural fields. These smallholder-based increases in trees are likely associated with people living in the houses in the area, some of which are visible in the contemporary photograph, and many others that are obscured by tree cover. The trees are not a solid planting, as it may appear from this oblique perspective, but rather are planted in rows on field borders, path edges and road boundaries. There are also small, scattered groups of trees planted on slopes too steep or rocky for crops.

A. B.

Figure 11. Cusco, Peru.
A. (1948) Incan site of Sacsayhuaman with three tiers of zigzag stone walls. Cusco is located in the valley behind the foreground hill. (West 1948, (SA1 [8]-14)
B. (2012) Native queñual trees have been planted on the slopes above the stone walls. (Photo taken by author)

Native queñual (Polylepis *spp*.) trees can be seen in Figure 11 on the hill directly behind the stone walls of Sacsayhuaman. These slow growing trees were planted sometime after the 1948 photograph was taken. The queñual can grow at very high elevations. A group of queñual on the upper slopes of Mt. Sajama in Bolivia between 4,800 and 5,200 meters is considered the highest forest in the world. Likely, the proximity of Sacsayhuaman influenced the decision to plant them here — plantations of queñual are rare, as they are slow-growing compared to exotic species such as eucalyptus and pine. The trees visible in the photograph are only the top portion of a same-age forest that covers the top half of the back of the same hill as well as the adjacent hill. Out of view, the lower half of the slope is covered with a less dense plantation of eucalyptus.

Close examination of the 1948 photographs shows that what appear to be trees on the background slopes are, in fact, shadows. There are, however, large patches of trees the newer photograph. These patches appear to be of similar size to those observed in Figure 9, and likely part of a similar government sponsored planting program.

A. B.

Figure 12. Huancavelica, Peru.
A. (1948) A view of Huancavelica looking southwest. Scattered dooryard trees are visible in growing in courtyards and small parks at street intersections. Some trees are growing on the flanks of the Ichu River, which flows through the center of the valley. (West 1948, SA1 [7A]-6)
B. (2012) The built-up area of Huancavelica has grown up the valley and up the steep slopes of the enclosing canyon walls. Many new trees are visible in large groups on the near and far slopes. (Photo taken by author)

In Figure 12, Huancavelica experienced a great deal of urban expansion since 1948. Despite the dramatic increase in urban land cover, many new trees are visible on both the near and far canyon wall slopes. Many of the new trees are part of a recent government / community partnership program designed to plant trees as a means of stabilizing soil on the steep slopes above Huancavelica as well as to recharge the local watershed (Otarola 2011). Smallholder increases can be seen there are more dooryard trees in the city and scattered smaller patches on the lower slopes, along the river's edge, and on paths and roadways.

A. B.

Figure 13. Huancavelica, Peru.
A. (1948) Looking south to north across the valley floor. (West 1948, SA1 [7A]-7)
B. (2012) Increased urban infrastructure and an increase in dooryard trees and smallholder plantings on lower slopes. (Photo taken by author)

As with the previous photo pair, Figure 13 looks south to north across the center of town on the valley floor. There are many more buildings and roads on the landscape in 2012 than in 1948, with urban infrastructure built right to the base of the steep rocky cliffs on the opposite canyon wall. The river has been channelized and contained within cement retaining walls. There are no agricultural areas, even of terraced plots found on many slopes the central sierra of Peru — the rocky cliff walls are too steep and rocky.

There are many new trees on the landscape, mostly in the form of the dooryard trees and some smallholder-based trees planted in small parks or on community land. The near and far slopes have scattered eucalyptus of various ages that were likely planted for a variety of reasons, including erosion control and for use as firewood or building materials.

A. B.

Figure 14. Huancavelica, Peru.
A. (1948) Looking northeast across Huancavelica. Note the mature eucalyptus in the foreground planted as dooryard trees. (West 1948, SA1 [7A]-4)
B. (2012) There is an increase in smallholder plantings as dooryard gardens and small groupings on the slopes in the background. (Photo taken by author)

In the mid-ground and background of Figure 14, there is a dramatic increase in dooryard garden trees and those planted in small, open groups on hill slopes. Two larger patches of trees can be seen on the background slopes in 2012 — photo center and right — that appear to be in the same location as patches from 1948. The 1948 trees could be eucalyptus or perhaps native queñual. West's notes mention the dooryard eucalyptus in the foreground, but do not make particular mention of the background trees. There are a few tall dooryard eucalyptus in the foreground in 1948 that are no longer on the landscape in 2012. Trees of the same height in the same location today would probably not appear as tall as the buildings around them have mostly grown from one-story to three and four stories.

A. B.

Figure 15. Huancavelica, Peru.
A. (1948) View from the south side looking directly north over Huancavelica. (West 1948, SA1 [7A]-3)
B. (2012) This photo shows a government/community cooperative tree plantation designed to control erosion on the steep slopes above the city of Huancavelica. (Photo taken by author)

The most notable change between the two photos in Figure 15 is the increase in the number and extent of urban structures and the large patch of trees on the steep slopes of the background canyon wall. The large patch of trees is part of a government/community cooperative tree plantation designed to control erosion on the steep slope on which it is planted. The trees are Eucalyptus *globulus*. Many slopes above Huancavelica are rocky and steep making agriculture impracticable. The building in the foreground is a train depot built after 1948 to serve the Huancavelica to Huancayo line.

Remote Sensing

I created tree cover maps using a supervised classification technique in ArcGIS 10.1. I selected training samples near the study sites to represent five land-cover types: forest, urban, agricultural, bare-earth, and shadow. I guided training sample shapes, sizes and locations by using high-resolution (approximately 1-meter) imagery overlaid over the Landsat scenes. Forest, agricultural, and urban cover boundaries that are often not easily distinguished in the Landsat imagery are easily differentiated at the higher resolution. While it is likely that this method enhances the accuracy of the final classified map, it is also limited by the fact that the high-resolution imagery was captured at a different (more recent) time than the Landsat imagery. Land-cover types and locations could have changed over the intervening period.

I combined the four non-forest land-cover categories into one category resulting in a map with only two land-cover categories: forest and non-forest. For display and visual analysis, I colored the tree cover cells bright green, made the non-forest cells transparent, and overlaid the resulting layer on a natural color Landsat image for each study site.

I created tree cover change maps for each study site by performing a raster difference calculation in ArcGIS on the tree cover map pairs 1984-2004. The raster calculation produced a map that showed areas of tree cover increase, tree cover decrease and areas with no change in tree cover between the two periods. Red pixels represent a decrease in tree cover, blue pixels represent an increase in tree cover, while I converted pixels representing areas of no change to null (clear) cells. For display and analysis, I overlaid this map over a natural color version of the of the 2004 Landsat images using bands 321 (RGB) for each of the three areas. I calculated an error matrix of producer and consumer accuracy for the 2004 images for 30 systematically sampled data points by comparing the classified image results to recent high resolution Google Earth imagery. High-resolution (approximately 1 meter) imagery is only available for recent time periods so error assessment using this method was not used for earlier (1984) image sets as it may not be as meaningful or reliable.

Analysis of forest cover change using remotely sensed imagery revealed areas of increased, decreased, and stable tree cover for all three study cities. Overall, patterns for the time period of this research suggest a net increase in tree cover across the region. Specific patterns of change for each area are discussed below.

For all three areas, there are large patches in 2004 of contiguous forest that are larger than the size of any patches that existed in 1984. This is beyond what the ground level repeat photography revealed, partly because their oblique perspective does not always allow discrimination of contiguous patches and other patterns such as multiple lines of windrows. The contiguous nature of the new patches suggests a different and increased level of social or government organization involved in the new areas.

Use of Landsat imagery to detect tree cover misses patches of trees smaller than its pixel size of 30 x 30 meters. Individual trees and small patches make up a substantial percentage of total tree cover in the study area. With higher resolution data that would include these trees, the actual area of tree cover, especially for Jauja and Cusco, would likely be much higher than what is reported in the results below. Similarly, Landsat data, due to its resolution, simply cannot see many of the kinds of tree cover change that might be linked to the scarcity and smallholder pathways of forest transition theory. Repeat photography, for this study at least, does a much better job at showing those types of changes.

Areas of shadow are always challenging to remote sensing analysis. Where there are shadows, there is little or no reflected energy to supply information about what might be there. Misclassification of land-cover is more likely in shadowed areas as there is simply less spectral information from what is there. Two aspects of this may affect the remote sensing results. First, the sun angle was slightly different between the image pairs, causing the south-facing areas in shadow to shift somewhat between the image pairs. Secondly, areas of plantation forest are more likely located on south-facing slopes than north-facing ones. North-facing slopes, with higher average insolation in the southern hemisphere, are commonly reserved for agricultural fields. The fact that trees are more likely located in shadowed areas means there is a higher probability of misclassifying forested areas than other land-cover types.

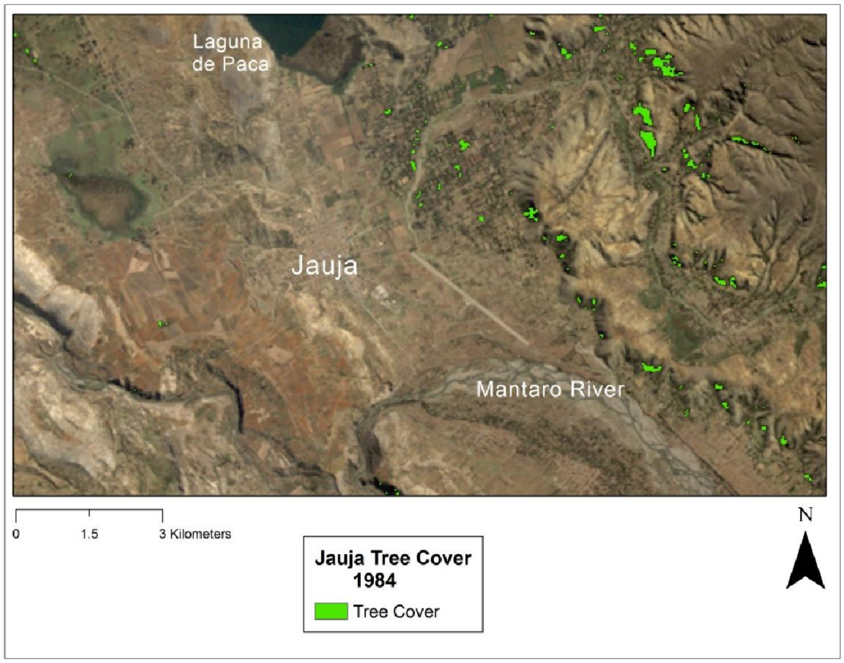

Figure 16. Map of tree cover for Jauja, 1984. Areas of tree cover are shown in bright green. Total tree cover within the boundary of the image is about 93 hectares.

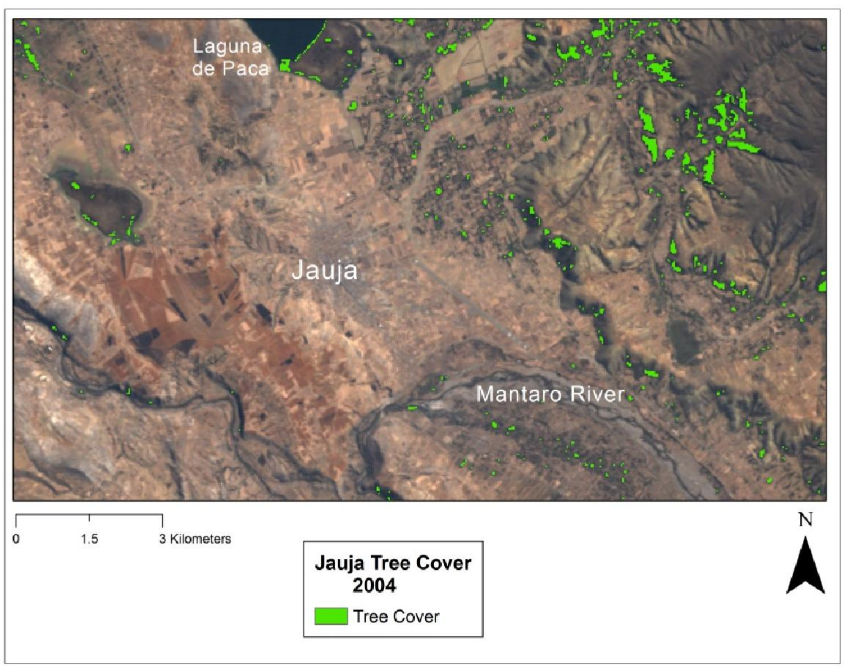

Figure 17. Map of tree cover for Jauja, 2004. Tree cover is shown in bright green. Total tree cover for the same area has increased to 258 hectares.

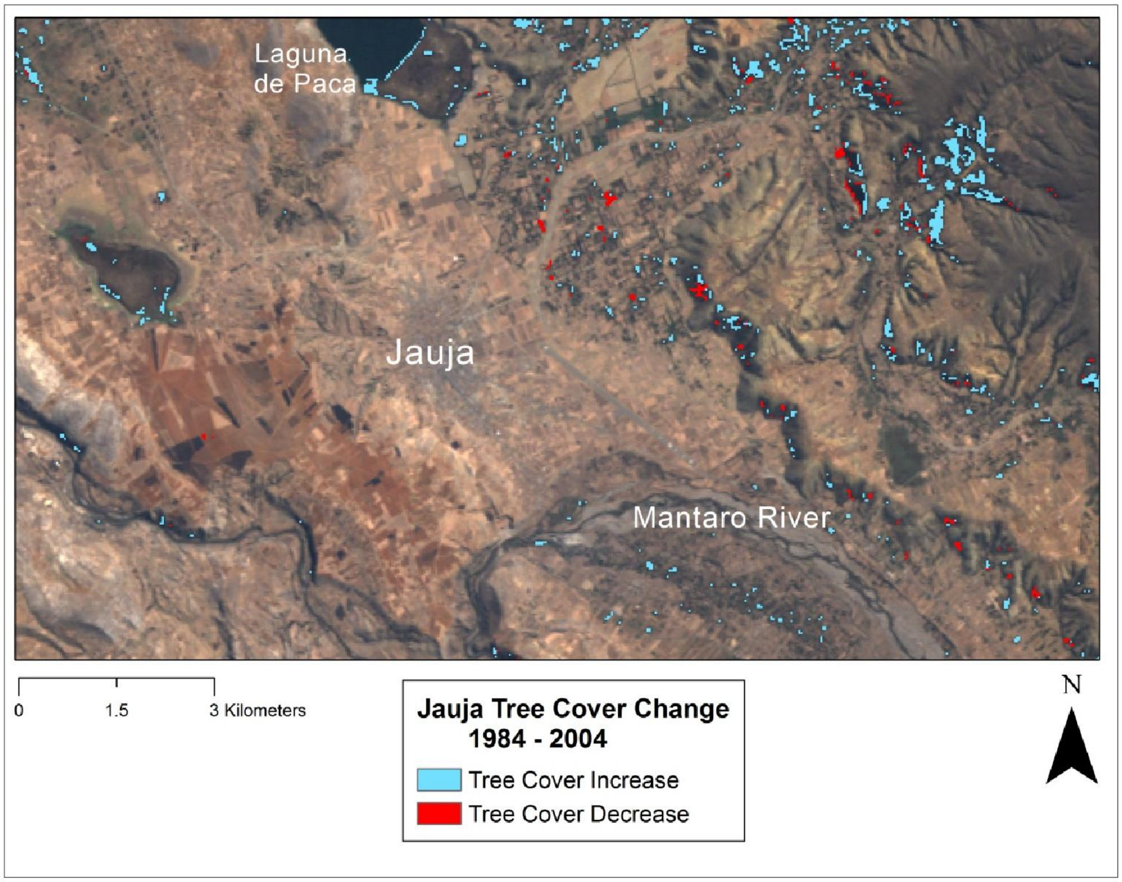

Figure 18. Map of tree cover change for Jauja 1984-2004. Increases are shown in blue, decreases in red.

The tree cover change image for the area around Jauja depicted in the map, 1984 to 2004, shows tree cover increases as blue and tree cover decreases in red (Figure 18). Though there were both increase and decreases, overall tree cover increased from 93 hectares in 1984 (Figure 16) to 258 hectares in 2004 (Figure 17), an increase of 165 hectares. Overall tree cover has increased, mostly in large patches on the south-facing slopes of the foothills to the east of the city. These patches range in size from approximately one to ten hectares in size. For comparison, an American football field (including the end zones) is a little over half a hectare. The size and location of these patches suggests they are part of ongoing state forest policy programs intended to establish forest plantations for their economic and environmental benefits. Change totals reported above are for the exact area represented in the image. Those figures, especially the increases, would likely be lower if the rectangular window of view were shifted west or southwest, or zoomed in closer to Jauja. Still, the increases observed here are likely connected with the people who live in or near Jauja and therefore relevant to this study. Total tree cover is likely underrepresented in Jauja compared to Huancavelica or Cusco using Landsat imagery because there are many areas of trees in the center of the images that are too small to be detected. As can be observed in the photographs of Jauja, such as Figure 6, these smallholder-based trees form windbreaks and fencerows and are a significant feature on the landscape. Percentage increases from one period to the next are likely exaggerated, as we are working from a (artificially) smaller tree cover total than actually exists. This method only compares two snapshots in time and does not account for the cutting and replanting of trees in the interim.

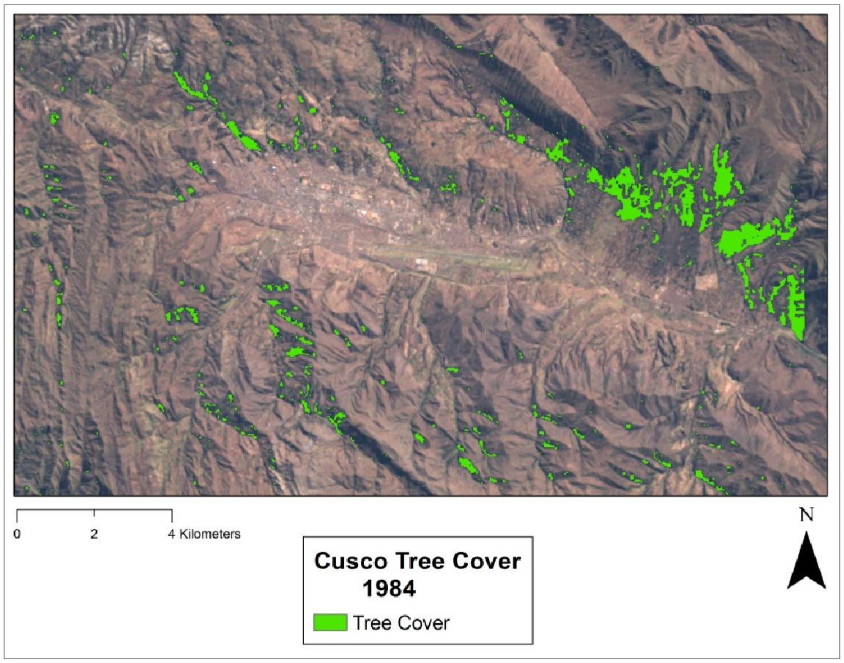

Figure 19. Map of tree cover for area around Cusco, Peru, 1984. Areas of tree cover are shown in bright green. For reference, the airport runway at the center of the image is about 3,300 meters long.

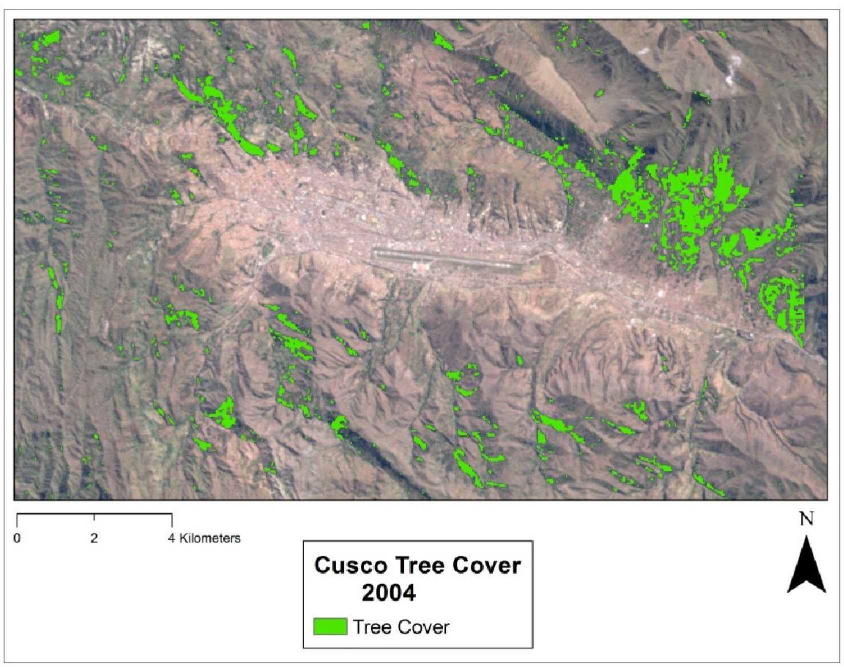

Figure 20. Map of tree cover for area around Cusco, Peru, 2004. Tree cover is shown in bright green. An increase in tree cover from 1984 is apparent with a just visual comparison.

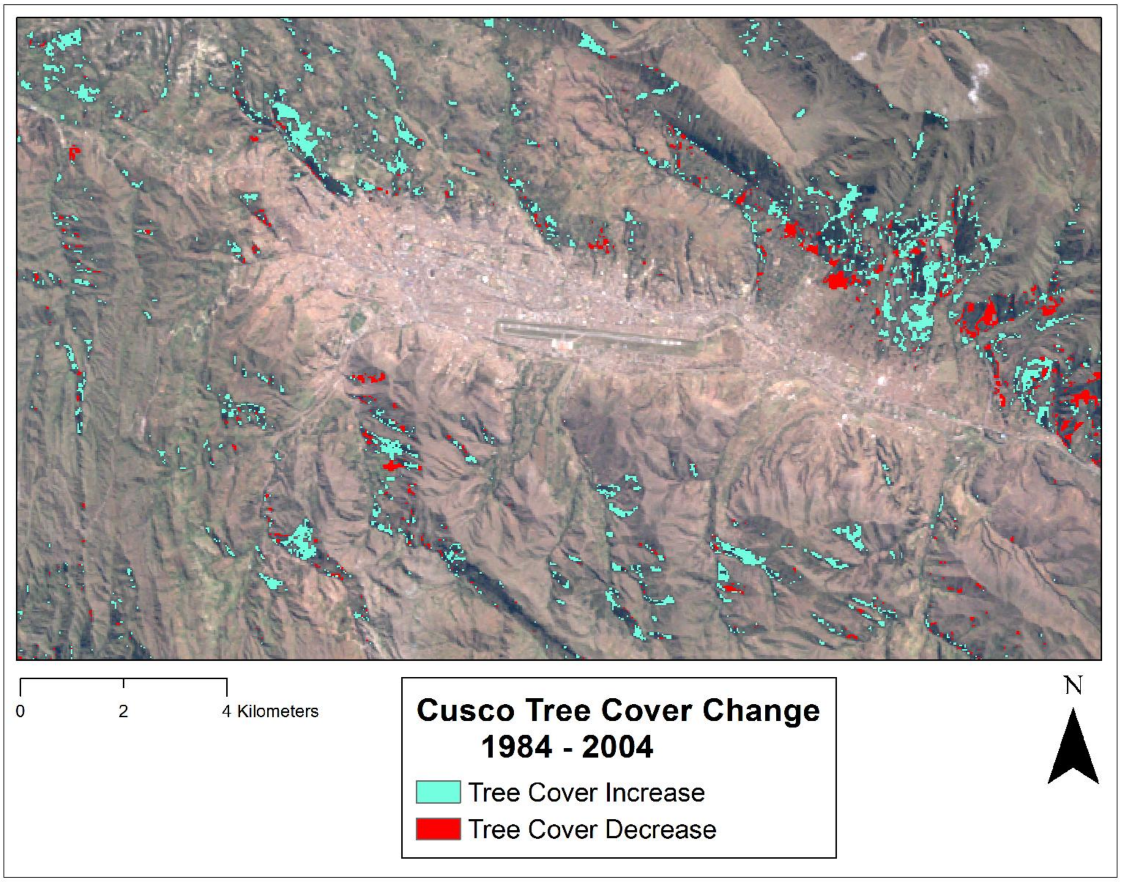

Figure 21. Map of tree cover change for Cusco, Peru, 1984–2004. Increases are shown in blue, decreases in red. Many of the decreases are likely due to urban expansion. Many of the increases are patches located adjacent to or near large patches of decrease.

The Cusco region depicted in the map experienced a large increase in tree cover during the period from 1984 to 2004, from 681 hectares to 1178 hectares, or a 72% increase. The change map (Figure 21) shows numerous areas of increase and decrease, with many new patches of forest between one and 15 hectares in size. The patches are irregularly shaped, which fits the mountainous topography of the sierra. As in Jauja and Huancavelica, plantations are usually established on south facing slopes that generally receive less sun in the southern hemisphere. North-facing slopes in rural areas are more often reserved for growing food crops.

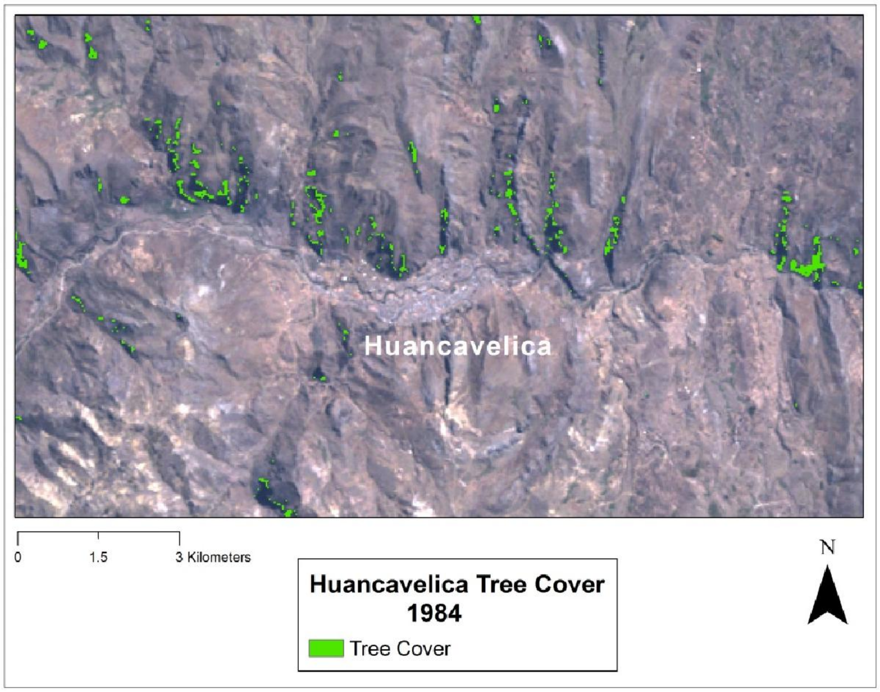

Figure 22. Map of tree cover for Huancavelica, Peru, 1984. Areas of tree cover are shown in bright green.

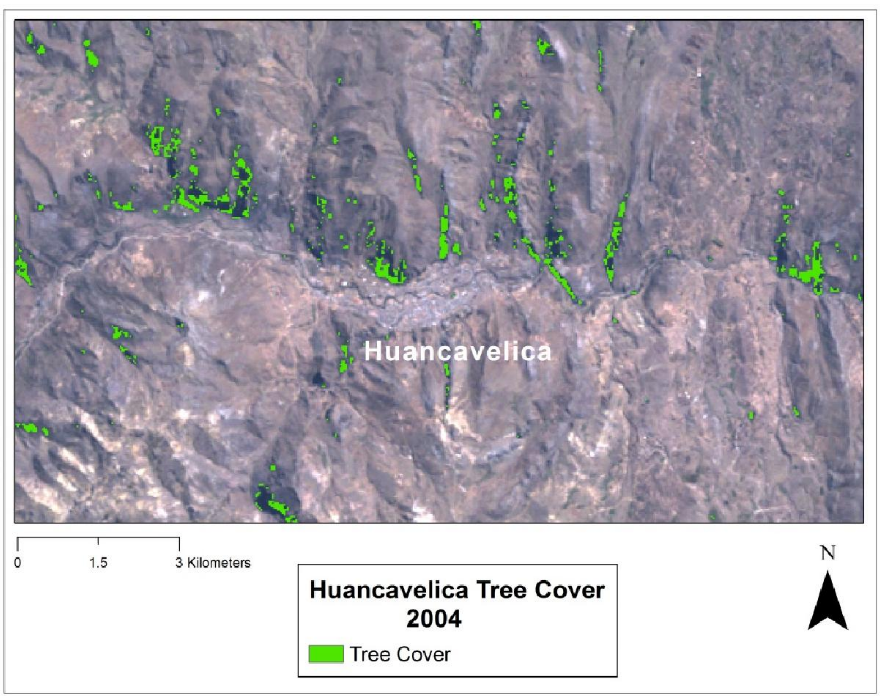

Figure 23. Map of tree cover for Huancavelica, Peru, 2004. Areas of tree cover are shown in bright green. Significant increases can be observed after a visual comparison with the 1984 map. Most of the increases are expansions of forested areas that already existed in 1984.

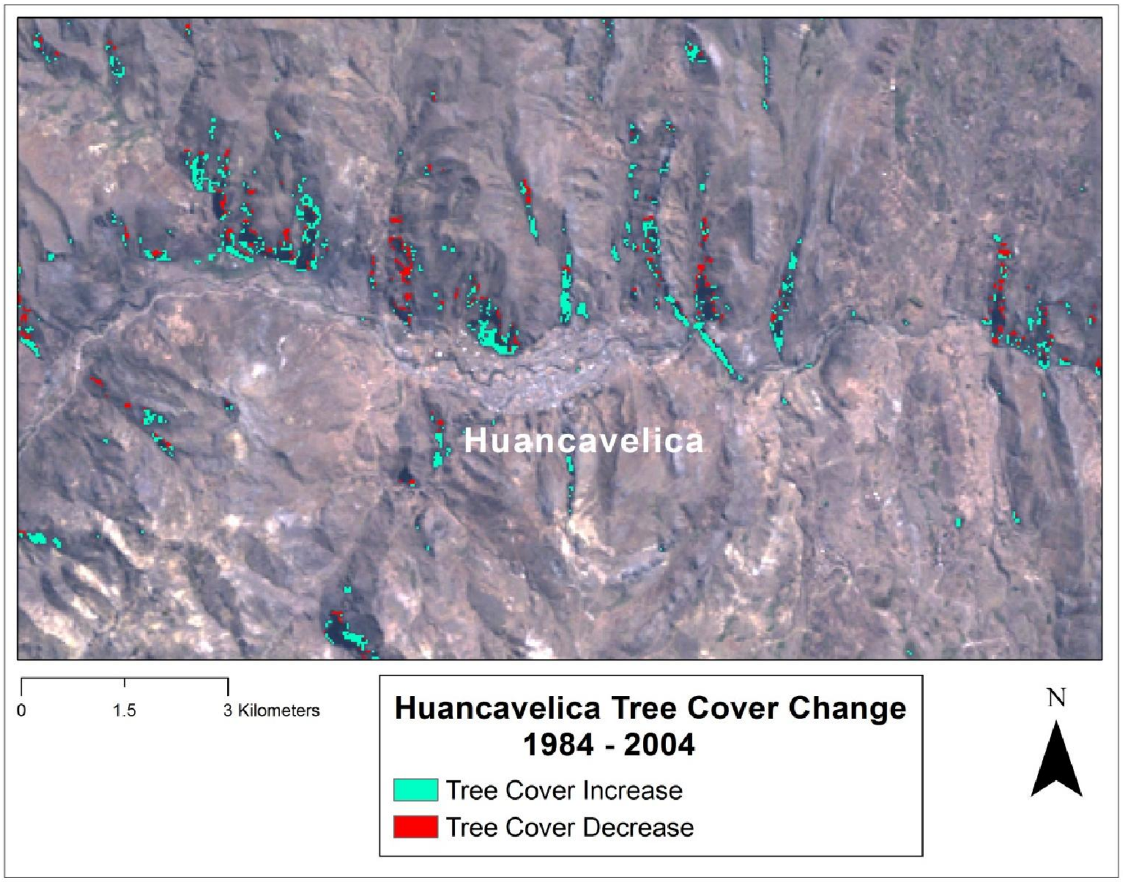

Figure 24. Map of tree cover change for Huancavelica, Peru, 1984 – 2004. Increases are shown in blue, decreases in red. Most of the increases in tree cover are on the slopes and in the canyons directly above, and on the north side, of the city.

Total tree cover increased in the area depicted in the map surrounding Huancavelica from 120 hectares in 1984 (Figure 22), to 226 hectares in 2004 (Figure 23) with a net increase of about 106 hectares, or 88%. Figure 24 shows increases and decreases. Both increases and decreases seem to be occurring on the steep slopes and in canyons directly north of the city. These slopes are steeper and rockier than those on the south side of the canyon. Many of patches are of the size — roughly one to ten hectares — to have been planted as part of a government/community partnership afforestation program.

Ethnography

Two semi-structured interviews were performed with forestry officials for the Huancavelica and Jauja areas. Both confirmed that many of the larger tracts of trees planted on hillsides around the cities were indeed planted as part of government sponsored programs. Usually these programs involved government supplied seedlings and expertise and local labor. The official for Huancavelica also produced a government document distributed to local communities that explains the watershed recharge and erosion control benefits of planting trees. People encountered during fieldwork were generally enthusiastic about the new trees on the landscape and many knew they were part of government efforts to recharge the local watersheds and control erosion.

CHAPTER VI

DISCUSSION

Overall, the repeat photography and remote sensing results show that for the areas around the study cities, there were more trees on the landscape in 2012 than in 1948. All twelve of the photo pairs showed more trees on the landscape, while the remote sensing results showed that there were increases in tree cover areas beyond what is visible in the photographs. Ethnographic methods confirmed that many of the larger patches of new trees were planted as part of government sponsored programs.

Eucalyptus are seen in almost all of the highland landscapes shown in the West photographs (including those I was not able to relocate and re-photograph). As he noted on a photo from 1948 of a group of trees in the Mantaro Valley, "Groves of eucalyptus trees furnish firewood and lumber for local use." (West 1948, SA1[7]-22). Timber from eucalyptus can be burned without drying — their sap aids combustion — making them useful as a fuel for cooking. During my research trip during summer 2012, I encountered firewood being used in a variety of ways, most often as fuel for cooking. However, I was surprised to see it used to heat bathing water in the medium sized hotel I stayed at while in Huancavelica. Figures 25 and 26 show a wood-fired boiler system and associated stack of firewood used to heat the guest room showers at my hotel. Someone appeared to add fuel to the fire every morning and evening.

Figure 25. Wood-fired water heater at hotel in Huancavelica, Peru. (Photo taken by author)

Figure 26. Eucalyptus firewood to be used in wood-fired water heater in Huancavelica, Peru. (Photo taken by author)

Reforestation is the expansion of forest cover when forests naturally regenerate on previously forested lands (Rudel et al. 2005). For the period of this study, afforestation is a better description of what is happening in the central sierra of Peru. Afforestation is the expansion of forest cover when trees are planted on land without trees. Most of the new trees and forests seen in the repeat photography and remote sensing are planted at the direction of individual people, communities, or governments.

In addition to the increase in trees on the landscape, another type of change that can be seen in the photo pairs is the expansion of the urban area of all three cities. Urban growth around Cusco is perhaps the most dramatic of the three and is likely a reflection of the fact that population increased by a significant amount in the period between the photographs. Much of these increases were due to the long-term trend of rural to urban migration. This movement of people to the cities was perhaps at its highest levels during the 1980s and early 1990s as migrants attempted to escape the violence of the armed conflict between the Peruvian military and the Sendero Luminoso by seeking the relative safety of the cities (Haller and Borsdorf 2012).

Forest Transition

Forest transition theory can help us think about the reasons why changes in tree cover occur. The number and type of explanatory pathways of forest transition theory seem to increase as new cases of local or regional tree cover increases are discovered. The five categories, or *pathways*, of forest transition from Meyfroidt and Lambin (2010) are economic development, forest scarcity, state forest policy, globalization, and smallholder intensification. Table 1 shows the repeat photo pairs and the pathway(s) associated with the tree cover change observed in them. Following the table is a discussion of the five pathways and a general discussion of how changes in tree cover observed in the photo pairs were categorized.

Table 1

Forest Transition Pathways and Repeat Photos of Highland Peru

Photo pairs	Economic Development	Forest Scarcity	State Forest Policy	Globalization	Smallholder Intensification
1. Figure 6			X		X
2. Figure 7					X
3. Figure 8			X		X
4. Figure 9					X
5. Figure 10					X
6. Figure 11		X	X		X
7. Figure 12		X			X
8. Figure 13			X		
9. Figure 14		X	X	X	X
10. Figure 15					X
11. Figure 16		X	X	X	X
12. Figure 17		X	X	X	

The *economic development* pathway suggests forest increases occur when marginal agricultural land is abandoned and spontaneous forests grow. Abandonment of marginally productive land has occurred in developed countries as rural workers are attracted by better labor opportunities in the cities and/or decreased demand for agricultural labor following agricultural intensification. I do not believe there are any examples of tree cover increases observed in the photo pairs or remote sensing results that fall within the economic development pathway. While some economic progress has occurred in the highlands of Peru, the pace of economic growth cannot be compared to that of any more-developed country. For smallholders that farm the land seen in most of the photos, the agricultural economy has likely not changed a great deal. Agricultural productivity has always been high in the Andes. Sophisticated erosion control and irrigation techniques have been in use in the Andes since well before the Incan era. Moreover, there is no example of agricultural land abandonment in the photos except for possibly Figure 8 where agricultural fields in the background slopes appear to be less used today than they were in 1948. However, there was no corresponding increase in trees except at field margins and rocky areas never used for agricultural crops.

The *forest scarcity* pathway is a type of "forest intensification" where "timber needs can be satisfied from limited areas of forest plantations thereby saving the remaining forests from exploitation pressure" (Meyfroidt and Lambin 2011, 348). Forest scarcity manifests itself as the planting of more trees in reaction to an actual or perceived increase in the scarcity of trees or tree products (Rudel, et al. 2005). This pathway was the most difficult to distinguish as a specific type of change observable in the photographs. This pathway is not associated with a particular pattern on the landscape but simplify reflects a general increase in tree cover. Increases in scattered trees, smallholder woodlots, and large plantations of trees could each represent the pattern of increase caused by this process. One or more of them are visible in each photo pair.

For this study, increases in the number of households that use firewood as a fuel for cooking will serve as a measure to indicate where the forest scarcity pathway might be at work. Firewood is used as a fuel for cooking in many highland households. For example, in the 2007 census, 90% of households report the use of firewood to cook in *Huertas* District that is seen in several of the photographs near Jauja. High use of firewood should influence people to grow more trees if they were perceived as a scarce resource. Tree cover increase observed in areas of increasing demand or use of firewood would likely fit the forest scarcity pathway of forest transition theory. Demand for firewood is not the only use for tree products in the highlands, but it is a significant one.

Table 2

Use of Firewood as a Fuel for Cooking for Select Cities in Highland Peru

Province	Population 1961	Population 2007	Households That Use Firewood for Cooking 1961	Households That Use Firewood for Cooking 2007	% of Households That Use Firewood for Cooking 1961	% of Households That Use Firewood for Cooking 2007
Cusco	95,088	367,791	5,095	15,298	28.3%	16.0%
Jauja	95,496	92,053	14,138	15,355	70.7%	63.9%
Huancavelica	73,927	142,723	8,450	15,532	48.2%	45.5%

The percentage and number of households using firewood for cooking varies among the three study cities (Table 2). All three show a drop in percentage of households using firewood in the last fifty years with Cusco declining the most from 28.3% in 1961 to 16.0% in 2007. This is probably caused by the increased availability of compressed liquid propane in the last twenty years in most larger cities of Peru. The percentage of households using firewood in Huancavelica and Jauja are much higher and remained relatively steady for the same period at about 45 and 65% respectively.

Since this thesis focuses on *increases* in tree cover and the potential causes of those increases, the absolute number of households using firewood is a more relevant measure. In 1961, a little over 5,000 households reported firewood use in Cusco province, tripling to over 15,000 by 2007, even as the percentage of households using firewood fell by nearly half. Huancavelica doubled the number of households using firewood to cook from 8,450 to 15,532 over the same period. Jauja province as a whole had a high percentage of households using firewood in both periods but experienced a relatively small increase in absolute numbers, from 14,138 in 1961 to 15,355 by 2007.

Because Cusco and Huancavelica experienced higher increases in the absolute number of households that use firewood, even as the percentage using it fell, I assigned the scarcity pathway to those photo pairs and not for those of Jauja. However, firewood use for cooking is only one possible measure to indicate scarcity as a driver of tree cover increases. Trees products are also used in the walls and roofs of buildings, to heat water in hotels, as fence posts, and for other uses. In my view, the forest scarcity pathway is operating in Jauja as well. This might be shown quantitatively had other measures or methods been used.

In future work, I plan to examine the connection between changes in tree cover and changes in firewood use by calculating the correlation between them. The degree of correlation over time might help determine the degree to which the demand for firewood is responsible for increases in tree cover. Data on the number of households using firewood to cook will be gathered at the province level for the three Peruvian censuses of 1981, 1993, and 2007. Total tree cover in hectares will be derived for the province level using Landsat data for the same years as the census data. This future work could provide more insight

Increases in tree cover are often the result of *state forest policy*, the third of five pathways. Governments sometimes put policies in place in response to scarcities of tree products, but Lambing and Meyfroidt (Lambin and Meyfroidt 2010) stress that these policies are often instituted without connection to forest scarcity.

Peru has the third-largest area of forest plantations in tropical America (820,000 hectares). Most plantations are located in the Andes and the main species being planted are *Eucalyptus globulus* (ITTO 2011). Traveling by road in my two-month visit in summer 2012 in central and southern Peru, I personally observed many of the large-scale efforts at establishing tree plantations, mostly of eucalyptus and pine from five to twenty years old.

Almost all plantation projects of the last 40 years in Peru are the result of government/community partnerships pairing Non-Governmental Organizations (NGOs) or state forestry departments with local community groups (Aguirre 2009, Gómez and Torres 2009). The government typically supplies funds, seedling trees, and technical expertise while communities supply the labor and land. Assisted with funds from the United States Agency for International Development (USAID), large government-sponsored programs for afforestation and reforestation expanded in the 1960s as economic development vehicles (Dickinson 1969). The large-scale plantations in the Department of Cusco planted during this period were seen as providing economic and social benefits. They provided "economic resources to the least privileged economic sector," the rural poor, while at the same time providing valuable timber and pulp for sawmills and paper factories in the southern third of the country (Ministerio de Agricultura 1976, C-1-1-21). During the presidency of Albert Fujimori in the 1990s, afforestation programs were promoted by the Peruvian National Soil and Water Conservation Agency (PRONOMACH) as a method to control soil erosion and recharge watersheds. The program was also a way for the Fujimori administration to "bootstrap" economic development in the Andes following the devastating decline the country's economy experienced during the peak of Sendero Luminoso activity in the 1980s. From 1993 to 2006, the PRONOMACH program of community afforestation installed 389,438 hectares of new forest in the country with the bulk occurring in the sierra (Ministerio de Agricultura 2007).

Although the government has had varying degrees of involvement in forest management, Peru has never nationalized them as Honduras did in the 1970s (McGregor 2011). There have always been community and, to a lesser extent, privately-owned forests in the highlands of Peru. The modern prevalence of community-owned property as a common form of land-tenure in highland Peru is a legacy of pre-colonial social and land-use practices where resources and labor were shared among extended family. After a long period of land consolidation into large estates during the colonial and modern eras, the haciendas were abolished in 1969. More than 8 million hectares were distributed to Agrarian Production Cooperatives (CAPS) and Social Interest Agricultural Societies (SAIS), modern forms of communal ownership and labor sharing reminiscent of the *Mit'a* arrangement of the Incan era (Burneo 2011).

For the purposes of this study, any increases of tree cover in contiguous patches are considered associated with a state forest policy pathway. By this definition, with the support of the remote sensing data below, there are many increases in tree cover seen in the photo pairs associated with state forest policy.

Globalization can be defined as the increasing exchange of goods and ideas in a world "in which international borders are diminished and a worldwide marketplace is created" (Domosh, et al. 2010, 14). Meyfroidt and Lambin (2010) call the *globalization* pathway in forest transition theory the modern version of the economic development pathway because most developing country economies are strongly tied to the world economy. The impacts of globalization can be seen on the landscape in many ways. Likewise, many increases in tree cover can be associated with, in part at least, globalization. Hecht et al. (2006) tied recent reforestation in El Salvador to remittances sent from migrant workers outside the country to the rural poor, which relieves pressures on the land.

In Peru, the globalization pathway is also strongly connected with the *state forest policy* pathway. Peru's large-scale government affiliated afforestation programs have a long history of international connections in the form of technical expertise and funding. The original large-scale efforts to establish small community-based plantations of eucalyptus in the 1960s were funded by the United States Agency for International Development (USAID) and the International Development Bank (IDB) (Dickinson 1969).

Globalization includes the diffusion and exchange of not just material goods but also of ideas. The connection between forest plantations and economic development is an international idea (Doughty 2000). Since 1980, more than half of the World Bank's forestry budget has involved tree cultivation, mostly of eucalypts and similarly adaptable species (ibid). International ideas about the benefits of afforestation for economic development and the environment permeate many government documents produced in Peru in the last 40 years (Ministerio de Agricultura 1976, Ministerio de Agricultura 2007, Fondo Nacional del Ambiente Peru 2007). The introduction to the 2005 National Reforestation Plan of Peru notes a number of ecological, social, political, but perhaps above all, economic reasons, for developing an aggressive reforestation program

(Ministerio de Agricultura 2005, 2). The presence of eucalypts themselves also point to a kind of globalization. They are an imported species accounting for perhaps a third of all plantation species worldwide (Doughty 2000, 178).

Certainly the larger patches visible in the photographs, especially those of Huancavelica, are the intersection of two effects of globalization — the idea that planted trees will offer watershed recharge and control erosion and the imported tree itself – combine to explain why this new patch of trees is associated with globalization. These relatively small plantings are not the result of large commercial or industrial interests who plant hundreds or thousands of hectares of trees as in other areas of Peru and other countries. However, the idea of using the trees for economic development, to generate "the most employment and [eradicate] poverty" (Ministerio de Agricultura 2005, 2) is an idea from the developed world.

For this study, classifying tree cover change seen in the photo pairs as connected with globalization was limited to those in Huancavelica where a local forestry official specifically pointed out patches of trees visible from his office window as having been planted to control erosion and recharge the watershed. These are two valid but internationally influenced ideas about the environmental benefits of planting trees. He also gave me a copy of a brochure produced by his office showing the techniques and advantages of planting trees on hillsides and stream banks to control erosion (Otarola 2011).

The remote sensing revealed that all three cities have large patches of tree cover increase that are likely connected to government plantation programs. For the reasons stated above, it can be argued that the each of these patches can also be assigned to the globalization pathway, but I have chosen not to do so here.

The last of the five pathways is *smallholder, tree-based land-use intensification* (Lambin and Meyfroidt 2010). It is perhaps the easiest to define and see on the landscape. Smallholder-based increases include expansion of trees in woodlots, agroforestry systems, gardens, hedgerows, and windbreaks. They allow a small-scale agriculturalist to diversify income and reduce risk. These smaller areas of trees are not typically captured in regional or national totals, but as mentioned above, they can be a valuable part of the landscape socially, economically, and ecologically.

Ten of twelve photo pairs have areas of smallholder increase visible, with multiple areas of increase typical at every study city. These are often in the form of windbreaks, fencerows, woodlots, and dooryard garden trees.

Combined, the photographic, remote sensing, and ethnographic data tell us a great deal about tree cover change in the context of forest transition theory for our three study cities. The two pathways most appropriate to describe the drivers of overall increase in tree cover in the area of the study cities are state forest policy and smallholder intensification. Forest scarcity and globalization are likely active in some form for each of the three areas, but I argue their presence is difficult to see on the landscape in any discrete and non-arbitrary way that separates them from the state policy and smallholder explanations. Government sponsored programs in Peru are sometimes likely driven by a genuine situation where trees are relatively scarce and the state reacts by installing a plantation forest. Evidence of state forest policy on tree cover based on the size of patches seen in the repeat photography and remote sensing is clear. However, a connection between scarcity and state forest policy was not observed in the ethnographic or documentary sources.

Smallholder increases in tree cover — as a source of tree cover increases — appear most visible in the landscape around Jauja as many new trees can be seen in many new small groupings planted as fencerows windbreaks and small woodlots mixed amongst productive agricultural fields of the flat Mantaro valley floor. Smallholder increases can also be seen as new trees planted in lines and groups on ridgelines and in gullies.

Forest transition theory has been modified and expanded in the last ten years, as the original conception did not fit recent cases of forest expansion in the tropical developing world. No one conception of the forest transition theory is likely to explain every instance of forest increase. For this study, forest transition theory as described by Meyfroidt and Lambin (2011) has several shortcomings.

The categories of explanation of forest transition theory are not discrete, and they are not mutually exclusive. Changes observed at the landscape scale and over long periods are often too complex to fit any single explanation. Because of this complexity, many pathways were assigned to the types of tree cover in many of the photo pairs. It is not always easy to assign a pathway to changes seen on the landscape. Moreover, it is easy to ascribe more than one. As a practical matter, in the repeat photography, there were many individual instances of tree cover increase that were very difficult to categorize as belonging to one pathway or another. Is a stand of trees planted with community labor and on community land but with government supplied seedlings and technical expertise part of state forest policy or smallholder intensification? As noted above, the same can be said of the overlap between state forest policy and globalization. In this study, it was possible to assign both to many of the same groups of tree cover increase observed in the photo pairs. In this context, almost every instance of government afforestation can also be thought of as an instance of globalization.

For this study, the scarcity pathway was not easily identifiable on the landscape. Almost any increase of tree cover in the landscape could be identified with forest scarcity. The fact that the scarcity pathway can arguably be responsible for almost any instance of tree cover increase makes the explanatory power of this pathway weak.

Ultimately, the situations under which increases happen are simply too complex for a single theory to account for all the possible conditions under which tree cover increase can take place. In their latest paper on the subject, Meyfroidt and Lambin emphasize that forest transition theory is a "contingent empirical regularity… not evolutionary stages…in a deterministic process." (Meyfroidt and Lambin 2011) In other words, it is probably not possible to specify all of the social and political conditions under which tree cover has increased or will increase in the future.

The general pattern of tree cover increases seen in the repeat photography is not necessarily representative of the central sierra of Peru as it is concentrated in three places. The remote sensing data set is more spatially comprehensive and yet does not cover the entire study area. The repeat photography sets were taken 64 years apart. Moreover, the temporal period of the remote sensing does not match that of the photographs. However, the combined data sets, along with ethnographic and documentary evidence, offer a more comprehensive picture about why there are more trees in and near the study cities and perhaps a little beyond. One can extrapolate to the entire region of the central highlands of Peru only with caution. It seems reasonable to assume that the type of increases observed around the area of the study cities is taking place around other cities in the highlands of central Peru. However, in rural areas, with fewer people and different social and political conditions, tree cover may not have experienced a similar increase.

CHAPTER VII

CONCLUSION

There are many well-documented cases of deforestation in developing countries, especially in those located in the tropical regions of the world (Aide, et al. 2013). However, there is a growing body of research that show areas of local or regional increases in tree cover (Bass 2004, Bass 2006, Farley 2010, Hecht and Saatchi 2007, Klooster 2003, Meyfroidt and Lambin 2008, Sanchez-Cuervo et al. 2012). This study provides another example of an area that has an increase in tree cover.

This study documents another case of tree cover increase in the tropics and contributes to our collective understanding of contemporary landscapes and environmental conditions in the world and complex ways people and the environment interact by documenting long-term landscape change in highland Peru.

The project used repeat photography as the primary method of data collection, with remotely sensed imagery and ethnographic data serving as complementary methods that support and inform the changes seen in the photographs. Repeat photography offered long-term ground level concrete evidence of the increases in tree cover that are taking place in highland Peru. The remote sensing data offered a way to verify and complement the observations made on the ground by showing the changes visible in the photographs were taking place for a larger area beyond the view of the camera.

Results of the repeat photography show that there are more trees on the landscape in and around the three study cities in 2012 than there were in 1948. The increases in tree cover visible in the photographs vary from new individual trees to larger patches of contiguous tree cover, usually on background slopes. Remote sensing results show that there is a significant increase between 1984 and 2004 in large patches of trees in areas beyond the view of the photographs.

The use of multiple methods was found especially useful when attempting to document the reasons causing the changes observed in the photography. Ethnographic and documentary data informed the reasons why changes might be taking place. It is possible with imagery alone — photographic or remotely sensed — to describe changes on the landscape, but ethnographic, documentary, or other evidence is needed to get at the processes causing the change in pattern. Even then, the explanation is never complete.

Forest transition theory offers explanatory pathways describing in a general way why many places in tropical developing countries have experienced increases in tree cover after periods of decline. Using forest transition theory as a framework for explanation in this thesis, tree cover increases were mostly due to smallholder intensification and state forest policy increases. However, the forces that shape changes in vegetation in the landscape are complex and intertwined. The variety of conditions under which tree cover changes take place imply that the causes of forest cover increases are spatially heterogeneous and not likely explained by any single set of explanations (Meyfroidt and Lambin 2011).

For future work, the study area could be expanded to the mountainous areas north and south. Socioeconomic and political as well as biophysical conditions are probably different and may result in a different pattern of tree cover increase. Secondly, I believe a cultural ecology of eucalyptus would be fruitful. An examination of the political economy and local perception of this important tree would likely yield deeper insight as to why this species is ubiquitous on the landscape.

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