Household and Community Effects on Land Use/Land Cover Dynamics in the Northern Ecuadorian Amazon

Christine M. Erlien
Dissertation

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Approved by
Dr. Stephen J. Walsh
Dr. Richard E. Bilsborrow
Dr. John W. Florin
Dr. Conghe Song
Dr. Thomas M. Whitmore

ABSTRACT

Christine M. Erlien: Household and Community Effects on Land Use/Land Cover Dynamics in the Northern Ecuadorian Amazon
(Under the direction of Dr. Stephen J. Walsh)

This research integrates social survey data, a remote sensing image time-series, ecological pattern metrics, and information describing local resource endowments, geographic accessibility, and the location and characteristics of communities through the use of geospatial data and a suite of spatial digital technologies. The goal is to address a set of research questions framed within the context of land use/land cover (LULC) change in the Northern Ecuadorian Amazon (NEA). This study examines LULC change processes from the perspectives of the community and the farm (or *finca*) to develop a deeper understanding of how community characteristics, linkages among communities, and feedbacks between communities and households affect changes in forest, agriculture, and urban LULC in the NEA.

This research examines three central issues. First, the research examines the spatial distribution, characteristics, and connectedness of communities in the NEA, as well as linkages among communities and between communities and households. The temporal and spatial distribution of communities illustrates the expansion of population into and throughout the region. Hierarchical cluster analysis results place communities in the NEA along a "development continuum." Analysis of functional relationships among NEA communities show that they operate in a manner expected by central place theory.

Second, the research characterizes landscape composition and dynamics of LULC change at the community level using remote sensing, spatial analysis, and statistical methods. Results show that distance is an important predictor of land cover. In addition, this research highlights that, despite the differences in proportion of various cover types in the areas surrounding different types of communities, each of the community types displays a similar relationship with the forest, agriculture, and pasture land cover classes with distance from community.

Third, this research models the influence of *finca*-level and community-level variables on LULC change at the *finca*-level. Demographic, socioeconomic, biophysical, and geographic variables (including new ways of measuring geographic access such as *existence of transportation* and *distance to sawmill or crop/animal market*) play statistically significant roles in shaping the composition and configuration of LULC on *fincas* in the NEA.

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INTRODUCTION

1. Overview

Land cover is defined as the biophysical attributes of the earth's surface, while land use is the purpose for which humans exploit land cover (Meyer and Turner 1992; Lambin et al. 2003). Land use and land cover (LULC) change transforms landscape composition and spatial structure through interactions among people, place, and environment. Landscape pattern and processes are interrelated, thus changes in processes that produce changes in pattern influence variations in resource flows and trajectories of land cover change. It is important to examine not only changes in landscape composition and spatial structure, but also the socioeconomic, biophysical, and geographical processes or drivers of change, their feedbacks, and their space-time lags. LULC changes have implications for biodiversity, climate change, carbon budgets, and human behavior. Examination of LULC change calls for the application of an integrated Land Change Science, in which social, ecological, and spatial approaches are brought to bear on research questions that are explicitly linked to the human dimensions of environmental change (Turner et al. 2004). This research aims to integrate social survey data, a remote sensing image time-series, ecological pattern metrics, and information concerning local resource endowments, geographic access, and frontier communities through the use of geospatial data and a suite of spatial digital technologies. The general goal is to address research questions framed within the context of LULC change, including deforestation, agricultural extensification, secondary forest succession, and urbanization in the Northern Ecuadorian Amazon (NEA).

In the NEA (Figure 1.1) rapid and dramatic landscape changes have occurred over the past 40 years, arising from land use changes initiated by colonists, indigenous peoples, communities, and oil companies. The NEA, comprised of the provinces of Sucumbios, Napo, and Orellana, is a frontier environment that has been affected by development starting in the late 1960s. In the early 1970s, migrants, hungry for land to call their own, began streaming into the area and claiming land for farms along roads recently built by oil companies. Deforestation at the farm level followed, initially ignited by squatting on accessible land that often evolved into secure land titles. Communities developed near oil encampments and at important road intersections.

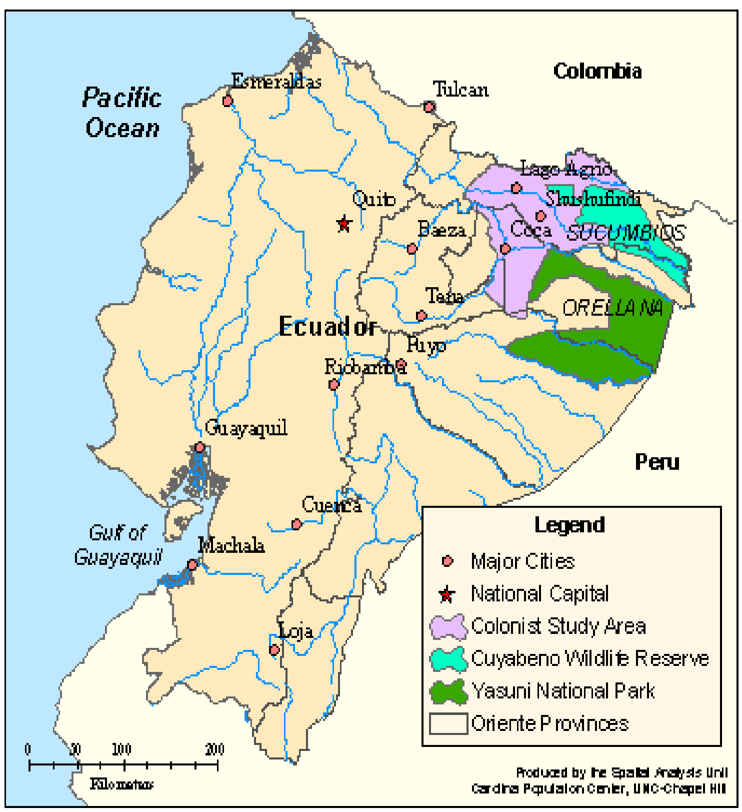

Figure 1.1. Colonist study area, as situated within the country of Ecuador. The study area encompasses portions of the provinces of Napo, Sucumbios, and Orellana.

Ecuador exhibits one of the highest deforestation rates in the world (FAO 2001), largely due to this in-migration, high local human fertility levels, and formation of increasing numbers of new households. Oil development continues in and around colonist (EIA 2008) and indigenous areas, as well as conservation forests (Finer et al. 2008, Environmental News Service 2005). Continued oil exploration and production maintains the cycle of road building and deforestation, prompting a call for roadless petroleum exploration (Finer et al. 2008).

1.1. **Study Objectives**

Understanding LULC change in the frontier environment of the NEA requires an understanding of the processes driving change and the direction of change they produce. This project seeks to examine land cover change processes from the dual perspectives of the community and the *finca*[1]. The perspective of community allows an examination of how community characteristics are related to land cover change in surrounding areas, while the *finca* perspective allows the integration of household demographics with higher-level influences (e.g., community characteristics) when examining land cover change at the *finca* level.

The primary objective of this research is to develop a richer understanding of how community characteristics, linkages among communities, and feedbacks between communities and households (i.e., socio-economic and demographic characteristics) affect

[1] A *finca* is a family farm. *Fincas* in this study area are generally 40-50 hectares in size; the spatial organization of the parcels is generally 250 m in width and 2000 m in length. Research in this study area, which commenced in 1990, was initially funded by the National Science Foundation and the World Wildlife Fund. At that time, 50 percent of the 418 survey households held legal title and 43 percent *certificado de posesión* (Bilsborrow et al. 2004). Funding from the National Aeronautics and Space Administration enabled a revisit of these *fincas* in 1999; only 34 percent (n=763) of the households at that time held titles, primarily because of land subdivision (Bilsborrow and Pan 2001).

change in forest, agriculture, and urban LULC in the NEA. For the purposes of this study, a community is defined as a cluster of households and associated infrastructure (e.g., schools, churches, businesses). A community affects landscape pattern both directly and indirectly (Schumann and Partridge 1989; Ozorio de Almeida 1992; Moran 1993; Furley 1994). Direct change is observed through community establishment and urban expansion. Indirect effects, attributed to (a) local demand for crops, animal goods, and wood, as urban populations grow; (b) national or international-level demand for goods such as coffee that is transmitted through crop prices offered to growers by community-based agricultural businesses (e.g., coffee roasters); and (c) development of new transportation routes that increase geographic accessibility of a place, prompt LULC changes in more distant areas through the geographic "reach" of communities. Communities may also act as service centers and thereby impact the landscape. Communities that provide services such as bus transportation facilitate movement of people and products in a bidirectional fashion between households and communities. Bus and *ranchera*[2] transport is extremely important in this sparsely populated region where there are few privately owned vehicles. In addition, the availability of off-farm employment in communities creates opportunities for cash earnings and possibly accumulation of household capital (Murphy et al. 1997). A community functioning as a market and/or service center or transportation hub creates feedbacks to household-level decisions concerning land use that result in *finca*-level LULC changes. Feedbacks may produce such change by increasing household capital stocks that can be used to gain access to technology, such as chainsaws or fertilizer, or by motivating land uses such as cropland or pasture through market demand.

[2] A smaller, open-sided vehicle.

1.2 **Conceptual Model**

The following conceptual model guided the development of the research aims that follow. The material contained in Figure 1.2 is modeled after frameworks that conceive of both proximate and underlying factors as they affect LULC change, i.e, Geist and Lambin (2001) and Rindfuss and colleagues (2003). Proximate factors are defined as human actions that directly alter land cover (Turner et al. 1993; Geist and Lambin 2001; Geist and Lambin 2002; Lambin et al. 2003); examples of proximate factors include agricultural expansion, wood extraction, and extension of transportation infrastructure. Underlying factors include social and environmental characteristics that influence or underpin proximate factors, such as in/out migration, markets, government policies, technological change, beliefs about or attitudes toward the environment, and characteristics of the biophysical environment (i.e., soils, topography.

Figure 1.2 shows both proximate and underlying factors at the *finca*-, community-, and regional/national/international levels that affect LULC patterns in the NEA. The primary proximate factor at the *finca*-level is land clearing for crops or pasture. Another proximate factor at the *finca* level is the expansion of transportation infrastructure. A number of underlying factors operate at the *finca*-level, ranging from biophysical and geographic aspects of *finca* location to socioeconomic and demographic characteristics of the household. Other underlying factors exist off-farm at the community-level as well. These community-level underlying factors include migration, population change, the existence of markets for agricultural products (e.g., crops or animals), employment opportunities, and transportation infrastructure (e.g., buses and *rancheras*). Underlying factors at the regional/national/international-level are economic (e.g., commodity pricing), infrastructural (e.g., road-building sponsored by the government or corporations), and institutional (e.g., land title, credit, government policies, technology and technical assistance).

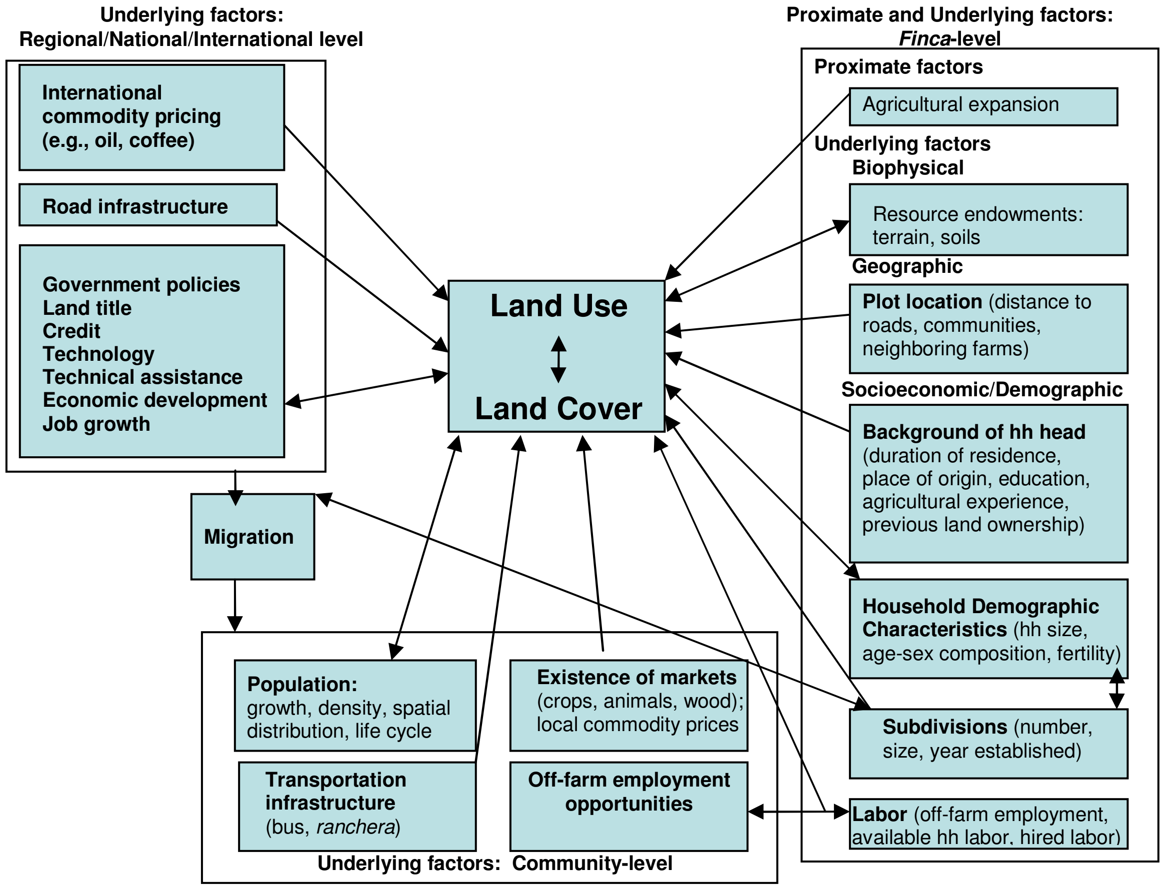

Figure 1.2. Conceptual model of the factors that affect land use in the NEA, after Geist and Lambin (2001) and Rindfuss et al. (2003a).

Choices of the proximate and underlying factors included in the conceptual model are drawn from the literature. Proximate causes of LULC change in tropical forests include agricultural expansion through shifting cultivation or pasture creation and wood extraction (Allen and Barnes 1985; Kaimowitz and Angelsen 1998; Geist and Lambin 2001; Geist and Lambin 2002). Shifting cultivation has often been cited as a cause of deforestation (Hecht and Cockburn 1989; Amelung and Diehl 1992; Myers 1993; Angelsen 1995; Thrupp et al. 1997; Ranjan and Upadhyay 1999), though Geist and Lambin (2001) note that shifting cultivation operates mainly in a synergistic manner in conjunction with other proximate factors. Expansion of road infrastructure serves as a proximate cause by opening forest land to logging and agricultural expansion, as well as by increasing access to markets (Chomitz and Gray 1996). Examples of variables cited as underlying causes include economic, demographic, and policy/institutional factors, such as markets and commodity prices, growth of urban populations or increases in rural density, settlement schemes, and tenure security (Geist and Lambin 2001; Wood 2002; Brondizio et al. 2002; Laurance et al. 2002).

Biophysical variables noted to serve as underlying causes include topography, soil quality, and forest size and fragmentation (Kaimowitz and Angelsen 1998; Geist and Lambin 2001; Laurance et al. 2002). Drivers determined to be important in studies of deforestation in the Amazon include population growth and agricultural expansion (Skole and Chomentowski 1994), agricultural labor supply (Southgate et al. 1991; Pichón 1997a; Pan et al. 2001), tenure security (Southgate et al. 1991; Pan et al. 2001; Wood and Walker 2001), accessibility (Pichón 1997a; Mena et al. 2006), length of settlement (Pan et al. 2001; Pichón et al. 2002), technology (Pichón 1997a), and biophysical factors such as soil fertility and topography (Pichón 1997a; Pan et al. 2001).

1.3. **Theoretical Overview**

Theory, as well as the drivers suggested by current LULC research, have guided the development of the research questions as well as the conceptual model. Population-environment theories provide a means to discuss population growth and LULC change (extensification and intensification) over time in the NEA. Central Place theory is used as an aid in describing the relationships among surveyed communities as well as between surveyed households and communities, while Agricultural Location theory is employed to examine the impact of accessibility on farm LULC dynamics. Landscape Ecology theory is used to describe the influence of factors interacting across space-time scales on pattern-process relationships.

1.3.1. **Population-Environment Theory: Conceptions of Population and LULC**

Lee (1986) states that the grand themes of macro-demographic theory are those of Malthus and Boserup. Both theories address population, environment, and technology, in terms of land use and food production (Marquette 1997). Malthusian theory (Malthus 1798; Bilsborrow and Geores 1994) posits that human population grows geometrically, while means of subsistence grow only arithmetically, so that a crisis eventually occurs in which demand for subsistence goods is left unmet. The demand for food can then only be met by using more labor on existing land, cultivating new land, or by improving (i.e., manure or other methods) existing cultivated lands (Malthus 1798). However, a crisis situation occurs if production ultimately cannot keep pace with the increased demand associated with population growth (Turner and Brush 1987), resulting in population reduction through "positive" checks (famine and increased mortality) or "preventative" checks (postponement of marriage and limitation of family size through "restraint") (Malthus 1798). Neo-Malthusian theory is concerned with environmental conditions and food security as they relate to food production as well as the condition of the earth's environment as it relates to the world's growing population. Neo-Malthusian theorists (e.g., Ehrlich et al. 1993) posit that the only way to alleviate a food shortage situation is to limit births and pursue ecologically sound methods of agricultural production.

Boserup (1965) considered non-demographic responses to population pressure and their implications for the environment. Boserup's conception of population includes population density as well as absolute size and growth. She contends that population pressure induces technological change. Technological change includes implementation of new tools, changes in technique such as reducing fallow time, use of inputs such as fertilizer, and investments in irrigation or terracing (Boserup 1965) as well as changing to higher-yielding crops (Lele and Stone 1989). Such technological advances allow for agricultural intensification, the process by which land is cropped more frequently or intensely than previously. Agricultural intensification, with accompanying higher labor demands, is expected to reduce local labor surplus and thus limit out-migration while simultaneously curbing the expansion of agricultural lands. Brush and Turner II (1987) extend Boserupian theory by expanding the demand forces that spur intensification to include biological (e.g., consumption demand), social (e.g., kinship responsibilities, taxes), and market forces.

The Malthusian conception construes population as a dependent variable that fluctuates with agricultural production, while the Boserupian conception sees population as an independent variable that impacts technological change and agricultural production (Marquette 1997). Works by Lee (1986) and Bilsborrow (1987) reinterpret these theories. Lee sees them as complementary, occurring at different times, and develops an economic model to determine the conditions under which Malthusian or Boserupian forces are likely to prevail. Bilsborrow, too, sees them as potentially complimentary and draws additionally upon Kingsley Davis' (1963) concept of multiphasic, or simultaneous response, which details how multiple demographic responses (e.g., delayed marriage, reduced fertility through contraception, sterilization, and abortion, and out-migration) may occur in response to population increase. Bilsborrow's conceptualization integrates demographic responses to population pressure with economic responses related to the maintenance of a particular standard of living (agricultural extensification or intensification) and classifies out-migration as a demographic-economic response. The degree of a response depends on the likelihood of other responses, since the more likely one response, the less likely another because the pressure on the system has been reduced. Households are expected to exhaust economic options before pursuing economic-demographic responses, and to pursue demographic responses only with the failure of the other strategies to cope with population pressure because of the additional stresses associated with economic-demographic and purely demographic responses (i.e., absence of a family member, movement from homeland, shift in sexual activity) (Bilsborrow 1987, Bilsborrow and Carr 2002).

1.3.2. **Central Place and Agricultural Location Theories**

Central place theory (Christaller 1933; translated in Baskin 1966) provides a framework with which to examine urbanization and the hierarchy of settlements in frontier areas through the lens of retail economics. The extent, or reach, of a community economically is related to costs associated with transport of the good in demand; distance, therefore, plays an important role. Community hierarchy, based on marketing, transportation, and economic principles, is theorized as a group of related settlements where those smaller in size provide only basic, or lower-order, functions to the population of a local geographic area, while larger communities serve a larger area with a greater range of goods and services (higher order functions). This research makes use of central place models as a base from which to examine linkages among communities in the NEA.

Agricultural location theory is generally attributed to von Thünen (translation, Wartenberg 1966). His work examined the interaction between agricultural prices, land rent (return from investment in land), and distance to market, based on the assumption that farmers seek to maximize profits. Assumptions made by the von Thünen model include the existence of only a single central city, surrounded by agricultural land with uniform biophysical attributes, where only one type of transportation to the city exists, and land use is expected to respond quickly to economic changes (translation, Wartenberg 1966). Increased agricultural demand in the central city is expected to increase agricultural prices, benefiting most those closer to the city; prices are thus expected to influence land use. The type of agriculture thus varies by location; von Thünen conceptualizes this variation as concentric rings around the city. In the ring closest to the town, production will focus on mainly high value perishable products (fruits, vegetables, milk) as well as products heavy or bulky in relation to their value (too expensive for more remote areas to transport). With increasing distance from the town, the products grown will be inexpensive to transport in relation to their value.

Although, as Grotewold (1959) points out, von Thünen's assumptions render constant or non-existent a number of factors that generally contribute to diverse land uses, the idea that central city demand influences land use in surrounding areas is still applicable in the NEA, given the role distance to market towns has been shown to play in the proportion of various cover classes on farms (Pichón 1997a, Pan and Bilsborrow 2005). In addition, agricultural land use in developing countries has been found to provide support for this model (O'Kelly and Bryan 1996).

1.3.3. **Landscape Ecology**

Landscape Ecology theory examines the relationship between spatial pattern and landscape processes at a variety of scales (Risser et al. 1984). Scale, pattern, and process are, therefore, critical to the study of landscape ecology. Landscape patterns are produced by interactions between the abiotic environment, biotic processes, and disturbance regimes. Patterns are examined in terms of both composition (number and proportions of patch types, evenness of their areal distribution) and configuration (spatial location, arrangement with regard to other patch types, shape complexity) (O'Neill et al. 1988; Gustafson 1998). Understanding the processes producing patterns is necessary to be able to better guide landscape management (Levin 1992).

Pattern metrics are used to assess landscape pattern by providing a way to quantify class, patch, and landscape-level characteristics including area, shape, connectivity, and diversity (O'Neill et al. 1988; Crews-Meyer 2002). Many pattern metrics are correlated, however, since the metrics are based on a small number of measurable patch characteristics, including patch type proportion, area, edge, and connectedness; they should, therefore, be chosen carefully to represent the factors of interest and avoid duplicating information (Riitters 1995).

Scale in landscape ecology is characterized in terms of grain and extent. Grain is defined as the spatial resolution of the data, and extent the size of the study area or length of time under consideration. Ecological processes vary in importance as well as in their effects at different scales (Risser et al. 1984), spatial as well as temporal. As such, these processes may be termed scale-dependent (Turner 1989; Walsh et al. 2001). Scale dependence implies that pattern or process may vary depending on the grain or extent examined. Scale dependence can affect study results depending on the precision with which study area and associated spatial and temporal scales are defined, the nature of the variables examined (local-scale biophysical variables versus more broadly defined variables such as deforestation), and the effort made to scale up from the local region (Gamble and Meentemeyer 1996).

Hierarchy theory is implicated in the study of scale because processes that operate at a particular spatial or temporal scale may affect processes at other spatial and temporal scales (Walsh et al. 1998). Hierarchy theory also highlights the importance of examining a range of scales in any study (Walsh et al. 1998, Turner et al. 2001, Walsh et al. 2001). A focal scale for the research is identified by the research question; the level above should be examined because it provides context for the focal level, while the level below provides information about processes or mechanisms observed at the focal level. While the importance of examining a range of scales is integral to landscape ecology, it is not unique to that discipline, as human ecology has its own parallels in progressive contextualization (Vayda 1983) and evenemental or event ecology (Vayda and Walters 1999)[3].

1.4. **Research Aims**

The primary objective of this research is to develop a better understanding of how community characteristics, linkages among communities, and feedbacks between communities and households (i.e., socio-economic and demographic characteristics) affect

[3] Progressive contextualization is a research strategy that focuses on significant human activities or human-environment interactions and seeks to examine the causes and effects of these activities by placing them in context at an increasingly larger scale/scope. Evenemental or event ecology, begins with an event or environmental change of interest and moves outward in space and time to examine changing causes and effects that produced the environmental change.

change in forest, agriculture, and urban LULC in the NEA. Three research aims have been developed to support this objective. The first research aim provides greater understanding of how communities have grown and changed through time, highlights relationships between them, and links farms to communities. The second aim provides a measure of ecological change around communities, through examination of pattern and extent of land cover change. The final research aim explores the socioeconomic, demographic, geographic, and biophysical drivers associated with land cover change at the *finca* level. This third research aim, by working to better define measures of community effects, extends previous work examining drivers of LULC change at the *finca* level. These research aims and related research questions are outlined below.

1.4.1. **Research Aim 1**

Examine the spatial distribution, characteristics, and connectedness of communities in the NEA, as well as the linkages among communities and between communities and households.

To understand landscape dynamics in the NEA, it is important to understand how communities in the region are spatially related and how such relations have changed through time as new communities were established, established communities evolved, and infrastructure connecting communities with economic enterprises, such as agricultural markets, expanded. Additionally, the characterization of communities in the NEA assists in understanding how the region is geographically and hierarchically organized. Examining the linkages between communities describes hierarchical relationships, highlights central places, and provides a measure of the thresholds associated with goods and services as well as the flows of people and government funds throughout the region. Research questions related to this research aim include:

- How are the survey communities arrayed in space and time?
- Do the survey communities show similarities that allow them to be sorted into groups?
- What are the functional relationships between households and communities as well as among communities in the NEA, and how do they change over time?

Communities (i.e., populated places) are the focus of this set of research questions. A 2001 survey of 59 communities (Bilsborrow 2002) thus provides much of the data used in support of this research aim. Spatial datasets employed include GPS locations of the communities and road shapefiles. In addition, socio-economic and demographic data come from a 1990/1999 longitudinal survey of *fincas* (Bilsborrow 2002, Pichón 1993).

1.4.2. **Research Aim 2**

Characterize landscape composition and dynamics of land cover change at the community level using remote sensing and spatial analysis methods.

The NEA has experienced intense change over the last 40 years. With the discovery of oil, attendant road construction, and spontaneous migration of colonists seeking land, the area has experienced rapid deforestation, at times, at some of the highest rates in the world (FAO 2001). The spatial pattern of land cover change is of great interest, because it impacts biodiversity, climate change, carbon budgets, and ecosystem functions. The main components of spatial pattern are composition and spatial configuration, or structure (O'Neill et al.1988; Gustafson, 1998). This research aims to contribute to the current state of knowledge on the composition and configuration of the landscape in the NEA by characterizing landscape composition and the dynamics of land cover change, as it relates to communities, using remote sensing and spatial analysis methods. Research questions related to this research aim include:

- Do communities of varying size and age produce significantly different pattern and extent of land cover change in their hinterlands?

Communities are the focus of this research question as well. To examine the pattern and extent of deforestation around communities, an area of influence is defined for each community. The area of influence for each community will be defined using the boundaries of census population sectors[4] indicated by census boundaries provided by the *Instituto Nacional de Estadística y Censos* (INEC). Using INEC boundaries not only provides a geographic limit for each of the communities, but also allows integration of the census data and the remote sensing results. Datasets employed in support of this research aim, therefore, include a remote sensing image time-series (i.e., 1973, 1986, 1989, 1999, 2002) and shapefiles describing community location, census sectors, and roads.

1.4.3. **Research Aim 3**

Model the influence of household and community-level variables on land use and land cover change at the finca level.

Linked by transportation, education, healthcare, employment, and agricultural product markets (crops and animals), communities exert an influence on households in surrounding areas. Previous work aiming at incorporating community effects on land-use and land-cover

[4] The word sectors, as used by INEC, indicates a sub-parroquia level boundary for which population data are collected. The word sectors used in this sense, therefore, has a different meaning from the word sectors as applied to discussions of the development sectors (groups of fincas) associated with the *Instituto Nacional de Desarrollo Agrario* (INDA).

have referenced survey measures of land use from the 1999 household survey (Pan 2003, Pan and Bilsborrow 2005) as well as land cover information derived from remote sensing (Pan et al. 2004). Pan (2003) uses general linear multivariate models (GLMM) as well as multilevel models. The multilevel models employed by Pan (2003) and Pan and Bilsborrow (2005) nest *fincas* within their nearest communities and incorporate distance (Euclidean) to central cities (Lago Agrio, Coca, Shushufindi, and La Joya de los Sachas). Both Pan (2003) and Pan and Bilsborrow (2005) examine community-level variables for the nearest community that include population; the presence of piped water, electricity, coffee roasters, civil registrar, health center, nurse, distance schooling, technical school, shops and restaurants, canoe transport, or a transportation cooperative; and year founded. Pan et al. (2004) incorporates community effects only insofar as incorporating the Euclidean and network distance to the *finca's* reference community. The following question aims to explain LULC patterns at the *finca* level by incorporating both *finca* and community-level variables.

- Do models that incorporate variables describing nearest and market communities produce better predictions of *finca* land use?

This work aims to further refine previous work modeling land use at the *finca*-level by re-examining how to incorporate the influence of both the nearest and market communities. The pattern of land use, as well as of land use change, is thus modeled at the *finca* level while incorporating community-level effects. Cross-sectional multivariate linear statistical models are generated for 1990 and 1999; multiple models are generated at each time point**.** *Dependent variables* for the cross-sectional models are generated from (1) remote sensing imagery (proportion of various land cover classes (i.e., forest, agriculture, pasture) and measures of pattern (patch density and landscape shape index)), and (2) household surveys. *Independent variables* that describe demographic, socioeconomic, biophysical, and geographic aspects of the *fincas* include date of settlement, household size, number of subdivisions, number of household members over age 15, number of males, education level of household head, amount of time dedicated to off-farm employment, soil type, and terrain. Geographic variables incorporate community-level effects and include distance to the closest health center/hospital, distance to nearest crop or animal market, distance to nearest coffee roaster, distance to nearest rice husker, and distance to nearest sawmill; all distances will be based on survey-reported measures of distance to the main road coupled with network distance calculations to the facilities of interest. Additional community-level variables include nearest and market community population and the existence of transportation infrastructure and number of trips per day that serve the *finca*. The Huber-White sandwich estimator (White 1980) is used to compute standard errors that are robust to clustering within communities.

1.5. **Rationale**

Human actions have produced major environmental changes. The impacts of global environmental change include climate change, biodiversity loss, soil degradation, and hydrological change (Meyer and Turner 1992, Eltahir et al. 1996, Chapin et al. 2000, Pielke et al. 2002, Gisladottir et al. 2005, Lambin et al. 2006). Global environmental changes also prompt concerns about ecosystem integrity and ecosystem services (Turner et al. 2004).

Land use and land cover changes are among the best documented global changes (Vitousek 1994). For this reason, much recent research, under the auspices of both national (e.g., U.S. Global Change Research Program, NASA's Land Cover Land Use Change

(LCLUC) research program, and the National Science Foundation's Human Dimensions of Global Change) and international (e.g., International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP)) organizations has been devoted to population-environment research as a component of global environmental change science, with a particular focus on land use and land cover dynamics. It is within this context that Drs. Bilsborrow and Walsh at University of North Carolina – Chapel Hill obtained funding for the examination of population-environment interactions and land use and land cover dynamics in the Northern Ecuadorian Amazon through a NASA program that examined LULC change in the Amazon basin (i.e., the Large-Scale Biosphere-Atmosphere Experiment (LBA-ECO)).

This type of research is seated within a long tradition of geographical research examining human-environment interactions, known as the man-land tradition (Pattison, 1990). From within this lineage have sprung major global reviews of human-environment interactions, which in turn prompted policy efforts and influenced research strategies. With the rise of research endeavoring to explain human-environment interactions and LULC change has come a host of methodological issues relating to the data used to characterize the landscape and its population. Methodological issues range from the impact of remote sensing spatial, temporal, and radiometric resolutions on the ability to meet the goals of the research question, to the resolution, or unit of analysis, examined when characterizing population, as well as to decision-making about how population and landscape should be linked.

The rationale for this research is thus three-fold. First, as the foregoing paragraphs establish, global environmental change is impacting the world in myriad ways, highlighting the necessity and urgency of obtaining greater understanding of human-environment interactions generally and LULC change in particular. Second, this work illustrates the methodological issues associated with population-environment research and how they are addressed. Finally, this project provides a contribution to the larger body of knowledge generated by the many researchers that have worked on the Ecuador project over the years, as well as to the knowledge generated by the Land Change Science community. The subsections that follow provide additional description of global reviews of LULC change, associated policy and research initiatives, and methodological and practical issues associated with this type of research.

1.5.1. Human-Environment Interactions

Three major long-term global "stocktakings" have highlighted or re-focused the world's attention on humans' impact on the environment. These global stocktakings have in common an attention to LULC change. The first, *Man and Nature,* or *The Earth as Modified by Human Action*, by George Perkins Marsh (1874), addressed issues of human interactions with the environment and land use and land cover dynamics. Marsh examined deforestation, desertification, soil erosion, and water resources (in terms of draining water bodies or modifying flow), as well as human impacts on plant and animal life. *Man and Nature* is recognized as being wide-ranging and synthetic (Kates et al.1990) as well as for its influence on views of nature-society relationships (Lowenthal 1958, Thomas 1956, Marsh 2003), given its challenge to conventional wisdom with its statement that humans, rather than being acted upon by the environment, acted upon the environment (Thomas 1956, Lowenthal 1990).

Despite Marsh's prose decrying humans' impact upon the natural world, geographers paid scant attention to the consequences of human-environment interactions for LULC change in the early part of the twentieth century, due primarily to the preoccupation with environmental determinism (Glacken 1956) and the backlash against it (Wilson 2005). This changed in 1955, with a symposium entitled "Man's Role in Changing the Face of the Earth", sponsored by the Wenner-Gren Foundation, resulted in the production of a second major global assessment of human-environment interactions. The symposium brought together an interdisciplinary group that included many geographers. *Man's Role in Changing the Face of the Earth* (Thomas 1956) emphasized human utilization of the environment and its impacts and highlighted the importance of understanding past and current history of global change processes. Kates et al. (1990) notes that this volume has had a lasting influence on scientists in the humanities and natural and social sciences, as it is characterized as a seminal work that influenced global-scale integrative thinking about the environment (Williams 1987, Hornsby 1998).

The desire to document global change as the world's population reached twice its level at the time of the Wenner-Gren Symposium ("Man's Role in Changing the Face of the Earth") and undertake a comprehensive, authoritative survey of environmental changes not attempted since *Man and Nature* prompted the third major long-term global stocktaking, *The Earth as Transformed by Human Action*. The symposium, "The Earth as Transformed by Human Action," (a paraphrase of Marsh's book title) occurred in 1987 and produced a volume entitled *The Earth as Transformed by Human Action*. This volume documented global environmental change over the previous 300 years, contrasted global and regional-level patterns of change, and explored major human forces driving environmental change.

The focus of *The Earth as Transformed by Human Action* differed slightly from *Man and Nature* and *Man's Role,* as the previous works focused on landscape change, while *The Earth as Transformed* addressed landscape change as well as changes in flows of materials and energy (Kates et al. 1990). Summaries of the symposium (Meyer and Turner 1990) suggest new research directions needed to examine regional and global environmental change and its drivers and frame an international interdisciplinary effort to accomplish these goals. The influence of this symposium can thus be seen in efforts to further define this interdisciplinary effort and associated research (Clark 1988, Riebsame et al. 1993, Turner et al. 1993, Turner et al. 1994, IGBP-IHDP 1999, Veldkamp and Lambin 2001, Global Land Project 2005)

1.5.1.1 Population and Environment: Policy

Concerns about human interactions with the environment have also led, in recent years, to major policy efforts; global policy efforts concerning issues of population-environment interactions span slightly more than 30 years. Concerns over human population growth prompted the first global intergovernmental conferences on population and the environment, which took place in the early 1970s. The “Conference on the Human Environment” (Stockholm, 1972) produced a declaration that conceded that population growth adversely affects the environment and appropriate action should be taken to maintain or improve the environment (UN 1973), and an action plan that served as the basis for United Nations (UN) activities in the 1970s and 1980s (UN 2001a, b). This conference recognized that development in some areas could be frustrated by population growth, while other areas would benefit from population growth through improved economic efficiency; the conference thus did not take a position on global effects of population growth (UN 2001 a,b).

The Stockholm meeting is important for its place as the first major, modern international gathering on human activities in relationship to the environment, as well as for its Declaration, which led to the founding of the United Nations Environment Programme (CIESIN 2007).

The "World Population Conference" (Bucharest, 1974) included a symposium entitled, "Population, Resources and Environment," in which discussions of the role and importance of population in environmental change occurred (UN 2001a). This conference recognized that international equity was in need of improvement and produced a plan that advocated that developed countries adopt appropriate policies on consumption, population, and investment (UN 2001b). This plan, however, did not include a thorough treatment of population-environment linkages (UN 2001a). The "International Population Conference" took place in Mexico City in 1984 and emphasized the need for national population goals and policies formulated with reference to long-term environmentally sustainable economic development. The importance of the Mexico City meeting lies with its emphasis on formulating national policy goals oriented toward environmentally sustainable economic development; such ideas became the cornerstone of development paradigm of the 1990s (UN 2001b).

In 1983, the United Nations established the World Commission on Environment and Development, chaired by Dr. Gro Harlem Bruntland. This commission was charged with proposing strategies for sustainable development and recommending strategies for cooperation among countries on issues related to population, resources, environment, and development (Bruntland 1987). The commission's recommendations lead to the "United Nations Conference on Environment and Development," or the "Earth Summit," (Rio de

Janeiro, 1992), which conceptualized relationships between population and the environment in terms of sustainable development (UN 1988). This conference produced five major agreements, some of which were legally binding. These documents included two treaties, the *Framework Convention on Climate Change* (UN 1992a), which provided a framework for intergovernmental efforts dealing with climate change, and *The Convention on Biodiversity* (UN 1993), which discussed conservation and sustainable use of biological diversity (Parson et al. 1992). The treaty agreements were legally binding. The other agreements produced included *The Rio Declaration* (UN 1992b), *Agenda 21* (UN 1992c), and the *Statement on Forest Principles* (UN 1992d). The *Rio Declaration* presents the concept of sustainable development as an alternative to choosing between economic growth and environmental protection (Parson et al. 1992, UN 2001a). *Agenda 21* detailed specific actions necessary for meeting the goal of sustainable development (Parson et al. 1992, UN 2001a). The *Statement on Forest Principles* set out principles for forest management, conservation, and sustainable development. Haas and colleagues (1992) laud the substantive contribution of *Agenda 21*and note that the level of participation, media attention, and involvement of NGOs bode well for the conference's impact on issues of environment and development. While the conference did little to resolve conflicts between developed and developing countries rooted in issues of consumption versus population growth, it did serve to create new and useful institutions (e.g., U.N. Council on Sustainable Devlopment (UNCSD)) and institutional processes such as Local Agenda21 and UNCSD's benchmarking process for national sustainable development strategies (Seyfang and Jordan 2002).

In 1994, the "International Conference on Population and Development" in Cairo focused on economic growth and sustainable development and examined trends in population and environment as related to economic growth and sustainable development (UN 2001a); the advances made were more significant than those of the "International Population Conference" in 1984. The Cairo conference was a notable departure from its predecessors in that the focus of population policy was less on global population growth and more on women's health, rights, status, and empowerment (McIntosh and Finkle 1995).

The "World Summit on Sustainable Development," or "Rio+10," (Johannesburg, 2002) aimed to assess progress in implementing plans adopted in Rio in 1992 and reinvigorate global commitment to sustainable development (Seyfang 2003, Skanavis and Sari 2004). Nevertheless, this most recent meeting did not live up to its promise. Seyfang (2003) indicates that the World Summit was a wasted opportunity because participating governments lacked political will to adopt ambitious action plans. Seyfang (2003) does, however, point out that the importance of this conference lies less in its meager policy gains than in the interactions and networking accomplished by citizens' groups who were energized to move grassroots sustainability efforts forward.

1.5.1.2. **Population-Environment Interactions and LULC Research**

The importance of population-environment interactions on policy agendas has been reflected in their prominence on research agendas. Both international (e.g., International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP)) and national (e.g., National Research Council (NRC)) initiatives have highlighted population-environment research within global environmental change science through a focus on land use dynamics and land cover (IGBP-IHDP 1995, 1999; NRC 1999). Building upon these initiatives, *Grand Challenges in Environmental Sciences* (NRC 2001) identified an environmental research agenda for the next decade. Central to National Research Council's recommendations was the interaction of people, place, and environment and LULC dynamics in time and space. Also cited was the importance of the continued development of spatial digital technologies for integrating scientific theory and space-based imagery. LULC change research is now a key element of national and international research agendas. National research programs include the U.S. Global Change Research Program (USGCRP 2003), NASA's Land Cover Land Use Change (LCLUC) and Large-Scale Biosphere-Atmosphere Experiment (LBA-ECO) research programs, and the National Science Foundation's (NSF) Human Dimensions of Global Change and Dynamics of Coupled Natural and Human Systems (as a topical area that falls within the Biocomplexity in the Environment program) research programs. International research programs include the Land-Use and Land-Cover Change (LUCC) project co-sponsored by the IGBP and IHDP, which has been succeeded by the Global Land Project (GLP), also co-sponsored by the IGBP and IHDP.

1.5.1.3. **LULC Research and Land Change Science**

Researchers involved in the study of LULC dynamics have given birth to what is being called Land Change Science (LCS) or integrated Land Change Science (Rindfuss et al. 2004). Integrated Land Change Science (Turner et al. 2004; Turner 2002) describes the science needed to pursue the questions of human-environment dynamics supported by programs such as IGBP-IHDP, NASA, NSF, or the USGCRP. This type of research aims to be synthetic rather than reductionist, providing a holistic look at systems in hopes that greater understanding will be generated and emergent properties identified. Integrated land-change science aims to achieve synthesis through the application of human, ecological, and spatial (GIS and remote sensing) science approaches to research problems (Liverman et al. 1998; Klepeis and Turner 2001; Turner 2002). Geography has a long history as a synthetic discipline, but the importance of human-environment systems and LULC change to current national and global research agendas has highlighted and elevated the importance of synthesis within geography (Turner et al. 2004).

Within the scope of a LCS project, LULC research is of importance because it is an integral component in a variety of environmental issues, ranging from climate change to the hydrological and carbon cycles, biodiversity, and soil degradation, as well as ecosystem integrity and ecosystem services (Lambin et al. 2003; Turner et al. 2004). Multiple interacting factors operating on a range of scales drive changes in land use and land cover (Lambin et al. 2003). As a result, LULC research examines change at a range of scales, from the local to the global, depending on the type of question and data availability.

General types of LULC studies include those that use remote sensing to describe the pattern and extent of LULC (Crews-Meyer 2002; Parmenter et al. 2003; Cardille and Foley 2003) and those that generate models to describe the change (Brown et al. 2000; Geoghegan et al. 2001; Pan et al. 2004), often within the context of place-based studies. Case studies that track LULC using household surveys (Pichón 1997a; Pichón 1997b, Marquette 1998, McCracken et al. 1999, Moran et al. 2003, Turner and Geoghegan 2003, Turner et al 2004, Bilsborrow et al. 2004) provide additional opportunities for tracking LULC through time. This project has components of all three study types, using remote sensing to examine the pattern and extent of landscape changes, integrating LULC data from household surveys, and modeling landscape change.

1.5.2. **Population-Environment Interactions & LULC Change: Methodological Issues, Linking, Practical Issues, and the Importance of Context**

Lutz and colleagues (2002) call for the population-environment community of researchers to develop its own set of methods and analytical tools. Interdisciplinary teams involved in land use and land cover change issues have been working on just that challenge (Liverman et al. 1998; Entwisle and Stern 2005). Research teams working in this area have noted that methodological issues exist in integrating spatial and social science data, such as effectively linking people to the landscape (Geoghegan at al. 1998, Entwisle et al. 1998, Rindfuss et al. 2002, Rindfuss et al. 2003a, Rindfuss et al. 2004, Walsh et al. 2004), choosing appropriate spatial and temporal data resolution (Rindfuss and Stern 1998), and protecting confidentiality (Rindfuss and Stern 1998; Rindfuss et al. 2003a, Van Wey et al. 2005), while taking care to integrate the wider contextual issues that face local actors (Chowdhury et al. 2006). These linking issues have been described in a variety of contexts, including Thailand (Entwisle et al. 1998; Rindfuss et al. 2002; Rindfuss et al. 2003a), Ecuador (Walsh et al. 2003; Bilsborrow et al. 2004; Walsh et al. 2004), Brazil (Wood and Skole 1998; Evans et al. 2001; Evans and Moran 2002; Walker et al. 2004), and the Yucatan (Geoghegan et al. 2001; Turner et al. 2004). Rindfuss and colleagues (2002) defines the domains of issues dealt with in such integrated LCS projects as methodological, linking, and practical issues.

1.5.2.1. **Methodological Issues**

The methodological issues that integrative projects deal with are related to how the data are collected to characterize landscape and population. Remote sensing is often used to characterize the landscape. The spatial, temporal, spectral, and radiometric resolution of the remote sensing instrument must be recognized when conceptualizing a project (Rindfuss et al. 2003a, Rindfuss et al. 2004); appropriate spatial and temporal data resolution are generally dictated by the research question as well as data availability. Remote sensing spatial resolution must be adequate to describe the parcels, patterns, and processes of interest. The temporal resolution with which the landscape is characterized is dictated by the return period of the remote sensing instrument, the number of useable images captured, and the depth of the image time series, while sensor spectral and radiometric resolutions affect how well land cover types may be discriminated. Another methodological issue associated with remote sensing is the use of ancillary data to improve classifications; ancillary data used should not also be used as inputs into statistical models (Rindfuss et al. 2004).

With regard to characterizing population, decisions need to be made regarding the resolution, or unit of analysis (e.g., individual, household, community), and the context, or areal dimension of the study (e.g., village, region, country) (Rindfuss et al. 2003a). While demographic data are available for many countries, census data are collected infrequently, often aggregated for confidentiality reasons, and generally not linked to land use (with the exception of agricultural censuses) (Rindfuss et al. 2003a). Temporal constraints on social data are thus based on the temporal window between data collections. Longitudinal survey designs and the use of retrospective and prospective questions are additional avenues that integrate temporal change into collection of social data (Rindfuss et al. 2003a) Temporal constraints can, however, result in spatial-temporal mismatches between an image time series and survey or census data (Rindfuss et al. 2004).

Chowdhury and colleagues (2006) note the necessity of examining multiple contextual levels when examining changes in land use. They describe the importance of integrating household-decision making processes and political-economic structures into LCS research and highlight the lack of studies that tackle both contextual levels. Their examination of household-decision making processes and political-economic structures, separately, then together, through a series of models, serves to highlight differences in explanatory relationships that may exist at each contextual level.

Additional methodological issues more recently brought into focus include error and uncertainty and research and reporting protocols (Rindfuss et al. 2004). Measures of error and uncertainty, generally applied to a particular standard within a discipline, are applied unevenly on multidisciplinary projects. In addition, no established protocol for best practices regarding reporting on site, data, and methods exists.

1.5.2.2. **Linking**

Linking issues require a choice of how to link people to the landscape (Rindfuss and Stern 1998, Rindfuss et al. 2003a, Rindfuss et al. 2004). This is important because the units of observation differ depending on whether the research interest is to follow the people (and the land they own and/or use) through time or to follow land parcels and the decision makers associated with them through time. These relationships may be one-to-one, reflecting a single household being linked to a single parcel, or one-to-many, where one household is linked to multiple parcels or a single parcel is linked to multiple households through processes such as subdivision (Rindfuss et al. 2003b, Walsh et al. 2003). Whether tracking a social unit or a landscape unit through time, it is likely there will be changes in the nature of the unit of observation (e.g., household membership may change due to birth, death, out-migration, or marriage; the landscape unit may change through subdivision) (Rindfuss et al 2003a).

Additional challenges associated with linking people to the landscape are related to the transformation of discrete data to continuous distributions or vice versa (Rindfuss et al. 2002). Discrete data may be transformed into continuous data using radial buffers, Theissen polygons, population-weighted Theissen polygons, fuzzy transition boundaries, or cadastral maps, though the tendency of cadastral maps to reflect ownership rather than land use may require additional data collection (Crawford 2002, Rindfuss et al. 2002, Rindfuss et al. 2003a). Continuous data are transformed into discrete data when data collected at the community level are associated with the community centroid.

The scale of observation, or level of aggregation, presents some interesting linkage issues as well. The finest level of observation for social data is that of the individual; individuals may be aggregated into households or into political or geographic units ranging from village, region, country or continental levels. The smallest unit of observation for remote sensing is the pixel, which varies according to the remote sensing instrument employed; pixels may be aggregated to represent single farms, villages, and other higher-level political or geographic units. Working with these various scales of analysis requires recognition of the scale-pattern-process paradigm, that the processes that influence landscape pattern may function only at particular spatial and temporal scales, and that the effects of these processes vary depending on the scale examined (Rindfuss and Stern 1998).

1.5.2.3. **Practical Issues**

Practical issues associated with integrated LCS studies include protection of confidentiality and assessment of data quality. Protection of confidentiality is an ethical responsibility and assists an investigator's ability to acquire cooperative respondents. However, government agencies including NIH, NSF, and NASA have been requesting release of data sets to other users. To comply and still maintain respondent confidentiality, techniques such as aggregating data, stripping name and locational identifiers, or spatially transforming mapped locations (i.e. "fuzzying spatial locations") have been employed (Rindfuss et al. 2003, VanWey et al. 2005). In the case of linking survey data to land use, protecting confidentiality and maintaining data integrity is slightly more problematic, as stripping away identifying information prevents other researchers from making the connection between household-level data and associated land use (Rindfuss et al. 2003). Aggregation protects confidentiality, but prevents analysis at lower levels (Rindfuss et al, 2003). Care also must be taken that map products, particularly those that integrate remote sensing, do not reveal respondent locations or aspects of land use that may be used to censure study participants (Rindfuss et al. 2003).

1.5.2.4. **Project Approach to Methods, Linking, Confidentiality & Context Issues**

This project approaches linking people to land from two perspectives, that of the community and that of the farm. Both units of analysis are followed through time. The spatial resolution of the available imagery (79m and 30m) is sufficient to track changes in land cover. Linking people to the land at the farm and community levels requires aggregation of remote sensing pixels to these levels.

The temporal resolution of the remote sensing images used in this project was dictated primarily by the number of useable images captured and the depth of the image time series. The image dates match well with available census data (± one year), allowing the census data to be used to provide additional context for change in the region. With regard to practical issues, maps included in this dissertation and related publications will be reviewed to ensure that they protect respondent confidentiality.

1.6. **Contribution**

This research will contribute to knowledge of human-environment interactions in the NEA, in particular, advancing understanding of the direct and indirect impacts of communities on land cover change, by examining each community's ecological footprint on the landscape, as well as how community-level characteristics impact farm-level land cover change. In addition, the proposed modeling effort adds depth to the examination of community-level effects on household level land use by 1) incorporating additional measures of community-level factors thought to influence land use compared to previous studies, and 2) including two cross-sectional dates (1990 and 1999). The proposed research integrates socioeconomic, demographic, biophysical, and geographical data sources, and as such contributes to the body of knowledge produced by the fledgling Land Change Science community. This dissertation also contributes by expanding knowledge about population growth and the direct and indirect effects of communities on LULC change in the NEA, contributing to the legacy of research focused on the NEA that began with Pichón and Bilsborrow's *finca* surveys in 1990 (Pichón 1993), evolved to include longitudinal *finca* surveys as well as community surveys (Bilsborrow 2002), and continues to the present day.

1.7. **Concluding Comments**

This section provides an outline of the remainder of the dissertation. Chapter 2 examines the regional site and context, providing political background on the settlement of the Ecuadorian Amazon as well as on the internal migration that promoted its settlement. Chapter 2 also outlines regional characteristics, including biophysical factors (climate, soils), agricultural patterns, resource extraction (oil, deforestation), and patterns of urbanization and population growth.

Chapters 3 through 5 focus on a central set of questions geared toward obtaining a greater understanding of the relevance and influence of survey communities on LULC dynamics in the NEA. Each of these chapters is presented in journal article format. Chapter 3 moves from the regional overview provided in Chapter 2 to bring the surveyed communities in the study area into greater focus. Chapter 3, therefore, examines how the surveyed communities are arrayed in space and the temporal dimensions of settlement in the NEA, analyzes similarities and differences among communities using cluster analysis, and discusses linkages among communities in light of household and community survey data as well as cluster analysis results.

Chapter 4 uses remote sensing and geospatial data to study landscape composition and land cover change dynamics in the areas surrounding survey communities. To examine the pattern and extent of deforestation around communities, an area of influence is defined for each community using the boundaries of the population sectors indicated by INEC census boundaries. Using INEC boundaries not only provides a geographic limit for each of the communities, but also allows integration of census data and the remote sensing results.

Chapter 5 models land use and land cover change at the *finca* level**,** incorporating measures of community influence. This work further refines previous work modeling land use at the *finca*-level by re-examining how to incorporate the influence of both the nearest and market communities. The pattern of land use, as well as of land use change, is modeled at the household level while incorporating community-level effects. Cross-sectional multivariate linear statistical models are generated for 1990 and 1999**.** *Dependent variables* for the cross-sectional models, generated from remote sensing imagery, include the proportion of various land cover classes (forest, agriculture, pasture) and measures of pattern (patch density, landscape shape index). *Independent variables*, drawn from theory and previous research, describe demographic, socioeconomic, biophysical, and geographic aspects of the *fincas* and incorporate community-level characteristics.

Chapter 6 synthesizes the work as a whole and provides conclusions. This final chapter will provide a synthesis of the foregoing chapters and identify future directions for research. Chapter 6 will, therefore, necessarily identify what has been learned from this study and identify what still needs to be learned.

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CHAPTER 2

REGIONAL SITE AND SITUATION

2. **Overview**

This study embraces an integrative perspective of theories and practices across the social, natural, and spatial sciences; examines the scales, patterns, and processes of LULC change; and integrates the drivers of land change by considering the linked farm and community factors of land conversion, within the context of local resource endowments, geographic accessibility, and exogenous shocks to the coupled human-natural system (e.g., commodity prices). This chapter provides context for the discussion of LULC change by outlining elements of the region's site and situation, as well as providing background on the region's physical and human systems, drivers of change, and feedback mechanisms.

2.1. **Political and Administrative Background**

2.1.1. **Political Background**

Colonization of the Amazon was the result of agrarian reform pursued by the Ecuadorian government beginning in the 1950s (MacDonald 1981). The government conceived of agrarian reform as a "pressure valve" that would diffuse tensions surrounding land tenure in the coastal and highland provinces. Historically, land tenure in Ecuador was based on the *latifundio/minifundio* relationship. Hanratty (1991) describes the scenario as the elite controlling the bulk of, and certainly the most desirable, land and those of lower social class possessing only small landholdings. In the Sierra, large landholders mainly utilized the valley floors, leaving land on the steeper slopes to the peasants, while in the Costa large landowners monopolized lands close to the rivers. Many of the *latifundia* were haciendas that engaged the local population in service tenancy, or *huasipunguaje.* Under this system, a service tenant exchanged work for the hacienda owner for usufruct rights to a 2 to 5 hectare subsistence plot and some access to forest wood, pastureland, and water elsewhere on the hacienda (Haney and Haney 1989).

Ecuador's first national agricultural census (1956) illustrated the country's uneven land distribution, as 1 percent of the total agricultural landholdings were shown to contain 56 percent of the cultivated land, while, at the other extreme 73 percent of the remaining farms shared approximately 7 percent of the land (Macdonald 1981). The government, wishing to more democratically distribute the land, felt it politically expedient to encourage colonization of the Amazon, lands described as unclaimed and unutilized, than to divest large landowners of their property. As a result, the *Instituto Nacional de Colonización* was formed within the *Ministerio de Agricultura* (MAG) in 1957.

With the Cuban Revolution in 1959 came increased stimulus for agrarian reform in Latin America (Feder 1971). The United States, through John F. Kennedy's Alliance for Progress, promised financial and technical aid for development if lands were redistributed, resulting in progressive legislation to alter land tenure throughout Latin America. In Ecuador, this movement resulted in the passage of the *Ley de Reforma Agraria y Colonización* in 1964 and establishment of the *Instituto Nacional de Reforma Agraria y Colonización* (IERAC), a successor to the *Instituto Nacional de Colonización*, to carry out the agricultural land reform program.

While these laws and institutions existed, the government did little to overtly encourage colonization of the Amazon. It was the discovery of oil in the Northern Ecuadorian Amazon in 1967, coupled with road building by the oil companies, that prompted spontaneous colonization of the region. The Ecuadorian government's plans for Amazonian colonization, coupled with the opportunities for settlement afforded by the oil company roads, resulted in population growth throughout Ecuador's Amazon, or *Oriente*.
Settlers that flooded into the region were provided provisional title (*certificado de posesión*) by IERAC once they presented evidence of land clearing for agriculture (Murphy 1998). Obtaining land title (*escritura*) was predicated on association with a *precooperativa*, or cooperative organization, as IERAC would only grant eligibility to for title to *fincas* that were members of such organizations (Bilsborrow et al. 2004).

Colonization of the Amazon was given high priority during the 1972-1979 military rule. The government wished to reduce population pressure in the Sierra and felt colonization of the Amazon would serve two purposes, by offering the greatest potential for colonization projects as well as serving as a defense against Peruvian invasion (Zevallos 1989). Colonization began to serve increasingly as an alternative rather than a complement to agrarian reform (Zevallos 1989). In 1977, the *Ley de Colonización de la Región Amazónica* was issued to direct colonization, and the *Instituto Nacional de Colonización de la Región Amazónica* (INCRAE) was created to direct, plan, and finance Amazonian colonization projects. Thereafter, coordination occurred through INCRAE, while IERAC provided land titles (Hicks 1991). IERAC's role in Amazon colonization was supplanted by the *Instituto Nacional de Desarrollo Agrario* (INDA), an organization characterized as weak and ineffective at granting land titles (Bilsborrow et al. 2004).

2.1.2. **Administrative Background**

Population growth in the region has been coupled with changes in administrative boundaries, as many new parroquias, cantons, and two new provinces were created in the years between 1974 and 2001. Data outlining dates of creation of parroquias, cantones, and provinces were obtained from the Insituto Nacional de Estadistica y Censos (INEC 2004). Data concerning changes in political-administrative divisions in Ecuador (i.e., provinces, cantones, and parroquias) were obtained from INEC publications (INEC 1974, INEC 1983, INEC 1990), while changes in geographic boundaries were noted from inspection of maps included in the documents describing political-administrative divisions as well as maps included in census publications (INEC 1991a, INEC 1991b, INEC 2003a, INEC 2003b, INEC 2003c).

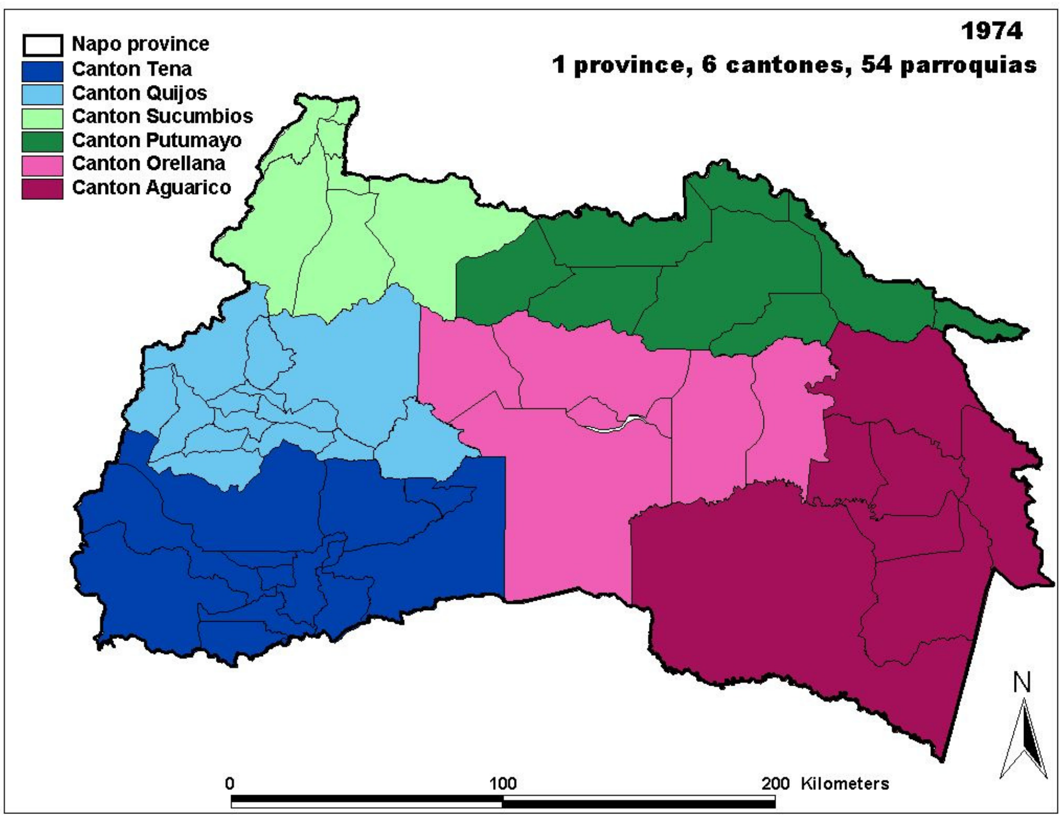

Figure 2.1. Administrative boundaries for Napo province associated with the 1974 census.

In 1974, the NEA was comprised of a single province, Napo, and the provincial capital located in Tena. In 1974 Napo province was comprised of six cantones[1] and fifty-four parroquias[2] (INEC 1974). Administrative boundaries for the province, cantones, and parroquias can be seen in Figure 2.1.

Population growth in the region between 1974 and 1982 resulted in changes to political-administrative divisions in the Napo province. By the 1982 census, the Napo province had created two cantones, Archidona and Lago Agrio, as well as four parroquias, for a total of eight cantones[3] and fifty-eight parroquias[4] (INEC 1983). Two of the new parroquias, El Dorado de Cascales and Lumbaqui, were created from parroquia Santa Rosa de Sucumbios in 1978. In 1979, canton Lago Agrio was formed from canton Putumayo. Canton Orellana formed two new parroquias, La Joya de los Sachas and Shushufindi Central,

[1]Tena, Aguarico, Orellana, Putumayo, Quijos, Sucumbios

[2]**Canton Aguarico (7 parroquias):** Nuevo Rocafuerte, Capitan Augusto Rivadeneira, Cononaco, Cuyabeno, Santa Maria de Huirima, Tiputini, Yasuni. **Canton Orellana (6 parroquias):** Puerto Francisco de Orellana (Coca), Limoncocha, Panacocha, Pompeya, San Roque, San Sebastian del Coca. **Canton Putumayo (8 parroquias):** Puerto El Carmen del Putumayo, Dureno, General Farfan, Palma Roja, Puerto Montufar (Puerto Bolivar), Puerto Rodriquez, Santa Cecilia, Santa Elena. **Canton Quijos (14 parroquias):** Baeza, Cosanga, Cuyuja, Diaz de Pineda, El Chaco, Gonzalo Pizarro, Linares, Oyacachi, Papallacta, San Francisco de Borja, San Jose de Payamino, Santa Rosa de Quijos, Sardinas, Sumaco. **Canton Sucumbios (7):** La Bonita, El Playon de San Francisco, La Sofia, Rosa Florida, San Pedro de los Cofanes, Santa Barbara, Santa Rosa de Sucumbios. **Canton Tena (12 parroquias):** Tena, Ahuano, Archidona, Avila, Carlos Julio Arosemena Tola, Cotundo, Chontapunta, Loreto, Pano, Puerto Misahualli, Puerto Nuevo (Puerto Napo), San Pablo de Uzhpayacu.

[3] **Napo cantones (8):** Tena, Aguarico, Archidona, Lago Agrio, Orellana, Putumayo, Quijos, Sucumbios.

[4]**Canton Aguarico (7 parroquias):** Nuevo Rocafuerte, Capitan Augusto Rivadeneira, Cononaco, Cuyabeno, Santa Maria de Huirima, Tiputini, Yasuni. **Canton Archidona (5 parroquias):** Archidona, Avila, Cotundo, Loreto, San Pablo de Uzhpayacu. **Canton Lago Agrio (3 parroquias):** Nueva Loja, Dureno, General Farfan. **Canton Orellana (8 parroquias):** Puerto Francisco de Orellana (Coca), Joya de los Sachas, Limoncocha, Panacocha, Pompeya, San Roque, San Sebastian del Coca, Shushufindi Central. **Canton Putumayo (5 parroquias):** Puerto El Carmen del Putumayo, Palma Roja, Puerto Montufar (Puerto Bolivar), Puerto Rodriquez, Santa Elena. **Canton Quijos (14 parroquias):** Baeza, Cosanga, Cuyuja, Diaz de Pineda, El Chaco, Gonzalo Pizarro, Linares, Oyacachi, Papallacta, San Francisco de Borja, San Jose de Payamino, Santa Rosa de Quijos, Sardinas, Sumaco. **Canton Sucumbios (9 parroquias):** La Bonita, El Dorado de Cascales, El Playon de San Francisco, La Sofia, Lumbaqui, Rosa Florida, San Pedro de los Cofanes, Santa Barbara, Santa Rosa de Sucumbios. **Canton Tena (7 parroquias):** Tena, Ahuano, Carlos Julio Arosemena Tola, Chontapunta, Pano, Puerto Misahualli, Puerto Nuevo (Puerto Napo).

from parroquia Francisco de Orellana in 1981. Canton Archidona was also formed in 1981, by reapportioning the parroquias associated with canton Tena. Administrative boundaries associated with the 1982 census can be seen in Figure 2.2; boundary data were not available at the parroquia level, thus parroquia boundaries are lacking for those cantones that were newly created or whose boundaries were revised in association with the creation of new parroquias.

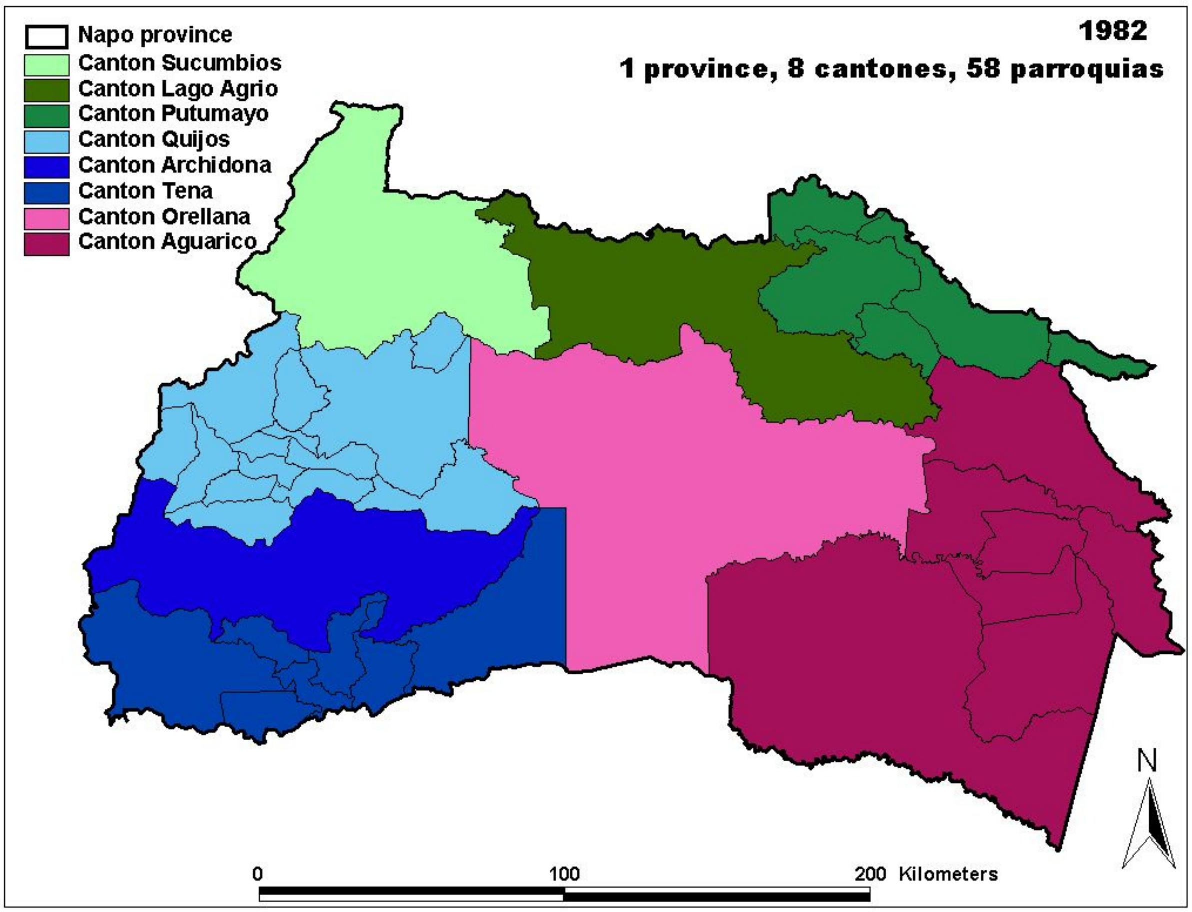

Figure 2.2. Administrative boundaries for Napo province associated with the 1982 census.

In 1989, Napo province split to form a second province, Sucumbios. Sucumbios selected Nueva Loja as its provincial capital. During the period between the 1982 and 1990 censuses, five additional cantones and nine parroquias were created. For the 1990 census, Napo province recorded seven cantones[5] and thirty-nine parroquias[6], while the Sucumbios province recorded six cantones[7] and twebty-eight parroquias[8]. In 1984, canton Shushufindi was formed from parroquias of canton Orellana (Shushufindi, Limoncocha, Pañacocha, San Roque). In 1985, canton Lago Agrio formed parroquia Tarapoa from parroquia Dureno and acquired parroquia Cuyabeno from canton Aguarico. Also in 1985, parroquia San Pedro de los Cofanes was renamed Puerto Libre. In 1986, canton Gonzalo Pizarro was created from portions of canton Sucumbios (El Dorado de Cascales, Santa Rosa de Sucumbios) and Canton Quijos (Gonzalo Pizarro, Lumbaqui, and San Pedro de los Cofanes). Parroquia Lumbaqui was reconfigured in 1987, in association with the formation of parroquia El Reventador. Cantones created in 1988 included canton El Chaco, formed from canton Quijos, and canton La Joya de los Sachas, formed from canton Orellana; within the new canton La Joya de los Sachas two new parroquias were created, Enokanqui and San Carlos. In 1989, canton Shushufindi formed two new parroquias, San Pedro de los Cofanes and Siete de Julio. In 1990, canton Cascales was formed from existing parroquias Gonzalo Pizarro, El

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[5] **Napo cantones (7):** Tena, Aguarico, Archidona, El Chaco, La Joya de los Sachas, Orellana, Quijos.

[6] **Canton Aguarico (6 parroquias):** Nuevo Rocafuerte, Capitan Augusto Rivadeneira, Cononaco, Santa Maria de Huirima, Tiputini, Yasuni. **Canton Archidona (6 parroquias):** Archidona, Avila, Cotundo, Loreto, San Pablo de Uzhpayacu, Puerto Murialdo. **Canton El Chaco (6 parroquias):** El Chaco, Diaz de Pineda, Linares, Oyacachi, Santa Rosa de Quijos, Sardinas. **Canton La Joya de los Sachas (5):** La Joya de los Sachas, Enokanqui, Pompeya, San Carlos, San Sebastian del Coca. **Canton Orellana (2 parroquias):** Puerto Francisco de Orellana (Coca), Dayuma. **Canton Quijos (7 parroquias):** Baeza, Cosanga, Cuyuja, Papallacta, San Francisco de Borja, San Jose de Payamino, Sumaco. **Canton Tena (7 parroquias):** Tena, Ahuano, Carlos Julio Arosemena Tola, Chontapunta, Pano, Puerto Misahualli, Puerto Nuevo (Puerto Napo).

[7] **Sucumbios cantones (6):** Lago Agrio, Cascales, Gonzalo de Pizarro, Putumayo, Shushufindi, Sucumbios.

[8] **Canton Cascales (3 parroquias):** El Dorado de Cascales, Sevilla, Santa Rosa de Sucumbios. **Canton Lago Agrio (5 parroquias):** Nueva Loja, Cuyabeno, Dureno, General Farfan, Tarapoa. **Canton Gonzalo Pizarro (4 parroquias):** El Reventador, Gonzalo Pizarro, Lumbaqui, Puerto Libre. **Canton Putumayo (5 parroquias):** Puerto El Carmen del Putumayo, Palma Roja, Puerto Montufar (Puerto Bolivar), Puerto Rodriquez, Santa Elena. **Canton Shushufindi (6 parroquias):** Shushufindi, Limoncocha, Panacocha, San Roque, San Pedro de los Cofanes, Siete de Julio. **Canton Sucumbios (5 parroquias):** La Bonita, El Playon de San Francisco, La Sofia, Rosa Florida, Santa Barbara.

Dorado de Cascales and Santa Rose de Sucumbios; within canton Cascales a new parroquia, Sevilla, was created. Also in 1990, Puerto Murialdo was created within canton Archidona, formed from parroquia Loreto. The administrative boundaries associated with the 1990 census are presented in Figure 2.3.

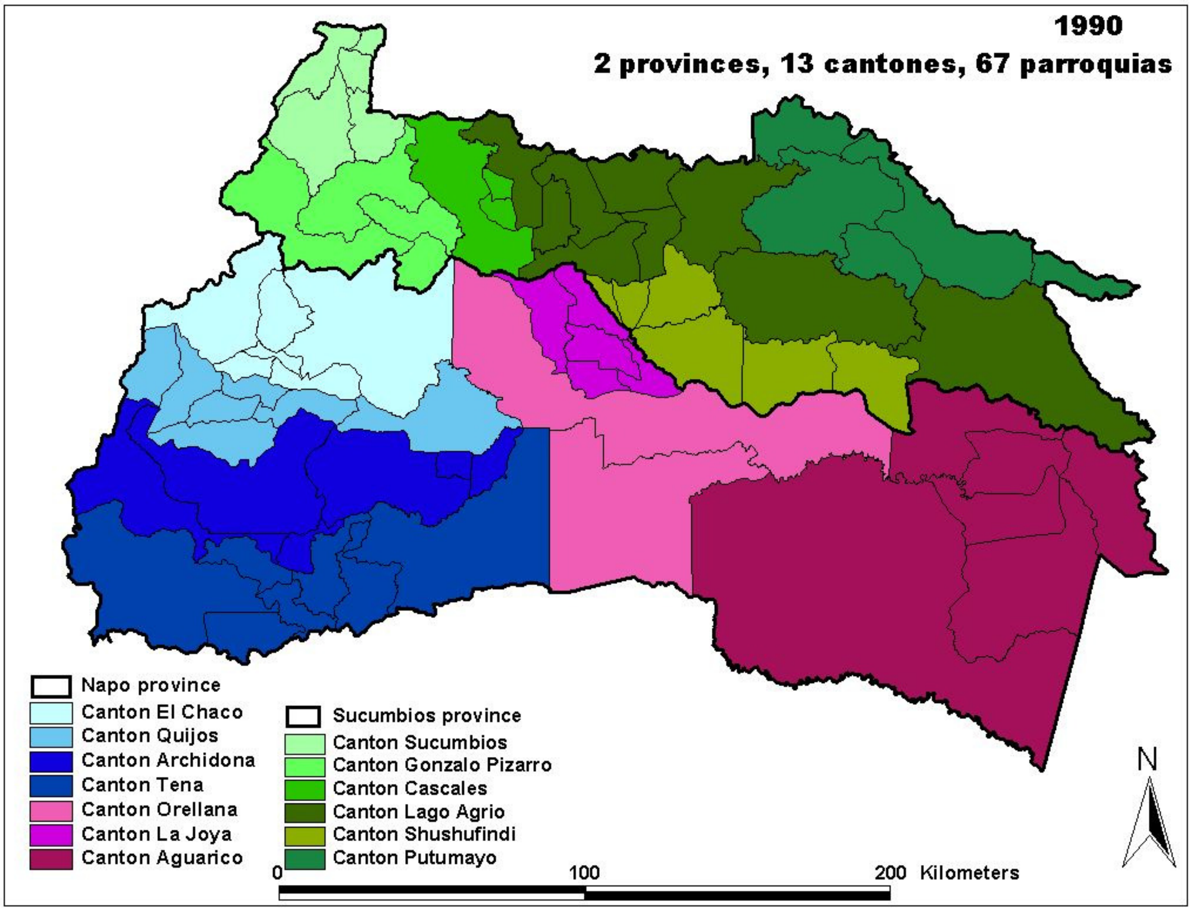

Figure 2.3. Administrative boundaries for Napo and Sucumbios provinces associated with the 1990 census.

A new province, three cantones and sixteen parroquias were formed in the period between the 1990 and 2001 censuses. Thus, by 2001, the NEA was home to three provinces, Napo[9], Sucumbios[10], and Orellana[11]. In 1990, canton Orellana formed two new parroquias,

[9] **Napo (5 cantones):** Tena, Archidona, El Chaco, Quijos, Carlos Julio Arosomena Tola.

Dayuma and Taracoa, from Puerto Francisco de Orellana. Canton Lago Agrio formed several new parroquias in 1991, including El Eno, created from parroquias Dureno and Nueva Loja, and Pacayacu, created from portions of parroquias General Farfan and Dureno. In 1992, canton Loreto was formed from portions of cantones Archidona, Quijos, and Tena, including parroquias Loreto, Avila, and Puerto Murialdo from Archidona, and San Jose de Payamino from canton Quijos. New parroquias created within canton Loreto included San Vicente de Huaticocha and San Jose de Dahuano. San Jose de Dahuano, in 1993, formed from Avila and part of canton Tena's parroquia Chontapunta. In 1994, parroquias Jambeli and Santa Cecilia were formed from portions of parroquia Nueva Loja. In addition, parroquia San Vicente de Huaticocha was formed from Avila. In 1996, canton Tena formed a new parroquia, Talag, from parroquia Pano. In 1998, two cantones were created, canton Carlos Julio Arosemena Tola from within canton Tena, and canton Cuyabeno from parroquias of canton Lago Agrio. Within the new canton Cuyabeno, parroquia Aguas Negras was formed from subdivision of parrroquia Tarapoa. Also in 1998, the province of Orellana was formed from cantones of the Napo province, La Joya de los Sachas, Orellana, Aguarico, and Loreto. As of the 2001 census, the region included sixteen cantones and seventy-six parroquias[12]. The administrative boundaries associated with the 2001 census are presented in Figure 2.4.

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[10] **Sucumbios (7 cantones):** Lago Agrio, Cascales, Cuyabeno, Gonzalo de Pizarro, Putumayo, Shushufindi, Sucumbios.

[11] **Orellana (4 cantones):** Orellana, Aguarico, La Joya de los Sachas, and Loreto.

[12] **Napo (23 parroquias). Archidona (3):** Archidona, Cotundo, San Pablo de Uzhpayacu. **El Chaco (6):** El Chaco, Diaz de Pineda, Linares, Oyacachi, Santa Rosa de Quijos, Sardinas. **Quijos (6):** Baeza, Cosanga, Cuyuja, Papallacta, San Francisco de Borja, Sumaco. **Tena (7):** Tena, Ahuano, Chontapunta, Pano, Puerto Misahualli, Puerto Nuevo (Puerto Napo), Talag. **Carlos Julio Arosemena Tola (1):** Carlos Julio Arosemena Tola. **Sucumbios (33 parroquias). Cascales (3):** El Dorado de Cascales, Sevilla, Santa Rosa de Sucumbios. **Cuyabeno (3):** Cuyabeno, Tarapoa, Aguas Negras. **Lago Agrio (7):** Nueva Loja, Dureno, El Eno, General

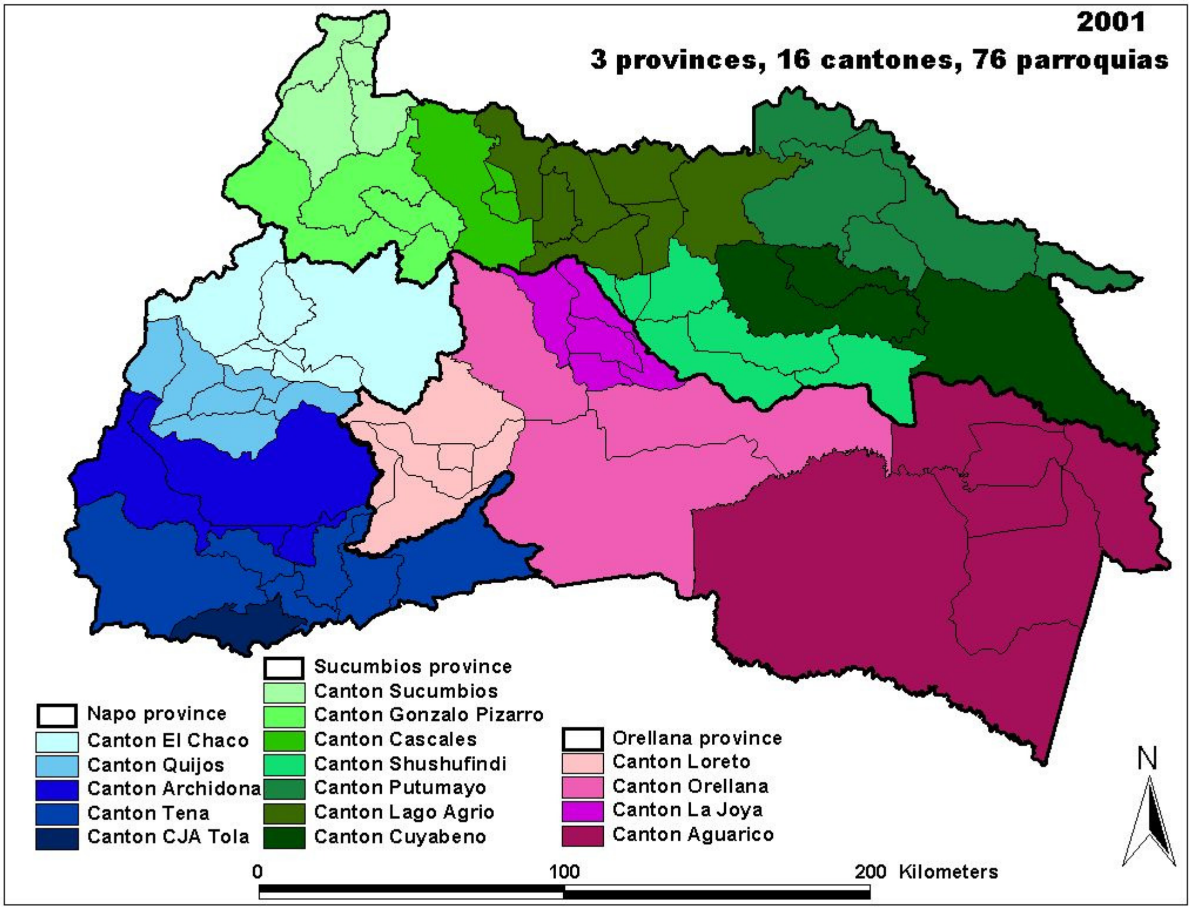

Figure 2.4. Administrative boundaries for Napo, Sucumbios, and Orellana provinces associated with the 2001 census.

2.2. **Migration**

2.2.1. **Internal Migration**

Population growth rates for 1974-2001 are shown in Figure 2.5. Note that comparing the slopes of the lines in Figure 2.5 highlights differences in population growth rates in the northern Amazonian province of Napo versus the southern Amazonian provinces. Figures

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Farfan, Jambeli, Santa Cecilia, Pacayacu. **Gonzalo Pizarro (4):** El Reventador, Gonzalo Pizarro, Lumbaqui, Puerto Libre. **Putumayo (5):** Puerto El Carmen del Putumayo, Palma Roja, Puerto Montufar (Puerto Bolivar), Puerto Rodriquez, Santa Elena. **Shushufindi (6):** Shushufindi, Limoncocha, Panacocha, San Roque, San Pedro de los Cofanes, Siete de Julio. **Sucumbios (5):** La Bonita, El Playon de San Francisco, La Sofia, Rosa Florida, Santa Barbara. **Orellana (20 parroquias). Aguarico (6):** Nuevo Rocafuerte, Capitan Augusto Rivadeneira, Cononaco, Santa Maria de Huirima, Tiputini, Yasuni. **La Joya de los Sachas (5):** La Joya de los Sachas, Enokanqui, Pompeya, San Carlos, San Sebastian del Coca. **Orellana (3):** Puerto Francisco de Orellana (Coca), Taracoa, and Dayuma. **Loreto (6):** San Jose de Payamino, Loreto, Puerto Murialdo, Avila, San Vicente de Huaticocha, San Jose de Dahuano.

2.6 and 2.7 further illustrate the process of population growth in the Ecuadorian Amazon. Examination of the slopes of the lines for the Amazonian provinces indicates that both the rural and urban populations in the Napo province have increased at rates higher than other provinces of the Ecuadorian Amazon; the NEA's proportion of urban residents increased from 7 to 35 percent between 1974 and 2001, with the proportion of rural population consequently decreasing from 93 to 65 percent during that time period. After 1982, the NEA's rural population grew more quickly than the other *Oriente* provinces.

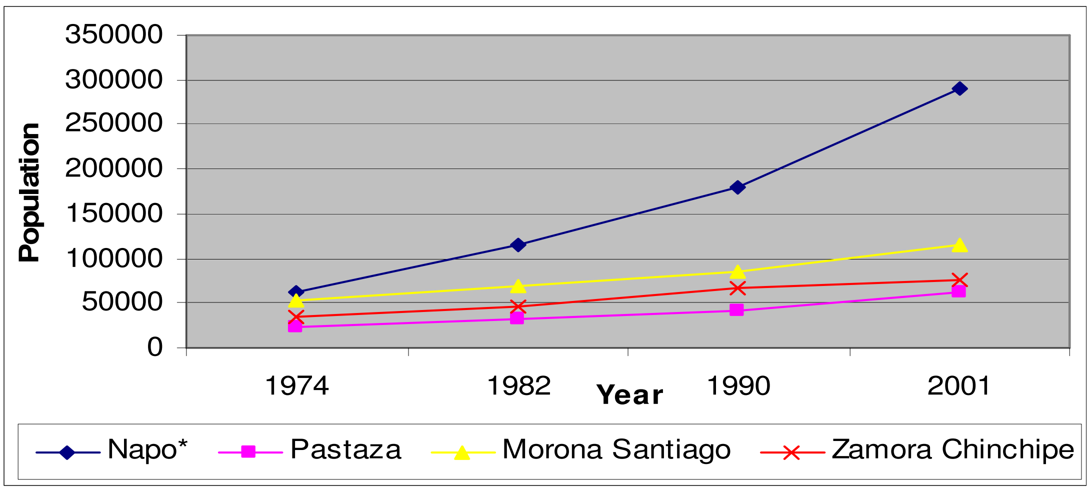


Figure 2.5. Population growth in the provinces of the Ecuadorian Amazon, 1974-2001 (INEC 1985, CEPAR 1993, INEC 2001). *The provinces of Sucumbios and Orellana were created from the Napo province; to appropriately reflect growth in the NEA, the populations of Sucumbios and Orellana were added to that of Napo for comparison with other provinces of the *Oriente* for the time period 1974-2001.

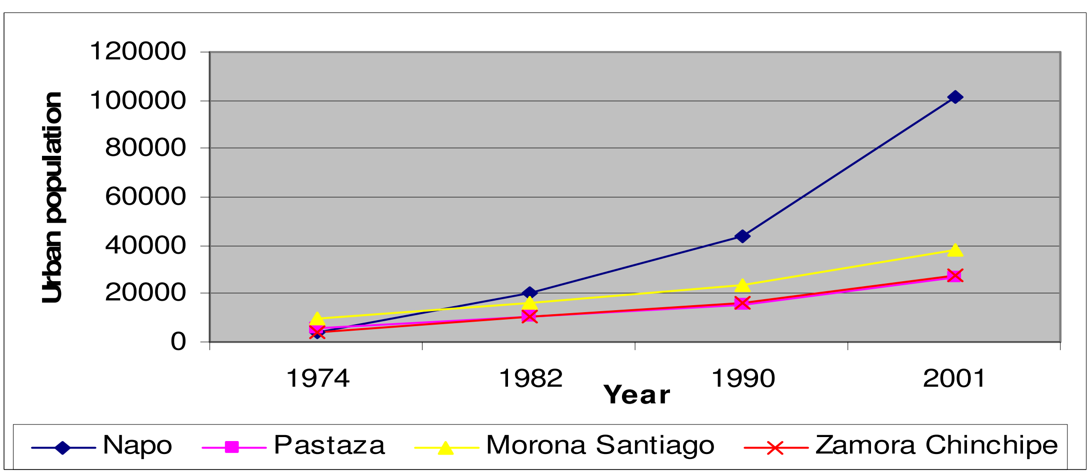


Figure 2.6. Urban population growth in the provinces of Ecuadorian Amazon, 1974-2001 (INEC 1985, CEPAR 1993, INEC 2001).

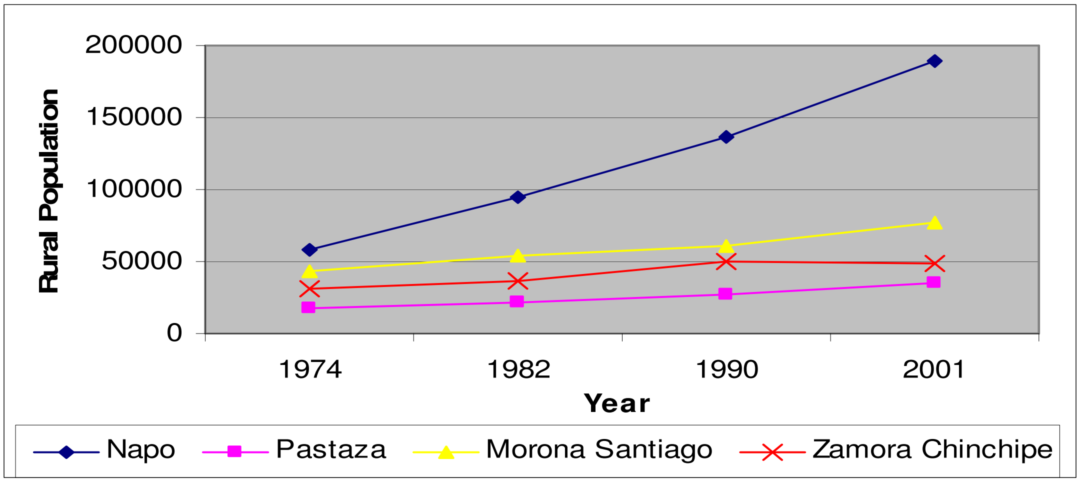


Figure 2.7. Rural population growth in the provinces of Ecuadorian Amazon, 1974-2001 (INEC 1985, CEPAR 1993, INEC 2001).

The *Oriente*'s proportion of Ecuador's total population has risen steadily over time. The 1974 census shows Ecuador's Amazonian population comprised 2.7 percent of Ecuador's total population; the percentage increased to 3.7 percent in 1990 and to 4.5 percent in 2001 (Bilsborrow 2003). National census data for the years 1974-2001 show that the Sierra provinces of Loja, Pinchinca, and Bolivar provided the largest numbers of migrants to the *Oriente*. The Costa provinces of Esmeraldas, Guayas, Los Rios, and Manabi, as well as the Sierran province of Tungurahua, also provided significant numbers of migrants. A map detailing the provinces of Ecuador is presented in Figure 2.8.

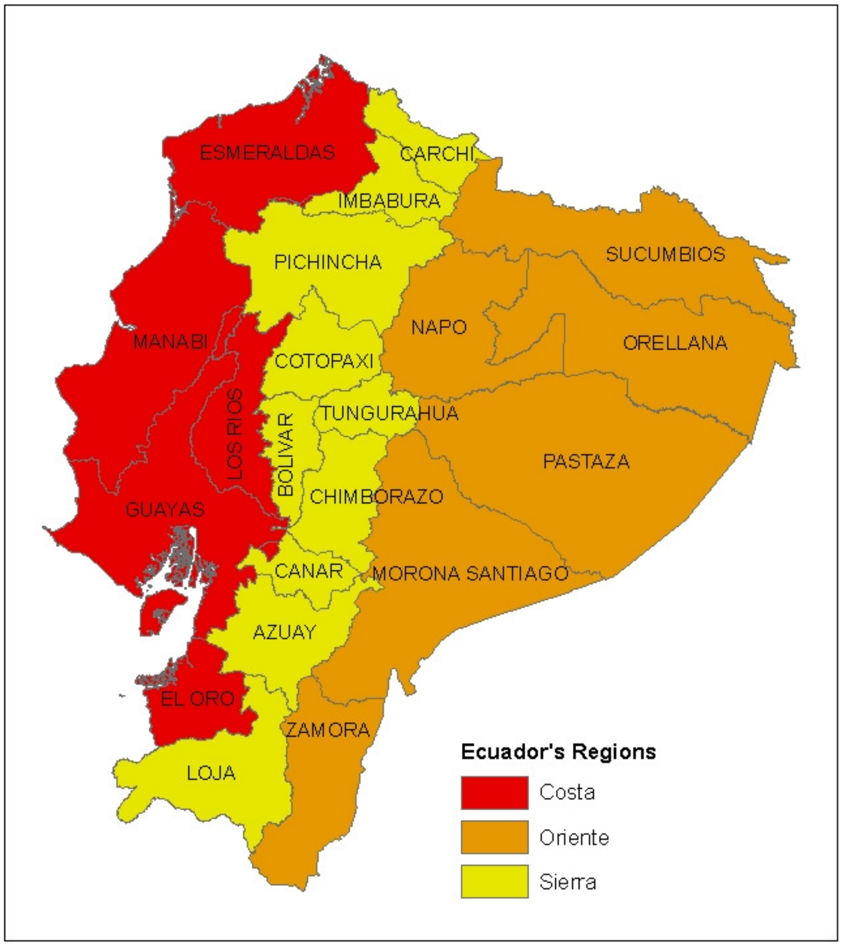


Figure 2.8. Provinces of Ecuador.

Though Brown and Sierra (1994) claim that *Oriente*-bound migrants follow a step migration pattern of movement from rural locales in the Sierra or Costa, to urban locales in the *Sierra* and *Costa*, then on to both urban and rural areas in the *Oriente*, evidence from longitudinal surveys (Bilsborrow 2002) shows that the sending, or source, communities were largely rural, with more than 85 percent of the settlers migrating to the NEA coming from rural areas in the *Sierra* or *Costa*. The migration flows resulted from macro-level forces including agrarian reform and regional development policies, population pressure, environmental degradation, the world market for petroleum, territorial disputes with Peru, road construction initiatives (Brown and Sierra 1994), and origin area characteristics

(Bilsborrow 2001). Individual-level factors that have influenced migration to the *Oriente* include migration networks and desires for land ownership as well as better opportunities to generate income.

Migration to the NEA has produced visible landscape-level impacts. Initial migrants occupied parcels along the roads. A linear settlement pattern resulted from the parcel design (50 ha; 250 m wide by 2,000 m long). Later migrants moved farther into the forest to claim land as trails called *lineas* were developed parallel to the main road at 2000 m intervals (Figure 2.9) (Hiroaka and Yamamoto 1980). Thus, layers of landholdings developed parallel to the main road. This pattern has resulted in up to 14 *lineas* in some parts of the study area, though 2 to 5 *lineas* are far more common.

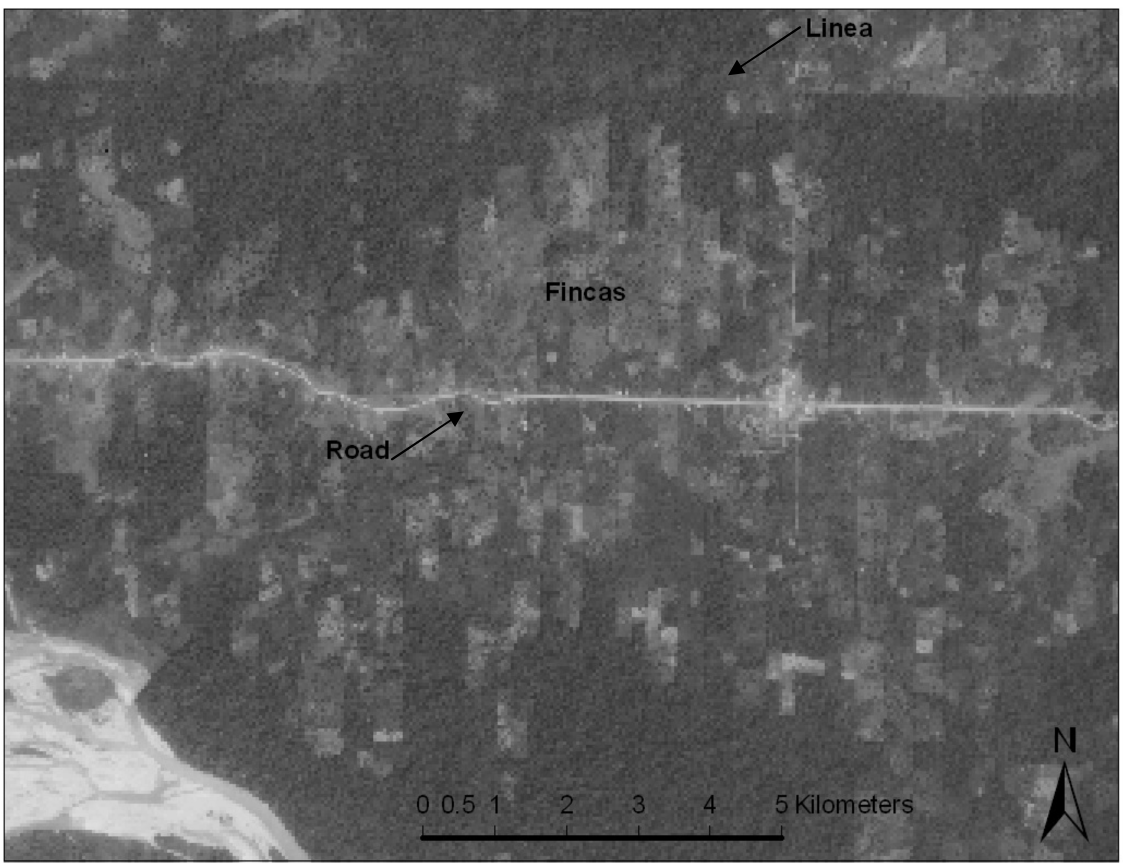


Figure 2.9. Settlement pattern with *lineas* evident to the north of the road, as indicated on a panchromatic aerial photograph from 1990 (1:60,000 scale, *Instituto Geográfico Militar* (IGM) in Quito, Ecuador).

2.2.2. **Immigration**

In Colombia, interactions between the Colombian military, paramilitary, and members of the guerilla movements *Fuerzas Armadas Revolucionarias de Colombia* (FARC) and the *Ejercito de Liberación Nacional (*ELN) have been associated with increasing violence through the 1990s (Bilsborrow and CEPAR 2006). The activities of the guerillas are centered in Putumayo, a Colombian province that borders Ecuador's northern Amazon region. The United States' participation in Plan Colombia, meant to fortify the Colombian army's opposition to the guerilla factions, has also served to increase the violence, and as a result, the number of refugees fleeing across the border into Ecuador (Bilsborrow and CEPAR 2006).

Recent work surveying Colombian migrants to Ecuador's border provinces (Sucumbios, Carchi, Esmeraldas, Imbabura, and Pinchincha) indicates that more than one-half of the migrants that have arrived since 2000 come from provinces along the border with Ecuador (Putumayo and Nariño) (Bilsborrow and CEPAR 2006). The heaviest flow of people fleeing violence in Colombia is from Putumayo into Sucumbios (Bilsborrow and CEPAR 2006). It might be reasonable, then, to assume that some large portion of the approximately 1 percent of the population of Sucumbios (2,202 people) identified by the 2001 census as "*extranjeros,*" or persons who had immigrated to the area from another country within the 5 previous years, are likely Colombian in origin; other "*extranjeros*" are likely involved in petroleum production or NGO work. While the presence of Colombians in the study area is not dangerous in and of itself, the presence of FARC guerillas in the northern portion of the study area has led to general uneasiness in the population as well as potentially unsafe conditions for research.

2.3 **Conceiving of the NEA as a Frontier**

A frontier may be defined as either a political boundary area (border between countries) or as a region of new settlement. Both types of frontier are integral in the history of migration to the Ecuadorian Amazon, especially because migration to the Amazon was encouraged from the perspective of national security as well as to relieve pressure on more densely populated areas of the country (Uquillas 1984). Frederick Jackson Turner prompted a new line of inquiry concerning the frontier in American history in an 1893 speech in which he shared his hypothesis that democracy and American character were developed through the process of frontier settlement (Webb 2003); this came to be known as the frontier hypothesis. It is, however, less the frontier hypothesis itself that seems useful in other contexts than Turner's descriptions of the frontier. For example, his descriptions of the frontier suggest fluidity and movement, "a continually advancing frontier line," rather than a static boundary line dividing two political entities. This concept is applicable to the examination of settlement and its pattern over time in the Ecuadorian Amazon because, as Barbier (1997) points out, migration of new settlers to frontier areas fuels frontier expansion and continued land conversions. Another of Turner's concepts that is applicable in the South American context is that of the frontier as a safety valve that releases social pressures in more settled areas (Pichón and Bilsborrow 1999, Bravo-Ureta et al. 1996, Findley 1988, Oberai 1988, Uquillas 1984). Frontier literature also points out the importance of transportation (e.g. road, rail) in frontier settlement (Hudson 1985); road infrastructure associated with the discovery of oil in was key in opening the Ecuadorian Amazon to migrants.

Frontiers are viewed as abundant in space and natural resources from the perspective of in-migrants (Lithwick et al. 1996). The extraction of natural resources (e.g., oil, wood) and agricultural activities often lead to agricultural extensification and then later to intensification, totally altering native vegetation. As the frontier is settled, there can be reorganization of how land is used (Elezar 1996). Each of these traits can be seen in the settlement and agricultural expansion that has taken place in the NEA.

Additionally, frontiers can be conceptualized as having both internal and external frontiers (Carr 2002). The external frontier is that land which is available for settlement. When all available land has been claimed, the external frontier is considered closed, but there may be internal frontiers along which further land cover changes occur as settlers clear their plots in phases as households grow and age (Rindfuss et al. 2007). The existence of internal frontiers in the NEA has been made evident by research examining the process of parcel subdivision in the NEA (Barbieri et al. 2005, Bilsborrow et al. 2004, Walsh et al. 2003, Walsh et al. 2002). Pressures associated with the closure of internal frontiers may encourage more intensive land use (Bilsborrow 1987), or demographic responses including delayed marriage, reduced fertility, or out-migration (Bilsborrow 1987; Davis 1963); out-migration may be either seasonal (i.e., for work) or permanent (Bilsborrow 1987). Barbieri (2005) illustrates the impact of internal frontiers on out-migration from households in the NEA, showing that households associated with subdivisions are more likely to participate in rural-urban migration.

2.4. **Biophysical Factors and Agriculture**

Biophysical factors are presented to provide context for vegetative growth and agricultural endeavors in the NEA. Climatic issues are implicated in remote sensing of this region, as the abundant rainfall precludes a pronounced dry season and thus does not produce pronounced seasonal phenological changes in vegetation. In addition, the persistent humidity and thus haze, clouds, and shadows often obscure the landscape. A brief overview of the region's terrain and soils is provided because of the importance of agriculture in the region.

2.4.1. **Climate**

Rainfall in the *Oriente* is abundant, averaging more than 3,000 mm per year. This rainfall is distributed throughout the year and, as a result, there is no pronounced dry season. It is estimated that 50 percent of the precipitation falling in Amazonia is recycled through evapotranspiration of its forests (Salati 1987). Day length in the *Oriente* varies little annually due to Ecuador's equatorial location. Solar radiation is high throughout the year, but much radiation is reflected by persistent cloud cover or scattered by moisture in the air (Hidore and Oliver 1989).

Average temperatures range from 25-28° C, with the "cooler" temperatures associated with the western portion of the region that borders the Andes. Temperatures vary little throughout the year; diurnal temperature fluctuations produce nocturnal cooling. The study area, dominated by humid tropical and very humid tropical climate regions (Figure 2.10), is classified as an *Af*, or tropical rainy, region through the Köppen classification system (Hidore and Oliver 1993).

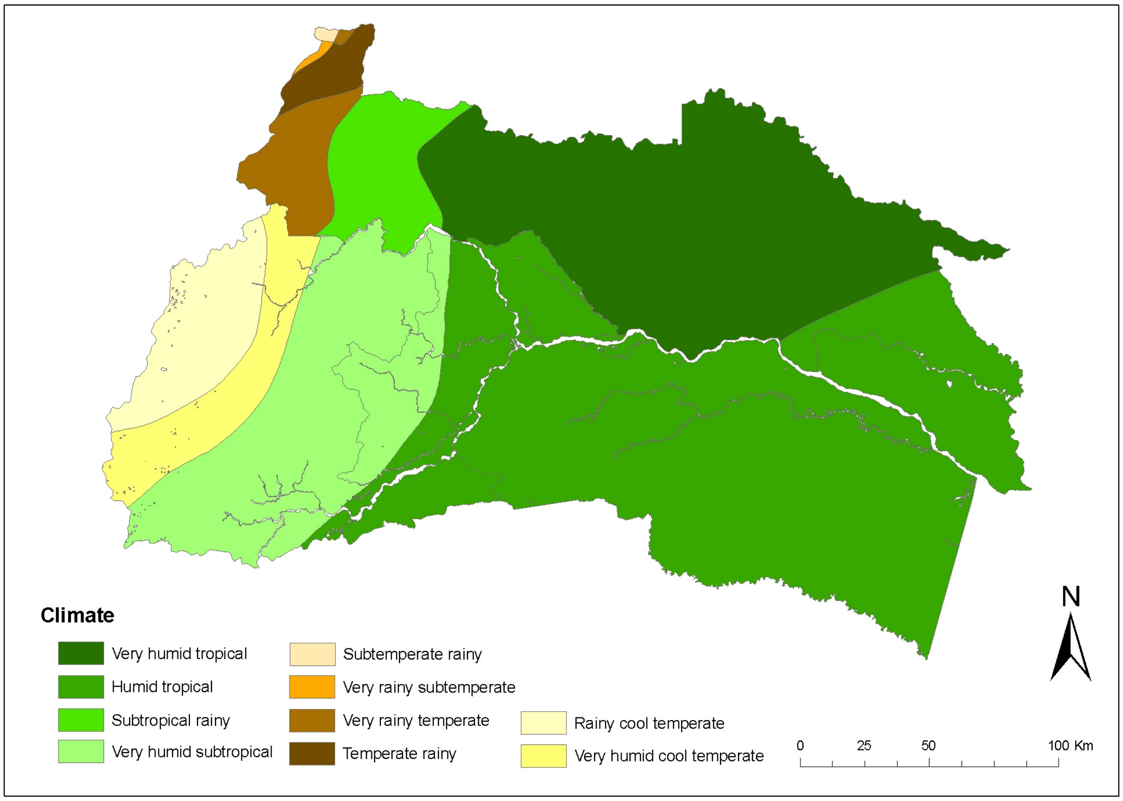


Figure 2.10. Climate regions of the *NEA* (Source: ECORAE).

2.4.2. **Terrain and Soils**

The NEA's highest elevations, and arguably greatest variety in terrain, is found along its western boundary, which abuts the eastern cordillera of the Andes Mountain range (Figure 2.11). Most of the rest of the NEA is less than 600 m above mean sea level. In Sucumbios, elevation ranges between 120 and 4,150 m, with a mean elevation of 628 m. In Orellana, elevation ranges between 56 and 3,745 m, with a mean elevation of 282 m. The range in elevation for Napo is between 235 and 5,720 m, with a mean of 1,943 m. The *fincas* surveyed in 1990 (Pichón 1993) and 1999 (Bilsborrow 2002), as well as the communities surveyed in 2000 are located in the portion of the NEA with less than 600 m of elevation.

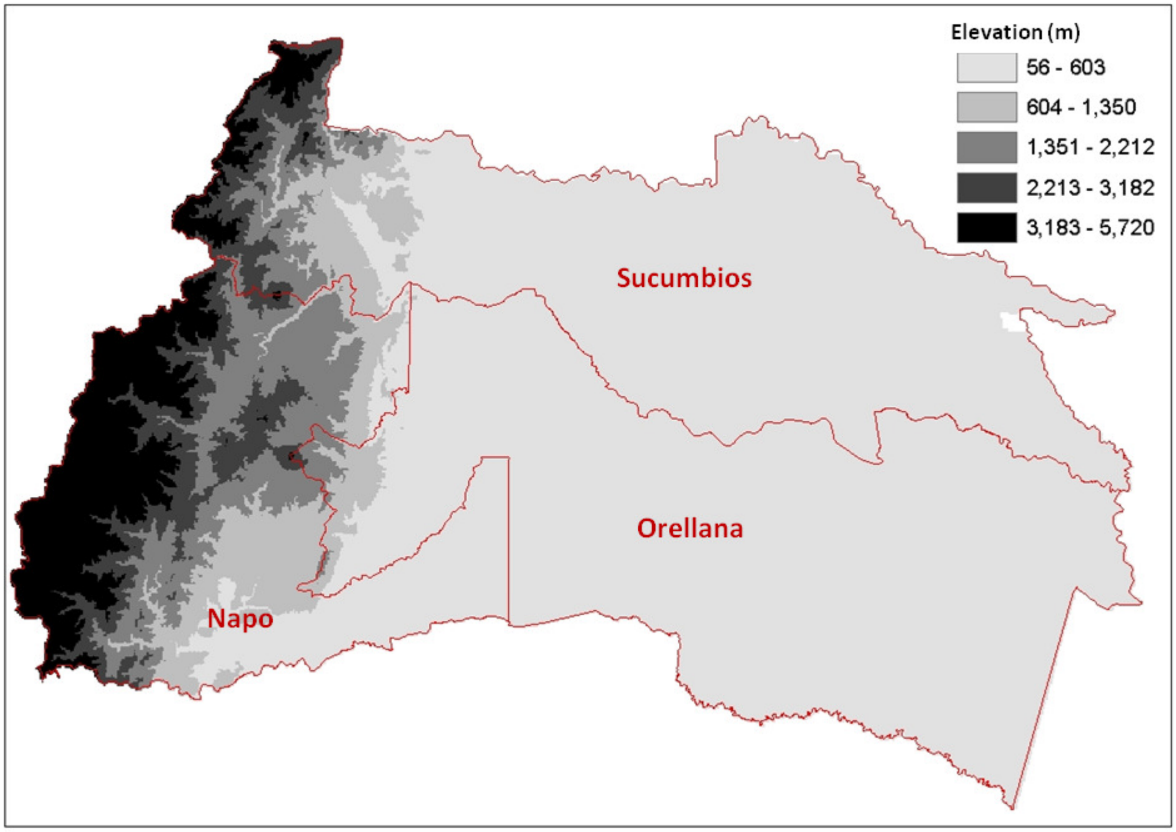


Figure 2.11. Elevation in the NEA, from 30m DEM created by M. Souris, Institut de Recherche pour le Développement (IRD).

Tropical soils are generally characterized as infertile. Low fertility is due in part to high rates of decomposition of organic matter and immediate uptake of nutrients by vegetation (tight nutrient cycling), as well as the tremendous amount of precipitation that the region receives, leaching nutrients from the soils. Organic input to the soils is further reduced when trees are cut, as forest vegetation provides the primary source of organic matter and many nutrients (Brady 1990).

The soils of the study area are more complex than the usual stereotypical tropical soils. They are primarily Inceptisols, with Histisols occurring in wetland areas. Inceptisols are weakly developed soils whose characteristics may include parent material resistant to weathering, location in extreme landscape positions such as steep slopes or depressions, abundance of volcanic ash, or a young geomorphic surface that has limited soil development (Buol et al.1989). Many of these Inceptisols have been influenced by volcanic ash and are therefore classified as Andepts; these soils have low bulk density and are generally high in fertility and organic matter content (USDA-NRCS 1999). Histisols are composed mainly of organic materials (12-18 percent by weight) that have come from the decomposition of animal and plant materials (Buol et al.1989). These soils have low bulk density, high water holding capacity, and are generally saturated. They are often used for crop or horticultural production, but also provide refugia for plants and wildlife.

With reference to Figure 2.12, the area north of the Aguarico River possesses high percentages of two types of Inceptisols, Oxic and Typic Dystropepts, which are either red or grey in color and low in fertility. The area between the Aguarico and Napo rivers is dominated by different types of Andepts (i.e., Vitrandepts and Dystrandepts) and is thus best suited for agricultural use due to the elevated fertility associated with soils of volcanic origin. South of the Napo River, there exists a mixture of Andepts and Dystropepts. In the most southern part of the study area, there is a large area of Fibrists, Histisols with a high percentage of fibrous materials.

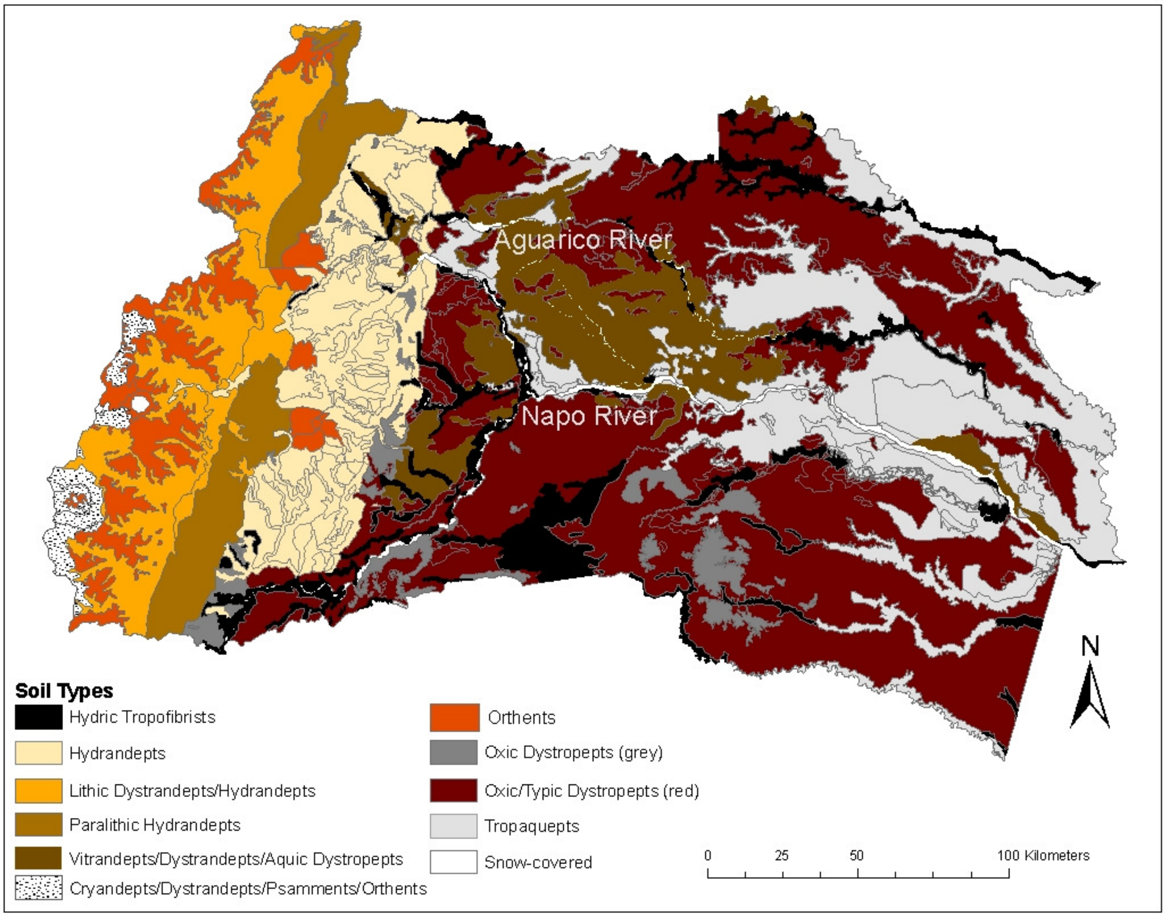


Figure 2.12. Soils of the NEA (ECORAE).

2.4.3. **Agriculture**

Agricultural production in the NEA is primarily by smallholders. The most recent agricultural census[13] showed that the most extensively planted commercial agricultural product in the NEA is overwhelmingly coffee, covering 54,888 hectares in 2001 (INEC 2002). Other extensively planted commercial/market agricultural crops include plantains (11,353 ha), cacao (11,998 ha), and African palm (14,010 ha) (INEC 2002). In terms of production, African palm ranked first at the time of the census (62,522 metric tons), followed

[13] The first Ecuadorian agricultural census was conducted in 1954. In 1968 an agricultural sample survey was carried out; in 1974 the second agricultural census was undertaken. The most recent agricultural census was conducted in 1999-2000.

by plantains (16,017 metric tons), coffee (10,876 metric tons), and palmito (6,465 metric tons) (INEC 2002). More recent data indicate that African palm (410,632 metric tons) and palmito (40,478 metric tons) production in the NEA had vastly increased by 2005 (MAG 2006). By 2005, plantain production had also increased (29,583 metric tons), as did coffee production (15,474 metric tons) (MAG 2006). Cacao has been expanding rapidly as well, from 959 metric tons in 2001 (MAG 2001) to 5,380 metric tons in 2005 (MAG 2006).

Coffee has historically been among the country's top export products. The most recent agricultural census indicated that the provinces of Sucumbios and Orellana accounted for approximately 15 percent of the area planted in coffee and 40 percent of national production (MAG 2002a; MAG 2002b); café robusta is the primary coffee variety planted in the Amazon (MAG 2002a). Note, however, that Ecuadorian coffee production decreased by almost one-half between 1990 and 2000 (MAG 2002c), and has continued to decline (MAG 2005). Low prices paid to coffee producers have discouraged new planting.

Cacao has intermittently been prominent as an export product. Cacao experienced a boom in Ecuador in the late 1800s and early 1900s that was followed by a dramatic decrease in production due to disease (Handelsman 2000). Resurgence in cacao production began in the mid-1950s, and rapid increases in production have resulted in current production levels far above those experienced early in the 20th century (Soria Vasco 2004). The most recent agricultural census indicated that as of 2000, cacao production in the NEA was not nearly as widespread as coffee (Table 2.1). Some intercropping of coffee and cacao also occurs; either crop may also be intercropped with native trees for shade.

Table 2.1. Important commercial crops in the NEA, according to the 2000 agricultural census (MAG 2002a; MAG 2002b).

	Area Planted (ha)*		
	Sucumbios	**Orellana**	**Napo**
Coffee	29,411	19,978	5,499
Cacao	4,186	3,565	4,247
African Palm	5,743	8,172	95

African palm production in the NEA is primarily a large commercial enterprise. Large parcels of land are dedicated to production, and approximately 14,000 hectares were in production as of the 2000 agricultural census (MAG 2002b); most of this area is in two plantations owned by *Palmeras del Ecuador* and *Palmoriente S.A*. African palm production in Ecuador has increased steadily since 1990 (MAG 2004a). The principal use of African palm fruit is in production of cooking oil for local consumption and export (MAG 2003).

2.5. **Resource Extraction**

2.5.1. **Oil**

Ecuador's economy relies heavily on petroleum production. As of 2008, oil provides almost half of Ecuador's export earnings and one-third of the government revenue (EIA 2008). Over the last 25 years, production has continued to rise, with the exception of a 6-month period following an earthquake-induced rupture of the *Sistema Oleoducto Trans-Ecuatoriano* (SOTE) or Trans-Ecuadorian Pipeline in 1987 (Figure 2.13). Ecuador is one of Latin America's largest crude oil exporters (EIA 2008) and thus an important player in world energy markets. Approximately 50 percent of Ecuador's oil production is exported to the United States (EIA 2008). As of January 2008, the volume of Ecuador's proven crude oil reserves was 4.5 billion barrels (EIA 2008), most in oil fields in the NEA. Major oil fields in the NEA include Shushufindi, Sacha, Dorine, and Eden Yuturi (EIA 2008), all of which are located in the study area.

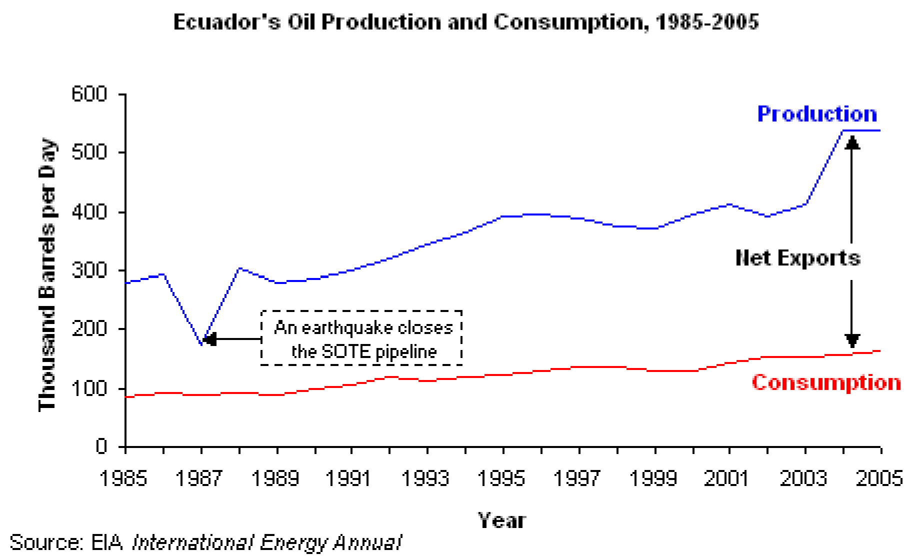


Figure 2.13. Ecuadorian oil production and consumption 1985-2005 (EIA 2007).

Oil transport from the NEA to the coast has been served for almost 35 years by the SOTE, which traces a 300 mile (500 km) route from Nueva Loja to Balao in Esmeraldas (Vázquez and Saltos 2003). The SOTE was built by Texaco and William Brothers. In September 2003, a new privately operated pipeline designed to carry heavier crude oil, the *Oleoducto de Crudos Pesados* (OCP), doubled the country's transport capacity. Seven companies were involved in the construction of the OCP: AGIP, Alberta Energy Company, Keer-McGee, Occidental, Pérez-Companc, Repsol-YPF, and Techint (Vázquez and Saltos 2003). Construction of the OCP has loosened constraints on transport capacity, thereby allowing private companies to increase production (EIA 2008). For most of its length, the OCP runs parallel to the SOTE, with the exception of a 100-mile (160 km) stretch near

Quito. The OCP crosses fragile ecological systems, including national parks and protected reserves, such as the Mindo Nambillo Cloudforest Reserve.

Future increases in oil production are likely to come from development of the Ishpingo-Tapococha-Tiputini block (EIA 2008), located in the southern portion of the study area. However, scientists and citizens alike are concerned about impacts additional roadbuilding will have on the Yasuní National Park. In fact, a group of scientists (Scientists Concerned for Yasuní National Park), including University of North Carolina at Chapel Hill professor and long-time NEA researcher Richard Bilsborrow, developed a report stressing that access to oil fields for drilling should be by helicopter only to limit adverse impacts on the park associated with road construction (e.g., migration, colonization, deforestation, illegal logging, and illegal hunting) (Finer and Huta 2005).

2.5.2. **Deforestation**

Three types of forest clearing are common in the Ecuadorian Amazon, clearing along corridors, fringe clearing along the edges of forest, and clearing of large blocks of land (Rudel and Horowitz 1993). All three types of clearing have been observed in the NEA, each attributable to different stakeholder groups. Land clearing along corridors was a product of oil road construction. When migrants began to arrive in the *NEA*, land along transportation corridors was claimed first. Deforestation was a product of the legalization process, as the *Ley de Tierras Baldias* required forest clearing and replacement with crop or pasture land to obtain legal title (Hicks 1991); this law, however, was not enforced (Murphy 1998).

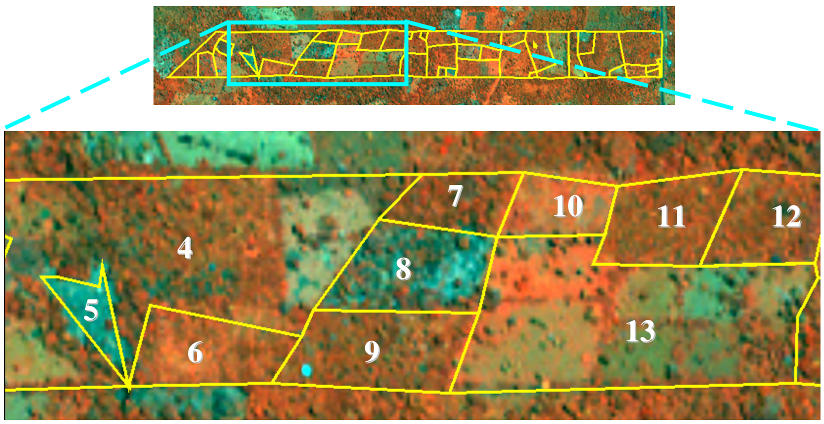
Fringe clearing has occurred as settlers engage in shifting cultivation on their *fincas*. As soil fertility in an area of cleared land decreases, the *finca* owner clears another patch of forest for agricultural use. Rather than the slash-and-burn method of clearing, clearing in the NEA amounts to "slash-and-mulch" due to high annual rainfall (Nicholaides et al. 1984; Pichón 1997). Wood harvested on the *finca* is generally used on the farm, or sold for use in domestic furniture and construction industries (MAG 2004b) or export (MAG 2004c).

Clearing of large blocks of land can be attributed mainly to two existing commercial African palm plantations. These plantations are located in the provinces of Sucumbios (Shushufindi area) and Orellana (Loreto and Coca areas). Palm oil companies *Palmeras del Ecuador* and *Palmoriente S.A*. own 24,000 hectares in the NEA, 14,000 hectares near Shushufindi and 10,000 hectares near Coca (Buitrón 2004). As of 2001, the area planted in African palm in the NEA was approximately 14,000 hectares (MAG 2002b), making further palm industry expansion and forest loss a future possibility.

Figures 2.14 and 2.15 illustrate the three types of clearing previously discussed. Figure 2.14 shows the clearing of large blocks of land, attributable to commercial palm production (A), northwest of Coca and west of La Joya de los Sachas, as well as clearing along transportation corridors. Note how the cleared lands radiate back from the main roads. Figure 2.15 shows how *finca* land use has changed over time. The land use trajectories in Figure 2.15 illustrate the process of fringe clearing and spatial diffusion.

Figure 2.14. A 1986 Landsat TM image illustrating two types of forest clearing: along corridors and large blocks of land.

The fringe clearing illustrated by the image and accompanying table in Figure 2.15 is emblematic of the forest fragmentation process that has been occurring in the NEA since settlers began to arrive *en masse* in the early 1970s. As population in the region has grown, the forests in the NEA have become more fragmented. Satellite imagery shows the NEA region to be primarily forested in 1973, but by 1986 the impact of population growth and agricultural expansion in the region is evident (Figure 2.16). Walsh et al. (2002) described land cover change and assessed forest fragmentation for the area around Nueva Loja for the time period 1973-1999. They showed a decrease in the proportion of the landscape in forest through time, from 85 percent in 1973 to 50 percent in 1986, 33 percent in 1996, and only 20 percent of the landscape by 1999. Concurrently, the proportion of the landscape in agriculture/pasture grew to 45 percent by 1996. Coupled with the decrease in forest cover and an increase in agriculture and pasture land cover types, the number of patches on the landscape rose over time (1973-1996), indicating that the changes in land cover proportions were coupled with increasing fragmentation within these land cover types.



Poly	t - 2	t - 1	t	t + 1
ID	Sec.	Sec.	Sec.	Pasture
4	Forest	Forest	Forest	Pasture
5	Sec.	Pasture	Pasture	Fallow
6	Forest	Coffee	Coffee	Fallow
7	Pasture	Pasture	Coffee	Palm
8	Pasture	Pasture	Palm	...

Figure 2.15. A 2002 Ikonos image illustrating fringe clearing on *fincas* and trajectories of change through time (from Walsh et al. 2003).

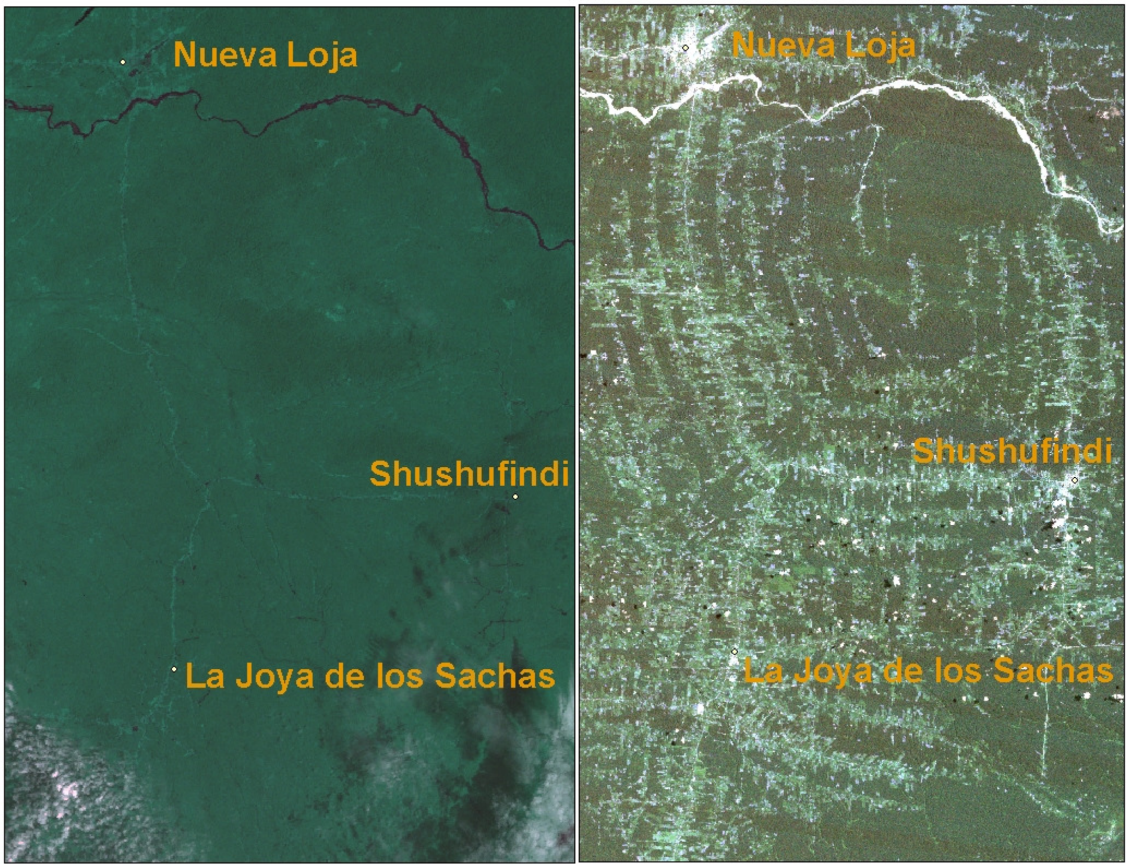


Figure 2.16. 1973 MSS and 1986 TM satellite images illustrating forest fragmentation in the NEA.

2.6. **Study Area within the NEA**

The section describes the study area in greater detail, giving particular attention to surveyed communities and surveyed households.

2.6.1. **Central Places**

The four largest communities in the NEA are Nueva Loja, Coca, La Joya de los Sachas, and Shushufindi (Table 2.2). Each of these communities had been established by the early 1970s and have experienced roughly similar average annual growth rates during each intercensal period. Nueva Loja is by far the largest community, with a population approaching 35,000 by 2001. Each of these communities may be considered central places in the NEA, as they provide the greatest variety of goods and services to other communities in the region.

Table 2.2. Population growth in central place communities in the NEA (1982-2001).

	1982 Pop.	**1990 Pop.**	**2001 Pop.**
Nueva Loja	7,237	13,165	34,106
Coca	3,996	7,805	18,298
La Joya de los Sachas	1,116	2,519	5,822
Shushufindi	1,874	4,806	10,559

Data source: INEC (1985, 1991c, 2003d)

2.6.2. **Community Survey Data**

In 2000, community-level interviews were developed and implemented to provide context and evaluate socio-economic, demographic, and land use changes that occurred between 1990 and 1999 (Bilsborrow 2002). Communities selected for interviews were chosen on the basis of their spatial proximity to households surveyed in 1990 (Pichón 1993) and 1999 (Bilsborrow 2002) as well as the linkages between households and communities suggested by household level interviews. The community surveys addressed many topics, including distance and access to reference communities (e.g., where they buy and sell goods, find education and health services, or seek spiritual nourishment), principal economic activities, local cultivation and yields, land tenure, facilities and infrastructure, transportation services, prices of basic goods, and types of agricultural and development assistance available. In addition, the community surveys included retrospective questions, designed to assess spatial and temporal changes since 1990, that addressed population growth, in- and out-migration, economic change, and the number and size of farms. In each community, several knowledgeable informants, including community leaders, local farmers, teachers, and health workers, responded to the questionnaires on behalf of their community. The community-level questionnaire was administered in 54 communities in 2000, and in several additional communities in 2002, bringing the total number of communities surveyed to 59.

2.6.2.1. **Surveyed Communities: Spatial and Temporal Dimensions of Settlement**

Each of the communities surveyed was asked about the date of establishment. Dates of establishment, ranging from the 1950s to the late 1990s (Table 2.3), were available for 95 percent of the communities surveyed (56 of 59). The bulk of the communities in the community survey dataset were established in the 1970s (n=31), though Coca was established in the 1950s and several communities as late as the 1990s (i.e., El Triunfo, Union Chimboracense, and Los Angeles). Figure 2.17 shows the areal distribution of communities grouped by decade of establishment.

Coca is the only study community that existed prior to the 1960s. It became established as a religious mission at a time when the only access was by water (Cabodevilla 1966), and later grew through association with one of the region's major oil fields, Auca. Coca is now considered one of the region's central cities. Most of the communities that established in the 1960s (n=8) did so in the last half of the decade, along the road that connected Tena to Nueva Loja, with the exception of 3 de Noviembre, San Sebastian del Coca, and Dayuma.

The other central cities in the region became established in the early 1970s. Nueva Loja and La Joya de los Sachas both became established in 1970, while Shushufindi's date of establishment was 1972. These communities arose in association with the region's other major oil fields, Lago Agrio, Sacha, and Shushufindi (Bromley 1972).

Table 2.3. Date of establishment for NEA communities surveyed in 2000.*

1950s			
Coca (1953)			
1960s			
5 de Agosto (1960)	3 de Noviembre (1965)	Dayuma (1968)	Dureno (1969)
San Sebastian del Coca (1965)	Santa Cecilia (1965)	Jambeli (1968)	Sevilla (1969)
1970s			
El Dorado de Cascales (1970)	La Victoria (1972)	La Primavera (1974)	Coop. San Antonio (1977)
Nueva Loja (1970)	Shushufindi (1972)	Union Milagrena (1975)	Eugenio Espejo (1977)
La Joya de los Sachas (1970)	Pacayacu (1972)	La Reforma (1975)	San Juan de Pozul (1978)
Jandiayacu (1970)	Nueva Vida (1973)	7 de Julio (1975)	Coop. Union Lojana (1978)
Conambo (1970)	San Pedro de los Cofanes (1973)	San Carlos (1975)	Recinto El Oro (1978)
El Eno (1970)	Enokanki (1974)	Armenia (1976)	El Dorado (1978)
Jivino Verde (1970)	Las Palmas (1974)	Virgen de Banos (1977)	Llurimagua (1979)
Lumbaqui (1971)	Mariscal Sucre (1974)	Pozo Ron (1977)	
1980s			
San Roque (1980)	Alamor (1980)	Patria Nueva (1980)	La Belleza (1982)
Bella Union del Napo (1980)	San Vicente (1980)	Taracoa (1981)	Bahia de Caraquez (1982)
Nueva Esmeraldas (1980)	10 de Agosto (1980)	Coop. Abdon Calderon (1981)	24 de Mayo (1985)
Guayacan (1980)			
1990s			
El Triunfo (1990)	Union Chimboracense (1995)	Los Angeles (1995)	

*3 of the 59 communities surveyed did not list dates of establishment: Union Manabita, Llumucha, and Union de los Rios

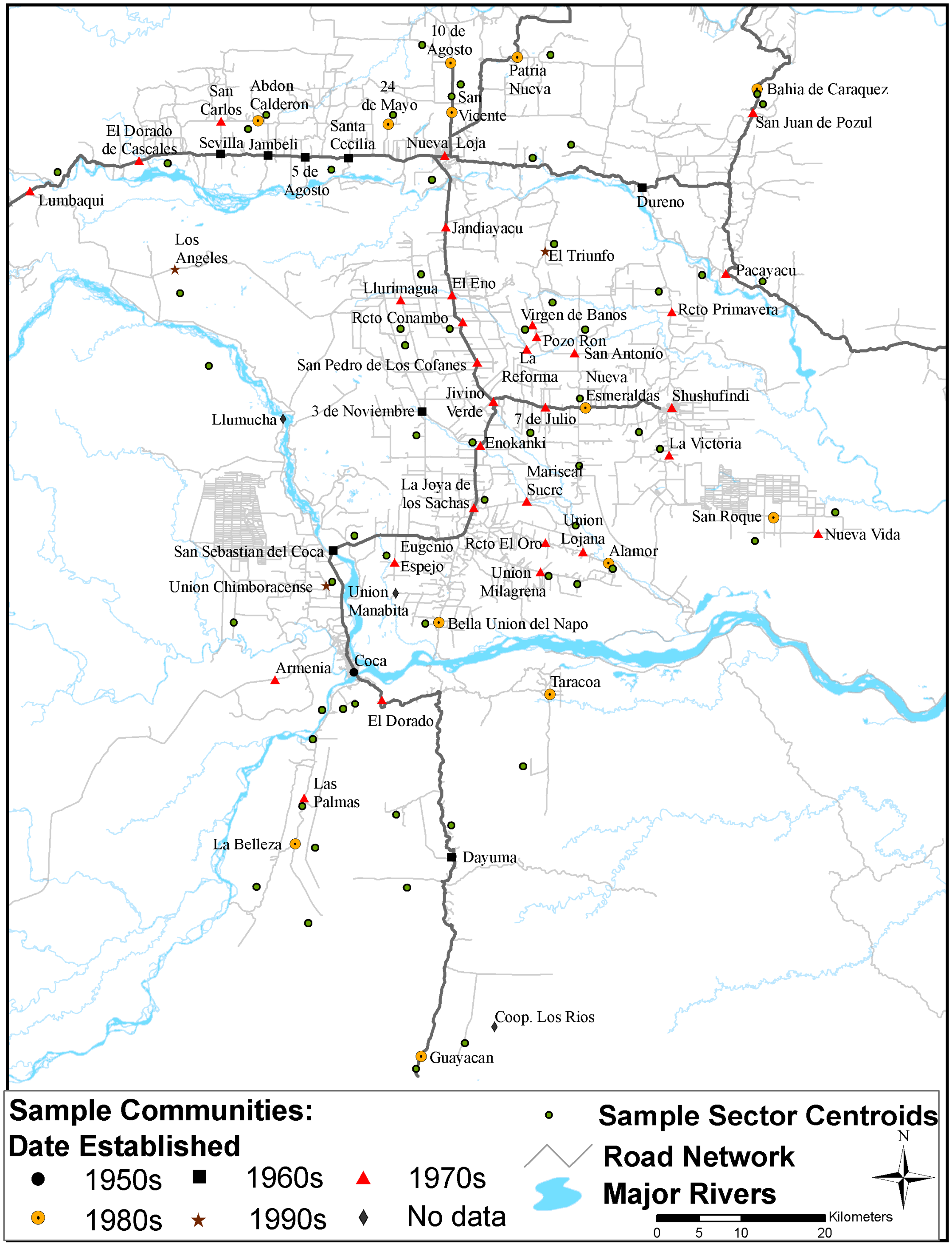


Figure 2.17. Sample sector and community survey locations, northern Ecuadorian Amazon.

The establishment of other communities was thus linked closely to the access provided by roads built by the petroleum industry. Between 1969 and 1971, Texaco-Gulf constructed roads linking Papallacta, just beyond the eastern cordillera of the Andes, to Nueva Loja (Bromley 1972). By the end of 1971, roads linking Nueva Loja with Coca and linking Shushufindi to the Nueva Loja-Coca route had been completed (Bromley 1972). Thus, in the early 1970s, seven communities sprang up along the north-south road connecting Coca and Nueva Loja. Four smaller communities became established in the areas surrounding Shushufindi in the early 1970s as well. Fourteen communities that established later in the 1970s were located, for the most part, at greater distance to the main roads (Nueva Loja-Coca, Shushufindi), with some clustering in the fertile agricultural region between the Napo and Aguarico rivers.

Communities that were established in the 1980s tended to be farther from the region's main roads, some establishing in the far northern (i.e., 10 de Agosto, Patria Nueva, and Bahia Caraquez) or southern (i.e., Guayacan) regions of the NEA. Only 3 of the surveyed communities were established in the 1990s. Two of the three are located at substantial distance from main roads.

2.6.2.2. **Surveyed Communities: Further Defining Central Places**

2.6.2.2.1. **Reference communities**

Examination of the 2000 community survey indicates that Lago Agrio received the largest number of responses (n=19, or 32 percent) to the question about "reference community." In the community survey, a reference community is defined as a community to which respondents would go for goods and services; respondents were able to select Nueva Loja, Coca, Shushufindi, or La Joya de los Sachas, or indicate another community. Table 2.4 outlines communities that cited Nueva Loja as their reference community. Most of these communities are located along the primary road that runs east-west through Nueva Loja, or along secondary roads that connect to it.

Table 2.4. Communities listing Nueva Loja as their reference community (n=19).

Reference community: Nueva Loja			
Community	INEC Population (2001)	Community	INEC Population (2001)
Jandiayacu	39	Patria Nueva	395
Bahia de Caraquez	104	5 de Agosto	432
Conambo	148	Dureno	535
Abdon Calderon	157	Jambeli	686
San Juan de Pozul	158	Santa Cecilia	695
10 de Agosto	182	El Eno	794
San Vicente	201	Sevilla	885
El Triunfo	209	Pacayacu	1724
Llurimagua	249	Nueva Loja	34106
San Carlos	388		

Coca and La Joya de los Sachas received an almost equal number of mentions as a reference community (Tables 2.5 and 2.6). Most of the communities that cite Coca as their reference community are located south of Coca on the primary road that runs north-south (Via Auca), or along secondary roads that connect to it. A few of the communities that cite La Joya de los Sachas as their reference community are located along the road connecting Coca to Nueva Loja (i.e., Enokanki, Jivino Verde), but most are located on connecting secondary roads.

Table 2.5. Communities listing Coca as their reference community (n=12).

Reference community: Coca	
Community	INEC Population (2001)
Union de los Rios	28
Llumucha	82
La Belleza	186
Guayacan	227
Las Palmas	231
Armenia	279
Union Chimboracense	288
El Dorado	343
Dayuma	499
Taracoa	710
San Sebastian del Coca	998
Coca	18298

Table 2.6. Communities listing La Joya de los Sachas as their reference community (n=13).

Reference community: La Joya de los Sachas	
Community	INEC Population (2001)
Union Manabita	62
3 de Noviembre	68
Alamor	122
Virgen de Banos	140
Eugenio Espejo	161
Enokanki	235
Mariscal Sucre	243
Union Milagrena	271
Union Lojana	307
Recinto El Oro	332
Bella Union del Napo	450
Jivino Verde	971
La Joya de los Sachas	5822

Shushufindi received the fewest mentions as a reference community (Table 2.7). A number of the communities referencing Shushufindi are located to its south (i.e., La Victoria, San Roque, Nueva Vida); several other communities citing Shushufindi as their reference community are located along the road connecting Shushufindi to the Nueva Loja –Coca road (i.e., Nueva Esmeraldas, 7 de Julio, Jivino Verde).

Communities that chose something other than one of the four largest communities in the NEA were in most cases, fairly small, with the exception of El Dorado de Cascales (Table 2.8). The locations cited as reference communities are generally the closest larger community that provides some array of services.

Table 2.7. Communities listing Shushufindi as their reference community (n=9).

Reference community: Shushufindi	
Community	INEC Population (2001)
Nueva Esmeraldas	167
San Roque	169
San Antonio	181
La Primavera	515
San Pedro de los Cofanes	519
Nueva Vida	625
7 de Julio	878
La Victoria	1172
Shushufindi	10559

Table 2.8. Communities listing their reference community as something other than the four largest communities in the NEA (n=6).

Reference community: Other		
Community	INEC Population (2001)	Reference Community
Pozo Ron	111	San Pedro de los Cofanes
24 de Mayo	112	Santa Cecilia
La Reforma	169	San Pedro de los Cofanes
Lumbaqui	2191	Cascales
Los Angeles	221	Cascales
El Dorado de Cascales	1312	Lumbaqui

2.6.2.3. **Agricultural Infrastructure**

Communities may be linked to one another based on the types of services in or infrastructure provided by a community. The communities offering these services and infrastructure to other communities thus become focal communities, or central places. Services offered in central places and not in other, lower-order communities, might include a civil register, hospital, markets for agricultural products (i.e., crop or animal markets), or agricultural processing establishments (i.e., rice husker, coffee roaster, sawmill). Given the focus of this research on land cover, the services or infrastructure thought to contribute to land cover changes are presented below (Tables 2.9-2.12).

Table 2.9 shows that the first coffee roasters in the region were located in the largest of the NEA's towns, Coca, Shushufindi, and Nueva Loja. The coffee roasters in these three communities account for approximately one-third of the roasters in the NEA. Almost forty percent of the communities with coffee roasters are located in the northern portion of the study area, in particular along the east-west road that connects Nueva Loja with Quito. Other communities with coffee roasters are distributed in relatively similar numbers around the other central cities.

Table 2.9. Location and number of coffee roasters for communities surveyed in 2000.

Location of coffee roasters (No.)	*Year Est.*	*Location of coffee roasters (No.)*	*Year Est.*
Coca (4)	1978	Nueva Vida (1)	1996
Shushufindi (6)	1983	La Primavera (1)	1996
Nueva Loja (4)	1984	El Dorado (1)	1996
San Pedro de los Cofanes (1)	1985	Taracoa (1)	1996
Santa Cecilia (3)	1990	El Eno (3)	1997
Jambeli (1)	1990	Armenia (3)	1999
Dureno (1)	1990	3 de Noviembre (1)	NA
Conambo (1)	1990	Jivino Verde (1)	NA
Pacayacu (2)	1990	Lumbaqui (1)	NA
Llurimagua (1)	1992	7 de Julio (3)	NA
La Reforma (1)	1993	Pozo Ron (3)	NA
Union Milagrena (2)	1994		

The pattern of rice huskers (Table 2.11) in the NEA is somewhat similar to that of coffee roasters, with the greatest number of rice huskers located along the Nueva Loja-Quito road. Most of the other rice huskers are located in La Joya de los Sachas, Shushufindi, and Coca. Sawmills, however, present a somewhat different picture (Table 2.10). While almost fifty percent of the communities with sawmills are located along the Nueva Loja-Quito road, approximately one-quarter of the total sawmills in the NEA are located in Coca or close by. One-half the agricultural and animal markets (Table 2.12) are located along the Nueva Loja-Quito road, with the remainder located primarily in large towns (i.e., Shushufindi, La Joya de los Sachas, and Coca).

Table 2.10. Location and number of sawmills for communities surveyed in 2000.

Location of sawmills (No.)	*Year Est.*
Coca (8)	1974
Nueva Loja (3)	1974
El Eno (1)	1978
Santa Cecilia (1)	1990
El Dorado de Cascales (5)	1990
Pacayacu (2)	1996
El Dorado (2)	1997
Dureno (1)	1998
San Pedro de los Cofanes (1)	1998
Sevilla (1)	2000
San Carlos (1)	2000
Nueva Esmeraldas (1)	2000
3 de Noviembre (1)	NA
Lumbaqui (1)	NA
Shushufindi (4)	NA
7 de Julio (1)	NA

Table 2.11. Location and number of rice huskers for communities surveyed in 2000.

Location of rice huskers (No.)	*Year Est.*
El Eno (1)	1980
Nueva Loja (4)	1984
Jambeli (1)	1990
La Joya de los Sachas (2)	1990
Pacayacu (1)	1990
Coca (2)	1994
Dureno (1)	1995
Sevilla (1)	1995
Shushufindi (2)	1995
San Pedro de los Cofanes (1)	1998
Lumbaqui (1)	NA

Table 2.12. Location of agricultural/animal markets for communities surveyed in 2000.

Location of markets for agriculture/animal markets	*Year Est.*
Sevilla	1964
Nueva Loja	1982
Lumbaqui	1990
Coca	1992
La Joya de los Sachas	1995
El Dorado de Cascales	NA
Shushufindi	NA
La Primavera	NA

2.6.2.4. **Other types of infrastructure**

Other types of infrastructure that are important to linkages among communities in the NEA include the existence of a 1) civil register, or government office where vital statistics (i.e., births, deaths) can be recorded, 2) secondary schools, since most communities possess only a primary school, thus requiring their children to travel to or reside in another community to receive secondary education, and 3) health centers/hospitals. The existence of these types of infrastructure in survey communities in the NEA are described in Tables 2.13 – 2.15. Civil registers (Table 2.13) are located in the largest communities (i.e., Nueva Loja, Coca, Shushufindi, and La Joya de los Sachas), as well as in several of the communities heading parishes, also known as *cabeceras parroquiales*. Hospitals/health centers (Table 2.14) are located throughout the study area, but almost one-half of the communities (n=11) listed as having these facilities are located along the Lago-Quito road. Most of the health centers/hospitals (n=18) are located in *cabeceras parroquiales*.

Table 2.13. Communities with civil register, from 2000 community survey.

Location of civil registers	*Year Est.*
Nueva Loja	1973
Shushufindi	1977
La Joya de los Sachas	1980
San Pedro de los Cofanes	1984
Coca	1989
Sevilla	1995
7 de Julio	NA
Dureno	NA
El Dorado de Cascales	NA

Table 2.14. Communities with hospitals or health centers, from 2000 community survey.

Location of healthcenters/subcenters	*Year Est.*
El Eno	1969
El Dorado de Cascales	1970
Nueva Loja	1974
Coca	1978
Shushufindi	1980
Lumbaqui	1980
Conambo	1981
Jivino Verde	1985
Sevilla	1985
San Sebastian del Coca	1987
La Joya de los Sachas	1988
San Pedro de los Cofanes	1988
Enokanki	1990
Dureno	1991
Taracoa	1993
San Roque	1994
Santa Cecilia	1994
Jambeli	1995
Armenia	1996
7 de Julio	1997
San Carlos	1999
La Primavera	2000

Dissertation fieldwork indicated the importance of children's education to parents in the NEA. If there is no local secondary school, parents 1) pay bus fare for their children to commute to the closest school, 2) rely on distance education, in which case the student brings home lessons and goes weekly into one of the major towns (e.g., Coca, Lago Agrio, La Joya de los Sachas) to take exams or teachers come to the community on Saturdays to administer exams, or 3) send the child to live in one of the larger towns for schooling. Secondary education (Table 2.15) is available in 20 of the surveyed communities. Almost one-half of these communities (n=9) are located along the Lago-Quito road, while the remainder are distributed in and around the other central cities (i.e., Shushufindi, La Joya de los Sachas, and Coca).

Table 2.15. Communities with secondary schools, from 2000 community survey.

Location of secondary schools	*Year Est.*
Jivino Verde	1970
Nueva Loja	1970
Coca	1979
Shushufindi	1980
Lumbaqui	1980
San Sebastian del Coca	1980
Sevilla	1981
La Joya de los Sachas	1982
El Dorado de Cascales	1984
Jambeli	1985
Pacayacu	1985
San Pedro de los Cofanes	1988
El Eno	1988
Dureno	1990
Taracoa	1990
Dayuma	1992
Armenia	1992
Santa Cecilia	1994
San Roque	1995
Enokanki	1997
Conambo	NA

Dissertation fieldwork interviews indicated that flows of funds are another way in which communities are linked to one another. Federal governmental funds are received from Quito by *canton* capitals. From the *canton* capitals, these funds are distributed to the *cabeceras parroquiales*, where the local administrator is responsible for managing the distribution of funds throughout the *parroquia*. These relationships have changed though time, as the region has grown. In the early 1970s, the NEA was comprised of a single province, with 6 cantons and 54 *parroquias*. The NEA now consists of 3 provinces, with 16 cantons and 76 *parroquias*. Growth in the number of *parroquias* in the study area results in some survey communities being linked to more than one *cabecera parroquial* over the time period 1974-2001. Tables 2.16 – 2.18 were constructed to examine how the survey communities were associated with various *cabeceras parroquiales* for each census time period. However, only canton-level spatial data were available for the 1982 census, making it impossible to determine with which *parroquia* a survey community was associated. These tables were constructed recognizing the date of establishment for each community and, thus, Table 2.16 only includes those communities established in 1974. Examining each community in reference to its *cabecera parroquial* yields insights as to how functional relationships (i.e., the distribution of funds in the region) have changed over time. These administrative changes have affected communities of all sizes, including the central cities. For example, before Nueva Loja became a *parroquia*, the community of Nueva Loja received its funds from Santa Cecilia. Both Shushufindi and La Joya de los Sachas were associated with the *cabecera parroquial* of Limoncocha as of the 1974 census, but had been designated as *cabeceras parroquiales* of their own *parroquias* by the 1982 census. As smaller communities have grown, they too have experienced such administrative changes. For example, note that Dayuma's *cabecera parroquial* was Pto. Francisco de Orellana (Coca) in 1974, but by 1990 Dayuma had become the *cabecera parroquial* of its own *parroquia*.

Table 2.16. Canton/parroquia information from 1974 census for communities surveyed in 2000.

Canton	*Parroquia*	*Cabecera Parroquial*	*Survey Communities*
Orellana	Pto. Francisco de Orellana	Pto. Francisco de Orellana	Coca, Dayuma, Los Rios, Union Manabita
Orellana	Limoncocha	Limoncocha	3 de Noviembre, Jivino Verde, Enokanki, La Joya de los Sachas, La Victoria, Mariscal Sucre, Nueva Vida, San Pedro de los Cofanes, Shushufindi
Orellana	San Sebastian del Coca	San Sebastian del Coca	Llumucha, San Sebastian del Coca
Putumayo	Dureno	Dureno	Conambo, Dureno, El Eno, Pacayacu, Recinto Primavera
Putumayo	Santa Cecilia	Santa Cecilia	5 de Agosto, Jambeli, Jandiayacu, Nueva Loja, Santa Cecilia, Sevilla
Sucumbios	Santa Rosa de Sucumbios	Santa Rosa de Sucumbios	El Dorado de Cascales, Lumbaqui
Tena	Chontapunta	Chontapunta	Las Palmas

Table 2.17. Canton/parroquia information from 1990 census for communities surveyed in 2000.

Canton	*Parroquia*	*Cabecera Parroquial*	*Survey Communities*
El Dorado de Cascales	El Dorado de Cascales	El Dorado de Cascales	El Dorado de Cascales
El Dorado de Cascales	Sevilla	Sevilla	Sevilla, San Carlos
Gonzalo Pizarro	Lumbaqui	Lumbaqui	Lumbaqui
La Joya de los Sachas	La Joya de los Sachas	La Joya de los Sachas	La Joya de los Sachas, Mariscal Sucre, Recinto El Oro, Union Milagrena
La Joya de los Sachas	Enokanki	Enokanki	3 de Noviembre, Enokanki, Llurimagua
La Joya de los Sachas	Pompeya	Pompeya	Alamor, Union Lojana
La Joya de los Sachas	San Carlos	San Carlos	Eugenio Espejo, Bella Union del Napo, Union Manabita
La Joya de los Sachas	San Sebastian del Coca	San Sebastian del Coca	San Sebastian del Coca
Lago Agrio	Dureno	Dureno	Dureno, Pacayacu
Lago Agrio	General Farfan	General Farfan	Bahia de Caraquez, Patria Nueva, San Juan de Pozul
Lago Agrio	Nueva Loja	Nueva Loja	5 de Agosto, 10 de Agosto, 24 de Mayo, Abdon Calderon, Conambo, El Eno, El Triunfo, Jambeli, Jandiayacu, La Reforma, Nueva Loja, Pozo Ron, Santa Cecilia, San Vicente, Virgen de Banos
Orellana	Pto. Francisco de Orellana	Pto. Francisco de Orellana	Armenia, Coca, El Dorado, Llumucha, Taracoa
Orellana	Dayuma	Dayuma	Dayuma, Guayacan, Los Rios
Shushufindi	Shushufindi Central	Shushufindi	Recinto Primavera, Shushufindi
Shushufindi	Limoncocha	Limoncocha	La Victoria, Nueva Vida, San Roque
Shushufindi	San Pedro de los Cofanes	San Pedro de los Cofanes	Jivino Verde, San Pedro de los Cofanes
Shushufindi	Siete de Julio	Siete de Julio	7 de Julio, Nueva Esmeraldas, San Antonio
Tena	Chontapunta	Chontapunta	La Belleza, Las Palmas

Table 2.18. Canton/parroquia information from 2001 census for communities surveyed in 2000.

Canton	*Parroquia*	*Cabecera Parroquial*	*Survey Communities*
El Dorado de Cascales	El Dorado de Cascales	El Dorado de Cascales	El Dorado de Cascales, Los Angeles
El Dorado de Cascales	Sevilla	Sevilla	Sevilla, San Carlos
Gonzalo Pizarro	Lumbaqui	Lumbaqui	Lumbaqui
La Joya de los Sachas	La Joya de los Sachas	La Joya de los Sachas	La Joya de los Sachas, Mariscal Sucre, Recinto El Oro, Union Milagrena
La Joya de los Sachas	Enokanki	Enokanki	3 de Noviembre, Enokanki, Llurimagua
La Joya de los Sachas	Pompeya	Pompeya	Alamor, Union Lojana
La Joya de los Sachas	San Carlos	San Carlos	Eugenio Espejo, Bella Union del Napo, Union Manabita
La Joya de los Sachas	San Sebastian del Coca	San Sebastian del Coca	Llumucha, San Sebastian del Coca
Lago Agrio	Nueva Loja	Nueva Loja	10 de Agosto, Jandiayacu, Nueva Loja, San Vicente
Lago Agrio	Dureno	Dureno	Dureno
Lago Agrio	General Farfan	General Farfan	Patria Nueva
Lago Agrio	El Eno	El Eno	Conambo, El Eno, El Triunfo, La Reforma, Pozo Ron, Virgen de Banos
Lago Agrio	Pacayacu	Pacayacu	Bahia de Caraquez, Pacayacu, San Juan de Pozul
Lago Agrio	Santa Cecilia	Santa Cecilia	24 de Mayo, Santa Cecilia
Lago Agrio	Jambeli	Jambeli	5 de Agosto, Abdon Calderon, Jambeli
Orellana	Pto. Francisco de Orellana	Pto. Francisco de Orellana	Armenia, Coca, El Dorado, Union Chimboracense
Orellana	Dayuma	Dayuma	Dayuma, Guayacan, Las Palmas, La Belleza, Los Rios
Orellana	Dayuma	Taracoa	Taracoa
Shushufindi	Shushufindi Central	Shushufindi	La Victoria, Recinto Primavera, Shushufindi
Shushufindi	San Roque	San Roque	Nueva Vida, San Roque
Shushufindi	San Pedro de los Cofanes	San Pedro de los Cofanes	Jivino Verde, San Pedro de los Cofanes
Shushufindi	Siete de Julio	Siete de Julio	7 de Julio, Nueva Esmeraldas, San Antonio

2.6.3. **Transportation and Connectivity**

Given the previously presented material, it is important to note how communities are connected through transportation linkages, since most people in the NEA do not possess cars or trucks. Three major bus companies operate within the NEA: Ciudad del Coca, Petrolera Shushufindi, and Putumayo. Ciudad del Coca's headquarters are in Coca. Petrolera

Shushufindi has headquarters in Shushufindi and Nueva Loja and an office in Coca. Putumayo's service for the NEA has it headquarters in Lago Agrio, as well as offices in La Joya de los Sachas and Coca. Ciudad del Coca has been operating since 1984, Petrolera Shushufindi since 1978 in Nueva Loja and since 1987 in Shushufindi; unfortunately, date of establishment data are not available for Putumayo. Ciudad del Coca (Figure 2.18) primarily serves communities to the south and west of Coca but has other routes that travel to Shushufindi and Nueva Loja (and thus, serves La Joya de los Sachas).

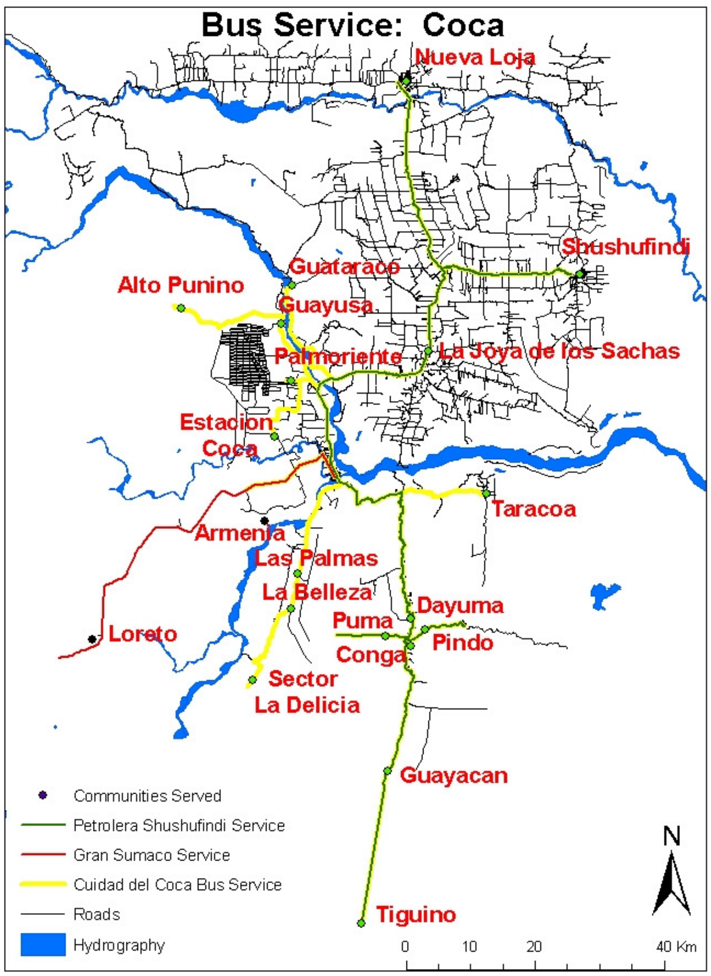


Figure 2.18. Bus and *ranchera* transport options originating in Coca.

Petrolera Shushufindi has several routes that originate in Nueva Loja. These routes serve communities along the Nueva Loja-Quito road (Figure 2.19). Routes include service from Nueva Loja to 1) west to Lumbaqui and on to Los Angeles, 2) south to El Eno and east to Llurimagua, 3) east to Dureno and then north to Columbia and south to Pacayacu, and 4) east and south to El Triunfo. Also originating in Nueva Loja are Putumayo's routes (Figure 2.20). Putumayo serves communities along the western portion of the Lago-Quito road, from Nueva Loja to El Dorado de Cascales, and communities located along the road north that connects Nueva Loja with the Colombian border, as well as providing service from Nueva Loja to Shushufindi and Coca. Putumayo also provides service from Coca and Nueva Loja to Quito. Petrolera Shushufindi also serves routes originating in Shushufindi, mainly serving communities in the surrounding area, though there are additional routes that provide service to Coca and Nueva Loja (Figure 2.21).

Rancheras, open-sided vehicles smaller than the buses, also provide transportation in the NEA. The *ranchera* companies include Alejandra Labaka, Compania Jivino Verde, and Gran Sumaco. Alejandro Labaka, established in 1996, has headquarters in La Joya de los Sachas and an office in Coca. Compania Jivino Verde was established in 2001; its headquarters is in La Joya de los Sachas. Gran Sumaco, established in 1997, operates out of Coca and serves communities west of Coca to Loreto (Figure 2.18). The majority of the communities served by both Alejando Labaka and Jivino Verde are in proximity to La Joya de los Sachas (Figures 2.22-2.23). From its Coca office, Alejandro Labaka serves communities south of Coca and, on a separate route, communities along the Rio Coca northwest to Lumbaqui (Figure 2.22). Jivino Verde serves a slightly different set of communities and covers less territory than Alejandro Labaka (Figure 2.23), likely related to this company's later date of establishment.

It is important to note that many of the routes served are unpaved roads. The road from Coca to Nueva Loja is paved, but has only been so since approximately 2000 (paving took place over various stretches between 1999 and 2001). The road that connects the Nueva Loja-Coca road to Shushufindi is not paved, but some sections approximate pavement, as they are covered in oil. The Nueva Loja-Quito road is paved west to Quito.

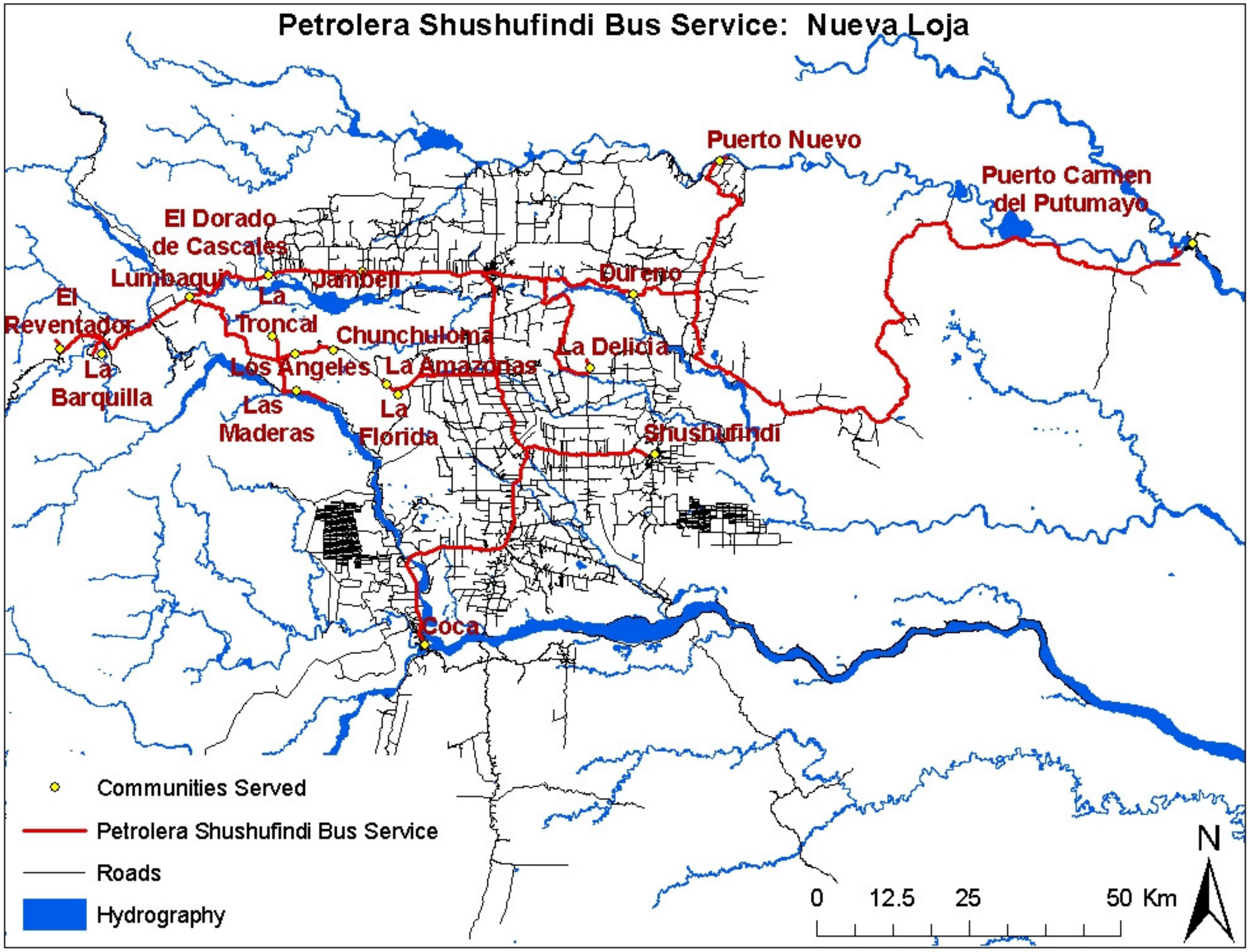


Figure 2.19. Petrolera Shushufindi service from Nueva Loja.

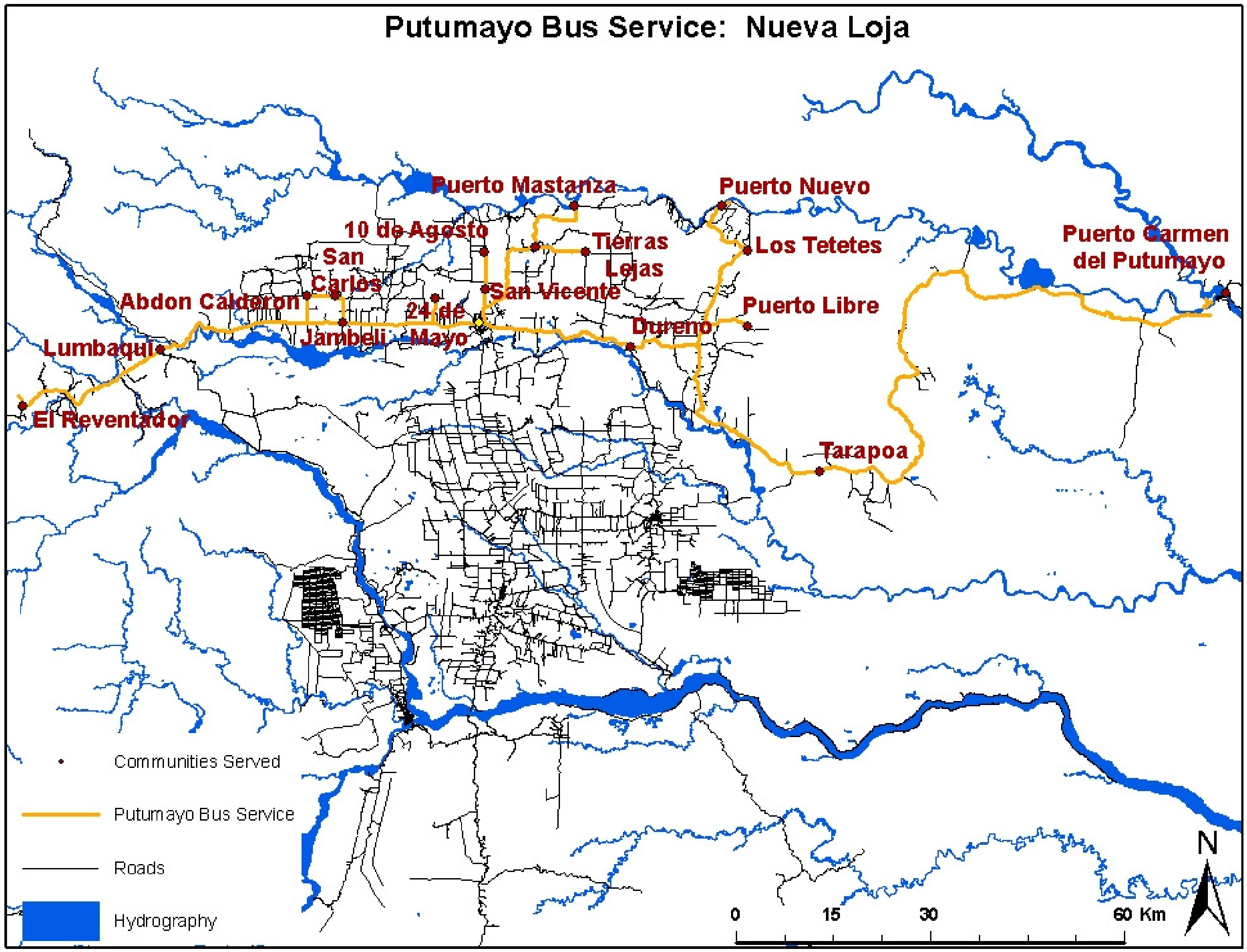


Figure 2.20. Putumayo service from Nueva Loja.

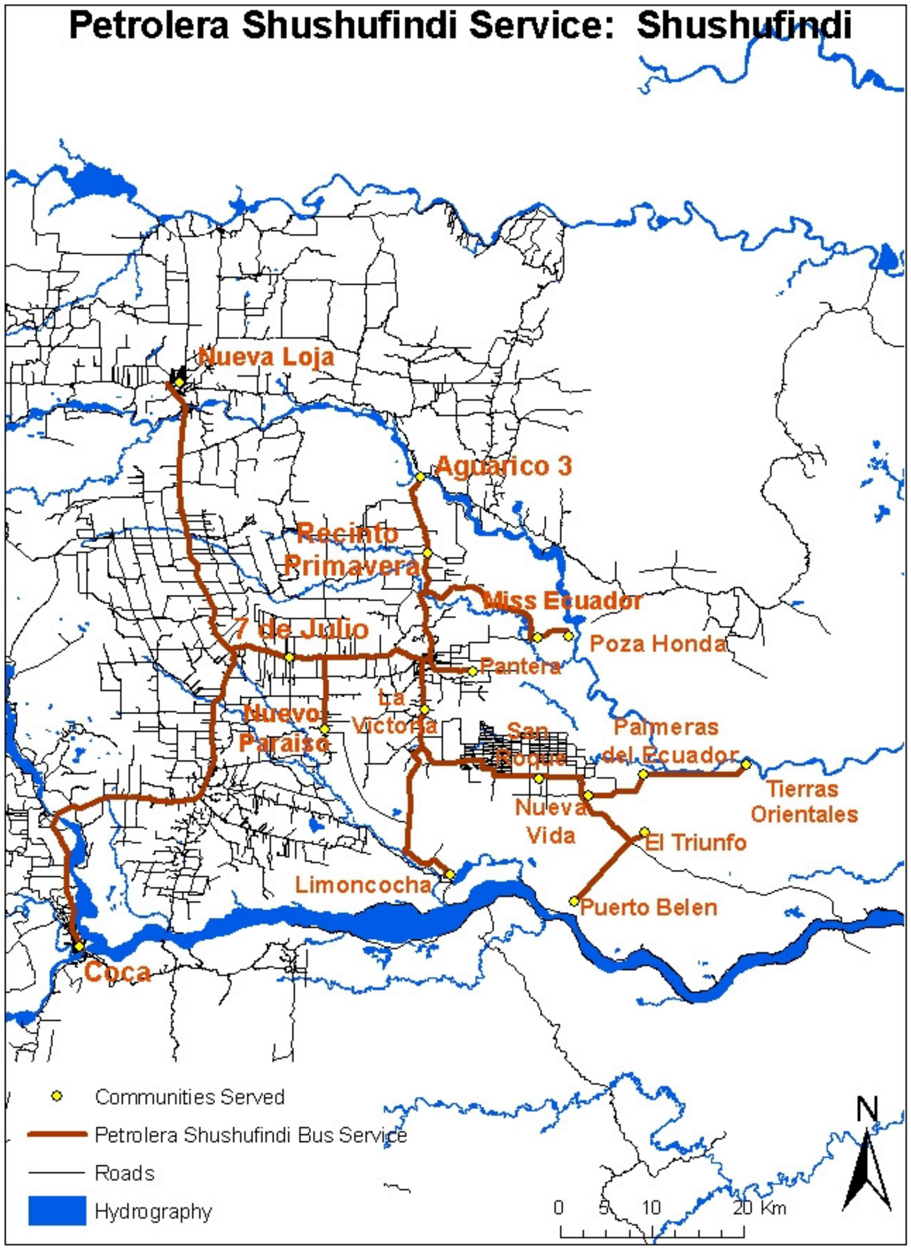


Figure 2.21. Bus transport options, Shushufindi.

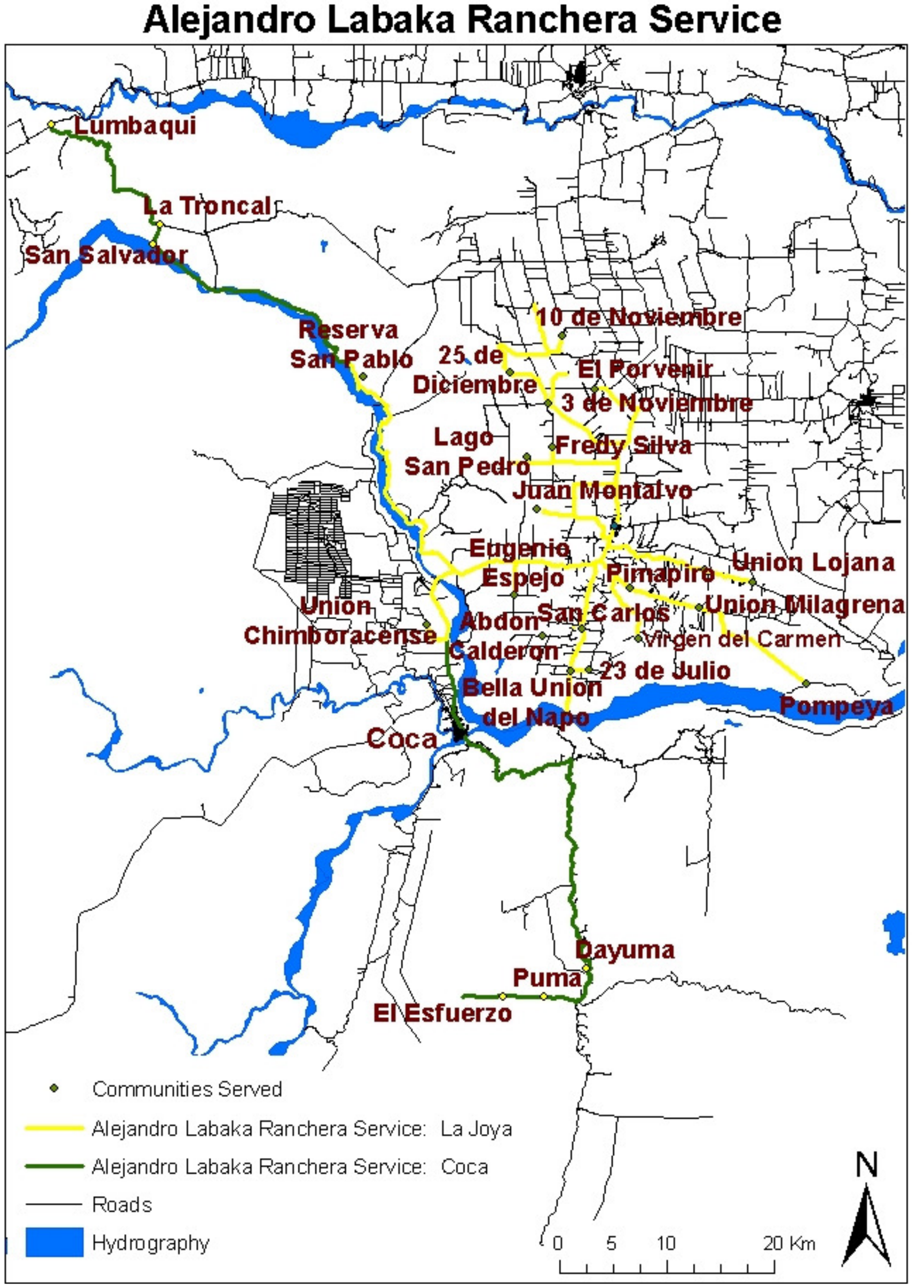


Figure 2.22. *Ranchera* transport by Alejandro Labaka from La Joya de los Sachas and Coca.

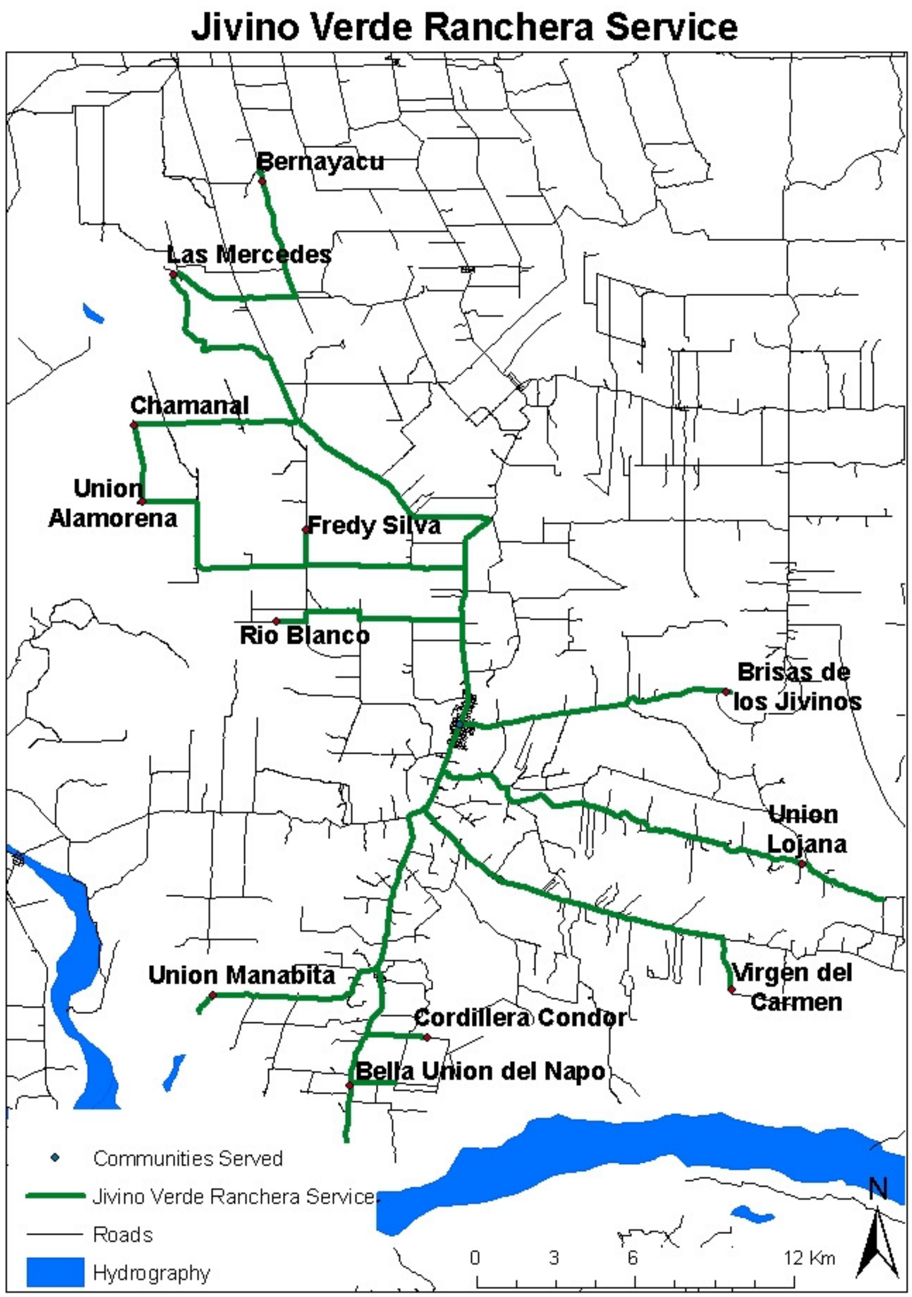


Figure 2.23. *Ranchera* transport by Jivino Verde from La Joya de los Sachas.

2.6.4. **Household Surveys**

Household surveys administered in 1990 and 1999 are described in Pichón (1993) and Bilsborrow (2002). The sampling design for the household surveys was based upon information provided by IERAC, the Ecuadorian land titling agency, about settlement areas (sectors) and the number of *fincas* in them; a two-stage sampling design was employed to obtain a representative random sample of farm plots settled by migrant families (Pichón 1997a). First, a sample of 64 sectors was selected from the 275 existing sectors. Then a group of 5 to 10 contiguous *fincas* was selected from within each of the sectors based on the sector's size. The first household survey, undertaken in 1990 by Richard Bilsborrow and Francisco Pichón, selected 480 *fincas*. Although the refusal rate was only 3 percent, some *fincas* were abandoned and one sector could not be located; the final sample was comprised of 408 *fincas* occupied by 418 farm households and represented a 5.9 percent sample of the colonist plots in the main colonization area (Bilsborrow et al. 2004, Pichón 1997b). In 1999, the 408 *fincas* were re-visited, and all farms and new subdivisions at those locations interviewed, resulting in 950 questionnaires being administered to the heads of household living on the original *fincas*, or *finca madres.* producing a sample of 823 farms. Given a 7 percent refusal rate, the final sample was comprised of 767 farms and 708 associated households, as well as 111 *solares*, or small housing lots, that resulted from subdivision and parcelization (Bilsborrow et al. 2004). The location of each *finca,* its subdivisions and dwellings was recorded using GPS.

A detailed questionnaire was administered to the head of the household and spouse separately. The questionnaires were modified somewhat between the 1990 and 1999 data collections, in part to include questions that reflected geographical relationships in the NEA. The head of household questionnaire gathered information on migration history and background, land acquisition and tenure, land use, farm production and inputs, and off-farm employment. The spouse provided data on household roster, migration background, emigration from the household, fertility, mortality, and health. Perception of and attitudes about local climate, soil quality, and forests were assessed for both the household head and spouse.

2.6.4.1. **Household Surveys: Characterizing Farms and Farm Households**

These longitudinal household survey data show that the average household population decreased between 1990 and 1999, while the total population on surveyed farms increased by approximately 40 percent (Walsh et al. 2002), indicating the establishment of newer, younger households on the farms during that period. A higher proportion of these newer heads of household were born in the study area (Walsh et al. 2002). While surveys noted material improvements in households by 1999, such as greater numbers with electricity, lower percentages of households had legal title to their land or owned cattle, and greater percentages were engaged in off-farm employment (Walsh et al. 2002).

Recent work (Walsh et al. 2002, Walsh et al. 2003, Bilsborrow et al. 2004; Barbieri et al. 2005) reveals a striking pattern of land subdivision among surveyed households. Almost 70 percent of the *fincas* surveyed in 1990 had been subdivided by 1999, with the pace of subdivision much more rapid toward the end of the 1990s (Bilsborrow et al. 2004); mean plot size in the sample thus decreased by approximately half, from 46.5 to 25.5 ha (Bilsborrow et al. 2004). Most subdivision is attributable to in-migration or inheritance (Barbieri 2005, Bilsborrow et al. 2004). With the improvement of road infrastructure, accessibility of farms to market improved greatly between 1990 and 1999, as seen by the shorter travel distances reported for walking to the road, distance by road, and distance by canoe (Walsh et al. 2002 , Bilsborrow et al. 2004).

2.6.4.2. **Household Surveys: Land Use and Land Cover Change**

The 1990 household survey (Pichón 1993) shows that farms produced a combination of subsistence and cash crops, with coffee serving as the primary cash crop (96 percent of the farms) and plantains, manioc, and corn providing subsistence on more than one-half the farms (Pichón 1996). Almost two-thirds of the households owned some cattle, though less than 7 percent of the sample possessed more than 20 head of cattle (Pichón 1996). Factors affecting land use included soils, topography, duration of settlement, and accessibility (Pichón 1996, Pichón 1997a, Pichón 1997b). Pasture area is seen to increase with farm size, while smaller farms show more forest clearing for annual and perennial crops (Pichón 1997b). Pichón (1997b) also illustrated that demographic factors influenced land use, as households with fewer members were shown to keep more area in forest, while larger households were positively associated with greater land area in perennials.

The 1999 household survey (Bilsborrow 2002) has also been used to examine questions of farm-level land use. Pan and Bilsborrow (2005) indicate population pressure, accessibility to road, labor, and proximity of households to communities as well as central place communities are strong predictors of land use, while Barbieri and colleagues (2005) flag duration of settlement as important. Barbieri (2005) also implicates off-farm employment in relation to land use, as he shows that farms with less land in crops/perennials or in pasture are more likely to have household members involved in off-farm employment. Using 1999 household survey data to compare older versus more recently established farms shows mean plot size of farms owned previous to the 1990 survey (34.2 ha) is almost twice that of the more recently established farms (18.4 ha) (Walsh et al. 2002, Bilsborrow et al.

2004). Older farms have higher percentages of forest and pasture, while newer ones have higher percentages of annual and perennial crops (Walsh et al. 2002, Bilsborrow et al. 2004).

Since land use is often implicated in associated land cover, as well as land cover changes, the drivers determined to be important in predicting deforestation are similar to those influencing land use. Important drivers highlighted by the household surveys include agricultural labor force (Pichón 1997a, Pan et al. 2001), tenure security (Pan et al. 2001), accessibility (Pichón 1997a, Mena et al. 2006, Bilsborrow et al. 2004), length of settlement (Pan et al. 2001, Pichón et al. 2002), technology (Pichón 1997a), and biophysical factors such as soil fertility and topography (Pichón 1997a, Pan et al. 2001). Pan and colleagues (2004) highlighted population size and composition, plot subdivision, topography, accessibility, and access to electricity as key factors predicting landscape complexity, as described through pattern metrics (contagion, landscape shape, and patch density).

2.7. **Concluding Comments**

This chapter describes a dynamic frontier region and presents an overview of the social, economic, and biophysical factors that shape the region. The next three chapters will present research on the impact of communities on LULC changes in the NEA at both the community- and farm-levels. Chapter 3 moves from the regional overview presented here to an analysis of similarities and differences among communities in the NEA. That chapter will discuss the linkages among communities in light of household and community survey data as well as the cluster analysis that associates communities based upon selected survey characteristics. The goal of chapter 3 is to use community characteristics to identify clusters of similar communities; these clusters will be used in a subsequent analysis of LULC change at the community-level.

Chapters 4 and 5 maintain the focus on communities. Chapter 4 uses remote sensing and geospatial data to study landscape composition and land cover change dynamics in the areas surrounding surveyed communities. Chapter 5 models land use and land cover change at the *finca* level**,** incorporating measures of community influence. Chapter 6 synthesizes the work as a whole and provides conclusions. This final chapter provides a synthesis of the foregoing chapters, identifies future research directions, and indicates accomplishments and continued challenges to the study of population-environment interactions in the northern Ecuadorian Amazon.

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CHAPTER 3

A CLUSTER ANALYSIS OF COMMUNITY TYPES IN THE NORTHERN ECUADORIAN AMAZON

3.1. Introduction

Colonization of the Ecuadorian Amazon resulted from agrarian reform pursued by the Ecuadorian government beginning in the 1950s (MacDonald 1981). The government conceived of agrarian reform as a "pressure valve" that would diffuse tensions surrounding land tenure in the coastal and highland provinces (Uquillas 1984; Oberai 1988; Pichón and Bilsborrow 1999). Colonization of the Ecuadorian Amazon is also related to development of the nation's oil reserves. Oil was discovered by Texaco in the Northern Ecuadorian Amazon (NEA) in 1967. As Texaco and other oil companies built roads into the region to facilitate transport of oil, migrants, hungry for land to call their own, began streaming into the area, claiming land for farms along these recently built roads. Communities developed near oil encampments, at important road intersections, and around newly settled development sectors. Since the early 1970s, the NEA (Figure 3.1), comprised of the provinces of Napo, Sucumbios, and Orellana, has gained population at rates higher than the southern portion of the Amazon or entire rest of the country (Table 3.1).

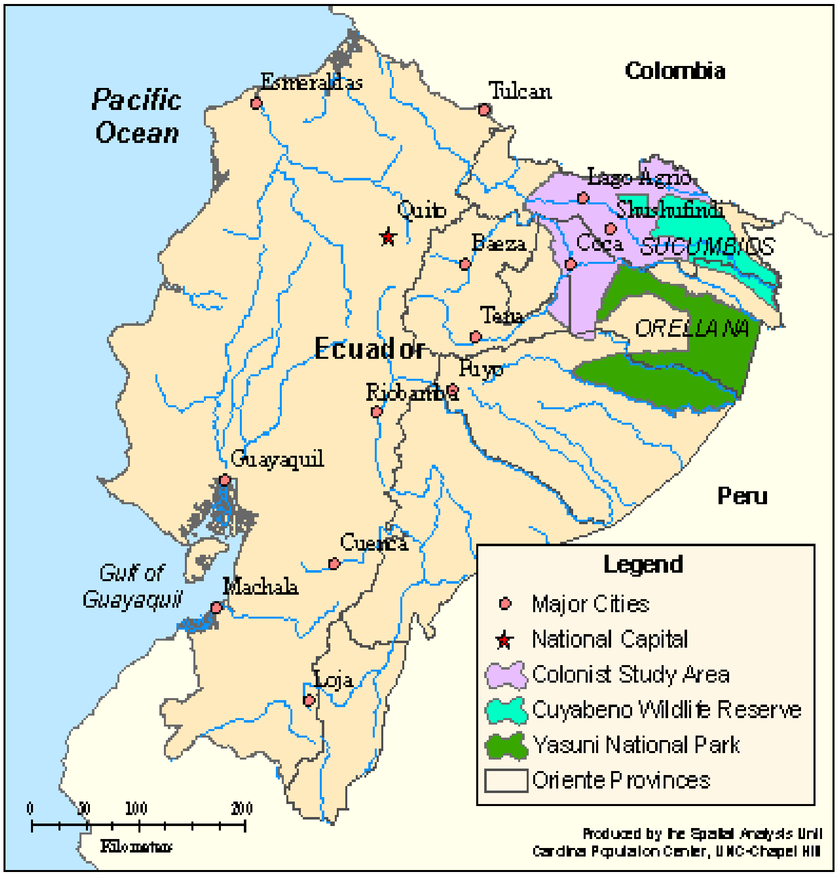

Figure 3.1. Colonist study area, as situated within the country of Ecuador. The study area encompasses portions of the provinces of Napo, Sucumbios, and Orellana.

Table 3.1. Average annual population growth rates in Ecuador, 1974-2001 (INEC, 1985, 1991, 2001).

	1974-1982 (%)	**1982-1990 (%)**	**1990-2001 (%)**
NEA*	7.70	5.61	4.31
Oriente	5.24	4.31	3.41
Ecuador	2.77	2.13	2.10

*Includes the provinces Sucumbios, Orellana, and Napo

Migration to the NEA and land cover dynamics stimulated by population changes in the region, as well as the NEA's biodiverse nature, provide the motivation for study of this region. In addition, the character of the NEA reveals important differences from other parts of the Amazon. For example, the NEA differs from the Brazilian Amazon in a number of ways, given that (a) the settlement process has been largely spontaneous and focused primarily on smallholdings rather than large ranches, (b) the settlement structure does not include large urban areas, and (c) neither cattle ranching nor large-scale timber extraction function as major drivers of land cover change (Walsh et al., 2003). Researchers affiliated with the Carolina Population Center at the University of North Carolina-Chapel Hill have been pursuing questions concerning population and the environment in the NEA since 1990. Population-environment interactions and resultant environmental change have been chronicled extensively using household survey data from 1990 and 1999 (Pichón 1993, Pichón 1997a, Pichón 1997b, Marquette 1998, Pichón and Bilsborrow 1999, Pan and Bilsborrow 2000, Bilsborrow and Pan 2001, Pan et al. 2001, Pan 2003, Bilsborrow et al. 2004, Pan et al. 2004, Pan and Bilsborrow 2005, Barbieri et al. 2006). Though researchers implemented a community survey in 2000 (Bilsborrow 2002), communities have received comparatively less attention.

This study, therefore, focuses on the community survey dataset, in an effort to better characterize NEA communities, as well as to describe their geographical and socioeconomic linkages to other communities in the region. Central place theory provides the theoretical background for this work, and cluster analysis methods are used to describe the results of the 2000 community survey. The objectives of this study are to (a) analyze similarities and differences among communities and (b) discuss linkages among communities in light of household and community survey data. This research contributes to the understanding of the NEA by providing a new dimension to the description of communities of the NEA; enriching analytical work at the household-level through greater understanding of community characteristics coupled with knowledge of household-community linkages; and providing data for future comparison of differences among community clusters on variables not included in the analysis, such as land cover dynamics. The sections that follow describe the theoretical and methodological background for this research, the community survey data and the variables selected for this analysis, results of the cluster analysis, discussion of the results, and conclusions drawn from the analysis.

3.2. **Theoretical Background**

Central place theory (Christaller 1933; translated by Baskin 1966) provides a means by which to describe and explain the location, size, functional characteristics, and spacing of central places (Berry and Parr 1988). Central places are described as those places within a system of settlements that provide some combination of goods and services to surrounding areas. Due to the various combinations of goods and services that might be provided by towns of differing sizes, relationships between communities are conceived of as hierarchical. Community hierarchy, based on marketing, transportation, and economic principles, is theorized as a group of related settlements in which communities of smaller size provide only basic, or lower-order, functions to a local geographic area, while larger communities serve a wider area with a greater range of goods and services (higher order functions). Central places in developing countries have been described as centers for marketing, services, commerce, transportation, and social interactions (Rondinelli 1983).

Central place theory is a concept that has continued to be tested empirically, as well a concept that has evolved, as research suggests modifications or extensions (Berry and Parr 1988). Studies using central place theory as a focus are often concerned primarily with the quantitative measures of market areas for goods, specifically for planning retail trade. Rather than looking to central place theory to inform retail economics in the NEA, however, this study uses central place theory as a framework within which the hierarchy of communities and the functional relationships that link them together can be explored.

3.3. **Methodological Background**

Cluster analysis is a method that allows classification of initially unclassified data into groups (Everitt et al. 2001), and, as such, it is considered an important exploratory data analysis tool (Lozano et al. 1998). Among the most popular clustering methods used in the social sciences are hierarchical agglomerative methods and iterative partitioning methods (Aldenderfer and Blashfield 1984). Hierarchical techniques classify the data into groups using multidimensional measures of distance or similarity in conjunction with a linkage rule. Distance and similarity measures are used to describe how the characteristics of classified objects map in multidimensional space. These measures are reviewed by Aldenderfer and Blashfield (1984) and Everitt and colleagues (2001).

Linkage rules dictate the criteria by which clusters are joined. Many linkage methods exist, but single linkage (Sneath 1957), complete linkage (Sorensen 1948), average linkage (Sokal and Michener 1958), and Ward's method (Ward 1963) are among the mostly widely used approaches (Aldenderfer and Blashfield 1984; Everitt et al. 2001). While each of these methods requires $n-1$ steps, where n refers to the number of observations in the dataset, to cluster a similarity matrix (Aldenderfer and Blashfield 1984), they differ in their definition of the distance (or similarity) between clusters (Everitt et al. 2001), part of each method's rules for cluster formation. For example, single linkage methods define the distance between two clusters as the minimum distance (greatest similarity) between two objects, one from each cluster (Aldenderfer and Blashfield 1984). When two objects join to form a cluster, the distance/similarity of all remaining objects to the individual members of the cluster is examined, and, for each object, the minimum distance/maximum similarity value among those identified for individual cluster members, is selected; the process continues until all objects have been clustered (Romesburg 1984). Complete linkage methods, however, define clusters based on the maximum distance (greatest dissimilarity) between a pair of objects, one from each cluster (Aldenderfer and Blashfield 1984). With complete linkage methods, the process begins with the two most similar/least distant objects joining to form a cluster, then the maximum distance/greatest dissimilarity for cluster members to all other objects is calculated. Using these maximum distance/greatest dissimilarity values, a new object is linked to a cluster by selecting the link with the least distance/greatest similarity, and the process continues until all objects have been clustered (Romesburg 1984).

Average linkage methods begin by joining the two most similar/least distant objects to form a cluster, then, for each object, the average distance/similarity between the object and the cluster members is calculated. Using these average distance/similarity values, a new object is linked to a cluster by selecting the link with the least distance/greatest similarity, and the process continues until all objects have been clustered (Romesburg 1984). Ward's method focuses on the objective of minimizing the increase in within-cluster sum of squares at each stage. The process begins by evaluating the variance values for all possible combinations of objects into clusters; formation of the initial cluster and all subsequent merger between objects and clusters are selected according to which object would result in the smallest increase in the sum of squares (variance) (Romesburg 1984). The use of an analysis of variance approach distinguishes this method from other hierarchical clustering methods (Gong and Richman 1995).

Each of the aforementioned hierarchical cluster analysis methods generates a nested data structure, in which groups are composed of subgroups. Dendrograms are two-dimensional diagrams used to graphically depict this nested data structure. The nodes of the dendrogram represent clusters, while the stems, or heights, represent the distance coefficient values at which various clusters combine (Everitt et al. 2001). For hierarchical agglomerative clustering processes, one analyzes the dendrogram by examining the nodes and noting the distance values at which nodes combine to form a cluster. The process begins with each observation representing its own individual cluster and culminates with all observations combined into a single cluster.

Iterative partitioning methods such as k-means assign data points to random clusters using an iterative method that involves initial partitioning of the dataset into a specific number of clusters. The partitioning algorithm searches for *k* representative objects within a dataset, from which clusters are derived and evaluated to determine which result produces the lowest average dissimiliarity (i.e., tightest clusters). Silhouette plots (Rousseeuw 1987) are used to display the derived clusters and provide an indication of the quality of the clustering by showing the arrangement of objects within clusters (Kaufman and Rousseeuw 1990).

Cluster analysis has both advantages and limitations. Advantages of this method include its ability to help sort data into groups, ease of use, and the opportunity to explore a dataset without having *a priori* hypotheses. There are cautions, however, associated with cluster analyses. For example, different clustering methods can and do generate different solutions for the same dataset. In addition, since hierarchical methods make only one pass through the data, a poor early partition will not be modified in successive iterations (Gower 1967; Kaufman and Rousseeuw 1990).

Within the field of geography, common use of cluster analysis is often seen in remote sensing. Spectral clusters are employed by unsupervised classification methods to derive classifications of remote sensing imagery that segment the image into clusters that are then assigned class labels by the user (Richards and Jia 2006; Jensen 2004). Cluster analyses have also been broadly applied in climatalogical research, for defining climatological regions, synoptic types, or weather regimes (Mimmack et al., 2001), as well as to many other types of questions, examining air traffic in Europe (Burghouwt and Hakfoort 2002), spatial patterns of polar bears and sea ice (Ferguson et al., 1998), and relationships between soil types and landscape position (Young and Hammer 2000).

Cluster analysis has also been applied in a variety of geographically-oriented studies focusing on cities. Neal (2006) used cluster analysis to classify cities by existing restaurant types, to identify what he terms "culinary deserts" and "gastronomic oases." Reese (2006) used cluster analysis to generate a typology of cities based on their economic development strategies. Cluster analysis has also been used to examine European cities within a network of global cities in a study that used globalization as the framework within which the cities interact and establish a hierarchy (Taylor and Derudder 2004). City-size distributions in the southwest United States (1890-1990) provided the focus of a cluster analysis performed by Garmestani et al. (2005). Although the aforementioned studies focus on populated places larger than those examined by this study, these studies suggest that the use of cluster analysis in developing a typology of places is a familiar concept in the literature.

3.4. **Data**

3.4.1. **Community Surveys**

Bilsborrow and colleagues developed a community-level survey, implemented in 2000, to provide context, evaluate change that occurred between 1990 and 1999, and better define the effects of economy and infrastructure on land use decisions in the local area (Bilsborrow 2002). The community-level questionnaire was administered in 54 communities in 2000, and in several additional communities in 2002, bringing the total number of communities surveyed to 59. The 59 communities range in population from 150 – 34,000 residents. Figure 3.2 shows the locations of surveyed communities in reference to the sectors in which household surveys were conducted.

Communities selected for interviews were chosen on the basis of their spatial proximity to households surveyed in 1990 and 1999 as well as the linkages suggested by those household-level interviews (e.g., where households buy and sell goods, seek education and health services, or attend church). The community surveys addressed issues including distance and access to reference communities, principal economic activities, local cultivation and yields, land tenure, facilities and infrastructure, transportation services, prices of basic goods, and types of agricultural and development assistance available. In addition, the community surveys included retrospective questions designed to assess spatial and temporal changes in these communities since 1990. The retrospective questions addressed topics including population growth, in- and out-

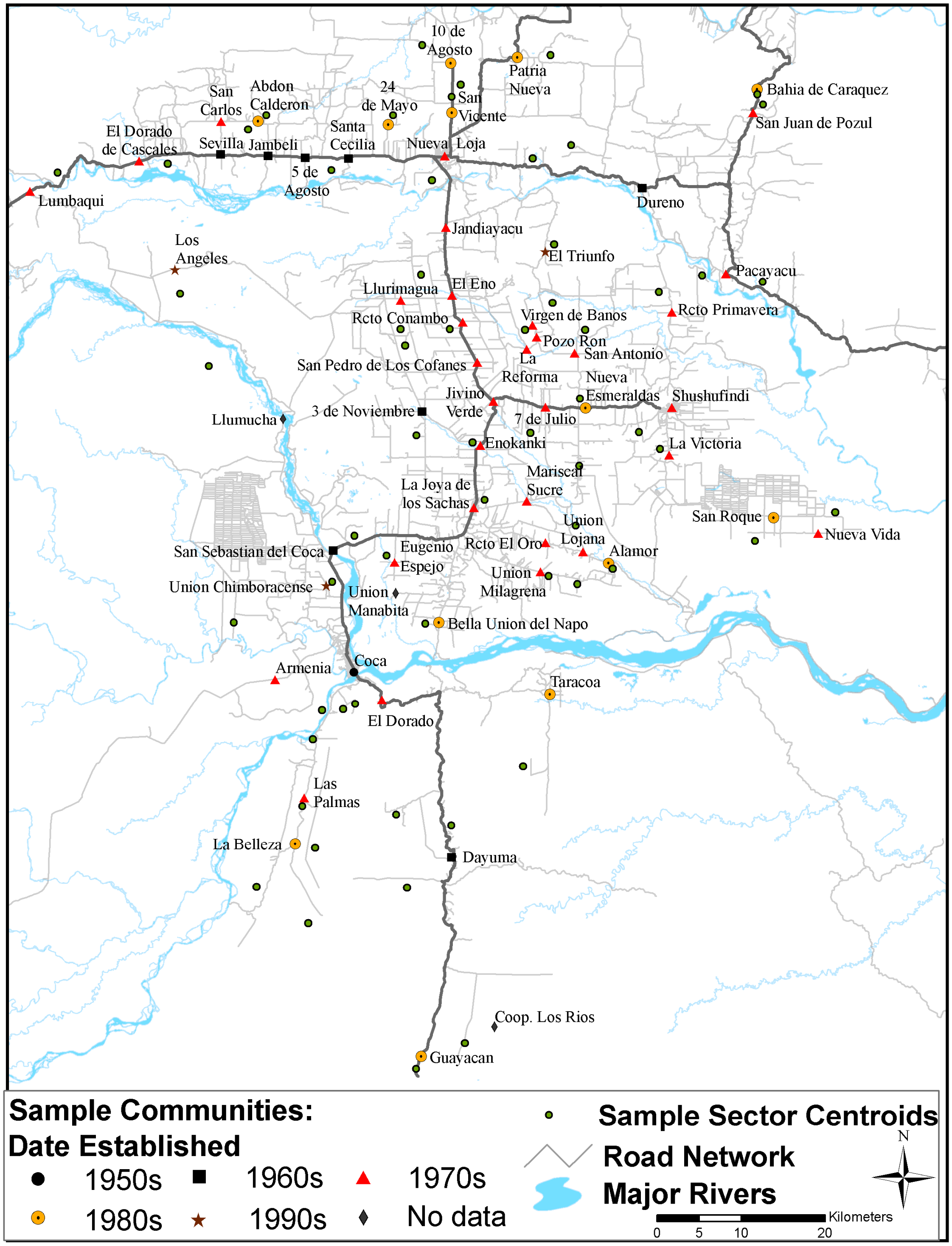

Figure 3.2. Sample sector centroids and community survey locations, Northern Ecuadorian Amazon.

migration, economic change, and the number and size of farms. In each community, several knowledgeable informants, including community leaders, local farmers, teachers, and health workers, responded to the questionnaires on behalf of their community.

The community questionnaires provided information used to address each of the study's objectives. For example, questions on the date of establishment of each of the communities were used in conjunction with road data and historical accounts to describe the spatial and temporal pattern of settlement in the NEA. Additional questionnaire items selected for use in the cluster analysis included population, primary crops, and existence of all types of infrastructure addressed in the survey (i.e., education, health, and government services; agricultural, educational, medical, and transportation infrastructure). These variables provide information for describing important and reliable differences among communities. For example, population was selected because counts for surveyed communities were verifiable using data acquired from the *Instituto Nacional de Estadisticas y Censos* (INEC). Infrastructure variables provide a measure for assessing community-level development. In addition, the selected infrastructure variables required the respondent to identify the presence/absence of institutions in a community and were, therefore, deemed more reliable indicators of development than questions that asked about the proportion of a community's population involved in various economic activities. Primary crops were selected in an effort to identify differences in agricultural production strategies among communities.

The full set of variables used in the cluster analysis portion of this study is described in Table 3.2. The variables are of two data types, continuous and binary. Population data, available through the community survey, often proved inconsistent with Ecuadorian census measures, prompting substitution of *localidad* data from Ecuador's 2001 census describing the population of communities. The population data are thus labeled as "INECPop2001." Respondents were asked to identify the principal crops grown in their community. Responses, which included coffee, cacao, maize, yucca, rice, platano, African palm, and sugar cane, were coded 1/0 for presence/absence. The various types of infrastructure addressed by the survey are presented as groups to more easily illustrate the breadth and depth of infrastructure evaluated. Within a single infrastructure category, multiple facilities may be listed. This occurs because of the differentiation in services represented by these various types of infrastructure. For example, within the category describing health facilities, the infrastructure presented includes a range of services, from the more fully-equipped health centers/hospitals to locations at which only basic medications are dispensed (i.e., pharmacies, health stands), or only health professionals other than doctors are available (i.e., midwife, nurse, healer). Multiplicity within these broad categories affords the ability to tease out subtle differences between the types of infrastructure available in a community. For this reason, even though a few infrastructure types were highly correlated with other infrastructure types, all variables were retained to maintain the ability to discriminate among communities. The location of each of these communities is shown in Figure 3.2.

Table 3.2. Description of 2000 community survey variables used in the cluster analysis portion of this study.

Variable	Type	Label
Population	Continuous	INECPop2001
Primary crops Coffee, cacao, platano, rice, maize, yucca, sugar cane, African palm	Binary	Coffee Cacao Platano Rice Maize Yucca Sugarcane Palm
Services Electricity, piped water, church, community house, civil register, bars/restaurants, shops	Binary	Elec PipedH20 Church Commhouse Civreg Barrest Shops
Agricultural infrastructure Coffee roaster, rice husker, sawmill, crop/animal market	Binary	Coffeeroast Ricehusk Sawmill Market
Medical infrastructure Health center, pharmacy, health stand, healer, midwife, nurse	Binary	Healthctr Pharm Healthstand Healer Midwife Nurse
Educational infrastructure Nursery, primary school, secondary school, distance secondary schooling, technical school	Binary	Nursery Primsch Secsch Distsch Techsch
Transportation infrastructure Existence of bus or *ranchera* service in 1990 and 1999	Binary	Bus90 Bus99 Ranchera90 Ranchera99

Survey communities, their age, 2001 population, and codes by which they are identified in cluster analysis results are listed in Table 3.3. Coca is the only study community that existed prior to the 1960s. Approximately 14 percent of the survey communities (n=8) became established in the 1960s, mostly in the last half of the decade. Close to 50 percent of the communities surveyed established in the 1970s (n=31). Thirteen of the survey communities, approximately 20 percent, came into being in the 1980s, while only three of the survey communities became established in the 1990s. Population size of these communities ranged from near 100 people to over 34,000 in 2001.

Table 3.3. Communities surveyed in 2000: characteristics and codes.

Community	Date Est.	2001 Pop.	Code	Community	Date Est.	2001 Pop.	Code
Abdon Calderon	1981	157	AbCa	Lumbaqui	1971	1,905	Lum
Alamor	1980	122	Ala	Mariscal Sucre	1974	243	MSuc
Armenia	1976	279	Arm	Nueva Esmeraldas	1980	167	NuEs
Bahia de Caraquez	1982	104	Bahia	Nueva Loja	1970	34,106	NuLo
Bella Union del Napo	1980	450	Bun	Nueva Vida	1973	625	NuVi
Coca	1953	18,298	Coca	Patria Nueva	1980	395	PaNu
Conambo	1970	148	Con	Pacayacu	1972	1,724	Paca
Dayuma	1968	499	Day	Pozo Ron	1977	111	Pozo
Dureno	1969	535	Dureno	San Antonio	1977	181	SanA
El Dorado	1978	343	Eldo	San Carlos	1975	388	SanC
El Dorado de Cascales	1970	1,312	ElDoC	Santa Cecilia	1965	695	SanCe
El Eno	1970	794	ElE	San Juan de Pozul	1978	158	SanJ
El Oro	1978	332	ElOr	San Pedro de los Cofanes	1973	799	SanP
El Triunfo	1990	209	ElTr	San Roque	1980	172	SanR
Enokanki	1974	235	Enok	San Sebastian del Coca	1965	998	SanS
Eugenio Espejo	1977	161	EugE	San Vicente	1980	201	SanV
Guayacan	1980	227	Guay	Sevilla	1969	885	Sev
Jambeli	1968	686	Jam	Shushufindi	1972	10,559	Shu
Jandiayacu	1970	39	Jan	Taracoa	1981	710	Tara
Jivino Verde	1970	971	JiV	Union Chimboracense	1995	388	UnC
La Belleza	1982	186	Bell	Union Lojana	1978	207	UnLo
Las Palmas	1974	231	Palm	Union Manabita	*	62	UnMa
Los Angeles	1995	221	LA	Union Milagrena	1975	271	UnMi
Los Rios	*	28	LRios	Virgen de Banos	1977	140	ViBa
La Joya de los Sachas	1970	5,822	LaJo	10 de Agosto	1980	182	10Ag
La Primavera	1974	515	LaP	24 de Mayo	1985	112	24deM
La Reforma	1975	179	LaRef	3 de Noviembre	1965	68	3deNo
La Victoria	1972	1,172	LaVi	5 de Agosto	1960	432	5deAg
Llumucha	*	82	Llum	7 de Julio	1975	1,433	7deJul
Llurimagua	1979	249	Llur				

*No date of establishment listed in the community survey

3.4.2. **Household Surveys**

Household surveys administered in 1990 and 1999 to both the *finca* head of household and spouse; Pichón (1993) describes the initial survey and Bilsborrow (2002) the 1999 survey. Given the timing of the community survey, this research focuses on comparing data from the 1999 survey with the results of the cluster analysis. Questions examined included those addressing purchases (i.e., food, clothing, furniture) and the location where households obtained education and health services; these questions are part of spouse of the head of household questionnaire.

3.5. **Methods**

Two hierarchical clustering methods were chosen for implementation, average linkage and Ward's method; k-means cluster analysis was not pursued because of the small sample size (n=59) and because k-means requires the user to specify the number of clusters. Both the average linkage and Ward's method provide the advantage of taking group structure into account, a quality not present in either the single linkage or complete linkage methods (McCune and Grace 2002). Ward's method was chosen for its ability to optimize the minimum variance within clusters, as it is based on minimizing increases in the error sum of squares as groups are joined. Average linkage was chosen from the many clustering methods available because it avoids the extremes of single linkage and complete linkage methods (Aldenderfer and Blashfield 1984). The single linkage method adds an object to a cluster based on similarity to a single object in that cluster, while complete linkage methods add an object to a cluster based on its similarity to all the cases in the cluster (Aldenderfer and Blashfield 1984). Average linkage methods, therefore, serve as a compromise between the two in that the average distance between all pairs of individuals (one from each group) is used to determine clusters.

Working with data of multiple types (i.e., the continuous and binary variables selected for this analysis) necessitated use of the Gower coefficient to generate measures of similarity (Gower 1971). The equation for the Gower coefficient is presented below (Eq. 1).

$$s_{ij} = \sum_{k=1}^{p} s_{ijk} w_{ijk} / \sum_{k=1}^{p} w_{ijk} \qquad \text{(Eq. 1)}$$

This equation calculates the similarity (s) between two objects by examining variable k for objects i and j. A weighting variable, w_{ijk}, is set to 1, unless missing values exist or negative matches (absence of variable k in common) are designated as lacking information, in which case w_{ijk} is set to 0. For binary variables, the information value of matching is specified by noting whether variables are symmetrical, i.e., equally informative whether both variables have values of 1 or 0, or assymetrical, where the case of both variables having values of 0 is considered non-informative. In this study, the binary variables represent various crops and types of infrastructure. Thus, variable values indicating presence (i.e., 1) in common are considered informative, while variables indicating absence (i.e., 0) in common are not. For continuous data, similarity is determined by the equation below, where R_k is the range of observations for the kth variable (Eq. 2).

$$s_{ijk} = 1 - | x_{ik} - x_{jk} | / R_k \qquad \text{(Eq. 2)}$$

The Gower coefficient may be selected as a method in SAS but is not available in Stata. The SAS program (version 9.1) was, therefore, used to generate a similarity matrix. In SAS, the data were standardized and the *distance* procedure implemented in conjunction with the Gower method. The resulting similarity matrix was then exported for use in Stata 9.

The similarity matrix was brought into Stata, then converted into a dissimilarity matrix. This step was made necessary by the requirement of Stata's cluster analysis command (*clustermat*) for a dissimilarity matrix. Hierarchical clustering methods (*averagelinkage* and *Ward'slinkage*) were then applied to the dissimilarity matrix.

Two indices, the Calinski-Harabasz Index (Calinski and Harabasz 1974) and the Duda-Hart Index (Duda and Hart 1973), are available in Stata to assist determination of the number of clusters in the dataset; these indices are referred to as stopping rules. Milligan and Cooper (1985) reviewed 30 stopping rules and indicated that the Calinski-Harabasz and the Duda-Hart indices were the best performers among those tested. Gordon (1998) verified Calinski-Harabasz's ability to perform well but indicated that the Duda-Hart index's requirement that a threshold be specified in order to evaluate whether a cluster should be subdivided is a characteristic that makes this stopping rule unsatisfactory. For this reason, the Calinski-Harabasz index was used a guide in determining the number of clusters.

The equation describing the Calinski-Harabasz index is presented below (Eq. 3). The *B* and *W* terms describe the between and within cluster sum of squares matrices, *n* represents the total number of items, and *k* the number of clusters in the solution (Milligan and Cooper 1985). Calinski and Harabasz (1974) suggest that the value of *k* chosen should be that for which the index has "an absolute or local maximum, or at least has a comparatively rapid increase" (p.12). The authors also note that if several local maxima exist, the computation can be stopped after the first local maximum is reached. The Calinski-Harabasz index is often referred to Calinski-Harabasz pseudo-F index since the index is seen to be analogous to the F-statistic in univariate analysis (Calinski and Harabasz 1974).

$$[traceB/(k-1)]/[traceW/(n-k)] \quad \text{(Eq. 3)}$$

Dendrograms were used to graphically present the similarity data. Romesburg (1984) points out that the dendrogram should be examined to determine the widest range within which the number of clusters remains constant. Dendrograms and stopping rules were thus analyzed together to determine the number of clusters present. Summary statistics were then generated for the number of clusters suggested by the dendrograms and stopping rules. Cophenetic correlation coefficient values (Sokal and Rohlf 1962) provided a way to measure how well the dendrogram fits the data matrix. The cophenetic matrix is populated with values for the fusion level at which a pair of objects appear together in the same cluster for the first time. The cophenetic correlation coefficient (CPCC) is the correlation between the entries of the dissimilarity matrix and those of the cophenetic matrix (Romesburg 1984).

3.6. **Results**

3.6.1. **Cluster Analysis of Community Survey Data**

Figures 3.3 and 3.4 describe how the communities cluster based on the selected community survey variables. Review of the stopping rules and the dendrograms suggest 3 clusters in the case of Ward's method and 4 clusters for the average linkage cluster analysis.

Review of the dendrogram (Figure 3.3) and the stopping rule values (Table 3.4) for the average linkage cluster analysis of the community dataset suggest a 4-cluster solution. Table 3.5 provides descriptive statistics for each variable over the 4 clusters. The communities in cluster 1 (n=26) all list coffee as one of their primary crops; other important crops include cacao (0.5) and maize (0.62). Most of the communities in cluster 1 have electricity (0.88), a church (0.88), community house (0.77), bars/restaurants (0.88), and all have shops. Between one-half and two-thirds of the communities in cluster 1 have piped water (0.65), a coffee roaster (0.65), rice husker (0.5), and sawmill (0.5). The communities in cluster 1 generally have multiple health care options, including health center/hospital (0.88), pharmacy (0.77), midwife (0.77), and nurse (0.81). In terms of educational infrastructure, most of these communities have a nursery (0.92), secondary school (0.77), and distance schooling (0.77); all the communities in cluster 1 have a primary school.

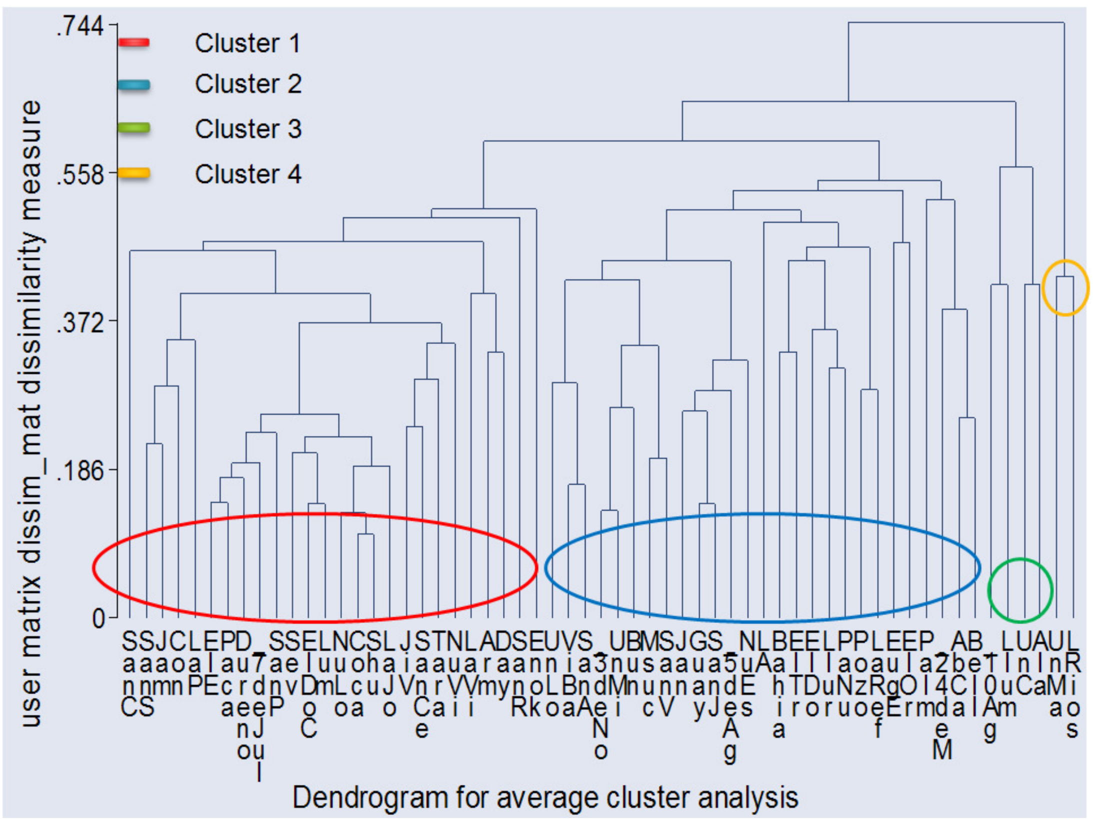

Figure 3.3. Dendrogram for average linkage cluster analysis.

Table 3.4. Calinski-Harabasz stopping rule values, average linkage cluster analysis.

Number of clusters	Calinski/Harabasz pseudo-F	Number of clusters	Calinski/Harabasz pseudo-F
2	6.59	9	9.8
3	6.49	10	9.89
4	21.1	11	9.35
5	16.24	12	8.62
6	14.43	13	8.94
7	12.42	14	8.33
8	10.81	15	7.96

Table 3.5. Mean and standard deviation values by cluster for the average linkage cluster analysis of the community dataset.

	Mean and Standard Deviation Values by Cluster[1]			
Variables	**Cluster 1 (n=26)**	**Cluster 2 (n=27)**	**Cluster 3 (n=4)**	**Cluster 4 (n=2)**
Population: inec_pop2001	3317.8 (7418.7)	217.2 (105)	168.5 (89.6)	45 (24)
Primary crops:				
Coffee	1 (0)	0.96 (.19)	0.5 (.58)	0.5 (.71)
Cacao	0.5 (.51)	0.26 (.45)	0.25 (.5)	1 (0)
Platano	0.23 (.43)	0.48 (.51)	0.5 (.58)	0 (0)
Rice	0.35 (.49)	0.30 (.47)	0.25 (.5)	0.5 (.71)
Maize	0.62 (.50)	0.74 (.45)	0.5 (.58)	1 (0)
Palm	0 (0)	0 (0)	0 (0)	0 (0)
Yucca	0.038 (.20)	0.037 (.19)	0.25 (5)	0 (0)
Sugarcane	0 (0)	0.074 (.27)	0 (0)	0 (0)
Services:				
Elec	0.88 (.33)	0.52 (.51)	0.5 (.57)	0 (0)
PipedH20	0.65 (.49)	0 (0)	0.25 (.5)	0 (0)
Church	0.88 (.33)	0.96 (.19)	0.75 (.5)	0.5 (.71)
Commhouse	0.77 (.43)	0.63 (.49)	1 (0)	0 (0)
Civreg	0.38 (.50)	0 (0)	0 (0)	0 (0)
Barrest	0.88 (.33)	0.074 (.27)	0 (0)	0 (0)
Shops	1 (0)	0.89 (.32)	1 (0)	0 (0)
Agricultural infrastructure:				
Coffeeroast	0.65 (.49)	0.22 (.42)	0 (0)	0 (0)
Ricehusk	0.5 (.51)	0.037 (.19)	0 (0)	0 (0)
Sawmill	0.5 (.51)	0.11 (.32)	0 (0)	0 (0)
Market	0.31 (.47)	0 (0)	0 (0)	0 (0)
Medical infrastructure:				
Healthctr	0.88 (.33)	0 (0)	0 (0)	0 (0)
Pharm	0.77 (.43)	0.41 (.50)	0 (0)	0 (0)
Healthstand	0.27 (.45)	0.074 (.27)	0 (0)	0 (0)
Healer	0.5 (.51)	0.11 (.32)	0 (0)	0 (0)
Midwife	0.77 (.43)	0.22 (.42)	1 (0)	0 (0)
Nurse	0.81 (.40)	0.11 (.32)	0 (0)	0 (0)
Educational infrastructure:				
Nursery	0.92 (.27)	0.85 (.36)	0 (0)	0 (0)
Primsch	1 (0)	0.96 (.19)	1 (0)	1 (0)
Secsch	0.77 (.43)	0 (0)	0 (0)	0 (0)
Distsch	0.77 (.43)	0.5 (.51)	0.5 (.51)	0.5 (.51)
Techsch	0.77 (.43)	0.29 (.47)	0.25 (.5)	0 (0)
Transportation infrastructure:				
Bus90	1 (.48)	0.15 (.36)	0 (0)	0 (0)
Bus99	0.88 (.33)	0.22 (.42)	0.25 (.5)	0 (0)
Ranchera90	0.73 (.45)	0.41 (.50)	0.77 (.43)	0 (0)
Ranchera99	0.96 (.20)	0.85 (.36)	0.77 (.43)	0 (0)

[1]**Cluster 1:** 7 de Julio, Armenia, Coca, Conambo, Dayuma, Dureno, El Dorado de Cascales, Enokanki, El Eno, Jambeli, Jivino Verde, La Joya de los Sachas, La Primavera, La Victoria, Lumbaqui, Nueva Loja, Nueva Vida, Pacayacu, San Carlos, San Pedro de los Cofanes, San Roque, San Sebastian, Santa Cecilia, Sevilla, Shushufindi, Taracoa
Cluster 2: 24 de Mayo, 3 de Noviembre, 5 de Agosto, Abdon Calderon, Bahia de Caraquez, Bella Union del Napo, El Dorado, El Oro, El Triunfo, Eugenio Espejo, Guayacan, Jandiayacu, La Belleza, Las Palmas, La Reforma, Los Angeles, Llurimagua, Mariscal Sucre, Nueva Esmeraldas, Patria Neuva, Pozo Ron, San Antonio, San Juan de Pozul, San Vicente, Union Lojana, Union Milagrena, Virgen de Banos
Cluster 3: 10 de Agosto, Alamor, Llumucha, Union Chimboracense
Cluster 4: Los Rios, Union Manabita

Bus and *ranchera* transportation has been available in most of the communities in cluster 1 since 1990 (bus90=0.65, bus99=0.88, ranchera90=0.73, ranchera99=0.96). All the communities with a civil register are associated with cluster 1. All the communities with markets for crops or animals (Coca, El Dorado de Cascales, La Joya de los Sachas, La Primavera, Lumbaqui, Nueva Loja, Sevilla, Shushufindi) are included in cluster 1 as well. In addition, all the communities with secondary schools (Armenia, Coca, Conambo, Dayuma, Dureno, El Dorado de Cascales, El Eno, Enokanki, Jivino Verde, La Joya de los Sachas, Jambeli, Lumbaqui, Nueva Loja, Pacayacu, San Pedro de los Cofanes, San Sebastian del Coca, San Roque, Santa Cecilia, Sevilla, Shushufindi, Taracoa) are members of cluster 1.

The communities in cluster 1 range in population from 148 (Conambo) to 34,106 (Nueva Loja). All but 5 of the 27 communities in cluster 1 have populations greater than 500 people; these communities with greater than 500 residents are the largest of the surveyed communities. The communities populating the other three clusters of the average linkage cluster analysis solution all have populations less than 500 people.

Cluster 2 (n=27) communities ranging in population from 39 (Jandiayacu) to 450 people (Bella Union del Napo). Most of the communities in cluster 2 list coffee (0.96), maize (0.74), and platano (0.48) as primary crops. In terms of services, approximately one-half the communities in cluster 2 have electricity (0.52). Most of the communities have a church (0.96), shops (0.89), and community house (0.63), but none have piped water. As a consequence of the lack of piped water, there are few bars/restaurants (0.07). Very few of the communities have a coffee roaster (0.22), rice husker (0.04), or sawmill (0.11). Medical infrastructure for the communities in cluster 2 consists primarily of pharmacies (0.41), as none of the communities have a health center/hospital, and very few list a health stand (0.07), healer (0.11), midwife (0.22), or nurse (0.11). Communities in cluster 2 generally have access to a nursery school (0.85) as well as a primary school (0.96), but none has a secondary school, though some have distance secondary schooling (0.30). These communities are not generally served by buses (bus90=0.15, bus99=0.22) and only had widespread access to *ranchera* service after 1999 (ranchera90=0.41, ranchera99=0.85).

Small communities populate cluster 3 (n=4) as well, with populations ranging from 82 (Llumucha) to 288 (Union Chimboracense). The communities in cluster 3 are not as focused on producing cash crops, with one-half the communities producing coffee and one-quarter cacao; platano and maize were also listed as important crops by one-half these communities. All of these communities have a community house and shops, and most (0.75) a church, but only one-half have electricity and one-quarter piped water. Midwives, present in each of these communities, provide the only access to medical care. None of the communities has a nursery school, but all have a primary school. Distance schooling is available in one of these communities. These communities do not have much access to transportation infrastructure, as there was no bus or *ranchera* service in 1990 and bus service began to only one of these communities in 1999.

The very smallest communities (n=2) make up cluster 4, Union Manabita (population=62) and Los Rios (population=28). These communities produce cash crops, including coffee (0.5) and cacao (1.0), as well as rice (0.5) and maize (1.0). Neither of these communities has a community house, bars or restaurants, shops, electricity, piped water, or a way to process or sell wood (sawmill), crops (market, coffee roaster, ricehusker), or animals (market); only one of them has a church. No medical infrastructure exists in either of these communities, and educational infrastructure consists only of primary schools. Neither bus nor *ranchera* transportation were available to either of these communities in 1990 or 1999.

Figure 3.4 illustrates the geography of the average linkage cluster analysis solution. The communities in cluster 1 exhibit clustering in space as well as geographical relationships to main roads. For example, several of the cluster 1 communities are located along the Neuva Loja–Quito road in the northern portion of the NEA. A number of other cluster 1 communities are located along other major roads, Jivino Verde-Shushufindi and Nueva Loja-Coca. Most of the communities along these major travel routes were established in the late 1960s and early 1970s. Communities in clusters 2, 3, and 4 are, generally, located at greater distance from these major travel routes and/or established later than those in cluster 1.

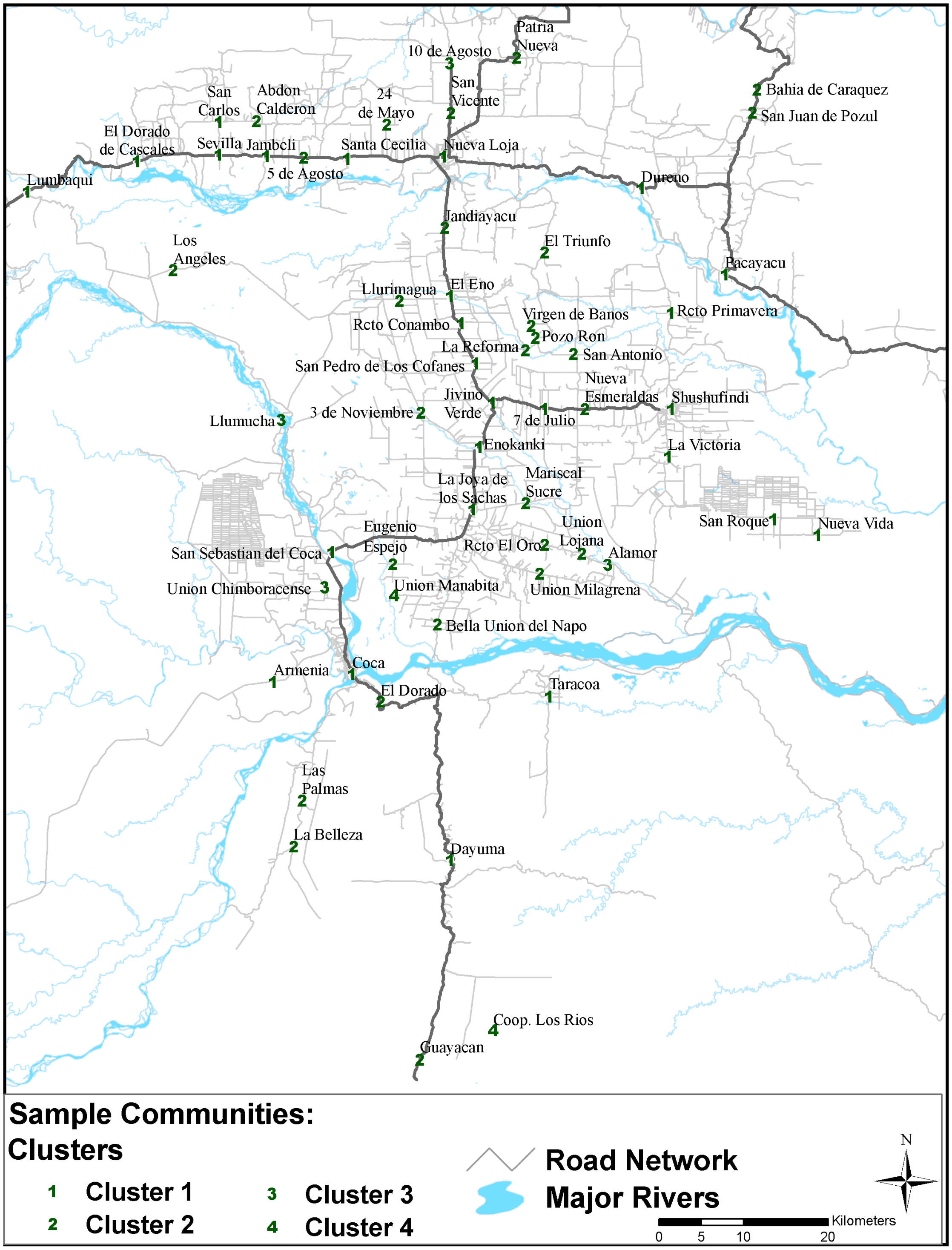

Figure 3.4. Average linkage cluster analysis solution, mapped by cluster.

Review of the dendrogram (Figure 3.5) and the stopping rule values (Table 3.6) for Ward's method cluster analysis of the community dataset suggest 2- or 3-cluster solutions. The 2-cluster solution represents the absolute maximum value for the Calinski-Harabasz pseudo-F statistic, while the 3-cluster solution represents its highest local maximum. The 2-cluster solution breaks the community dataset into clusters of 15 and 44 communities. The size of cluster 2 (n=44), coupled with intimate knowledge of the communities in the dataset through extensive travel and work in the NEA, suggests that variability among the communities in cluster 2 might be better described by another cluster solution. For this reason, the 3-cluster solution was examined and described. Table 3.7 provides descriptive statistics for each variable over the suggested clusters.

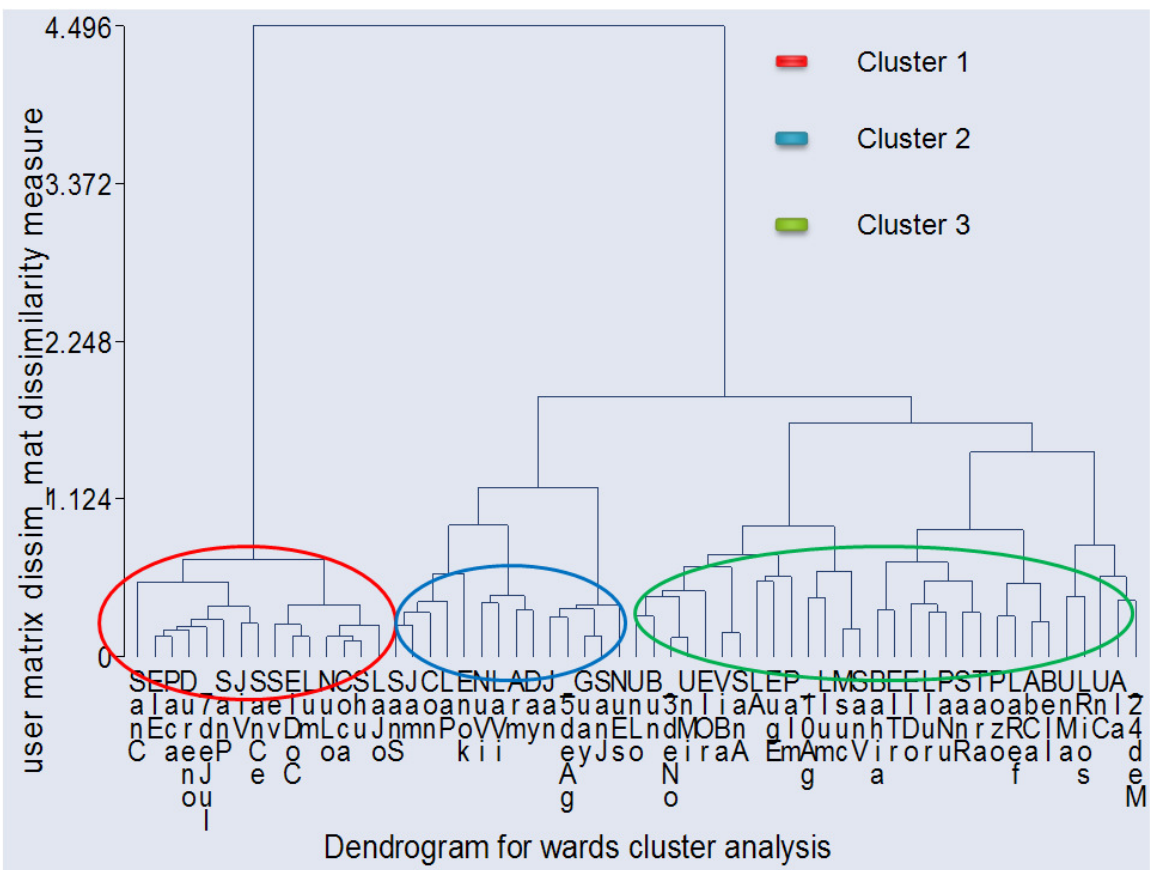

Figure 3.5. Dendrogram for Ward's method cluster analysis.

Table 3.6. Calinski-Harabasz stopping rule values, Ward's method cluster analysis.

Number of clusters	Calinski/Harabasz pseudo-F	Number of clusters	Calinski/Harabasz pseudo-F
2	30.89	9	15.15
3	23.82	10	14.62
4	18.93	11	14.22
5	20.03	12	13.56
6	18.81	13	13.60
7	16.67	14	13.12
8	15.85	15	12.70

Table 3.7 details the number of communities in each cluster and provides descriptive statistics for the Ward's method cluster solutions. The 2- and 3-cluster solutions include the same communities in cluster 1 (n=15). The 3-cluster solution splits the communities that, in the 2-cluster solution, were members of cluster 2 (n=44) into two smaller clusters of 14 (cluster 2) and 30 (cluster 3) communities.

Cluster 1 (n=15) includes the communities with larger populations and the greatest array of services. Cluster 1 communities range in population from 388 (San Carlos) to 34,106 (Nueva Loja); this cluster includes most, but not all, of the communities with the largest population. All the communities in cluster 1 have electricity, and most (0.93) have piped water. For this reason, cluster 1 has a larger proportion of bars and restaurants than any of the other clusters. A higher proportion of communities in cluster 1 have coffee roasters (0.73), rice huskers (0.8), sawmills (0.87), and agricultural and animal markets (0.47) than in other clusters. All the communities with a civil register are located in cluster 1. There is better medical infrastructure in the communities of cluster 1, as all communities have a health center or hospital as well as a pharmacy, and many additionally possess a health stand (0.4), healer (0.47), midwife (0.73), and nurse (0.93). In terms of educational infrastructure, the availability of

Table 3.7. Mean and standard deviation values by cluster for the Ward's method cluster analysis of the community dataset.

	Mean and Standard Deviation Values by Cluster[1]			
Variables	**Cluster 1 (n=15)**	**Cluster 2, 2-cluster (n=44)**	**Cluster 2, 3-cluster (n=14)**	**Cluster 3, 3-cluster (n=30)**
Population: inec_pop2001	5348.4 (9386)	287.9 (240.6)	441.4 (335.6)	216.2 (136.6)
Primary crops:				
Coffee	1 (0)	0.91 (.29)	1 (0)	0.87 (.35)
Cacao	0.6 (.51)	0.32 (.47)	0.14 (.36)	0.4 (.5)
Platano	0.13 (.35)	0.44 (.50)	0.64 (.50)	0.33 (.5)
Rice	0.33 (.49)	0.32 (.47)	0.36 (.50)	0.3 (.47)
Maize	0.67 (.49)	0.68 (.47)	0.57 (.51)	0.5 (.58)
Palm	0 (0)	0.068 (.25)	0 (0)	0.1 (.31)
Yucca	0 (0)	0.068 (.25)	0.071 (.27)	0.067 (.25)
Sugarcane	0 (0)	0.045 (.21)	0 (0)	0.067 (.25)
Services:				
Elec	1 (0)	0.55 (.50)	0.71 (.47)	0.47 (.51)
PipedH20	0.93 (.26)	0.091 (.29)	0.21 (.42)	0.03 (.18)
Church	1 (0)	0.86 (.35)	0.79 (.43)	0.95 (.31)
Commhouse	0.8 (.41)	0.66 (.48)	0.79 (.43)	0.6 (.5)
Civreg	0.67 (.49)	0 (0)	0 (0)	0 (0)
Barrest	1 (0)	0.23 (.42)	0.43 (.51)	0.13 (.35)
Shops	1 (0)	0.89 (.32)	0.93 (.27)	0.87 (.35)
Agricultural infrastructure:				
Coffeeroast	0.73 (.46)	0.27 (.45)	0.36 (.5)	0.23 (.43)
Ricehusk	0.8 (.41)	0.045 (.21)	0.071 (.27)	0.033 (.18)
Sawmill	0.87 (.35)	0.068 (.25)	0.071 (.27)	0.067 (.25)
Market	0.47 (.52)	0.022 (.15)	0.071 (.27)	0 (0)
Medical infrastructure:				
Healthctr	1 (0)	0.18 (.39)	0.43 (.51)	0.067 (.25)
Pharm	1 (0)	0.36 (.49)	0.43 (.51)	0.33 (.48)
Healthstand	0.4 (.51)	0.068 (.25)	0.071 (.27)	0.067 (.25)
Healer	0.47 (.51)	0.20 (.41)	0.5 (.52)	0.067 (.25)
Midwife	0.73 (.46)	0.43 (.50)	0.64 (.5)	0.33 (.48)
Nurse	0.93 (.26)	0.22 (.42)	0.36 (.5)	0.17 (.38)

[1]**Cluster 1:** 7 de Julio, Coca, Dureno, El Dorado de Cascales, El Eno, Jivino Verde, La Joya de los Sachas, Lumbaqui, Nueva Loja, Pacayacu, San Carlos, San Pedro de los Cofanes, Santa Cecilia, Sevilla, Shushufindi
Cluster 2, 2-cluster: 10 de Agosto, 24 de Mayo, 3 de Noviembre, 5 de Agosto, Abdon Calderon, Alamor, Armenia, Bahia de Caraquez, Bella Union del Napo, Conambo, Dayuma, El Dorado, El Oro, El Triunfo, Enokanki, Eugenio Espejo, Guayacan, Jambeli, Jandiayacu, La Belleza, Las Palmas, La Primavera, La Reforma, Los Angeles, Los Rios, La Victoria, Llumucha, Llurimagua, Mariscal Sucre, Nueva Esmeraldas, Nueva Vida, Patria Neuva, Pozo Ron, San Antonio, San Juan de Pozul, San Roque, San Sebastian, San Vicente, Taracoa, Union Chimboracense, Union Lojana, Union Milagrena, Union Manabita, Virgen de Banos
Cluster 2, 3-cluster: 5 de Agosto, Armenia, Conambo, Dayuma, Enokanki, Guayacan, Jambeli, Jandiayacu, La Primavera, La Victoria, Nueva Esmeraldas, Nueva Vida, San Juan de Pozul, San Sebastian
Cluster 3, 3-cluster: 10 de Agosto, 24 de Mayo, 3 de Noviembre, Abdon Calderon, Alamor, Bahia de Caraquez, Bella Union del Napo, El Dorado, El Oro, El Triunfo, Eugenio Espejo, La Belleza, Las Palmas, La Reforma, Llumucha, Llurimagua, Los Angeles, Los Rios, Mariscal Sucre, Patria Neuva, Pozo Ron, San Antonio, San Roque, San Vicente, Taracoa, Union Chimboracense, Union Lojana , Union Milagrena, Union Manabita, Virgen de Banos

Table 3.7 (cont'd). Mean and standard deviation values by cluster for the Ward's method cluster analysis of the community dataset.

Variables	Mean and Standard Deviation Values by Cluster			
	Cluster 1 (n=15)	**Cluster 2, 2-cluster (n=44)**	**Cluster 2, 3-cluster (n=14)**	**Cluster 3, 3-cluster (n=30)**
Educational infrastructure:				
Nursery	0.87 (.35)	0.77 (.42)	1 (0)	0.67 (.48)
Primsch	1 (0)	0.98 (.15)	1 (0)	0.97 (.18)
Secsch	0.8 (.41)	0.18 (.39)	0.43 (.51)	0.067 (.25)
Distsch	0.93 (.26)	0.34 (.48)	0.43 (.51)	0.3 (.47)
Techsch	0.47 (.52)	0.068 (.25)	0.071 (.27)	0.067 (.25)
Transportation infrastructure:				
Bus90	0.36 (.48)	0.18 (.39)	0.57 (.51)	0 (0)
Bus99	0.93 (.26)	0.36 (.48)	0.93 (.27)	0.1 (.31)
Ranchera90	0.93 (.26)	0.36 (.48)	0.71 (.47)	0.2 (.41)
Ranchera99	0.93 (.26)	0.77 (.42)	1 (0)	0.67 (.48)

secondary (0.8), distance (0.93), and technical schooling (0.47) is best in cluster 1 communities. Most (0.93) of the communities in cluster 1 have had access to both bus and *ranchera* transportation since 1990.

Cluster 2 (n=14) communities are characterized by a slightly more limited array of goods and services. Cluster 2 communities range in population from 39 (Jandiayacu) to 1172 residents (La Victoria). Fewer communities have electricity (.71) and piped water (0.21) than in cluster 1. The proportion of communities with agricultural infrastructure is also lower, with only 36 percent of the communities with a coffee roaster and less than 10 percent with a rice husker, sawmill, or agricultural/animal market. Variety in choices for medical care is not as available in the communities of cluster 2, as approximately 40 percent have a health center or pharmacy, and less than 10 percent a health stand. Midwives are available in a proportion (0.64) only slightly lower than that for cluster 1. Educational infrastructure is comparable to cluster 1 at the nursery and primary school level, but fewer communities in cluster 2 have secondary (0.43), distance (0.43), and technical (0.071) schooling. Fewer of the communities in cluster 2 had access to bus and *ranchera* transportation in 1990.

Cluster 3 includes communities that range in population from 28 (Los Rios) to 710 (Taracoa). A much smaller proportion of communities in cluster 3 have electricity (.47) and piped water (0.03). The proportion of communities with agricultural infrastructure is also lower, with 23 percent of the communities with a coffee roaster, less than 10 percent with a rice husker or sawmill, and no communities with an agricultural or animal market. Medical infrastructure is more limited than in cluster 2, as one-third of the communities in cluster 3 have a pharmacy or midwife, approximately 20 percent a nurse, and less than 10 percent a health center, health stand, or healer. Educational infrastructure is comparable across clusters 1, 2, and 3 only at the primary school level. Cluster 3 communities, on average, have the least access to nursery (cluster 1, .87; cluster 2, 1.0; cluster 3, .67) and secondary (cluster 1, .8; cluster 2, .43; cluster 3, .067) schools. In addition, both clusters 2 and 3 show lower proportions of distance (cluster 2, .43; cluster 3, .071), and technical (cluster 2, .3; cluster 3, .0.67) schooling than cluster 1, in which almost all the communities have distance schooling and close to 50 percent have technical schools. In 1990, none of the communities in cluster 3 had access to bus transportation, and a very low proportion (.21) to *ranchera* transportation. Access to *ranchera* transportation was available in a larger proportion (.67) of the communities in 1999, though still substantially less than the proportion of communities in cluster 2 served by *rancheras* in 1999.

Figure 3.6 illustrates how the Ward's method cluster analysis solution maps spatially. The communities in cluster 1 illustrate a pattern similar to that seen in Figure 3.4, with cluster 1 communities located along the Neuva Loja–Quito road, the Jivino Verde-Shushufindi road, and Nueva Loja-Coca road. While some of the communities in clusters 2 and 3 are located along these major travel routes, most are located at some distance from these roads.

To determine which of the cluster solutions, average linkage or Ward's method, produced the best solution, a cophenetic correlation analysis was performed. The data from the dissimilarity matrix was correlated with distance values from the dendrograms; these distance values indicate when objects appear together in a cluster for the first time. The cophenetic correlation data suggest that the average linkage cluster analysis provides the best solution, as the correlation of the average linkage fusion levels with the dissimilarity data (0.85) is quite close to 1 (perfect correlation) and much higher than the correlation found for the Ward's method cluster analysis (0.45). It is appropriate, therefore, to say that the average linkage cluster analysis solution fits the data better.

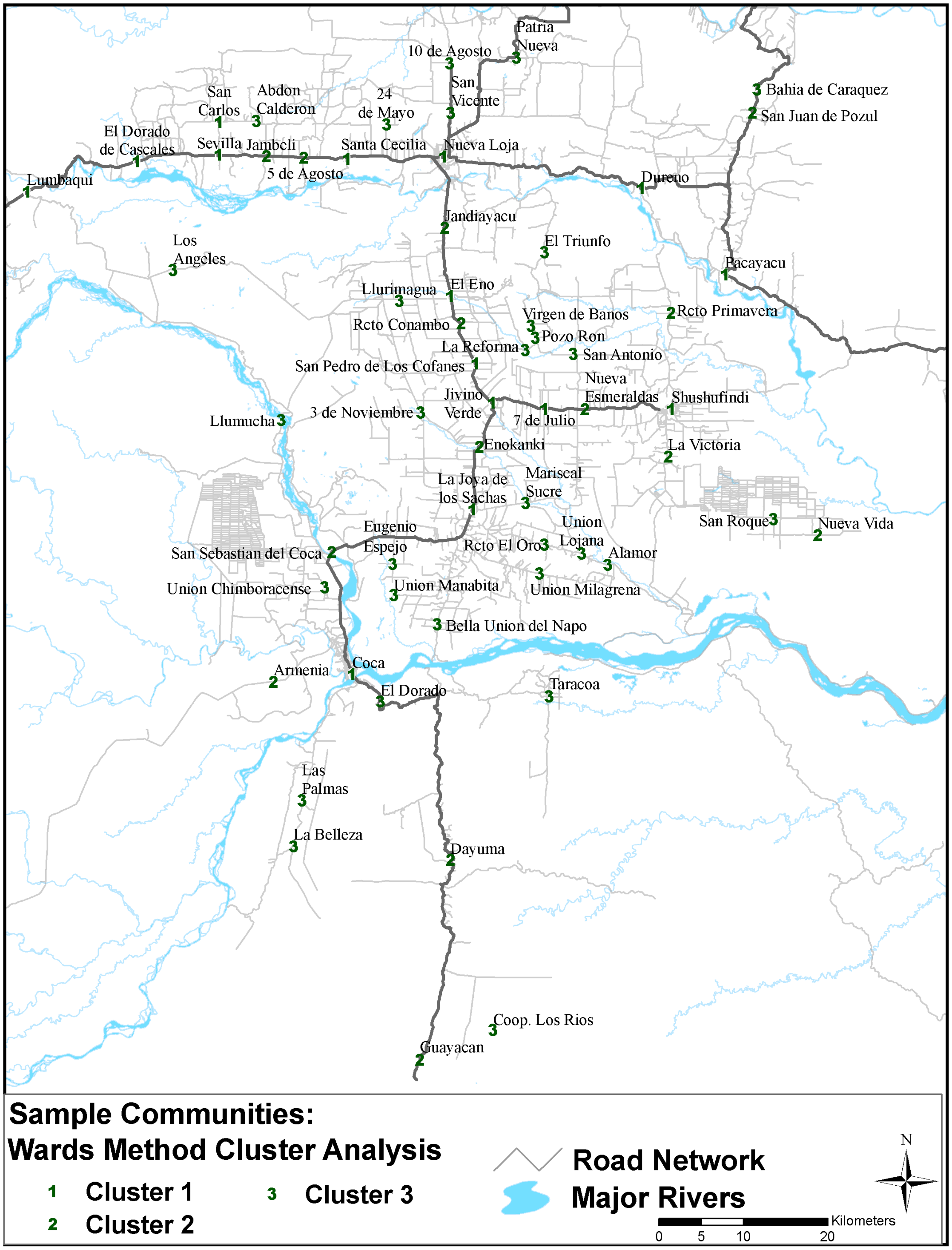

Figure 3.6. Ward's method cluster analysis solution, mapped by cluster.

3.7. **Discussion**

How are communities in the Northern Ecuadorian Amazon related to one another? Discussion of these linkages between communities will weave together central place theory, the results of the cluster analysis, and data from the household surveys (1990, 1999), as well as dissertation data collection. Using the language of central place theory, the study area may be viewed as a set of higher order communities associated with a group of lower order communities. The higher order communities, those with the greatest array of goods and services, are found in cluster 1 of both the average linkage and Ward's method cluster analyses. Linkages between these higher order communities and lower order communities (clusters 2-4 of the average cluster analysis and clusters 2-3 of the Ward's method cluster analysis) are described with the aid of the household and community surveys. The household surveys are used to illustrate linkages between higher order and lower order communities by associating communities nearest to surveyed households with those households. Having a "nearest community" provides a point of reference when examining questions addressing the locations of purchases (food, clothing, agricultural inputs), medical care, or education.

Higher order communities are part of the cluster (cluster 1 in both cluster analyses) that shows the widest variety of goods and services, which would make them attractive to persons in other, lower order communities that do not have such options. Lower order communities (those communities in clusters 2-4 in the average linkage cluster analysis and 2-3 in Ward's method cluster analysis) are related to these higher order communities by transportation; most people travel by bus or *ranchera*, since private vehicle ownership is uncommon. The cost of transport to higher order communities is positively associated with distance, while the frequency of transport is negatively associated. The cluster analysis results indicate that lower order communities generally have nursery and primary schools, but secondary schools are located primarily in the higher order communities.

Health services are distributed throughout the study area, but access varies by the type of community. For example, the smallest of the lower order communities may not have access to health services, while slightly larger communities may have a pharmacy or a health center and have access to a nurse, midwife, and/or traditional healer. The largest communities provide access to a range of health services, both public and private.

Some administrative services, such as the civil register where births and deaths are recorded, are located only in the higher order communities; Ecuador's political-administrative organizational structure dictates that civil registers be located in canton capitals and *cabeceras parroquiales*. With regard to administration, the Ecuadorian government distributes money to the provincial capitals, which then distribute the money to the cantons, which then in turn distribute to the *parroquias* (parishes). Coca, the capital of the province Orellana, and Nueva Loja, the capital of the province Sucumbios, thus have strong ties to Quito. The cantons and parraoquias in each of the provinces are thus linked to Coca or Nueva Loja for budgetary reasons.

Markets provide an additional way in which communities are linked. Only a select group of communities have rice husking or coffee roasting facilities, sawmills, and animal or crop markets. Communities are thus linked to one another commercially through production and commerce. In addition to these agriculture-oriented markets, communities may be linked as well by demand for household goods not available in smaller communities (e.g., items such as machetes or chainsaws) or entertainment (i.e., bars, restaurants).

The most prominent of the higher order communities are Nueva Loja, Shushufindi, La Joya de los Sachas, and Coca. The designation of these four communities as highest order communities is also suggested by both 1990 and 1999 household survey results. For example, responses to the 1990 survey show that 78 percent of the households that purchased pesticides and 74 percent of those purchasing medicine for their livestock did so in one of these four communities. In addition, 70 percent of food purchases occurred in one of these four communities.

The 1999 household survey asks a greater number of questions in which households reference communities, covering topics including medical care (births, birth control, sickness), purchases of food and clothing, and education were used as indicators of higher order reference communities. Responses to the 1999 household survey show that approximately 35 percent of women chose to have their most recent live birth at a hospital/health center or private clinic. Close to 70 percent of the women choosing to have their most recent birth in a hospital/health center did so in Nueva Loja or Coca, while more than 85 percent of the private clinic births took place in Nueva Loja, Shushufindi, or La Joya de los Sachas. Among women using birth control, 52 percent obtain the method of their choice in Nueva Loja, Shushufindi, La Joya de los Sachas, or Coca. For general health problems, more than 70 percent of survey respondents sought medical treatment from a hospital, health center, private clinic, or traditional healer in Nueva Loja, La Joya de los Sachas, Shushufindi, or Coca.

Responses to survey questions concerning the location of purchases of food, clothing, and large household goods (e.g., furniture) also point to these four communities in the greatest percentages. More than 70 percent of the food purchases by households interviewed in 1999 occured in Nueva Loja, La Joya de los Sachas, Shushufindi, and Coca. Of those purchasing clothing, 98 percent of the purchases occurred in Nueva Loja, La Joya de los Sachas, Shushufindi, and Coca. Among those making major purchases such as furniture, close to 88 percent of households chose to make their purchases in Nueva Loja, La Joya de los Sachas, Shushufindi, or Coca.

Examination of household responses, noting especially the communities nearest to each of the households, provides a picture of how these highest order communities are linked to other higher order communities as well as lower order communities. For example, Table 3.8 shows that people in both higher order communities (e.g., 7 de Julio, Dureno, Pacayacu, Santa Cecilia) as well as lower order communities (e.g., 3 de Noviembre, San Antonio, Virgen de Banos) interact with these highest order communities when making food purchases. Examination of the communities nearest households with regard to other types of purchases (i.e., clothing, furniture) show similar patterns.

Primary education produces a decidedly different pattern of interaction with other communities than does secondary education. Of those interviewed in 1999 whose children attend primary school, most (74 percent) attend school in the community nearest to their farm, while 26 percent of the primary students attend school in another close-by community. Secondary education presents a different picture. Of the students attending secondary school, 64 percent study in a community outside of the community nearest to their farm, primarily because their community lacks a secondary school. Among these students studying outside the nearest community, 62 percent attend secondary school in Nueva Loja, La Joya de los Sachas, Coca, or Shushufindi.

Table 3.8. Household survey data (1999) describing food purchases by households and associating higher order communities where food was purchased to the communities nearest to purchasing households.

NUEVA LOJA (n=188 hh)		
7 de Julio	El Triunfo	Patria Nueva
10 de Agosto	La Primavera	San Antonio
24 de Mayo	Llurimagua	San Carlos
Abdon Calderon	Los Angeles	Santa Cecilia
Bahia de Caraquez	Lumbaqui	San Juan de Pozul
El Dorado de Cascales	Nueva Esmeraldas	San Vicente
Conambo	Nueva Loja	Virgen de Banos
Dureno	Pacayacu	
SHUSHUFINDI (n=84 hh)		
7 de Julio	La Victoria	San Antonio
Abdon Calderon	Nueva Esmeraldas	San Roque
Conambo	Nueva Vida	Shushufindi
La Primavera		
JOYA DE LOS SACHAS (n=134 hh)		
3 de Noviembre	Eugenio Espejo	Union Chimboracense
7 de Julio	Joya de los Sachas	Union Lojana
Alamor	Llumucha	Union Milagrena
Bella Union	Los Angeles	Virgen de Banos
Enokanki	San Sebastian del Coca	
COCA (n=87)		
Armenia	Guayacan	Llurimagua
Coca	La Belleza	San Sebastian del Coca
Dayuma	Las Palmas	Taracoa
Eugenio Espejo	Llumucha	Union Chimboracense

The geography of clusters of communities, as depicted in Figures 3.4 and 3.6, while describing the current state of relationships among communities, also has implications for the future of the region. Relationships within the current hierarchy of central places would be expected to change through time as communities grow in population, changes occur in the array of goods and services offered, and accessibility changes with placement of new roads. These changes may take place as current higher order communities (cluster 1) evolve, as population growth and accumulation of additional infrastructure and services makes them more comparable to the region's highest order communities (i.e., Nueva Loja, Coca, La Joya de los Sachas, and Shushufindi), or as lower order communities emerge as higher order communities through development of a broad enough array of goods/services. Expected population growth will likely produce additional lower order communities linked to newer higher order communities. In the examples presented here, the emergence of lower order communities is most likely to occur among cluster 2 communities of the cluster solutions. Spatially, cluster 2 communities at greatest distance from the highest order communities are most likely to emerge as new higher order communities, as distance from the highest order communities will provide tangible benefits to residents of surrounding areas in terms of greater ease of access to goods and services.

3.8. **Conclusions**

Cluster analysis, as applied to the 2000 community dataset, has provided insights into how communities in the study area are related. The cluster analysis, used in conjunction with household survey data from 1990 and 1999, provides a richly textured picture of how communities in the NEA are related to one another. In addition, the combination of the cluster analysis and the household survey data provides support for the validity of the use of central place theory in the NEA.

The results also show that the communities in various clusters are arrayed along what may be called a “development continuum,” where the communities in cluster 1 show the greatest array of goods and services, while the remaining clusters do not offer the same level of products and service. These results prove interesting for several reasons. First, the place of a community within the regional hierarchy is linked to its impact on the surrounding landscape. Communities may be expected to impact land cover in both direct and indirect ways, changing the landscape directly through expansion, or areal growth, or indirectly by influencing change through connections between communities. Lambin and colleagues

(2001) illustrate this concept of indirect change through their discussion of how urban areas affect land use and land cover change, not primarily because of their size on the landscape, but though urban-rural connections that promote landscape change in surrounding areas. While communities in this study have not been presented as "urban," the communities in cluster 1 are certainly larger and more developed than their counterparts and would, therefore, have a greater impact on the surrounding landscape. Higher order (cluster 1) communities may affect land cover change in surrounding areas through (a) higher local demand for crops, animal products, and wood as urban population grows; (b) national or international-level demand for goods such as coffee or cacao that is transmitted through prices offered to growers for their crops in markets in these communities; (c) attractiveness of *solares* (small lots close to communities) for settlement; and (d) development of new transportation routes that increase accessibility to market towns. In addition, off-farm employment availability in communities creates opportunities for accumulation of household capital (Murphy et al. 1997), and thus may produce land cover changes either by increasing household capital stocks that can be used to gain access to technology such as chainsaws or fertilizer, or, alternatively, by influencing landowners to decrease on-farm investments in favor or preserving accumulated capital.

Secondly, knowledge about the differences among these communities will be helpful in future modeling efforts, particularly in the development of rules for cellular automata (CA) models of land cover change, as different rules concerning land cover change could be developed for communities in the various clusters. Third, cluster analysis methods could also be helpful from a policy perspective. Preliminary analyses examining clusters of particular types of infrastructure (i.e., market, education, transportation, healthcare) highlight clusters of communities that are not well-served and could thus assist policymakers in targeting extension of services.

The expectation that the more-developed communities will produce greater landscape change through their linkages to surrounding rural areas leads to a discussion of future work. The results of this cluster analysis will be used in conjunction with pattern metric data derived from remote sensing images. Using cluster analysis results, communities will be grouped to compare land cover patterns and assess whether significant differences in land cover exist between clusters.

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CHAPTER 4

CHARACTERIZING LANDCOVER DYNAMICS AT THE COMMUNITY LEVEL IN THE NORTHERN ECUADORIAN AMAZON

4.1. **Introduction**

Colonization of the Ecuadorian Amazon resulted from agrarian reform pursued by the Ecuadorian government beginning in the 1950s (MacDonald 1981). The reform policies and the colonization of the Ecuadorian Amazon were meant to serve as a “pressure valve” that would diffuse tensions surrounding land tenure in the coastal and highland provinces (Uquillas 1984; Oberai 1988; Pichón and Bilsborrow 1999). In addition, spontaneous migration into the region resulted from development of the nation’s oil reserves. Oil was discovered by Texaco in the Northern Ecuadorian Amazon (NEA) in 1967, and as Texaco and other oil companies built roads into the region to facilitate exploration and transport of oil, migrants began streaming into the area, claiming land for farms, initially along the recently built roads. Since the early 1970s, the NEA (Figure 4.1), comprised of the provinces of Napo, Sucumbios, and Orellana, has gained population at rates higher than the southern portion of the Amazon as well as the rest of the country (Table 4.1).

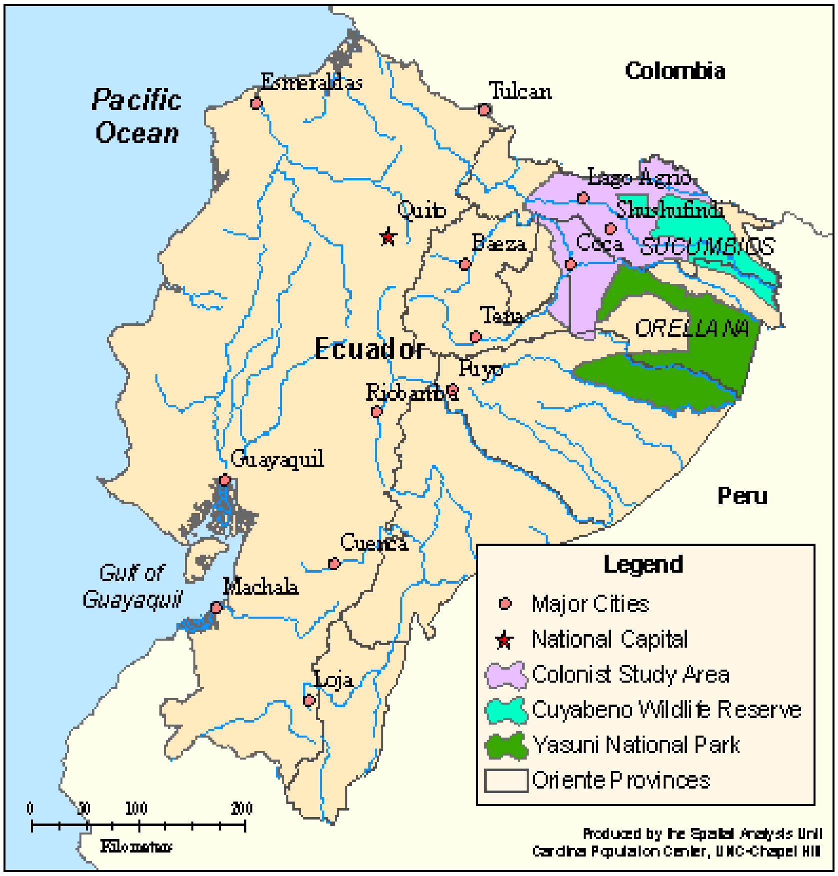

Figure 4.1. Colonist study area, as situated within the country of Ecuador. The study area encompasses portions of the provinces of Napo, Sucumbios, and Orellana.

Table 4.1. Average annual population growth rates in Ecuador, 1974-2001 (INEC, 1985, 1991, 2001).

	1974-1982 (%)	1982-1990 (%)	1990-2001 (%)
NEA*	7.70	5.61	4.31
Oriente	5.24	4.31	3.41
Ecuador	2.77	2.13	2.10

*Includes the provinces Sucumbios, Orellana, and Napo

As a result, the NEA has experienced intense land cover change over the last 40 years (Figure 4.2). With the discovery of oil, attendant road construction, and spontaneous migration of colonists seeking land, the area has experienced rapid deforestation, at times at some of the highest rates in the world (FAO 2001). The spatial pattern of such land cover change is of great interest, as it impacts biodiversity, climate change, carbon budgets, and ecosystem functions; the main components of spatial pattern are composition and spatial configuration, or structure (O'Neill et al.1988; Gustafson 1998). This research contributes to the current state of knowledge on the composition and spatial configuration of the landscape in the NEA by characterizing landscape composition and the dynamics of land cover change, using remote sensing and spatial analysis methods. The intent is to assess the spatial pattern of LULC change relative to communities in the NEA.

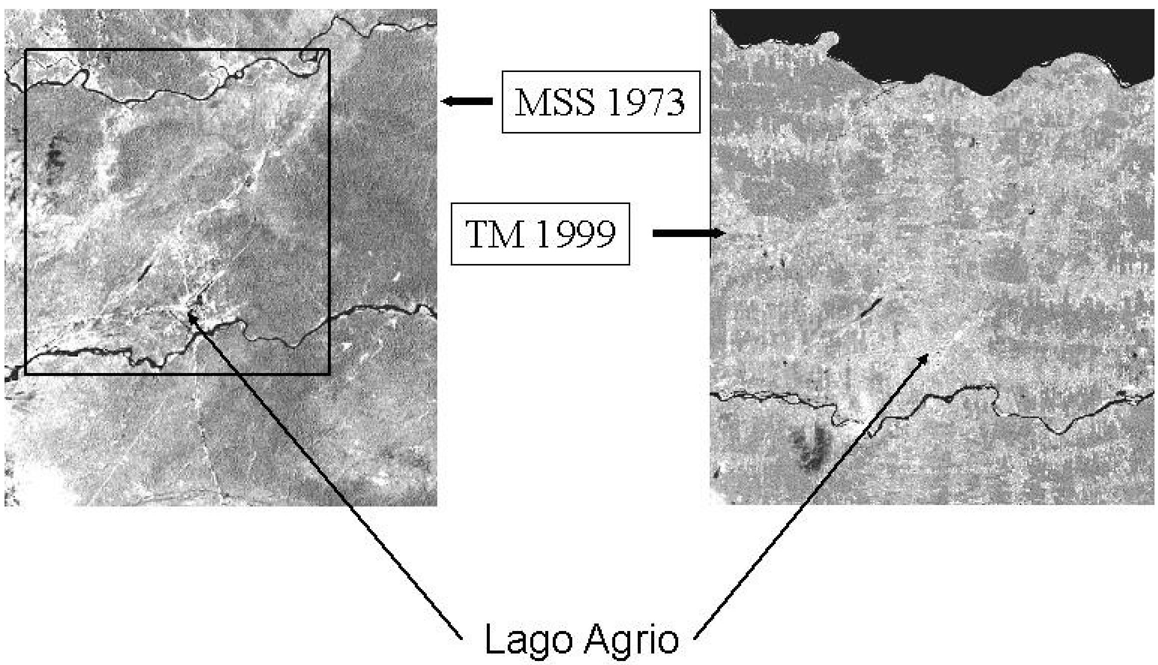

Figure 4.2. Land cover change around Lago Agrio (1973-1999), as seen from Landsat Multispectral Scanner (MSS) and Landsat Thematic Mapper (TM) image data.

This study focuses on characterizing landcover patterns and changes in the areas surrounding communities of varying size and age in the Northern Ecuadorian Amazon. Theoretical bases for this work are rooted in landscape ecology, in which scale, pattern, and process are linked, and agricultural location theory, in which agricultural land use is expected to respond to factors including demand and distance to a central city. An objective of this study is to employ gradient analysis in the examination of LULC change patterns over time and space around surveyed communities in the NEA. The goal is to determine whether significantly different land cover patterns are seen as a function of distance from communities, and whether significant differences in pattern exist among communities of different types (i.e., by age, level of development). A second objective of this study is to examine landcover dynamics within the context of population changes over time. This work contributes to our understanding of the NEA by providing greater accounting of the direct and indirect impact of communities on LULC change and increasing our understanding of urbanizing areas in the NEA. This work also contributes to a growing Land Change Science (LCS) literature by describing landcover patterns and changes over time in urban or urbanizing areas with explicit human-environment implications. The sections that follow describe previous work, the theoretical and methodological background for this work, the datasets used in this analysis, results of the remote sensing and statistical analyses, discussion of results, and conclusions drawn from the analysis.

4.2 **Previous Work**

Gradient analysis is an established method of examining how patterns change across space. Initial studies involving gradient analysis (Whitaker 1967) examined changes in patterns of plant species along environmental gradients. Gradient analysis has, however, been applied in other ways. For example, McDonnell and Pickett (1990) pointed out that gradient analysis could be usefully employed in examining ecosystem structure and function along urban-rural gradients. Since then, a number of studies have used gradient analysis as the basis for their study of change in plant or animal assemblages with distance from urban areas. Among those that incorporate a landscape ecology perspective, focusing broadly on the gradient of landscape patterns associated with urban or urbanizing areas, are Luck and Wu (2002), Seto and colleagues (2005), Wu and colleagues (2006), Xie and colleagues (2006), Yu and Ng (2007), and Weng (2007). These studies show that the metrics used to quantify landscape composition and configuration change with distance from the populated center of interest, as well as through time. However, Seto and colleagues (2005) point out that there are few studies focused on developing country contexts where rapid urban growth is likely to occur in the next 30 years. This study aims to fill this gap, as the Ecuadorian Amazon, unlike the Brazilian Amazon, is not yet home to large urban areas. The Northern Ecuadorian Amazon is an area whose trajectory may be termed one of "incipient urbanization," making understanding of historical LULC patterns all the more important for future decision-making.

4.3. **Theoretical Background**

4.3.1. **Scale, pattern, process**

Landscape Ecology theory examines the relationships between spatial patterns and landscape processes at a variety of scales (Risser et al. 1984). Scale, pattern, and process are, therefore, critical to the study of landscape ecology. Landscape patterns, produced by interactions between the abiotic environment, biotic processes, and disturbance regimes, may be examined in terms of composition (i.e., number and proportions of patch types, evenness of their areal distribution) and/or configuration (i.e., spatial location, arrangement with regard to other patch types, shape complexity) (O'Neill et al. 1988; Gustafson 1998). Understanding the processes producing patterns is necessary to be able to better guide landscape management (Levin 1992).

Pattern metrics are used to assess landscape pattern by providing an approach to quantify class, patch, and landscape-level characteristics including area, shape, connectivity, and diversity (O'Neill et al. 1988; Crews-Meyer 2002). Many pattern metrics are correlated, however, since the metrics are based on a small number of measurable patch characteristics, including patch type proportion, area, edge, and connectedness; they should, therefore, be chosen carefully to represent the factors of interest and avoid duplicating information (Riitters 1995).

Scale in landscape ecology is characterized in terms of grain and extent. Grain is defined as the spatial resolution of the data, and extent is the size of the study area or length of time under consideration. Ecological processes vary in importance as well as in their effects at different scales (Risser et al. 1984), spatial as well as temporal. As such, these processes may be termed scale-dependent (Turner 1989; Walsh et al. 2001). Scale dependence implies that patterns or processes may vary depending on the grain or extent examined. Scale dependence can affect study results depending on the precision with which study area and associated spatial and temporal scales are defined, the nature of the variables examined (e.g., local-scale biophysical variables versus more broadly defined variables such as deforestation), and the efforts made to scale-up from the local region (Gamble and Meentemeyer 1996).

Hierarchy theory is implicated in the study of scale since processes that operate at a particular spatial or temporal scale may affect processes at other spatial and temporal scales (Walsh et al. 1998). Hierarchy theory also highlights the importance of examining a range of scales in any study (Walsh et al. 1998, Turner et al. 2001, Walsh et al. 2001). A focal scale for the research is identified by the research question; the level above should be examined because it provides context for the focal level, while the level below provides information about processes or mechanisms observed at the focal level.

4.3.2. **Direct and Indirect Effects of Communities on Landscape Patterns**

A community affects landscape patterns both directly and indirectly (Schumann and Partridge 1989, Ozorio de Almeida 1992, Moran 1993, Furley 1994). Direct change is observed through community establishment and growth or expansion, whereas indirect effects are LULC changes in more distant areas created by the geographic "reach" of communities. Community effects on an "area of influence" may be attributed to (a) elevated local demand for crops, animal goods, and wood as urban population grows; (b) national- or international-level demand for goods such as coffee or cacao that is transmitted through prices offered to growers for their crops; (c) attractiveness of *solares* (small lots close to communities) for settlement; and (d) development of new transportation routes that increase geographic accessibility of a place, thereby redefining "reach."

Communities may also act as service centers and, thereby, indirectly impact the landscape. Communities that provide services, such as bus transportation, facilitate movement of people and products in a bidirectional fashion between households and communities. Bus and *ranchera* transport is extremely important in the NEA, as the region is sparsely populated and few own vehicles. Access to such transportation, particularly to towns with agricultural or animal markets, may affect farm-level land use decisions. In addition, the availability of off-farm employment in communities creates opportunities for cash earnings and possible accumulation of household capital (Murphy et al. 1997) which may affect land use and land cover through access to technology, such as chainsaws or fertilizer, or by providing money to invest in establishing or extensifying crop or pasture lands.

4.3.2. **Agricultural location theory**

Agricultural Location theory is generally attributed to von Thünen (translation, Wartenberg 1966). His work examined the interaction between agricultural prices, land rent (i.e., return from investment in land), and distance to market, based on the assumption that farmers seek to maximize profits. Assumptions made by the von Thünen model include the existence of only a single central city, surrounded by agricultural land with uniform biophysical attributes, where only one type of transportation to the city exists, and land use is expected to respond quickly to economic changes. Increased agricultural demand in the central city is expected to increase agricultural prices, benefiting most those closer to the city; prices are thus expected to influence land use. The type of agriculture thus varies by location; von Thünen conceptualizes this variation as concentric rings around the city. In the ring closest to the city, production will focus on perishable products (fruits, vegetables, milk) as well as products heavy or bulky in relation to their value (too expensive for more remote areas to transport). With increasing distance from the town, the products grown will be inexpensive to transport in relation to their value.

Although, as Grotewold (1959) points out, von Thünen's assumptions render constant or non-existent a number of factors that generally contribute to diverse land uses, the idea that central city demand influences land use in surrounding areas is still applicable in the NEA, given the role distance to market towns has been shown to play in the proportion of various cover classes on farms (Pichón 1997). In addition, agricultural land use in developing countries has been found to provide support for this model (O'Kelly and Bryan 1996).

4.4. **Methodological Background**

4.4.1. **Pattern metrics**

The term "pattern metrics" refers to a group of indices that have been developed for evaluation of categorical maps (McGarigal 2002). Landscape pattern metrics focus on the composition and configuration of the classes included in categorical maps and thus the spatial and geometric properties of these maps. Pattern metrics are commonly defined at three levels: patch, class, and landscape. Patch-level metrics are defined for individual patches and characterize their spatial character and context, while class-level metrics examine all the patches of a particular type, producing an average or weighted-average value depending on whether large patches contribute more heavily to the index. Landscape-level metrics are integrated over all the class types over the extent of the data, producing an average or weighted average value. Limitations of pattern metrics include redundancy in information due to correlation between metrics (Riitters 1995), as well as sensitivity to the level of detail in categorical map data (Li and Wu 2004). In addition, care should be taken in analyzing pattern metrics, as interpretation should be made given an understanding of the methods of spatial pattern analysis as well as the concepts from which the methods were developed (Li and Wu 2004).

4.4.2. **Logistic regression**

Logistic regression is a statistical method used for modeling categorical response variables. The dependent variable is often characterized as a dichotomous variable; however, dichotomous variables are simply a special case in which a categorical variable has a binary response structure (e.g., yes/no). Logistic regression describes the relationship between the categorical response variable and one or more continuous and/or categorical explanatory variables. The logistic regression model is described by Equation 1. In Equation 1, the logit function, or logged odds found by taking the natural logarithm of the odds of experiencing an event *($P_i/(1-P_i)$)*, is set equal to the sum of an intercept (α) and the parameters (β_i) of the independent variables (X_i).

$$\ln\left[\frac{P_i}{(1-P_i)}\right] = \alpha + \beta_1 X_1 + \beta_2 X_2 \qquad \text{(Eq. 1)}$$

One may move from logged odds to odds by taking the exponent of each side of the equation, as illustrated in Equation 2. Taking the exponent eliminates the logarithm on the left side of the equation and leaves the odds.

$$\frac{P_i}{1-P_i} = e^{\alpha + b_1 X_1} = e^{\alpha} * e^{b_1 X_1} \qquad \text{(Eq. 2)}$$

Odds are examined as to whether they indicate an increased likelihood of occurrence (coefficient greater than 1), unchanged likelihood (coefficient equal to 1), or decreased likelihood of occurrence (coefficient less than 1). One may obtain an odds ratio by dividing the odds associated with one category by that of another.

4.5. **Data**

4.5.1. **Community survey**

Bilsborrow and colleagues developed a community-level survey, implemented in 2000, to provide context, evaluate change that occurred between 1990 and 1999, and better define the effects of economy and infrastructure on land use decisions in the local area (Bilsborrow 2002). The community-level questionnaire was administered in 54 communities in 2000, and in several additional communities in 2002, bringing the total number of communities surveyed to 59. The 59 communities range in population from 150 – 34,000 residents. Figure 4.3 shows the locations of surveyed communities in reference to the sectors in which 1990 and 1999 household surveys were conducted.

Communities selected for interviews were chosen on the basis of their spatial proximity to households surveyed in 1990 and 1999 as well as the linkages suggested by those household-level interviews (e.g., where households buy and sell goods, seek education and health services, or attend church). The surveys addressed issues including distance and access to reference communities, principal economic activities, local cultivation and yields, land tenure, facilities and infrastructure, transportation services, prices of basic goods, and types of agricultural and development assistance available. In addition, retrospective questions, designed to assess spatial and temporal changes in these communities since 1990, addressed population growth, in- and out-migration, economic change, and the number and size of farms. In each community, several knowledgeable informants, including community leaders, local farmers, teachers, and health workers, responded to the questionnaires on behalf of their community.

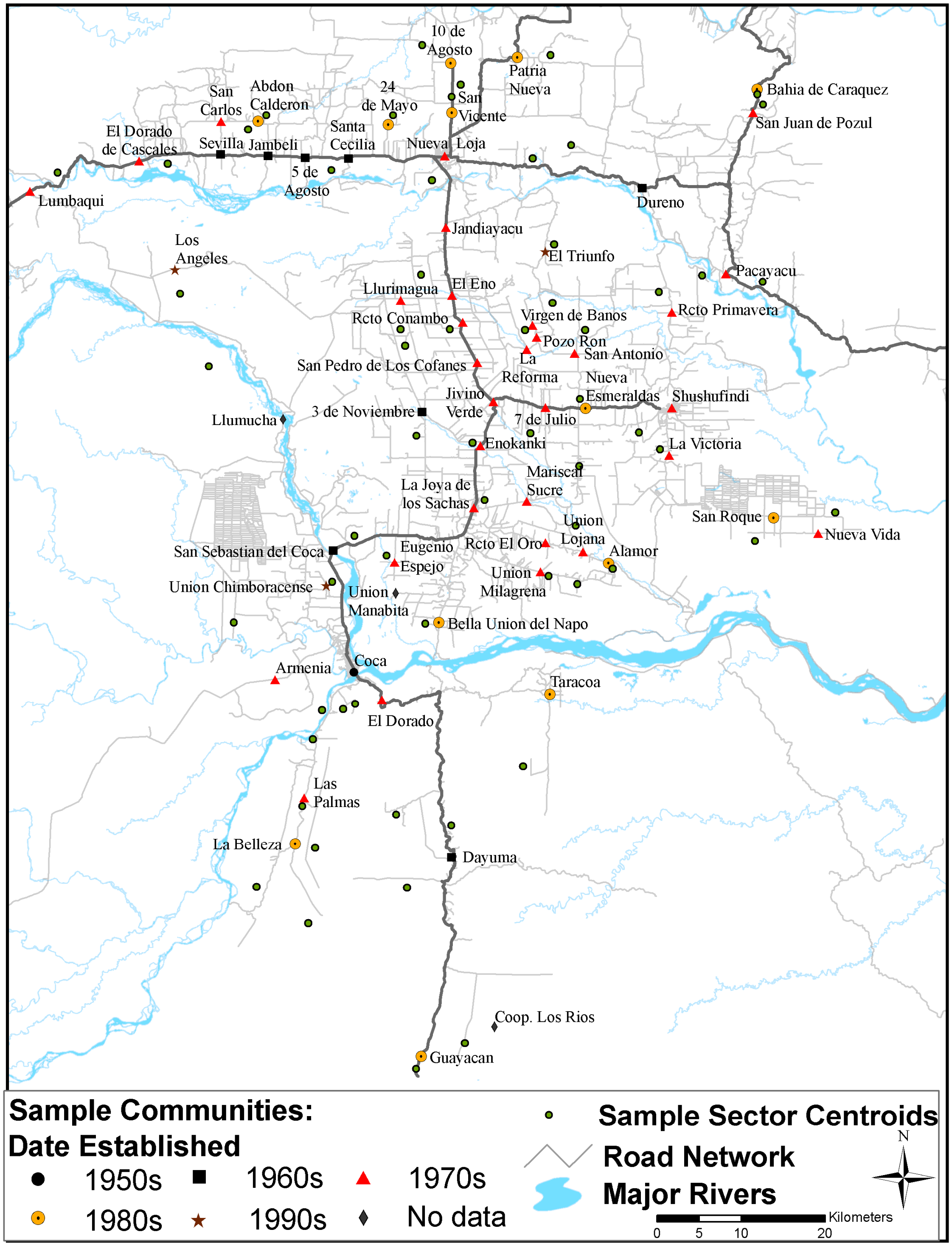

Figure 4.3. Sample sector centroids and community survey locations, Northern Ecuadorian Amazon.

4.5.2. **Classified Landsat TM imagery**

A classified image time-series of Landsat TM images (1986, 1989, 1996, 1999, 2002; Path 9/Row 60) was used in this research. The time-series imagery was classified using a hybrid supervised-unsupervised classification method (Messina and Walsh 2001)[1]. Land cover classes in these images include forest, pasture, crops, barren, urban, and water. Radiometric correction was applied, as examination of landscape change over time necessitates radiometric correction so that pixel values are comparable between images (Song et al. 2001). The 5s (Tanre et al. 1990) absolute radiometric correction algorithm was applied to the image time-series after the images were converted to "top of the atmosphere" (TOA) reflectance values.

4.6. **Methods**

4.6.1. **Pattern Metrics**

In defining the pattern and extent of land cover change around communities, two methods were employed. First, multiple 250 m buffers were created around each of the communities to allow examination of land cover within a 2 km radius. Second, an "area of influence" was defined for each community, using the population sectors that intersected the buffers. Population census sectors are sub-parroquia boundaries for which census data are collected by the *Instituto Nacional de Estadística y Censos* (INEC). The land cover changes observed at the sector-level are meant to provide context for the

[1] An unsupervised classification was applied first; the spectral signatures generated were evaluated using transformed divergence. The results from the initial unsupervised classification were evaluated, and any classes that displayed confusion were subset and run through the unsupervised classification separately. These new signatures were added to the original signature set; this augmented signature set was used for supervised classification. Training data for the supervised classification were obtained from fieldwork in the study area.

changes seen in the area immediately surrounding each community. Figure 4.4 depicts the use of the buffers and sector-level boundary data.

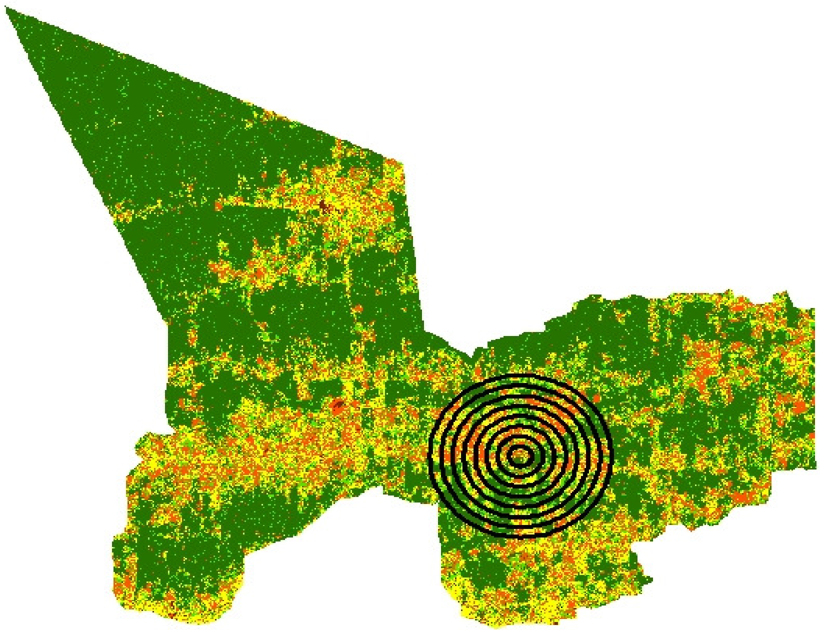

Figure 4.4. Sector-level boundary and 2 km buffer around community.

Within each of these buffers and sectors, pattern metrics were calculated. The metrics chosen for use in this study were selected to represent composition and spatial configuration, while minimizing redundant information. This study focuses on class-level metrics and examines them at both the buffer- and sector-level.

4.6.2. **Classifying Communities**

To compare differences among the 59 communities, they were grouped. While examining communities by age required only a simple classification, grouping communities by level of development was somewhat more difficult. This was accomplished using cluster analysis to evaluate the communities based on the various types of infrastructure they possess (e.g., birth and death registries, crop and animal markets, hospitals and other medical infrastructure, primary and secondary schools); see Chapter 3. The cluster analysis produced three groups, and these groups were labeled as communities with high, medium, and low levels of development.

4.6.3. **Logistic regression**

The logistic regression models used the proportion of various land cover types (i.e., forest, agriculture, pasture, urban) as the dependent variable. Thus, this model provides the probability that any pixel will be a particular land cover type (e.g., forest/not forest or agriculture/not agriculture). Independent variables include buffer distance, age of community, and level of development. Outcomes are modeled independently, and the interaction effects explored include distance, date of establishment, and time.

4.7. **Results**

4.7.1. **Across All Image Years**

Table 4.2 provides land cover proportions in distance buffers around communities across all image years, with Figure 4.5 illustrating the proportions graphically. Proportion of forest increases with distance from communities, while proportion of agriculture decreases with distance. Land in pasture increases immediately outside the first buffer and maintains a fairly constant proportion thereafter. Proportion urban is generally low, but greatest in the buffer in which the communities are located.

Table 4.2. Proportion land cover in various classes, by distance buffer, across all image years.

	Land Cover Class (%)			
Buffers	Forest	Ag Crops	Pasture	Urban
0-250	27.14	51.26	2.26	5.53
250-500	37.39	27.97	15.56	2.75
500-750	41.74	24.91	15.82	2.02
750-1000	45.97	23.1	14.7	1.45
1000-1250	50.01	20.89	14.25	1.1
1250-1500	53.14	19.39	13.25	0.92
1500-1750	55.3	18.06	12.96	0.93
1750-2000	56.71	17.43	12.97	0.83

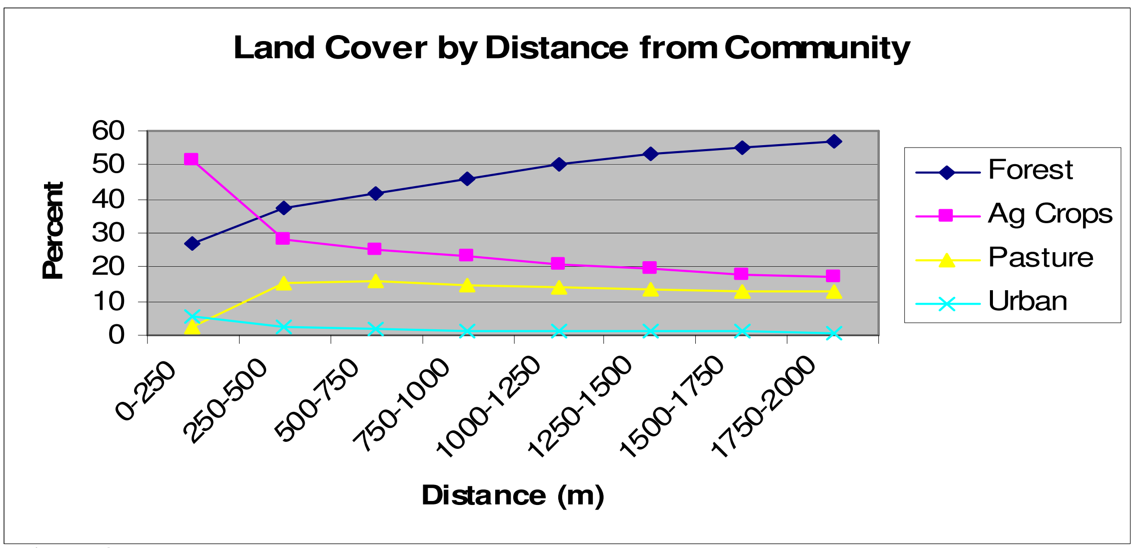

Figure 4.5. Proportion land cover in various classes, by distance buffer, across all image years.

Tables 4.3-4.6 provide estimates of the likelihood of each land cover in various buffers, with the buffer that contains the community (0-250) serving as a reference. In all but two cases, the estimates are significant at the 0.01 level. Across all image years, the likelihood of the forest pixel class increases with distance from the community, with the likelihood of finding forest close to three times as likely in the furthest buffer (Table 4.3). Table 4.4 shows that across all image years, the likelihood of the agriculture class decreases with distance from the community, although the decrease in the likelihood of agriculture pixels is not as striking as the increasing odds observed for forest. Pasture has greater likelihood of existing in buffers closest to the communities (250-500 m and 500-750 m) than in the buffer in which the community is found (Table 4.5). The likelihood of pasture decreases with distance from the communities. Across all image years, the likelihood of the urban class decreases with distance from the community (Table 4.6). Urban pixels are five times more likely to be found in the 250-500 m buffer than in the 1750-2000 m buffer.

Table 4.3. Odds ratios for existence of forest by distance buffer across all image years.

Contrast Estimate Results							
Contrast	**Estimate**	**Standard Error**	**Alpha**	**Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
O-250 vs 250-500	1.5178	0.0508	0.05	1.4214	1.6208	155.17	<.0001
O-250 vs 500-750	1.7444	0.0721	0.05	1.6086	1.8917	180.98	<.0001
O-250 vs 750-1000	2.0025	0.093	0.05	1.8284	2.1933	223.7	<.0001
O-250 vs 1000-1250	2.3355	0.1147	0.05	2.1212	2.5715	298.24	<.0001
O-250 vs 1250-1500	2.5628	0.1291	0.05	2.3219	2.8286	349.26	<.0001
O-250 vs 1500-1750	2.7725	0.1408	0.05	2.5099	3.0626	403.48	<.0001
O-250 vs 1750-2000	2.9293	0.1497	0.05	2.6501	3.2379	442.34	<.0001

Table 4.4. Odds ratios for existence of agriculture by distance buffer across all image years.

Contrast Estimate Results							
Contrast	**Estimate**	**Standard Error**	**Alpha**	**Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
O-250 vs 250-500	0.658	0.0178	0.05	0.624	0.6939	238.49	<.0001
O-250 vs 500-750	0.5611	0.0185	0.05	0.526	0.5985	307.51	<.0001
O-250 vs 750-1000	0.5127	0.0197	0.05	0.4755	0.5527	303.28	<.0001
O-250 vs 1000-1250	0.4479	0.018	0.05	0.414	0.4846	399.18	<.0001
O-250 vs 1250-1500	0.4081	0.0162	0.05	0.3775	0.4412	507.26	<.0001
O-250 vs 1500-1750	0.3771	0.0148	0.05	0.3491	0.4074	613.58	<.0001
O-250 vs 1750-2000	0.3579	0.0131	0.05	0.3331	0.3845	786.8	<.0001

Table 4.5. Odds ratios for existence of pasture by distance buffer across all image years.

Contrast Estimate Results							
Contrast	**Estimate**	**Standard Error**	**Alpha**	**Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
O-250 vs 250-500	1.1359	0.0311	0.05	1.0767	1.1985	21.73	<.0001
O-250 vs 500-750	1.1072	0.0377	0.05	1.0358	1.1836	8.95	0.0028
O-250 vs 750-1000	1.0209	0.0368	0.05	0.9513	1.0955	0.33	0.5664
O-250 vs 1000-1250	0.9623	0.0357	0.05	0.8948	1.0348	1.08	0.2997
O-250 vs 1250-1500	0.9044	0.0349	0.05	0.8385	0.9756	6.76	0.0093
O-250 vs 1500-1750	0.8736	0.0339	0.05	0.8096	0.9427	12.09	0.0005
O-250 vs 1750-2000	0.8765	0.0342	0.05	0.812	0.946	11.45	0.0007

Table 4.6. Odds ratios for existence of urban by distance buffer across all image years.

Contrast Estimate Results							
Contrast	**Estimate**	**Standard Error**	**Alpha**	**Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
O-250 vs 250-500	0.5465	0.0531	0.05	0.4517	0.6613	38.6	<.0001
O-250 vs 500-750	0.3828	0.0512	0.05	0.2945	0.4975	51.51	<.0001
O-250 vs 750-1000	0.2446	0.0346	0.05	0.1854	0.3229	98.9	<.0001
O-250 vs 1000-1250	0.1822	0.0244	0.05	0.1401	0.2368	161.75	<.0001
O-250 vs 1250-1500	0.1541	0.0193	0.05	0.1206	0.197	223.64	<.0001
O-250 vs 1500-1750	0.1341	0.0154	0.05	0.107	0.168	305.3	<.0001
O-250 vs 1750-2000	0.1167	0.0131	0.05	0.0937	0.1454	366.74	<.0001

Table 4.7 shows land cover proportions by level of development (as defined by cluster analysis) in communities across all image years, with Figure 4.6 illustrating the proportions graphically. Proportion of forest is higher around less developed communities, while proportion of agriculture is highest around the most developed communities. Land in pasture maintains a fairly constant proportion. Proportion of urban is generally low, but greatest around communities identified as most developed.

Table 4.7. Land cover proportions, by community development type, across all image years and all distance buffers.

Land Cover Class (%)				
Development	**Forest**	**Ag Crops**	**Pasture**	**Urban**
Most (n=26)	40.33	25.87	14.57	3.63
Intermediate (n=27)	49.88	22.09	13.92	0.07
Least (n=6)	57.65	16.94	12.94	0.43

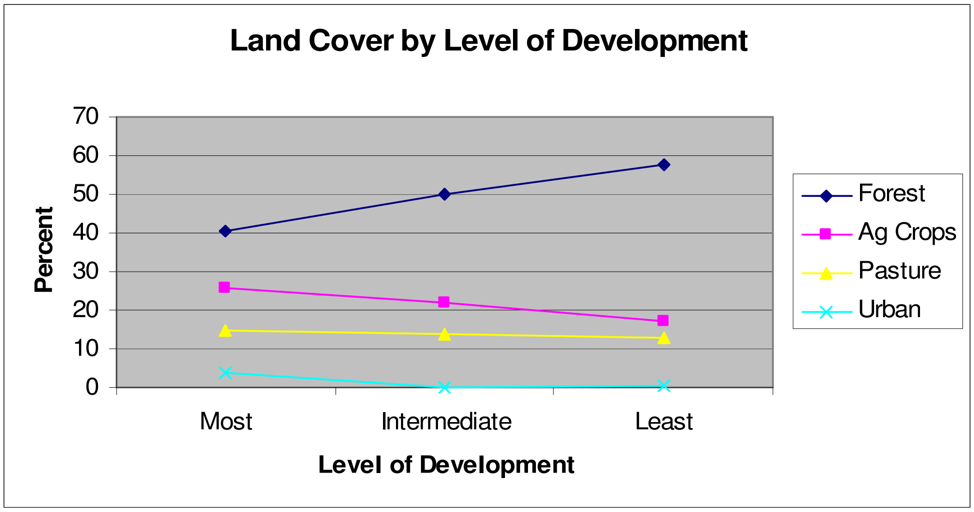

Figure 4.6. Land cover proportions, by community development type, across all image years and all buffers.

Contrasts describing the odds ratios of land cover classes (forest, pasture, agriculture) in communities of varying levels of development are shown in Table 4.8. In all cases, the most developed communities are the reference category. Contrasts are significant at the 0.01 level in all but two cases; contrasts between communities with highest and intermediate levels of development were not significant for forest and pasture. The existence of forest is 60 percent more likely in communities of low levels of development. The existence of agriculture is less likely in communities of intermediate (22 percent less) or low (41 percent less) levels of development than in communities with higher levels of development. The existence of pasture is 12 percent less likely around communities in the lowest development level than around the most developed communities.

Table 4.8. Odds ratios for land cover types by community development type, across all image years and all distance buffers.

Contrast Estimate Results							
Contrast	**Estimate**	**Standard Error**	**Alpha**	**Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Forest Most Developed vs. Intermediate Development	1.313	0.2158	0.05	0.9513	1.812	2.74	0.0976
Forest Most vs. Least Developed	1.6449	0.2212	0.05	1.2638	2.1409	13.7	0.0002
Agriculture Most Developed vs. Intermediate Development	0.7858	0.0723	0.05	0.6562	0.941	6.87	0.0088
Agriculture Most vs. Least Developed	0.5903	0.0456	0.05	0.5073	0.6868	46.54	<.0001
Pasture Most Developed vs. Intermediate Development	0.9311	0.0672	0.05	0.8082	1.0726	0.98	0.3227
Pasture Most vs. Least Developed	0.8881	0.0533	0.05	0.7896	0.9989	3.92	0.0478

Table 4.9 shows land cover proportions by community age (as defined by community survey) across all image years. Proportion of forest is highest around the communities most recently established. Proportion of agriculture is noticeably higher in communities established between 1950 and 1979 than in communities established in the 1980s or 1990s. While the proportion of land in pasture does not vary greatly across the age classes, higher proportions are found in the middle age classes than for communities with earliest or latest date of establishment. Proportion of urban is greatest for the oldest communities.

Table 4.9. Land cover proportions, by community age class, across all image years and all distance buffers.

Land Cover Class (%)				
Date of Est.	**Forest**	**Ag Crops**	**Pasture**	**Urban**
1950s (n=1)	17.13	25.61	10.11	16.31
1960s (n=8)	47.61	21.39	15.71	0.68
1970s (n=31)	49.75	22.28	13.72	1.11
1980s (n=13)	56.09	17.7	13.18	0.01
1990s (n=1)	64.67	14.76	11.37	0

4.7.2. **Individual Image Years**

Figures 4.7-4.9 examine the proportion of pixels in each land cover class (forest, agriculture, pasture) for each image year (1973, 1986, 1989, 1996, 1999, 2002). Figure 4.7 shows that forest was the primary LULC class in the 1973 image; it also illustrates the transition in LULC that took place between 1973 and 1986, with the amount of forest surrounding communities decreasing dramatically. The proportion of forest by distance for the following image years shows a strikingly similar pattern. While the proportion of forest continues to decrease, the trajectory for each year remains remarkably similar. Proportion of forest for 1989 does, however, provide an exception, as the slope of the line is different from either the previous or following years.

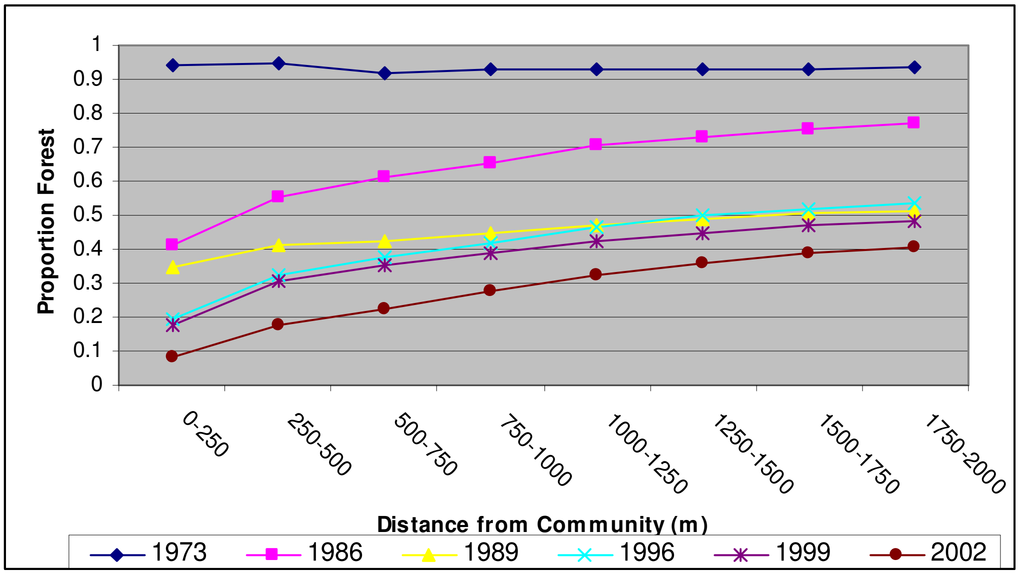

Figure 4.7. Proportion of forest in each image year, across all distance buffers.

Given that the forest class dominated the 1973 image, agriculture and pasture classes are examined for image years 1986-2002. Proportion of agriculture in the buffers closest to the communities increases over time, suggesting agricultural expansion (Figure 4.8); note, however, that the proportions in 1996 and 1999 are higher than in 2002. Proportions of agriculture between 1999 and 2002 in buffers beyond 250-500m showed only modest increases. This graph illustrates the rapid loss of forest cover in the buffers closest to communities that occurred between 1973 and 1986, as well as how forest loss slowed between 1989 and 1999.

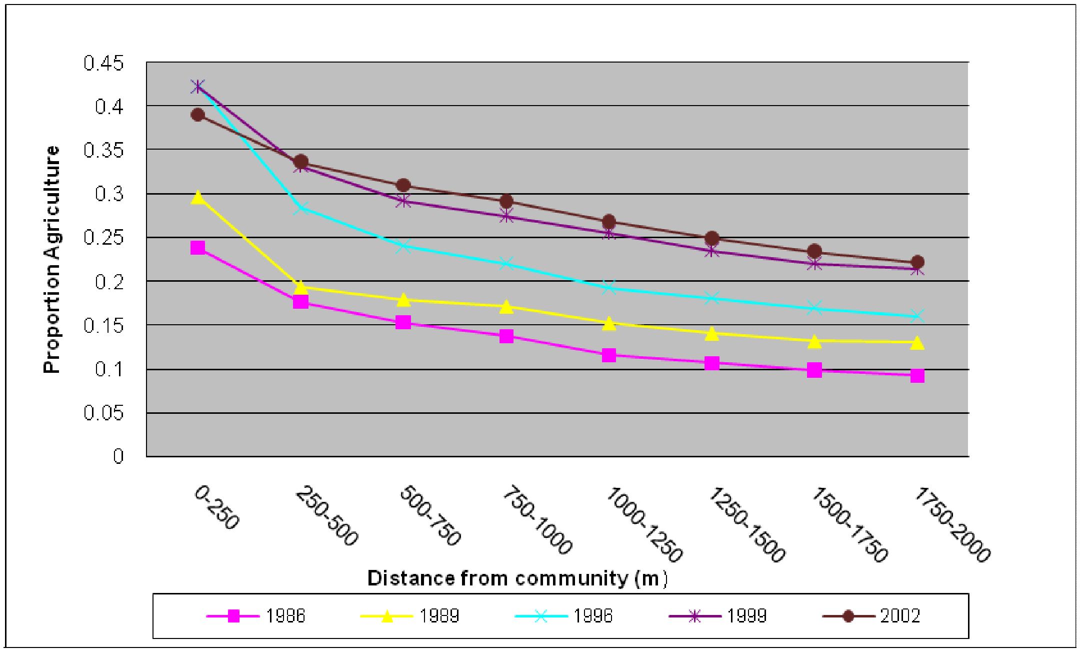

Figure 4.8. Proportion of agriculture in each image year, across all distance buffers.

Figure 4.9 shows a general increase in the proportion of pasture through time and illustrates that a threshold exists (250-500m) beyond which the proportion of pasture remains relatively constant.

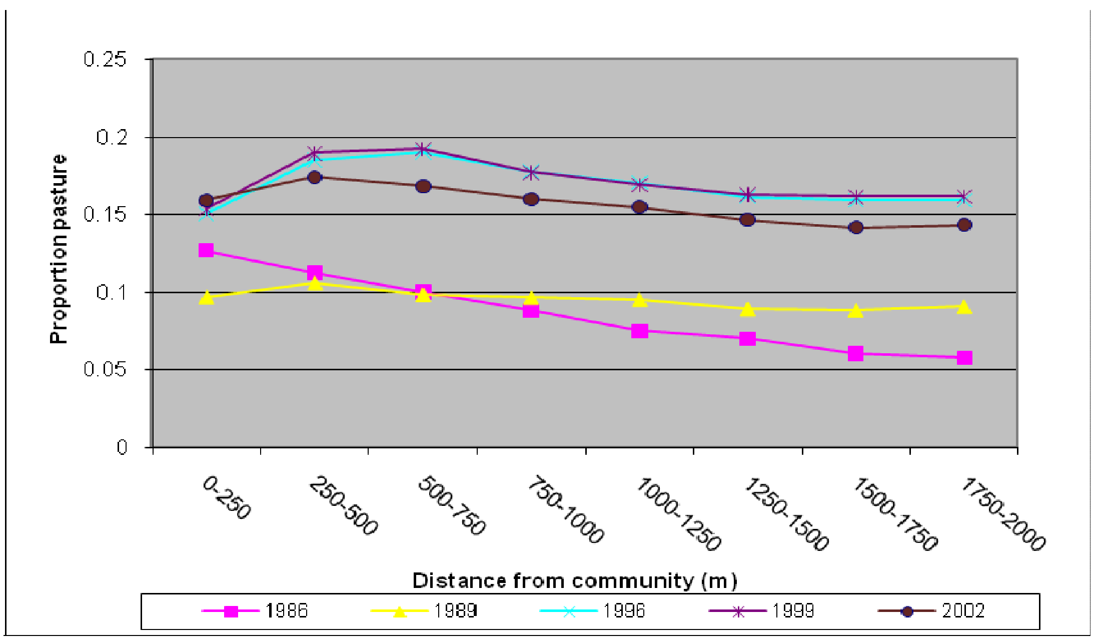

Figure 4.9. Proportion of pasture in each image year, across all distance buffers.

4.7.2.1. **Land Cover Patterns by Community Age Class**

Figures 4.10-4.12 illustrate differences in proportion of forest in communities of varying age. Given that only a single community, Coca, was established previous to 1960, and only three communities (El Triunfo, Union Chimboracense, and Los Angeles) were established in the 1990s, the age classes examined were those for communities established in the 1960s, 1970s, and 1980s. The figures illustrate a consistent pattern of proportion of forest increasing with distance from communities, while decreasing through time. Communities established in the 1960s (Figure 4.10) maintain lower proportions of forest through time than communities established in the 1970s (Figure 4.11) and 1980s (Figure 4.12). Proportion of agriculture decreases with distance from community, though proportion of agriculture increases through time in all but the closest buffers. Across distance and time, proportion of agriculture is slightly less for communities established later (i.e., 1980s vs. 1960s and 1970s). Across all image dates, proportion of pasture is higher in the buffers closest to the communities and decreases slightly with distance.

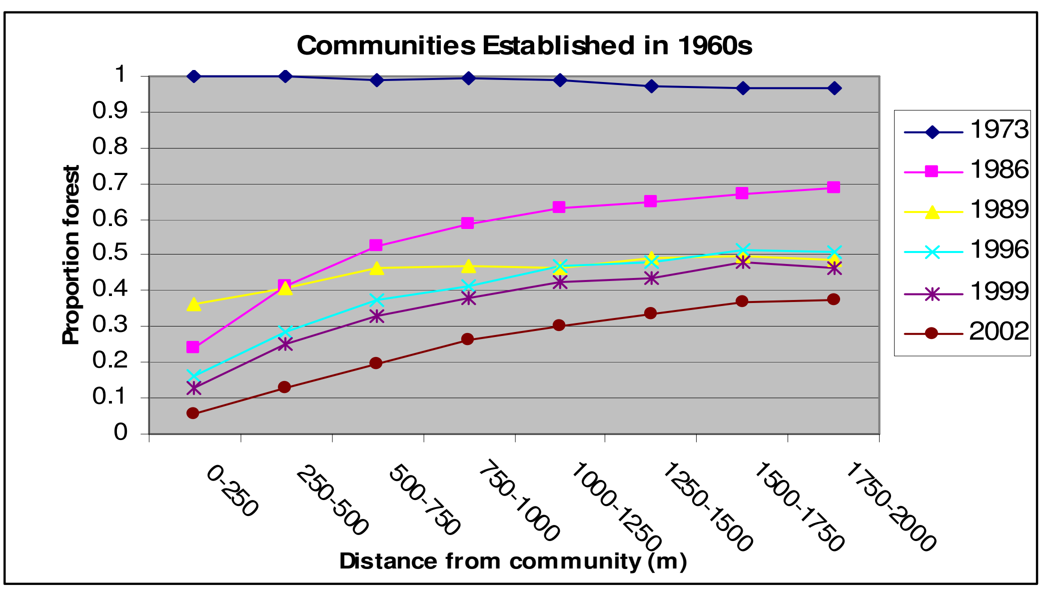

Figure 4.10. Proportion of forest in each image year, across all distance buffers, for communities established in the 1960s.

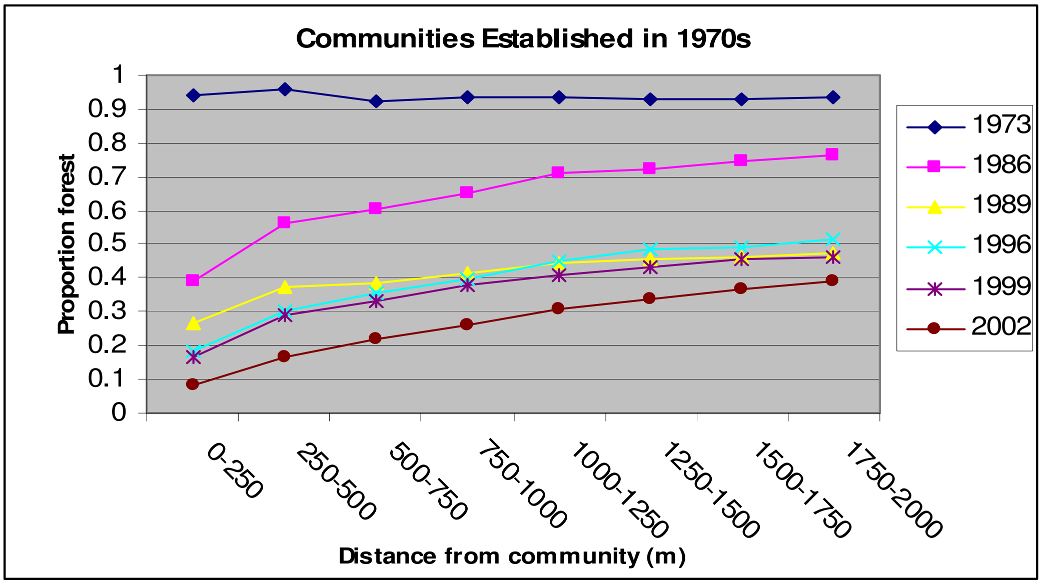

Figure 4.11. Proportion of forest in each image year, across all distance buffers, for communities established in the 1970s.

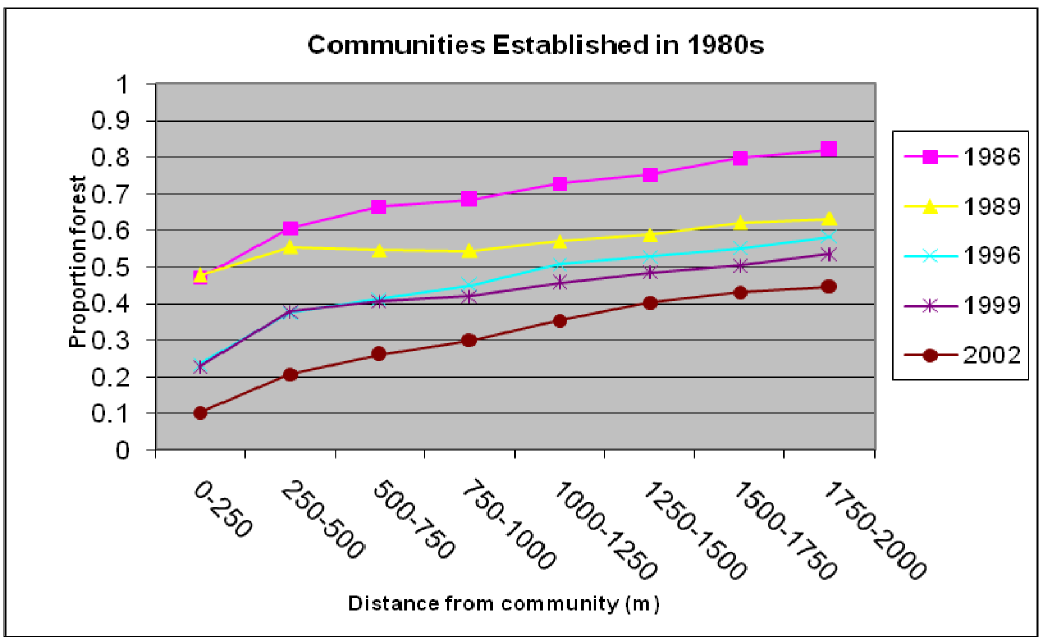

Figure 4.12. Proportion of forest in each image year, across all distance buffers, for communities established in the 1980s.

Examination of trends in forest cover change over time show that the difference in proportion of forest in various distance buffers, however, is small but significant. Thus, despite the fact that proportion of forest is decreasing through time, since the likelihood of forest increases with distance from communities, the likelihood estimates for contrasts between the 0-250 distance buffer and buffers further from communities increase slightly.

4.7.2.2. **Land Cover Patterns by Community Development Level**

Figures 4.13 through 4.15 depict change in forest cover through time (1973-2002). Communities of all levels of development show similar proportions of forest in 1973. However, differences between communities of different development types are clear in 1986, as the most developed communities (Figure 4.13) show lower percentages of forest than communities of either intermediate (Figure 4.14) or low (Figure 4.15) levels of development.

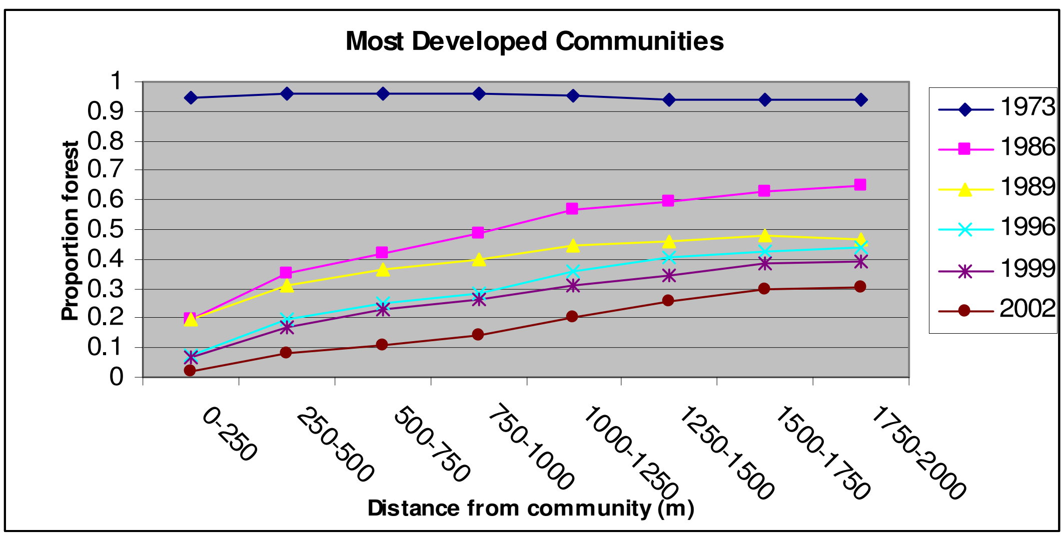

Figure 4.13. Proportion forest in each image year, across all distance buffers, for communities with highest level of development.

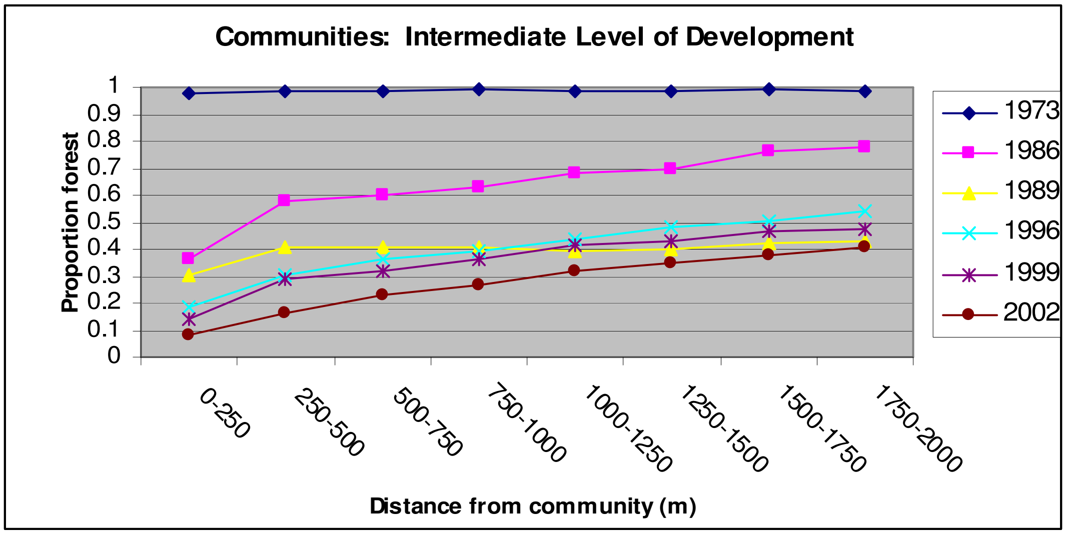

Figure 4.14. Proportion forest in each image year, across all distance buffers, for communities with intermediate level of development.

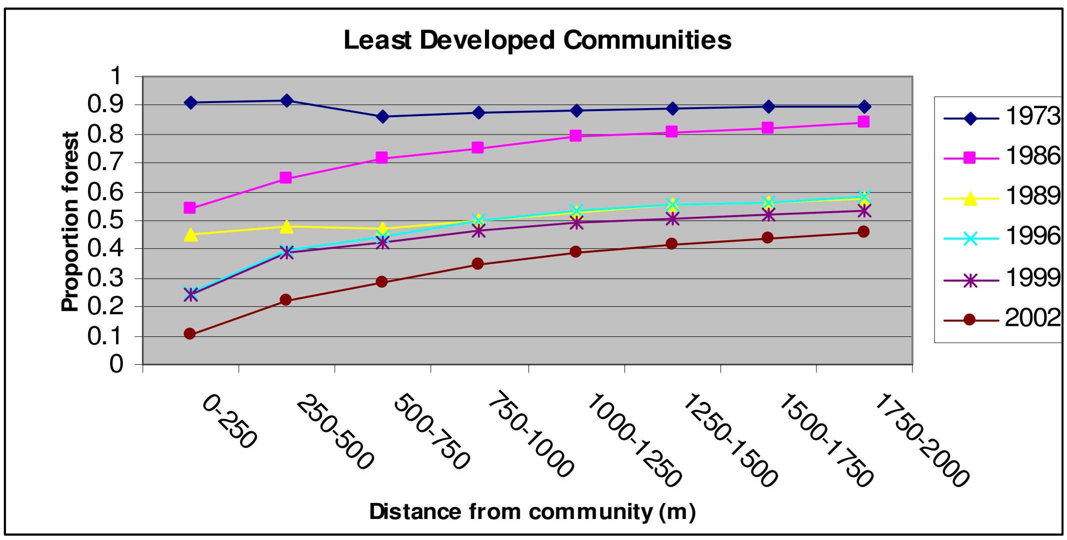

Figure 4.15. Proportion forest in each image year, across all distance buffers, for communities with lowest level of development.

Additional analyses show that across time the proportion of agriculture around communities decreases with distance regardless of level of development. However, the proportion of agriculture around communities of all levels of development increases between 1986 and 1999. Between 1999 and 2002, though, the proportion of agriculture in closest proximity to communities of all development levels decreases.

4.8. **Land Cover Change at the Sector Level**

Table 4.10 tracks land cover change for sector in which survey communities are located for the years 1986-2002. Between 1986 and 2002, sector-level forest percentages decreased, though the decrease was not monotonic; forest patch density increased. The increase in pasture and agriculture percentages provide evidence of agricultural expansion. As sector-level percentages of agricultural and pasture land cover increased, so did their patch densities. Urban expansion through time is also evident in the increase in urban land cover percentages through time.

Table 4.10. Sector-level land cover percentages (PlanD) and patch densities (PD) for 1986-2002.

	1986	**1989**	**1996**	**1999**	**2002**
PlanDForest					
Mean	78.01	47.15	58.37	52.83	46.54
Max	96.68	82.07	85.33	77.20	79.23
Min	28.44	0.97	35.79	32.15	18.33
SD	12.31	23.87	12.12	10.85	15.87
PlanDPasture					
Mean	5.11	7.46	14.40	14.65	13.05
Max	12.60	13.59	19.83	20.43	16.62
Min	0.54	0.26	5.07	6.45	5.98
SD	2.85	3.66	3.72	3.56	3.18
PlanDAgriculture					
Mean	7.65	10.07	13.83	18.30	19.56
Max	17.85	21.23	25.35	25.35	35.98
Min	0.70	1.05	4.28	6.79	6.10
SD	3.89	5.02	4.61	6.22	6.96
PlanDUrban					
Mean	0.64	0.73	0.68	0.59	1.03
Max	3.31	3.72	3.74	2.95	5.69
Min	0.00	0.00	0.00	0.01	0.10
SD	0.77	1.06	0.92	0.80	1.13
PDForest					
Mean	2.45	2.30	8.79	14.56	11.93
Max	6.46	4.93	18.37	29.10	20.51
Min	0.22	0.49	1.68	3.43	3.15
SD	1.63	1.26	4.05	6.85	4.57

Table 4.10. (cont'd)

	1986	**1989**	**1996**	**1999**	**2002**
PDPasture					
Mean	21.21	39.97	47.80	42.42	50.40
Max	38.44	59.50	56.70	51.92	60.27
Min	3.63	1.56	20.50	24.32	26.56
SD	9.03	17.68	8.05	6.88	8.84
PDAgriculture					
Mean	10.51	27.27	29.21	27.05	31.35
Max	18.18	44.26	38.46	38.46	39.86
Min	1.16	1.66	10.43	16.47	15.54
SD	4.53	12.80	6.82	4.32	5.68
PDUrban					
Mean	1.37	0.72	0.84	0.81	2.68
Max	4.66	3.74	4.24	3.56	8.83
Min	0.02	0.02	0.02	0.06	0.76
SD	1.13	0.82	0.92	0.67	1.64

4.9. **Changes in Population and Administrative Boundaries at the *Parroquia* Level**

Table 4.11 and Figures 4.16 through 4.19 describe changes in population and administrative boundaries between 1974 and 2001. Figure 4.16 shows the administrative boundaries of the Northern Ecuadorian Amazon associated with the 1974 census. By 1974, 29 of the 59 communities interviewed in 2000/2002 were established. These communities were located in 8 *parroquias*, Chontapunta (Canton Tena), Puerto Francisco de Orellana (Coca), Limoncocha, and San Sebastian del Coca (Canton Orellana), Santa Cecilia, Dureno, and General Farfan (Canton Putumayo), and Santa Rosa de Sucumbios (Canton Sucumbios).

Population growth in the region between 1974 and 1982 resulted in changes to political-administrative divisions in the Napo province (Figure 4.17). Changes in political-administrative boundaries affected the *canton* and/or *parroquia* with which several of the communities were associated; by 1982 survey communities were associated with 11 different *parroquias*. For example, the creation of *parroquias* El

Dorado de Cascales and Lumbaqui from *parroquia* Santa Rosa de Sucumbios, the creation of canton Lago Agrio from canton Putumayo, and the creation of *parroquias* La Joya de los Sachas and Shushufindi Central from *parroquia* Francisco de Orellana affected surveyed communities.

By the 1990 census, survey communities were associated with 18 different *parroquias* (Figure 4.18) primarily due to the creation of canton Shushufindi from *parroquias* of canton Orellana (Shushufindi, Limoncocha, Pañacocha, and San Roque). Within canton Shushufindi, several new *parroquias* were associated with surveyed communities, including Shushufindi Central, Limoncocha, San Pedro de los Cofanes, and Siete de Julio. Several additional *parroquias* were created by the 2001 census (Taracoa, Jambeli, El Eno, Pacayacu), thus surveyed communities were associated with 22 total parroquias by the time of the 2001 census (Figure 4.19).

Given changes in *parroquia* boundaries between censuses, it is not possible to comment on parroquia-level population change in all cases. Examining canton-level population change, however, shows which portions of the study area have experienced the greatest population changes. The central portion of the study area, consisting of *cantones* Orellana and Putumayo, experienced the greatest population change between 1974 and 1982. Between 1982 and 1990, total population growth was again greatest in the central portion of the study area, though the northwestern portion of the study area added nearly as many people. The central portion of the study area experienced the greatest population change in the 1990 – 2001 intercensal period as well.

Table 4.11. Canton and parroquia-level population for cantons in which surveyed communities are located.

Parroquias	1974 Pop.	Average Annual Pop. Change Rate '74-'82	1982 Pop.	Average Annual Pop. Change Rate '82-'90	1990 Pop.	Average Annual Pop. Change Rate '90-'01	2001 Pop.
Canton Orellana	9,988	13.41	29,189	9.45	54,844[4]	4.38	100,557
Pto. Francisco de Orellana	3,178		8,366		15,199		26,274
Limoncocha	2,808		2,678		3,465		3,819
Panacocha	149		291		218		1,207
Pompeya	1,167		1,758		1,369		1,596
San Roque	122		345		525		2,411
San Sebastian del Coca	2,564		2,001		1,733		3,842
La Joya de los Sachas			9,186		7,453		12,573
Shushufindi Central			4,564		10,870		18,989
San Pedro de los Cofanes					1,784		2,544
Enokanki					3,755		5,529
San Carlos					1,883		2,823
Siete de Julio					2,115		3,214
Dayuma					4,475[5]		11,695
Taracoa							4,041[11]
Canton Putumayo	9,099	13.58	26,969	6.69	46,048	4.18	77,682
Pto. El Carmen del Putumayo	1,119		1,467		1,872		2,130
Dureno	715		5,114[1]		7,308		3,019
General Farfan	22		1,713[1]		4,891		5,542
Palma Roja	478		802		2,066		2,997
Puerto Montufar	92		10				110
Puerto Rodriguez	208		201		182		206
Santa Cecilia	5,961						3,759
Santa Elena	504		626		674		728
Nueva Loja			17,036[1]		25,533		39,924[12]
Cuyabeno					247[6]		316
Tarapoa					3,275[7]		5,185
Aguas Negras							1,142[13]
El Eno							5,593
Pacayacu							6,627
Jambeli							2,324

Table 4.12 (cont'd)

Parroquias	1974 Pop.	Average Annual Pop. Change Rate '74-'82	1982 Pop.	Average Annual Pop. Change Rate '82-'90	1990 Pop.	Average Annual Pop. Change Rate '90-'01	2001 Pop.
Canton Sucumbios	3,509	5.54	5,465	9.76	11,927	2.68	16,015
La Bonita	287		310		464		553
El Playon de San Francisco	849		1,032		1,174		1,255
La Sofia	73		40		51		86
Rosa Florida	167		57		47		304
San Pedro de los Cofanes	152		318				
Santa Barbara	729		838		705		505
Santa Rosa de Sucumbios	1,252		15		280		422
El Dorado de Cascales			1,597[2]		2,959[8]		4,602
Sevilla					1,775[8]		2,385
Lumbaqui			1,258[2]		1,736[9]		1,702
El Reventador					1,198		1,125
Gonzalo Pizarro					1,093		2,278
Puerto Libre					445		798
Canton Tena	29,712	6.85	41,071[3]	4.79	55,246	4.64	80,093
Tena	5,434		9,400		13,790		22,965
Ahuano	2,259		3,143		3,778		4,773
Archidona	5,757		4,983		5,758		8,305
Avila	743		1,542		4,482		2,902
Carlos Julio Arosemena Tola	1,837		1,739		1,780		2,943
Cotundo	3,244		4,150		3,205		6,793
Chontapunta	1,962		3,869		7,056		6,298
Loreto	831		1,252		905		1,811[14]
Pano	1,496		1,859		2,399		913
Pto Misahualli	1,954		2,950		3,579		4,369
Puerto Nuevo	3,003		3,101		3,365		4,389
San Pablo de Ushpayacu	1,192		3,083		3,295		3,453
Puerto Murialdo					1,854[10]		1,967
Talag							2,300
San Jose de Payamino							2,782
San Jose de Dahuano							3,333
San Vicente de Huaticocha							67

1 Canton Lago Agrio formed from Canton Putumayo; includes parroquias Nueva Loja, Dureno, and General Farfan
2 Parroquias El Dorado de Cascales and Lumbaqui formed from parroquia Santa Rosa de Sucumbios.
3 Canton Tena creates Canton Archidona from parroquias Archidona, Avila, Cotundo, Loreto, and San Pablo de Ushpayacu.
4 Canton Orellana subdivides to create cantones Shushufindi and La Joya de los Sachas. Parroquias Shushufindi, Limoncocha, Pañacocha, San Pedro de los Cofanes, and Siete de Julio comprise canton Shushufindi. Parroquias La Joya de los Sachas, Enokanki, Pomeya, San Carlos, and San Sebastian del Coca comprise canton La Joya de los Sachas.
5 Parroquia Dayuma formed within canton Orellana.
6 Parroquia Cuyabeno acquired from canton Aguarico.
7 New parroquia formed within Canton Lago Agrio.
8 Canton Cascales formed from parroquias El Dorado de Cascales and Santa Rosa de Sucumbios; new parroquia Sevilla formed within canton Cascales.
9 Lumbaqui becomes part of canton Gonzalo Pizarro; other parroquias include El Reventador, Gonzalo Pizarro, and Puerto Libre.
10 New parroquia created within canton Archidona.
11 New parroquias formed from canton Orellana.
12 Canton Lago Agrrio forms new parroquias, El Eno, Pacayacu, Jambeli, and Santa Cecilia.
13 Parroquia Aguas Negras is created from parroquia Tarapoa. New canton Cuyabeno is formed from parroquias Cuyabeno, Tarapoa, and Aguas Negras.
14 Loreto becomes a canton of province Orellana; its parroquias are Loreto, San Jose de Payamino, San Jose de Dahuano, and San Vicente de Huaticocha.

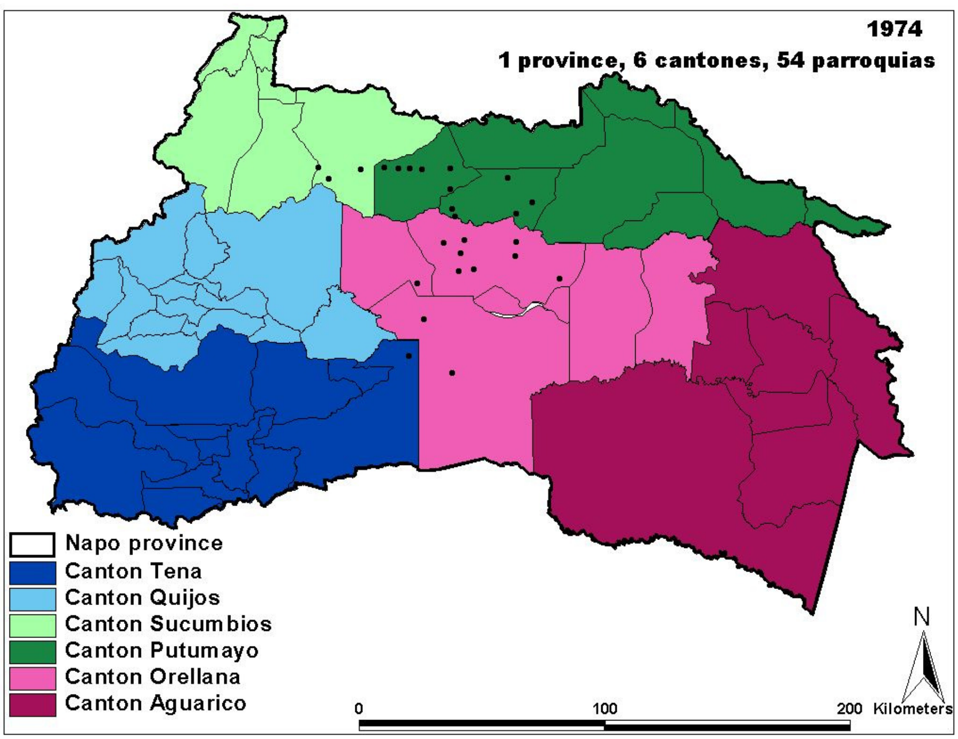

Figure 4.16. Administrative boundaries for Napo province associated with the 1974 census.

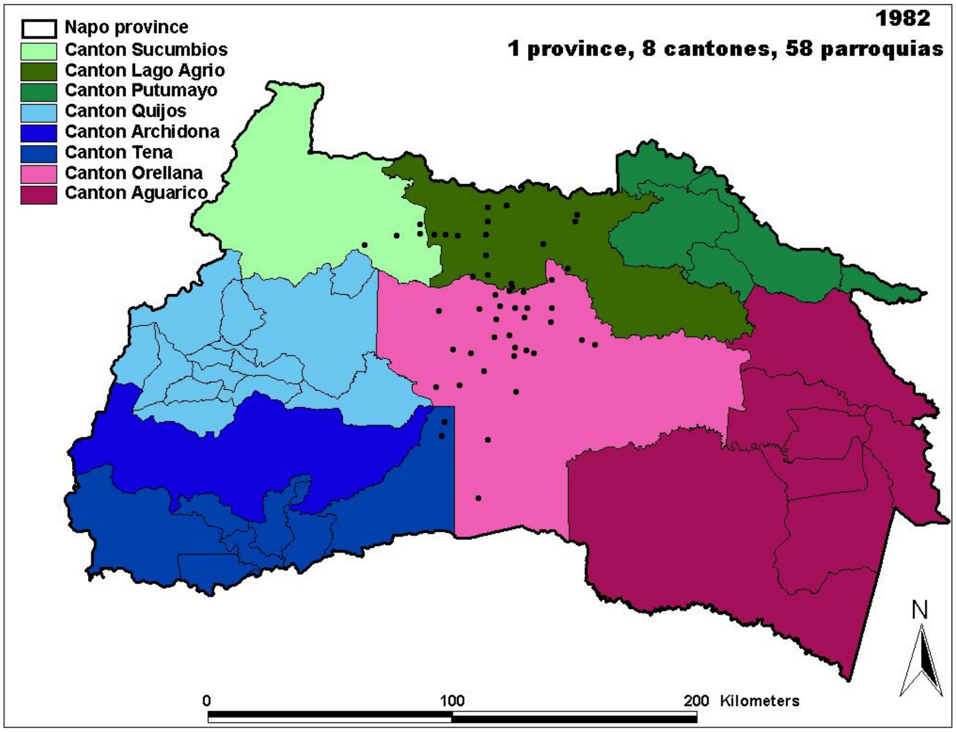

Figure 4.17. Administrative boundaries for Napo province associated with the 1982 census.

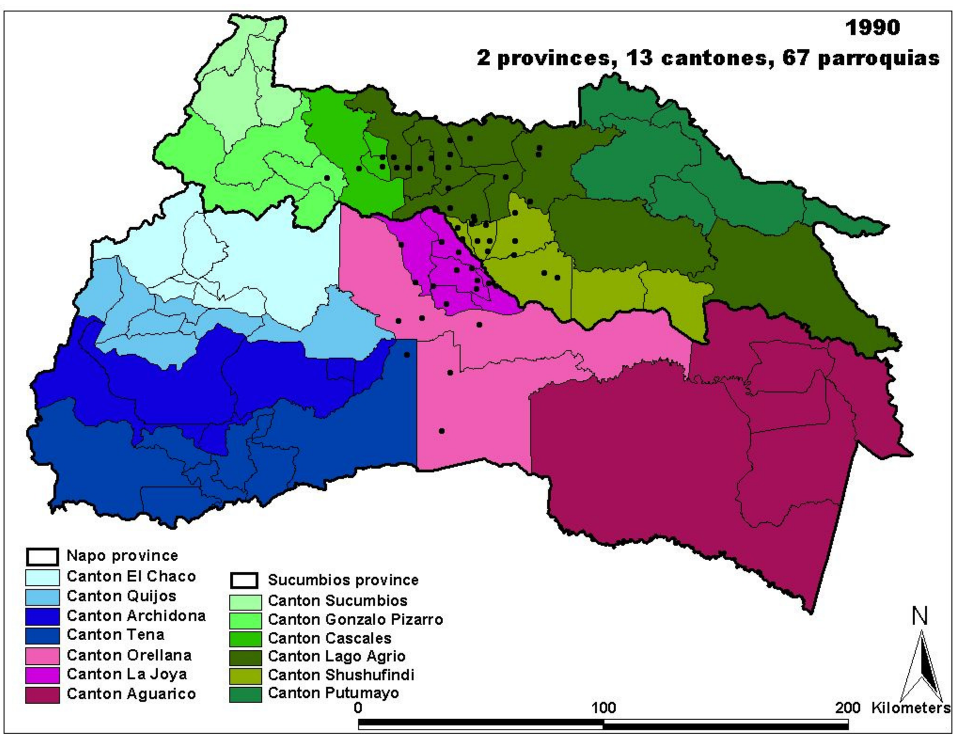

Figure 4.18. Administrative boundaries for Napo and Sucumbios provinces associated with the 1990 census.

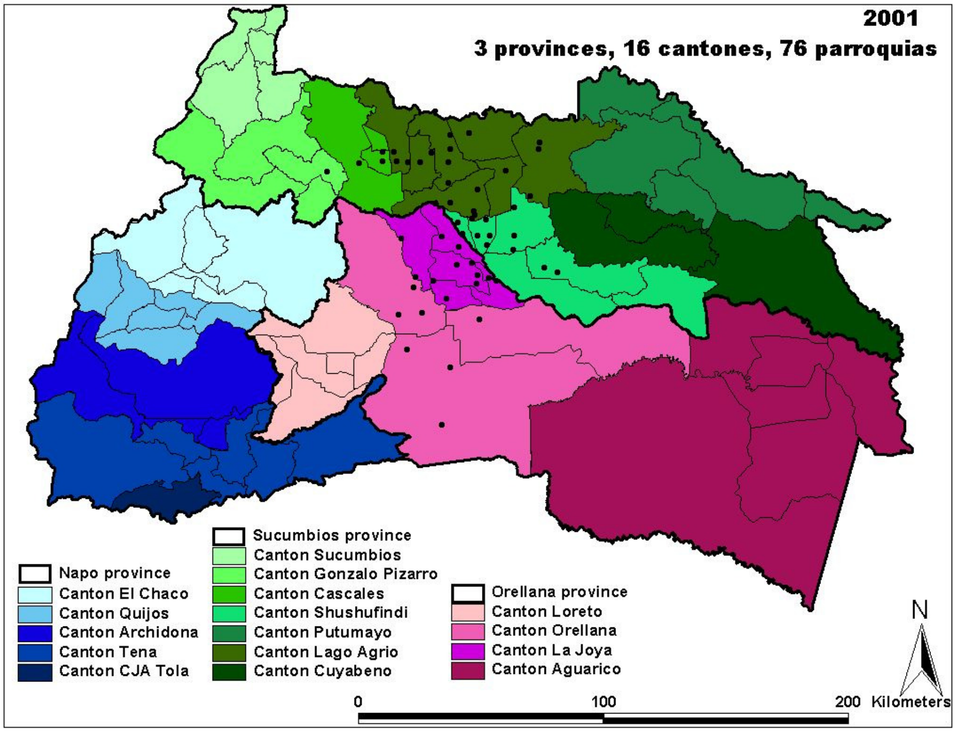

Figure 4.19. Administrative boundaries for Napo, Sucumbios, and Orellana provinces associated with the 2001 census.

4.10. **Discussion**

The land cover trends observed between 1973 and 2002 were not altogether unexpected, but examining trends across all image years, for individual years, and by distance from community, age of community, and level of development did prove revealing. While forest decreased across all image years and agriculture and pasture increased, the patterns with distance from communities showed an increase in forest and a decrease in agriculture; pasture increased up to a certain distance, then maintained a consistent percentage. Thus, while migration into the Amazon prompted deforestation and accompanying settlement and population growth maintained forest losses and encouraged agricultural expansion, land cover changes were modified by distance from community.

Agriculture's decreasing share of the landscape with distance is in line with agricultural location theory, as areas closer to communities should experience lower product transport costs. Note, however, that the level of detail afforded by the remote sensing imagery does not allow discrimination between products with varying levels of perishability. Thus, rather than being able to comment on the patterns associated with various types of agricultural products, one may only note that the closer plots are more likely to exhibit agricultural expansion than are plots further from communities. The land cover patterns seen for pasture may also be discussed with reference to agricultural location theory, as products greater in bulk are more likely to be produced nearer to communities. Pasture land cover, with its tendency to increase until a threshold distance from the community is met, may be related to low costs of transport (i.e., herding) within a certain distance from communities.

Examining land cover proportions by level of development illustrates how different types of communities impact the landscape in different ways. The communities in the "most developed" category include those with the greatest array of services and the bulk of the communities highest in population. A higher proportion of the most developed communities that support coffee roasters, sawmills, rice huskers, and all the study area's agricultural and animal markets, are located in these "most developed" communities. Given the characteristics of the most developed communities, it is not surprising that these communities have lower proportions of forest and higher proportions of agriculture and urban land covers over time than their less developed counterparts (Table 4.7). Differences in land cover proportions between community development types were significant in most cases, particularly for contrasts between the most and least developed communities, though differences between communities in the most and intermediate development categories on forest and pasture classes were not significant (Table 4.8). The existence of significant differences among land cover patterns for communities in different development classes highlights the usefulness of this classification scheme in examining the impact of communities in the northern Ecuadorian Amazon on the surrounding landscape.

While levels of development proved a useful way of categorizing communities to examine their impact on the landscape, community age provided another interesting method. Examining communities according to their date of settlement provided a way to examine whether land cover trends around communities as they develop are similar across time. Results indicate that forest percentages are highest in communities most recently established, and agriculture percentages highest in communities with earlier dates of establishment (Table 4.9). Communities established earlier have had longer to grow in population, expanding in terms of both their direct and indirect impacts on the landscape. The patterns seen in forest and agricultural land cover may be attributed to the indirect effects of communities as they grow in population and increase local demand for crops, animal goods, and wood. In addition, creation of *solares,* small lots with agricultural plots and limited forest cover, in proximity to some of the most developed communities may also contribute to the patterns seen in forest and agricultural land covers.

Examining individual image years for land cover patterns associated with communities in different age classes tells an interesting story as well. Results show that communities of various ages do indeed experience similar land cover change trajectories over time. This is helpful to know when considering how to model land cover changes in the Northern Ecuadorian Amazon. Such results indicate that cellular automata or agent-based models could parameterize communities in different age classes in similar ways.

Given the proclivity of those interested in landscape ecology to examine scale, pattern, and process, it is important to address how these issues played out in this study. Scale was incorporated into this study by examining land cover change in the areas around surveyed communities as well as in the sectors in which they were located. Sector-level land cover patterns show the same trends as observed in proximity to communities, indicating that the processes operating at each scale are similar.

Relating land cover change patterns to population change was, however, slightly more complicated. From the remote sensing point of view, difficulties associated with cloud cover make it impossible to examine canton- and parroquia-level land cover changes over time for those cantons and parroquias in which our surveyed communities are located. In terms of population data, an additional, lower level of population data, the census sector, is available starting with the 2001 census. The imagery used in this study provided census sector-level land cover data with low cloud cover percentages for all but a few of the surveyed communities. However, given the association of census sector-level population data with only the most recent census, it is thus impossible to link such fine-level population data with land cover changes through time. The most detailed linkage between population data and land cover change that could be expected may be derived from either coupling cloud-free (or nearly so) images with parroquias whose boundaries have not changed between census dates or from examining correlations between census sector-level population and land cover data.

4.10. **Conclusions**

The results presented here provide a measure of the impacts of communities in the Northern Ecuadorian Amazon on their surrounding landscape over time, validate agricultural location theory, and provide evidence that communities impact the landscape in similar ways as they age, and at different intensities depending on their level of development. This work is significant in that it provides greater knowledge of direct as well as indirect impacts of communities on LULC change, increases understanding of urbanizing areas in the NEA, and contributes to Land Change Science (LCS) literature.

Despite the knowledge gained in examining buffers around these communities, pattern around these communities should be explored in additional ways, most importantly in terms of the primary roads associated with each community. Buffers around roadways at the depth of typical farms (2000 m) would provide a measure not only of the patterns generated by farms in proximity to these communities, but also provide a way of examining patterns at various distances from the main roads in the northern Ecuadorian Amazon (Nueva Loja-Quito, Nueva Loja-Coca, Jivino Verde-Shushufindi).

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CHAPTER 5

INCORPORATING COMMUNITY EFFECTS IN THE CHARACTERIZATION OF HOUSEHOLD-LEVEL LAND USE/LAND COVER DYNAMICS IN THE NORTHERN ECUADORIAN AMAZON

5.1. **Introduction**

Colonization of the Ecuadorian Amazon primarily resulted from agrarian reform pursued by the Ecuadorian government beginning in the 1950s (MacDonald 1981) that was meant to serve as a "pressure valve" to diffuse tensions surrounding land tenure in the coastal and highland provinces (Uquillas 1984; Oberai 1988; Pichón and Bilsborrow 1999). More importantly, spontaneous migration into the region resulted from development of the nation's oil reserves. Oil was discovered by Texaco in the Northern Ecuadorian Amazon (NEA) in 1967. As the oil companies Texaco and Gulf built roads into the region to facilitate exploration and transport of oil, migrants began streaming into the area, claiming land for farms along the recently built roads. The *Instituto Nacional de Reforma Agraria y Colonización* (IERAC), an organization established by the Ecuadorian government and charged with carrying out agricultural land reform, legitimized this process of claiming land, granting provisional title (*certificado de posesión*) to settlers once they presented evidence of land clearing for agriculture (Murphy 1998). Since the early 1970s, the NEA (Figure 5.1), currently comprised of the provinces of Napo, Sucumbios, and Orellana, has gained population at rates much higher than the southern portion of the Ecuadorian Amazon as well as the rest of the country.

As a result, the NEA has experienced intense land use/land cover (LULC) change over the last 40 years. With the discovery of oil, attendant road construction, and spontaneous migration of colonists seeking land, the region has experienced rapid deforestation and agricultural extensification. The spatial pattern of such LULC change is of great interest, as it impacts ecological goods and services, such as biodiversity, nutrient flux, and carbon budgets, as well as climate change and human behavior through the interaction between pattern-process relations and human-environment interactions.

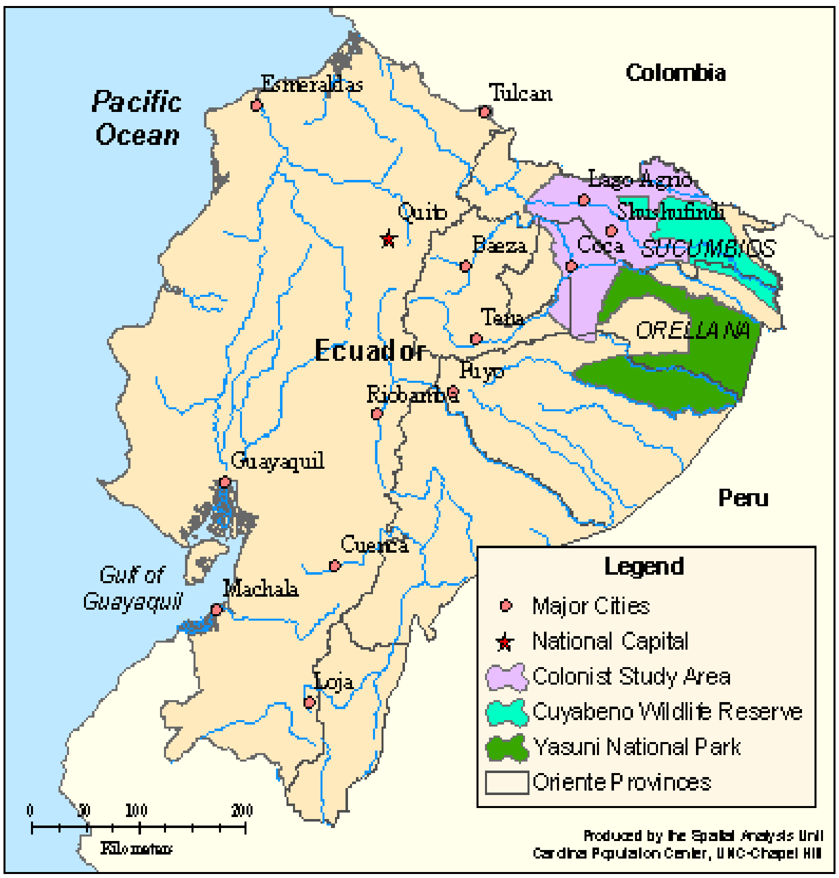

Figure 5.1. Colonist study area, the NEA, within the country of Ecuador. The study area encompasses portions of the provinces of Napo, Sucumbios, and Orellana.

This study focuses on characterizing the pattern, process, and change of LULC on *fincas*, or farms, in the NEA. The farm is the areal unit of social-ecological analysis, the household is the demographic unit of analysis, and communities are used to define central places, while the 30-m pixel is used to characterize LULC dynamics on farms, or *fincas*. The theoretical bases for this work are rooted in landscape ecology, with its ability to characterize interactions among scale, pattern, and process; central place theory, that addresses the direct and indirect impacts of communities on LULC change on *fincas*; and Land Change Science, that describes the drivers of change, particularly deforestation and agricultural extensification. The central approach followed in this research is to model LULC patterns across time and space at the *finca*-level, while incorporating community-level effects, by employing cross-sectional multivariate linear models that adjust for clustering of observations within communities. This work contributes to our understanding of LULC patterns in the NEA by providing greater accounting of the indirect impact of communities on LULC change. This work also contributes to prior work in the NEA by extending previous models of land use at the *finca*-level that have aimed to incorporate community effects (e.g., Pan and Bilsborrow 2005) by introducing new measures of the influence of nearest and market communities on LULC patterns. The sections that follow describe previous work, the theoretical and methodological background for this work, the datasets used, results of the remote sensing and statistical analyses, discussion of results, and conclusions drawn from the analysis.

5.2 **Previous Work**

Previous work focused on this study area has modeled LULC by referencing survey measures of land use from the 1990 (Mena 2007, Pichón and Bilsborrow 1999, Pichón 1997a, Pichón 1993) and 1999 household surveys (Pan and Bilsborrow 2005, Pan 2003), as well as LULC information derived from remote sensing (Pan et al. 2004). Previous work utilizes a variety of model structures. For instance, Pichón (1993, 1997a) utilized ordinary least squares and Tobit regression techniques, while Pichón and Bilsborrow (1999) discussed the use of seemingly unrelated regression. Pan (2003) used a general linear multivariate model in predicting farm-level land use patterns, Pan and colleagues (2004) implemented a generalized linear mixed model, and Pan (2003) and Pan and Bilsborrow (2005) analyzed multilevel models as predictors of farm-level land use. Pan and colleagues (2007) utilized ordinary least squares, random effects, and spatial regression models, and Mena (2007) used a geographically-weighted regression model to account for LULC change on household farms. Each of the modeling approaches address the issue of spatial autocorrelation in the clustering of farms in development sectors.

The hypothesized influence of communities on *finca*-level LULC prompted efforts to introduce community effects into statistical models, as communities are thought to exert an influence on household decision-making in surrounding areas through transportation linkages, off-farm employment, commerce, institutions, and agricultural product markets (i.e., crops and animals). Pan (2003), Pan and colleagues (2004), Pan and Bilsborrow (2005), and Pan and colleagues (2007) incorporated community effects by utilizing distance (i.e., Euclidean and network) from the farm to the nearest community and to primary market communities (i.e., Lago Agrio, Coca, Shushufindi, and La Joya de los Sachas). The general linear multivariate and multilevel models employed by Pan (2003) included independent variables such as road access to the finca, distance to the road, and distance to the nearest community, distance to central places (Lago Agrio, Coca, Shushufindi, and La Joya de los Sachas), and indicators of the existence of a coffee roaster, civil registrar, health center, and shops or restaurants in the community nearest to the *finca* (the multilevel model omits the existence of a health center as a variable). Pan and colleagues (2004) utilize a similar set of variables to Pan (2003), including independent variables such as road access to the *finca*, distance to the road, and distance to nearest community, while adding variables for network and Euclidean measures of distance to the reference community mentioned in the 2000 community survey. Pan and Bilsborrow (2005) continue to use independent variables describing road access to the *finca*, walking distance to the road, distance to nearest community, and the existence of electricity, a civil registrar, coffee roaster, health center, and shops and restaurants. Additional community variables incorporated by Pan and Bilsborrow (2005) include distance to the nearest of the four central places (i.e., Lago Agrio, Coca, Shushufindi, and La Joya de los Sachas), community population, the year founded, and the existence of piped water, a nurse, transportation by canoe, bus, or *ranchera*, and the existence of distance or technical schools in the nearest community. Pan and colleagues (2007) focused on road access, distance to road, and distance to nearest major city.

5.3. **Theoretical Background**

5.3.1. **Landscape Ecology**

Landscape ecology theory examines the relationship between spatial pattern or structure and landscape process at a variety of space and time scales. Landscape patterns, produced by the interaction between the abiotic environment, biotic processes, and disturbance regimes, can be examined through measures of composition (e.g., number and proportions of patch types, evenness of their areal distribution) and/or configuration (e.g., spatial location, arrangement with regard to other patch types, shape complexity) (O’Neill et al. 1988, Gustafson 1998). Understanding the processes producing patterns is necessary to guide landscape management (Levin 1992) and to assess the causes and consequences of landscape dynamics.

Pattern metrics are used to assess landscape pattern by quantifying spatial organization or structure at the class, patch, and landscape-level. Typical pattern metrics include measures of area, shape, connectivity, and diversity (O'Neill et al. 1988; Crews-Meyer 2002). Many pattern metrics are correlated, as the metrics are based on a small number of measurable patch characteristics, including patch type proportion, area, edge, and connectedness; they should, therefore, be chosen carefully to represent the factors of interest and to avoid duplicating the effects of interest (Riitters 1995).

Scale in landscape ecology is characterized by grain and extent. Grain is defined as the spatial resolution of the data, and extent as the size of the study area or length of time under consideration. Ecological processes vary in importance as well as in their effects at different scales (Risser et al. 1984), spatial as well as temporal. As such, these processes may be termed scale-dependent (Turner 1989, Walsh et al. 1999, Walsh et al. 2001). Scale dependence implies that patterns or processes may vary depending upon the grain or extent of the study. Scale dependence can affect study results depending upon the precision with which the study area and associated spatial and temporal scales are defined, the nature of the variables examined (e.g., local-scale biophysical variables versus more broadly defined variables such as deforestation), and the effort made to scale from the local to the regional (Gamble and Meentemeyer 1996).

Hierarchy theory is implicated in the study of scale as processes that operate at a particular spatial or temporal scale may affect processes at other spatial and temporal scales

(Walsh et al. 1998). Hierarchy theory also highlights the importance of examining a range of scales in any study (Walsh et al. 1998, Walsh et al 1999, Turner et al. 2001, Walsh et al. 2001). A focal or "characteristic" scale for the research is identified by the research question; the scale above the characteristic scale provides context, whereas the scale below the characteristic scale provides information about processes or mechanisms at the focal level.

5.3.2. **Direct and Indirect Effects of Communities on Landscape Patterns**

A community affects landscape pattern both directly and indirectly (Schumann and Partridge 1989, Ozorio de Almeida 1992, Moran 1993, Furley 1994). Direct change is observed through community establishment and growth or expansion, whereas indirect effects are LULC changes in more distant areas created by the geographic "reach" or influence of communities. Community effects on an "area of influence" may be attributed, for instance, to (a) elevated local demand for crops, animal goods, and wood products as urban population grows; (b) national- or international-level demand for goods such as coffee or cacao that is transmitted through prices offered to growers for their crops; (c) attractiveness of *solares* (i.e., small lots close to communities) for settlement; (d) loans and technical assistance, that influence or enable land use changes, provided by banks or government offices; and (e) development of new transportation routes that increase geographic accessibility of a place, thereby redefining "reach."

Communities may act as service centers and thereby indirectly impact the landscape. Communities that provide services such as bus transportation facilitate movement of people and products in a multidirectional fashion between households, communities, and other locales. Transport, from buses as well as smaller, open-sided vehicles called *rancheras*, is extremely important in the NEA, as the region is sparsely populated and few households own vehicles. Access to such transportation, particularly to towns with agricultural or animal markets (and other services), may affect household behavior and farm-level land use decisions. In addition, the availability of off-farm employment in communities creates opportunities for cash earnings and possibly accumulation of household wealth and assets (Murphy et al. 1997), which may in turn also affect land LULC through access to technology, such as chainsaws or fertilizer, or by providing money to invest in establishing or extensifying crop or pasture lands.

5.3.3. **Drivers of land cover change**

5.3.3.1. **Deforestation**

Drivers of deforestation are many and varied, often conceptualized in terms of proximate or underlying (distal) factors. Proximate factors are defined as factors that directly alter LULC land cover; underlying causes underpin the proximate causes and operate at local, national, or global scales (Geist and Lambin 2001; Lambin et al.2003). Proximate causes of deforestation include agricultural expansion through shifting cultivation or pasture creation, wood extraction associated with commercial logging or household use, extension of road or market (i.e., crops, animals, wood) infrastructure, and clearing associated with extractive industries such as oil or mining (Pichón 1992; Allen and Barnes 1985; Kaimowitz and Angelsen 1998; Geist and Lambin 2001; Geist and Lambin 2002). Shifting cultivation has often been cited as a primary cause of deforestation (Amelung and Diehl 1992; Myers 1993; Angelsen 1995; Ranjan and Upadhyay 1999) in tropical forests, but Geist and Lambin

(2001) state that it operates mainly in a synergistic manner in conjunction with other proximate factors. Examples of variables cited as underlying causes include economic, demographic, and policy/institutional factors such as commodity prices, growth of urban populations or increases in rural density, settlement schemes, and tenure security (Geist and Lambin 2001; Wood 2002; Brondizio et al. 2002; Laurance et al. 2002), all of which may shape demand and market processes. Expansion of road infrastructure can also serve as an underlying cause by facilitating agricultural colonization of an area (Carr 2001). Biophysical variables that serve as underlying factors include topography, soil quality, location of water sources, and pests (Kaimowitz and Angelsen 1998; Geist and Lambin 2001; Laurance et al. 2002).

Drivers determined to be important in studies of deforestation in the Amazon include population growth and agricultural expansion (Skole and Chomentowski 1994), agricultural labor force (Southgate et al. 1991; Pichón 1997a; Pan et al. 2001), tenure security (Southgate et al. 1991; Pan et al. 2001), road accessibility (Pichón 1997a; Mena et al. 2006), length of settlement (Pan et al. 2001; Pichón et al. 2002), technology (Pichón 1997a), and biophysical factors such as soil fertility and topography (Pichón 1997a; Pan et al. 2001).

5.3.3.2. **Agricultural Extensification**

Both Chayanovian theory and household life cycle theory have been offered as useful frameworks for examining the relationship between household demographics and land clearing in agricultural frontiers. Chayanovian theory relates household demographic characteristics, specifically age composition, to available labor and related LULC changes, particularly agricultural expansion (Ellis 1993; Thorner et al. 1986). Chayanov's theory assumes that 1) the household does not hire labor or participate in outside work, 2) access to land is flexible (i.e., the opportunity exists to expand cultivation with increasing available labor), 3) farm output may be used for subsistence as well as market purposes, and 4) household production is motivated by social norms concerning the minimum acceptable level of consumption/income (Ellis 1988). The life cycle concept is integral to Chayanovian theory, as the age of the household head as well as the ratio of producers to consumers (i.e., estimated from household numbers of children, working adults, and elderly) influence the amount of cultivated land.

Household life cycle theory focuses on family life as a series of evolutionary stages that have implications for LULC change. The household life cycle perspective has been employed extensively in the Amazon to examine the effects of demographic processes on land use (e.g., see; Barbieri et al. 2006, Moran et al. 2003, McCracken et al. 2002, Walker et al. 2002, Perz 2001, Marquette 1998, Walker and Homma 1996). Stages in the household life cycle are determined by age of the household head and the ratio of producers to consumers (factors cited by Chayanov's theory), as well as the use of hired labor and the existence of off-farm income (Walker et al. 2002). Household life cycle theory describes how a young family claims land, clearing it slowly at first, then more quickly as children transition from dependents to laborers. Young families, with less available labor, clear forest primarily for annual crops, though as the their households age and more labor is available, extensification of cropland to incorporate perennials, development of pasture lands, and intensification of agricultural production or engagement in off-farm employment are possible. As young adults leave the farm, the corresponding decrease in available demand and labor results in less cropped area and increased focus on cattle raising, given its low labor requirement. If older children instead stay on the farm and start their own families, additional agricultural extensification for subsistence is expected.

5.4. **Methodological Background**

5.4.1. **Pattern metrics**

The term “pattern metrics” refers to a group of indices that have been developed for evaluation of categorical maps (McGarigal 2002). Landscape pattern metrics focus on the composition and spatial configuration of the classes included in categorical maps and thus the spatial and geometric properties of these maps. Pattern metrics are commonly defined at three levels, the patch, class, and landscape. Patch-level metrics are defined for individual patches and characterize their spatial character and context, while class-level metrics examine all the patches of a particular type, producing an average or weighted-average value depending on whether large patches contribute more heavily to the index. Landscape-level metrics are integrated over all the class types over the extent of the data, producing an average or weighted average value. Limitations of pattern metrics include redundancy in information due to correlation between metrics (Riitters 1995), as well as sensitivity to the level of detail in categorical map data (Li and Wu 2004). In addition, care should be taken in analyzing pattern metrics, as interpretation requires an understanding of the methods of spatial pattern analysis as well as the concepts from which the methods were developed (Li and Wu 2004).

5.5. **Data**

5.5.1. **Household Survey**

Household surveys were administered in 1990 (Pichón 1993) and 1999 (Bilsborrow 2002). The sampling design for the household surveys was based upon information provided by IERAC, the Ecuadorian land titling agency, about settlement areas (sectors) and the number of *fincas* in them; a two-stage sampling design was employed to obtain a representative random sample of farm plots settled by migrant families. First, a sample of 64 sectors was selected from the 275 existing sectors. Then a group of 5 to 10 contiguous *fincas* was selected from within each of the sectors based on the sector's size. The first household survey, undertaken in 1990 by Richard Bilsborrow and Francisco Pichón, selected 480 *fincas*. Although the refusal rate was only 3 percent, some *fincas* were abandoned and one sector could not be located; the final sample was comprised of 408 *fincas* occupied by 418 farm households and represented a 5.9 percent sample of the colonist plots in the main colonization area (Pichón 1997b). In 1999, the 408 *fincas* were re-visited, and all farms and new subdivisions at those locations interviewed, resulting in 950 questionnaires being administered to the heads of household living on the original *fincas*, or *finca madres*, producing a sample of 823 farms. Given a 7 percent refusal rate, the final sample was comprised of 767 farms and 708 associated households, as well as 111 *solares*, or small housing lots, that resulted from subdivision and parcelization. The location of each *finca,* its subdivisions, and dwellings was recorded with GPS.

A detailed questionnaire was administered to the head of the household and spouse separately. The questionnaires were modified somewhat between the 1990 and 1999 data collections. The head of household questionnaire gathered information on migration history and background, land acquisition and tenure, land use, farm production and inputs, and off-farm employment. The spouse provided data on household roster, migration background, emigration from the household, fertility, mortality, and health. Perception of and attitudes about local climate, soil quality, and forests were assessed for both the household head and spouse.

5.5.2. **Community Survey**

In 2000, community-level interviews were developed and implemented to provide context, evaluate change that occurred between 1990 and 1999, and better define the interactions between households and surrounding communities (Bilsborrow 2002). The community-level questionnaire was administered in 54 communities in 2000, and in several additional communities in 2002, bringing the total number of communities surveyed to 59. The 59 communities range in population from 150 – 34,000 residents. Figure 5.3 shows the locations of surveyed communities in reference to the sectors in which household surveys were conducted.

Communities selected for interviews were chosen on the basis of their spatial proximity to surveyed households as well as the linkages suggested by household-level interviews. The surveys addressed issues including distance and access to reference communities (e.g., where they buy and sell goods, seek education and health services, or obtain spiritual nourishment), principal economic activities, local cultivation and yields, land tenure, facilities and infrastructure, transportation services, prices of basic goods, and types of agricultural and development assistance available. In addition, retrospective questions, designed to assess spatial and temporal changes in these communities since 1990, addressed population growth, in- and out-migration, economic change, and the number and size of farms. In each community, several knowledgeable informants, including community leaders, local farmers, teachers, and health workers, responded to the questionnaires on behalf of their community.

5.5.3. **Classified Landsat TM imagery**

A classified time-series of Landsat Thematic Mapper (TM) images for 1986 and 1999 (Path 9/Row 60) was used in this research. The time-series imagery were classified using a hybrid supervised-unsupervised classification method developed by Messina and Walsh (2001)[1]. LULC classes in these images include forest, pasture, crops, barren, urban, and water. Radiometric corrections were applied, as examination of landscape change over time necessitates radiometric correction so that pixel values are comparable between images (Song et al. 2001). The 5s (Tanre et al. 1990) absolute radiometric correction algorithm was applied to the image time series after the images were converted to top of the atmosphere (TOA) reflectance values.

5.6. **Methods**

5.6.1. **Landsat TM Imagery and Pattern Metrics**

Landsat imagery was resampled to 1m resolution to minimize the area affected by intersection with the *finca* polygon boundary, as pixels coming into contact with a boundary may be discarded if their center does not fall within the boundary. Pattern metrics were

[1] An unsupervised classification was applied first; the spectral signatures generated were evaluated using transformed divergence. The results from the initial unsupervised classification were evaluated, and any classes that displayed confusion were subset and run through the unsupervised classification separately. These new signatures were added to the original signature set; this augmented signature set was used for supervised classification. Training data for the supervised classification were obtained from fieldwork in the study area.

generated by first clipping the 1986 and 1999 TM imagery using *finca* boundaries in ArcInfo Grid, then inputting the clipped GRID files into Fragstats (McGarigal et al. 2002). The metrics chosen for use as dependent variables in this study were selected to represent composition and spatial configuration, while minimizing redundant information. The *percentage of landscape* (PLand) metric describes landscape composition, while *patch density* (PD) and the *landscape shape index* (LSI) describe landscape configuration. The *percentage of landscape* describes the proportion of each land cover class on the landscape. *Patch density* describes the number of patches per landscape area and may be examined on a per-class basis or for the entire landscape; patches were defined according to the 8-neighbor rule (e.g., orthogonal and diagonal cells). The *landscape shape index* describes landscape complexity by calculating the ratio of edge present in the landscape to the value for edge if the landscape were comprised of a single patch. The metrics calculated at each level are listed in Table 5.1.

Table 5.1. Pattern metrics applied to classified imagery at the *finca* level.

Pattern metrics	
Class-level	**Landscape-level**
Percentage of landscape (PlanD)	PD
Patch density (PD)	LSI
Edge Density (ED)	
Landscape shape index (LSI)	

5.6.2. **Models: Variable Description**

LULC patterns are modeled at the farm level, while incorporating community-level effects. Cross-sectional multivariate linear statistical models are generated for 1990 and 1999; multiple models are generated at each time point**.** *Dependent variables* for the cross-sectional models are generated from remote sensing imagery measures of pattern (i.e., proportion of *finca* landscape in forest, agriculture, pasture; patch density; landscape shape index). *Independent variables* are selected to represent *finca*- and community-level drivers of LULC change; these drivers are depicted graphically in Figure 5.2. The independent variables describe demographic, socioeconomic, biophysical, and geographic aspects of the *fincas*. Both the dependent and independent variables are described in Table 5.2.

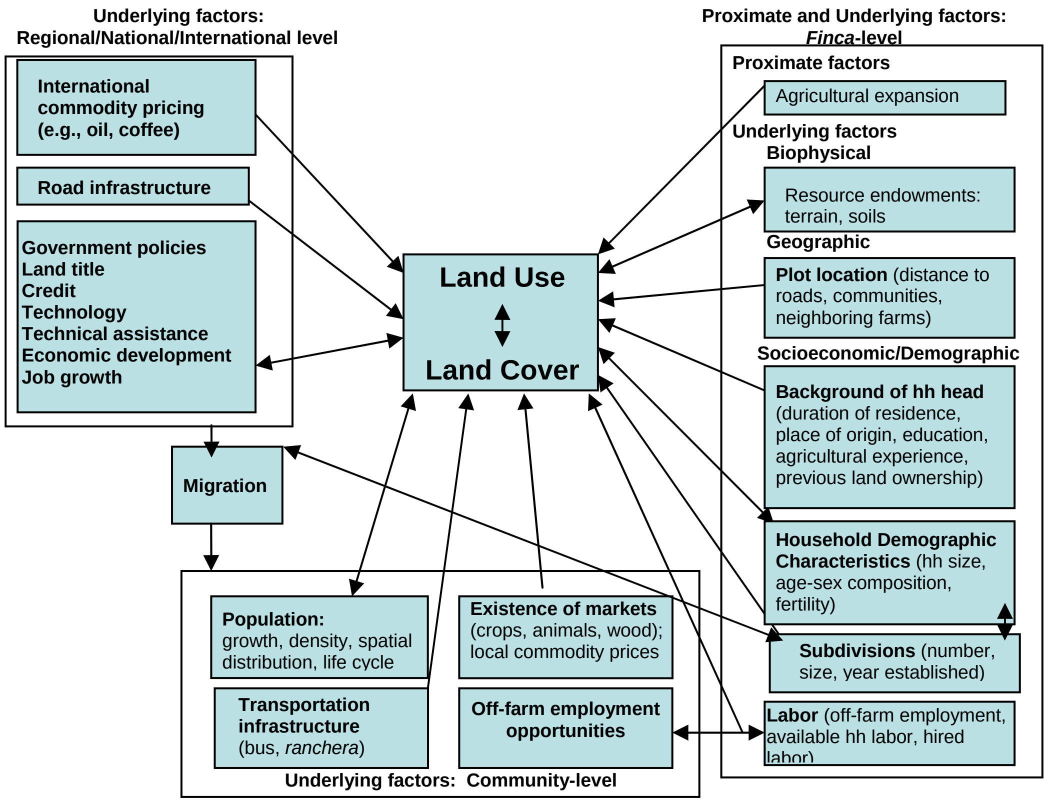

Figure 5.2. Conceptual model of the factors that affect land use in the NEA, after Geist and Lambin (2001) and Rindfuss et al. (2003).

Demographic variables were selected for their ability to represent aspects of the household life cycle (i.e., *males, children*) as well as the impact of population on the *finca* (i.e., *total population of the finca*). Greater numbers of adult males are expected to reduce forested area and increase area in crops and pasture due to greater availability of farm labor (Pichón 1993, Pichón 1997a, Pichón and Bilsborrow 1999, Barbieri et al., 2006). Greater numbers of children are expected to be associated with more cropped land, as subsistence needs rise with greater numbers of dependents (Barbieri et al., 2006, Carr 2004). Larger numbers of *finca* residents are expected to reduce forest at the expense of crop and pasture areas due to increased subsistence demands as well as a larger pool of available labor (Barbieri et al., 2006). The *subdivisions* variable is included as an indicator of population pressure; its hypothesized effect is to reduce forest and increase land in crops (Pan and Bilsborrow 2005). Given the aggregated nature of the *finca* data, *year finca established* is used to represent life cycle aspects of the *finca* (Pan and Bilsborrow 2005), since duration of settlement on the plot has been associated with LULC changes including initial clearing for subsistence crops, and later clearing for cash crops and pasture (Walker et al. 2002, Pichón et al. 2002, McCracken et al. 1999, Pichón 1997a).

Table 5.2. Variable names and descriptions.

Variable Name	**Description**
Demographic Factors	
Males	Number of adult males on *finca* (> age12)
Children	Number of children on *finca* (<age 12)
Total *finca* population	Number of adults and children on *finca*
Year *finca* established	Year in which the *finca* was established
Subdivisions	Number of *finca* subdivisions
Socioeconomic Factors	
Off-farm employment	Total person-months of off-farm employment
Hired Labor	Total person-months of hired labor
Title	Percent of *finca* with full title or *certificado de posesión*
Electricity	Percent of *finca* with electricity
Biophysical Factors	
Black Soil	Percent of *finca* described as having black soil
Topography	Percent of *finca* described as having flat land
Geographic Factors	
Access	Year-round vehicle access to *finca*
Transportation	1990: Existence of bus and/or *ranchera* service in community closest to *finca* (0=neither, 1=either, 2=both) 1999: Number of trips per day (bus and *ranchera*) serving a community
Distance to sawmill	Road distance (km) to nearest sawmill
Distance to rice husker	Road distance (km) to nearest rice husker
Distance to coffee roaster	Road distance (km) to nearest coffee roaster
Distance to market	Road distance (km) to nearest crop/animal market
Nearest comm. population	Population of community nearest to *finca*.

Socioeconomic variables selected included person-months of *off-farm employment,* person-months of *hired labor, title,* and access to *electricity*. Socioeconomic variables represent on-farm investments (i.e., hired labor) and tenure security (i.e., title), as well as activities that might make engagement in agriculture less profitable or desirable (i.e., off-farm employment). Hired labor is hypothesized to impact LULC through deforestation and agricultural expansion (Pan and Bilsborrow 2005, Pan et al. 2001, Pichón and Bilsborrow 1999, Kaimowitz and Angelsen 1998, Marquette 1998, Pichón 1997a). Land tenure security is expected to reduce deforestation and agricultural expansion, as tenure insecurity promotes land claim techniques that result in land cover changes such as deforestation (Geist and Lambin 2001, Southgate et al. 1991). Off-farm employment is expected to decrease LULC change due to decreased on-farm labor availability (Barbieri et al. 2006, Kaimowitz and Angelsen 1998, Pichón 1997a) as well as reduced dependence on subsistence agriculture (Mulley and Unruh 2004). Access to electricity is thought to increase LULC change by increasing work output on the farm as well as expanding knowledge of farming techniques through radio or television broadcasts (Pan et al. 2004).

Biophysical variables selected included *terrain* and *soil type*. Variable terrain is thought to affect land cover change, as rugged terrain is less likely to be cleared than flatter areas (Pan and Bilsborrow 2005, Kaimowitz and Angelsen 1998, Pichón 1997a). Soil types that are more productive are associated with a greater likelihood of clearance for agricultural use (Pan and Bilsborrow 2005, Pichón 1997a).

Geographic variables were selected to highlight issues of accessibility as well as incorporate community-level effects. Geographic variables included *road access, distance to the nearest crop or animal market, distance to nearest coffee roaster, distance to nearest rice* *husker*, and *distance to nearest sawmill*, and *transportation* (i.e., existence of *bus* or *ranchera* infrastructure in the nearest community (1990) or number of bus and *ranchera* trips per day (1999)) serving a community. These variables are included to incorporate effects of geographic accessibility on LULC change. The extension of transportation infrastructure and increased market accessibility have been noted to impact LULC, particularly forest conversion to agricultural land uses (Mena et al. 2006, Geist and Lambin 2001, Kaimowitz and Angelsen 1998, Pichón 1997a). *Nearest community population* was also included to represent the population to which a *fincas*' agricultural production might be marketed.

The Huber-White sandwich estimator (White 1980) is used to compute standard errors that are robust to clustering within communities. The use of the sandwich estimator assumes that observations are independent between clusters but does not require that they are independent within a cluster.

5.6.3. **Models: Dataset Creation**

Variables available through the 1990 (Pichón 1993) and 1999 (Bilsborrow 2002) household surveys were aggregated to the *finca* level. For *fincas* with subdivisions, the aggregated variable indicates the percent of the *finca* with a particular characteristic (i.e., *black soils, flat topography, electricity, title*), or the sum of the values of a particular characteristic (i.e., *males, children, total finca population, subdivisions, off-farm employment or hired labor*). Variables available through the community survey were associated with *fincas* through linkage to the nearest community (i.e., bus and *ranchera* service, existence of sawmill, coffee roaster, rice husker, or crop/animal market). The *transportation* variable for 1990 was developed from the community survey (Bilsborrow 2002), while the *transportation* variable for 1999 was created from fieldwork data collected through interviews of bus and *ranchera* companies serving the Ecuadorian Amazon. In addition, a number of variables were derived using GIS, including variables describing *distance to nearest community, distance to nearest rice husker, sawmill, coffee roaster, or crop/animal market*. Variables describing the *nearest community population* were developed using Ecuadorian census data. A complete list of the variables used in this study is presented in Table 5.2.

Using GIS software, the distances from each household GPS point to the nearest road and from that point on the road to the nearest community and nearest market (crops/animals, wood, rice, coffee) communities were calculated. The two values were summed to obtain total distance from the household to these communities. Tables 5.3 and 5.4 describe the nearest community to groups of *fincas*, and the market communities associated with them in 1990 and 1999; there are substantial differences due to expansion in agricultural infrastructure between 1990 and 1999.

Population values for survey communities in 1990 and 1999 were determined using Ecuadorian census data from the 1990 and 2001 censuses. *Localidad* data from the 2001 census, which tabulate population values for populated places in Ecuador (i.e., villages, towns, and cities), provided a better estimate of the 1999 population of survey communities than the 2000 community survey, as community survey data highlighted confusion in responses to questions concerning population of surveyed communities (i.e., some response values were close to those in the census data, while other responses indicated population values close to the population of the *parroquia* in which the surveyed community was located). Population values for surveyed communities in 1990 were determined in one of two ways. If the surveyed community was a *cabecera parroquial* in 1990, its population was obtained from census records. Population for other surveyed communities was estimated based on the growth (1990-2001) experienced by the *parroquia* in which it was located. Thus, if the *parroquia* population in 2001 was 1.5 times that in 1990, the *localidad* population value in 2001 was divided by 1.5 to obtain an estimate of the surveyed community's 1990 population.

5.6.4. **Models: Linking Survey and Remote Sensing Datasets**

Survey and remote sensing data were linked through *finca* identification numbers. Once the data sets were linked, remote sensing data were evaluated to determine whether *finca* coverage was 100 percent. As clouds were coded to background, they were not part of the sum; sums less than 100 flagged *fincas* with significant cloud coverage for omission. *Fincas* with less than 98 percent coverage were omitted from the dataset. Tables 5.3 and 5.4 describe the number of *fincas* linked to each community in the forest, crop, and pasture datasets for 1990 and 1999.

5.6.5. **The Modeling Process**

The datasets were evaluated to ensure that statistical assumptions for multivariate regression were met. Plots of the dependent versus the independent variables were reviewed to verify that linear relationships existed. Outliers were identified by examining residuals, leverage values, and Cook's D (1977) statistics. Observations flagged by these tests were examined and removed from the dataset. The distribution of the dependent variables was plotted against a normal distribution; in cases where the distribution of the dependent variable was non-normal[2], the variables were transformed, then tested for normality using the Shapiro-Wilk (1965) test. The Breusch-Pagan (1980) test for heteroskedasticity was used to verify that there was constant variance in the residuals; the *a priori* expectation was that heteroskedasticity should not be an issue due to the focus on *finca* data, in which the farms are mostly forty to sixty hectares in size.

Correlations among variables (Appendix A) were assessed as well. Two geographic variables describing agricultural infrastructure (i.e., *distance to rice husker*, *distance to coffee roaster*) were thus removed from the dataset prior to modeling due to high correlation with the other variables describing agricultural infrastructure (i.e., *distance to sawmill*, *distance to crop/animal market*); given that each of the market variables capture something similar, those market variables retained capture the essence of the distance effect. The models were then run with the independent variables described in Table 5.2 (with the exception of *total finca population*), and the models assessed for adequacy by inspecting the signs of the variables in relation to theoretical expectations. Variables were flagged for removal for various reasons. For example, the socioeconomic variable *title* was removed from the models because of its lack of importance given that the unit of observation is the original *finca (finca madre)* rather than the individual farm households occupying the *finca*. The socioeconomic variable *electricity* was removed given its association with nearness to main roads; the variable *access* captures a similar effect. The demographic variables *males* and *kids* were removed and replaced with *total finca population,* as *total finca population was* highly correlated with both variables and seemed to better capture demographic effects. The models were then rerun with *total finca population* used to describe demographic pressure on LULC. The final models are described in Tables 5.9 and 5.10.

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[2] Forest, pasture, and crop data for 1990, as well as patch density and landscape shape index data for 1990, proved non-normal. The forest dataset was transformed by squaring the data, while a square-root transformation was used in all other cases.

Table 5.3. Communities, linked *fincas* (no.). and nearest and market (coffee, rice, wood, crop/animal) communities in 1990 for the forest (f), crop (c), pasture (p) datasets.

Nearest Community	*Fincas* Linked	Nearest			
		Sawmill	**Rice Husker**	**Coffee Roaster**	**Crop/ Animal Market**
10 de Agosto	$11^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
24 de Mayo	$6^{f, c, p}$	Santa Cecilia	Nueva Loja	Santa Cecilia	Nueva Loja
3 de Noviembre		El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
5 de Agosto	$3^{f, c, p}$	Santa Cecilia	Jambeli	Jambeli	Sevilla
7 de Julio	$3^{f, c, p}$	El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Abdon Calderon	$10^{f, c, p}$	Santa Cecilia	Jambeli	Jambeli	Sevilla
Alamor	$5^{f, c, p}$	El Eno	La Joya de los Sachas	Shushufindi	Nueva Loja
Armenia		Coca	La Joya de los Sachas	Coca	Nueva Loja
Bahia de Caraquez	$7^{f, c, p}$	Nueva Loja	Pacayacu	Dureno	Nueva Loja
Bella Union del Napo	$10^{f, c, p}$	Coca	La Joya de los Sachas	San Pedro de los Cofanes	La Joya de los Sachas
Coca	$5^{f, c, p}$	Coca	La Joya de los Sachas	Coca	Nueva Loja
Dayuma	15^{f}, $9^{c,p}$	Coca	La Joya de los Sachas	Coca	Nueva Loja
Dureno	$6^{f, c, p}$	Nueva Loja	Pacayacu	Dureno	Nueva Loja
El Dorado		Coca	La Joya de los Sachas	Coca	Nueva Loja
El Dorado de Cascales	$7^{f, c, p}$	El Dorado de Cascales	Jambeli	Jambeli	Nueva Loja
El Eno		El Eno	El Eno	Recinto Conambo	Nueva Loja
El Triunfo	$5^{f, c, p}$	Nueva Loja	Nueva Loja	San Pedro de los Cofanes	Nueva Loja
Enokanki	$9^{f, c, p}$	El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Eugenio Espejo	$5^{f, c, p}$	Coca	La Joya de los Sachas	Coca	Nueva Loja
Guayacan		Coca	La Joya de los Sachas	Coca	Nueva Loja
Jambeli		Santa Cecilia	Jambeli	Jambeli	Sevilla
Jandiayacu		El Eno	El Eno	Recinto Conambo	Nueva Loja
Jivino Verde		El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
La Belleza		Coca	La Joya de los Sachas	Coca	Nueva Loja
La Joya	$8^{f, c, p}$	El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
La Reforma		El Eno	El Eno	San Pedro de los Cofanes	Nueva Loja
La Victoria	$3^{f, c, p}$	El Eno	Pacayacu	Shushufindi	Nueva Loja
Las Palmas	19^{f}, 16^{c}, 15^{p}	Coca	La Joya de los Sachas	Coca	Nueva Loja
Llumucha		Coca	La Joya de los Sachas	Coca	Nueva Loja
Llurimagua	$6^{f, c, p}$	El Eno	El Eno	Recinto Conambo	Nueva Loja
Los Angeles		El Dorado de Cascales	Jambeli	Jambeli	Lumbaqui

Table 5.3. (cont'd)

Nearest Community	*Fincas* Linked	Nearest: Sawmill	Nearest: Rice Husker	Nearest: Coffee Roaster	Nearest: Crop/ Animal Market
Los Rios		El Dorado	Coca	El Dorado	Coca
Lumbaqui	$3^{f, c, p}$	El Dorado de Cascales	Jambeli	Jambeli	Lumbaqui
Mariscal Sucre		El Eno	La Joya de los Sachas	San Pedro de los Cofanes	La Joya de los Sachas
Nueva Esmeraldas	$12^{f, c, p}$	El Eno	La Joya de los Sachas	Shushufindi	Nueva Loja
Nueva Loja	$11^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Nueva Vida	$8^{f}, 7^{c,p}$	El Eno	La Joya de los Sachas	Shushufindi	Nueva Loja
Pacayacu	$5^{f, c, p}$	Nueva Loja	Pacayacu	Dureno	Nueva Loja
Patria Nueva	$8^{f, p}, 7^{c}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Pozo Ron	$2^{f, c, p}$	El Eno	El Eno	San Pedro de los Cofanes	Nueva Loja
Recinto Conambo	$9^{f, c, p}$	El Eno	El Eno	Recinto Conambo	Nueva Loja
Recinto El Oro		El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Recinto Primavera	$11^{f, p}, 10^{c}$	El Eno	Pacayacu	San Pedro de los Cofanes	Nueva Loja
San Antonio	$5^{f, c, p}$	El Eno	El Eno	San Pedro de los Cofanes	Nueva Loja
San Carlos	$1^{f, c, p}$	El Dorado de Cascales	Jambeli	Jambeli	Sevilla
San Juan de Pozul	$4^{f, c, p}$	Nueva Loja	Pacayacu	Dureno	Nueva Loja
San Pedro de los Cofanes		El Eno	El Eno	San Pedro de los Cofanes	Nueva Loja
San Roque	$1^{f, p}$	El Eno	La Joya de los Sachas	Shushufindi	Nueva Loja
San Sebastian	$8^{f, c, p}$	Coca	La Joya de los Sachas	Coca	Nueva Loja
San Vicente	$7^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Santa Cecilia	$1^{f, c, p}$	Santa Cecilia	Jambeli	Santa Cecilia	Nueva Loja
Sevilla		El Dorado de Cascales	Jambeli	Jambeli	Sevilla
Shushufindi	$3^{f, c, p}$	El Eno	El Eno	Shushufindi	Nueva Loja
Taracoa	$7^{f}, 3^{c}, 5^{p}$	Coca	La Joya de los Sachas	Coca	Nueva Loja
Union Chimboracense		Coca	La Joya de los Sachas	Coca	Nueva Loja
Union Lojana	$9^{f, c, p}$	El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Union Manabita		El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Union Milagrena	$13^{f, c, p}$	El Eno	La Joya de los Sachas	San Pedro de los Cofanes	Nueva Loja
Virgen de Banos	$8^{f, c, p}$	El Eno	El Eno	San Pedro de los Cofanes	Nueva Loja

Table 5.4. Communities, linked *fincas* (no.), and nearest and market (coffee, rice, wood, crop/animal) communities associated with them in 1999 for the forest (f), crop (c), pasture (p) datasets.

Nearest Community	*Fincas* Linked	Nearest			
		Sawmill	**Rice Husker**	**Coffee Roaster**	**Crop/ Animal Market**
10 de Agosto	$11^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
24 de Mayo	$6^{f, c, p}$	Santa Cecilia	Nueva Loja	Santa Cecilia	Nueva Loja
3 de Noviembre		3 de Noviembre	San Pedro de los Cofanes	3 de Noviembre	La Joya de los Sachas
5 de Agosto	$3^{f, c, p}$	Santa Cecilia	Jambeli	Jambeli	Sevilla
7 de Julio	$5^{f, c, p}$	7 de Julio	San Pedro de los Cofanes	7 de Julio	Shushufindi
Abdon Calderon	$8^{f, c, p}$	San Carlos	Jambeli	Jambeli	Sevilla
Alamor	$5^{f, c, p}$	Nueva Esmeraldas	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Armenia		Coca	Coca	Armenia	Coca
Bahia de Caraquez	$6^{f, c, p}$	Dureno	Dureno	Dureno	Nueva Loja
Bella Union del Napo	$10^{f, c, p}$	3 de Noviembre	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Coca	$7^{f, c, p}$	Coca	Coca	Coca	Coca
Dayuma	$7^{f, c, p}$	El Dorado	Coca	El Dorado	Coca
Dureno	$6^{f, c, p}$	Dureno	Dureno	Dureno	Nueva Loja
El Dorado		El Dorado	Coca	El Dorado	Coca
El Dorado de Cascales	$7^{f, c, p}$	El Dorado de Cascales	Sevilla	Jambeli	El Dorado de Cascales
El Eno		El Eno	El Eno	El Eno	Nueva Loja
El Triunfo	$5^{f, c, p}$	San Pedro de los Cofanes	San Pedro de los Cofanes	Pozo Ron	Nueva Loja
Enokanki	$7^{f, c, p}$	3 de Noviembre	La Joya de los Sachas	Jivino Verde	La Joya de los Sachas
Eugenio Espejo	$5^{f, c, p}$	Coca	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Guayacan		El Dorado	Coca	El Dorado	Coca
Jambeli		Sevilla	Jambeli	Jambeli	Sevilla
Jandiayacu		El Eno	El Eno	El Eno	Nueva Loja
Jivino Verde		San Pedro de los Cofanes	San Pedro de los Cofanes	Jivino Verde	La Joya de los Sachas
La Belleza		Coca	Coca	Coca	Coca
La Joya	$8^{f, c, p}$	3 de Noviembre	La Joya de los Sachas	Jivino Verde	La Joya de los Sachas
La Reforma		San Pedro de los Cofanes	San Pedro de los Cofanes	La Reforma	Shushufindi
La Victoria	$5^{f, c, p}$	Shushufindi	Shushufindi	Shushufindi	Shushufindi
Las Palmas	$11^{f, c, p}$	Coca	Coca	Coca	Coca
Llumucha		Coca	Coca	Coca	Coca
Llurimagua	$5^{f, c, p}$	El Eno	El Eno	Llurimagua	Nueva Loja
Los Angeles		Lumbaqui	Lumbaqui	Lumbaqui	Lumbaqui
Los Rios		El Dorado	Coca	El Dorado	Coca

Table 5.4. (cont'd)

Nearest Community	*Fincas* Linked	Nearest			
		Sawmill	**Rice Husker**	**Coffee Roaster**	**Crop/ Animal Market**
Lumbaqui	4 $^{f, c, p}$	Lumbaqui	Lumbaqui	Lumbaqui	Lumbaqui
Mariscal Sucre		Nueva Esmeraldas	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Nueva Esmeraldas	9 $^{f, c, p}$	7 de Julio	Shushufindi	7 de Julio	Shushufindi
Nueva Loja	8 $^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Nueva Vida	8 $^{f, c, p}$	Shushufindi	Shushufindi	Nueva Vida	Shushufindi
Pacayacu	5 $^{f, c, p}$	Pacayacu	Pacayacu	Pacayacu	Nueva Loja
Patria Nueva	7 $^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Pozo Ron	2 $^{f, c, p}$	San Pedro de los Cofanes	San Pedro de los Cofanes	Pozo Ron	Recinto Primavera
Recinto Conambo	3 $^{f, c, p}$	El Eno	El Eno	Recinto Conambo	Nueva Loja
Recinto El Oro		3 de Noviembre	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Recinto Primavera	11 $^{f, c, p}$	Shushufindi	Shushufindi	Recinto Primavera	Recinto Primavera
San Antonio	3 $^{f, c, p}$	Nueva Esmeraldas	San Pedro de los Cofanes	Pozo Ron	Recinto Primavera
San Carlos	1 $^{f, c, p}$	El Dorado de Cascales	Sevilla	Jambeli	Sevilla
San Juan de Pozul		Dureno	Dureno	Dureno	Nueva Loja
San Pedro de los Cofanes		San Pedro de los Cofanes	San Pedro de los Cofanes	San Pedro de los Cofanes	La Joya de los Sachas
San Roque		Shushufindi	Shushufindi	Nueva Vida	Shushufindi
San Sebastian	6 $^{f, c, p}$	Coca	Coca	Coca	Coca
San Vicente	8 $^{f, c, p}$	Nueva Loja	Nueva Loja	Nueva Loja	Nueva Loja
Santa Cecilia	1 $^{f, c, p}$	Santa Cecilia	Jambeli	Santa Cecilia	Nueva Loja
Sevilla		Sevilla	Sevilla	Jambeli	Sevilla
Shushufindi	6 $^{f, c, p}$	Shushufindi	Shushufindi	Shushufindi	Shushufindi
Taracoa	7 $^{f, c, p}$	El Dorado	Coca	Taracoa	Coca
Union Chimboracense		Coca	Coca	Coca	Coca
Union Lojana	9 $^{f, c, p}$	Nueva Esmeraldas	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Union Manabita		3 de Noviembre	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Union Milagrena	13 $^{f, c, p}$	3 de Noviembre	La Joya de los Sachas	Union Milagrena	La Joya de los Sachas
Virgen de Banos	8 $^{f, c, p}$	San Pedro de los Cofanes	San Pedro de los Cofanes	Pozo Ron	Recinto Primavera

5.7. **Results and Discussion**

5.7.1. **Fragmentation Statistics**

Tables 5.5 and 5.6 describe class-level (i.e., forest, crops, and pasture) and landscape-level (i.e., *finca*) fragmentation statistics for the 1986 and 1999 images of surveyed *fincas*. Class-level fragmentation statistics show that the mean percentage of the *finca* landscape (*PLand*) occupied by forest decreased markedly between 1986 and 1999, while the share of the landscape in crops and pasture increased. The density of patches (*PD*) increased for all patch types, suggesting a more fragmented landscape by 1999. Edge density (*ED*) increased across class types between 1986 and 1999 as well, indicating that the shapes of patches of various LULC types became more complex, thus suggesting a decrease in the aggregation of various patch types. The increasing landscape shape index (*LSI*) values highlight greater complexity of patch shapes over time and point to disaggregation of patches as well.

Table 5.5. Class-level (forest, crop, pasture) fragmentation statistics; mean and standard deviation values for 1986 and 1999.

	Land Cover Class					
	Forest		**Crops**		**Pasture**	
Fragmentation Statistic	**1986**	**1999**	**1986**	**1999**	**1986**	**1999**
PLand	79.71 (17.00)	55.20 (19.25)	8.96 (6.82)	19.72 (11.53)	5.43 (4.15)	15.85 (6.30)
PD	8.47 (7.10)	30.20 (19.41)	19.12 (11.95)	42.80 (15.78)	31.07 (17.84)	61.49 (18.56)
ED	63.65 (41.78)	164.35 (48.59)	60.64 (42.06)	141.67 (65.69)	54.99 (37.93)	144.67 (51.38)
LSI	2.84 (0.99)	5.35 (1.62)	3.92 (1.39)	6.19 (1.58)	4.28 (1.61)	6.81 (1.44)

Table 5.6. Mean and standard deviation values for landscape (*finca*)-level fragmentation statistics, 1986 and 1999.

Fragmentation Statistic	1986	1999
PD	69.85 (45.97)	183.66 (57.68)
ED	101.61 (74.02)	262.98 (88.62)
LSI	3.46 (1.39)	6.20 (1.64)

5.7.2. **Characterizing Fincas, 1990 and 1999**

Tables 5.7 and 5.8 set the context for the statistical models by characterizing changes on the *fincas* between 1990 and 1999; Table 5.8 relates variables to LULC. Total population on the *fincas* increased between 1990 and 1999 (Table 5.7). In both 1990 and 1999, as the number of males on the *finca* increased, the proportion of forest decreased, and the amount of crop and pasture land increased (Table 5.8). The number of females and number of children showed a similar relationship to forest, crops, and pasture in 1990 and 1999.

The number of years the head had resided on the plot showed a modest increase between 1990 and 1999 (Table 5.7) that points to the relationship with subdivision; those living on subdivisions of the original farm (*finca madre*) have lower values for duration. The number of subdivisions increased over time as well (Table 5.7), due to in-migration to the region as well as the process of parents giving children land on which to set up a separate household. Table 5.8 shows that the longer the head has resided on the *finca*, the lower the proportion of forest and the greater the proportion of crop and pasture land; this relationship holds true for both 1990 and 1999. The 1990 and 1999 data also reveal that a greater number of subdivisions is generally related to less forest and more pasture and cropland.

The socioeconomic data in Table 5.7 show an increase in off-farm employment coupled with a decrease in hired labor between 1990 and 1999. Pan and colleagues (2004) indicate that the increase in off-farm employment between 1990 and 1999 results from increased population density on the *fincas* coupled with smaller plot size; Barbieri and colleagues (2006) point out that smaller plot sizes encourage and often require off-farm employment as a risk diversification strategy. Given the smaller plot sizes in 1999, there is less need for hired labor; note the decrease in the mean number of person-months of hired labor between 1990 and 1999 (Table 5.7). While more person-months of hired labor is associated with less forest and more crops and pasture land in both 1990 and 1999, more time spent in off-farm employment exhibited a decrease in forest cover by 1999, which may be an indicator that off-farm employment earnings were used to hire labor for extensification or intensification of crop or pasture lands (Table 5.8).

The proportion of *fincas* with a full title decreases between 1990 and 1999 (Table 5.7), which is related to the process of subdivision (Bilsborrow et al., 2004); those with title tend to have less forest and more crop and pasture land (Table 5.8). This relationship is expected (Bilsborrow and Pan 2001, Pan and Bilsborrow 2000, Pichón 1997a), given that a land title in the NEA provides access to credit, which allows farmers to purchase cattle and convert land to pasture. The number of households with access to electricity increased between 1990 and 1999 (Table 5.7), an indicator of expansion of electrical infrastructure in the NEA. *Fincas* with access to electricity tend to have less land in forest and more in crops and pasture (Table 5.8).

Biophysical factors did show some changes between 1990 and 1999. The proportion of *fincas* reporting black soil decreased by 1999 (Table 5.7). Given that farmers generally have a more accurate perception of *finca* topography than soils, this change is not altogether surprising; due to the variable nature of soils on the landscape, as farmers clear new areas, they may encounter different soil types. Those *fincas* that did report black soil show lower proportions of forest and higher proportions of crop and pasture land (Table 5.8), consistent with Pichón and Bilsborrow (1999). Fewer farms report flat topography in 1999 than in 1990 (Table 5.7); this may result from agricultural expansion from portions of the *finca* best-suited to agriculture (i.e., flattest) to areas with less desirable (i.e., hillier) topography. Those farms reporting flat topography have lower proportions of forest and higher proportions of crop and pasture land (Table 5.8).

Geographic factors indicate that *finca* access to roads increased slightly between 1990 and 1999, and that bus and *finca* transportation increased over time as well (Table 5.7), thus making it easier to travel within the NEA and increasing farmers' ability to bring products to market. *Fincas* with access to bus and *ranchera* transportation generally have lower proportions of forest and higher proportions of crop and pasture land (Table 5.8). Distance from *fincas* to the various types of agricultural infrastructure (sawmills, rice huskers, coffee roasters, and crop/animal markets) decreased between 1990 and 1999 as well (Table 5.7). The expansion of transportation infrastructure between 1990 and 1999 and the increased accessibility of agricultural infrastructure by 1999 provide farmers with better access to towns, markets, and businesses to whom their *finca's* products might be sold. Table 5.8 shows that *fincas* closer to various types of agricultural infrastructure (sawmills, rice huskers, coffee roasters, crop/animal markets) generally have lower proportions of forest and higher proportions in crops and pasture (Table 5.8). Evidence of expanding population in the NEA and the growth of study communities is seen in the large increase in the mean size of study communities between 1990 and 1999 (Table 5.7).

Table 5.7. Descriptive statistics for demographic, socioeconomic, biophysical, and geographic variables for *fincas*, from 1990 and 1999 survey data.

Variable	Mean (S.D.) 1990 (n=270)	Mean (S.D.) 1999 (n=239)
Demographic Factors		
Males	2.52 (1.83)	3.71 (2.83)
Females	2.01 (1.60)	2.86 (2.22)
Children < 12 years of age	2.66 (2.41)	3.64 (3.60)
Total *Finca* Population	7.21 (4.81)	10.2 (7.62)
Head Duration of Residence (years)	10.2 (6.01)	14.0 (10.4)
Subdivisions	1.13 (.407)	2.13 (1.72)
Socioeconomic Factors		
Off-Farm Employment (person-months)	3.14 (7.82)	17.7 (30.6)
Hired Labor (person-months)	6.49 (8.68)	2.17 (4.08)
Title or *Certificado de Posesión*	.981 (.093)	.713 (.403)
Electricity	.147 (.355)	.367 (.432)
Biophysical Factors		
Black Soil	.652 (.477)	.496 (.474)
Flat Topography	.413 (.490)	.335 (.443)
Geographic Factors		
Vehicular Access	.485 (.501)	.543 (.499)
Bus Transportation in Nearest Comm.	.311 (.463)	.414 (.494)
Ranchera Transportation in Nearest Comm.	.492 (.501)	.849 (.358)
Distance to sawmill	25.6 (16.2)	15.3 (11.7)
Distance to rice husker	24.8 (22.4)	13.5 (9.5)
Distance to coffee roaster	17.9 (11.3)	9.01 (9.16)
Distance to market	56.8 (37.7)	16.0 (11.9)
Nearest community population size	863.7 (2424.1)	2017.9 (5808.1)

Table 5.8. Descriptive relationship between LULC and demographic, socioeconomic, biophysical, and geographic variables in 1990 and 1999.

Variable Description	Frequency		*Finca* Area In Forest (%)		Frequency		*Finca* Area In Crops (%)		Frequency		*Finca* Area In Pasture (%)	
	1990 (n=270)	1999 (n=239)	1990	1999	1990 (n=244)	1999 (n=235)	1990	1999	1990 (n=250)	1999 (n=245)	1990	1999
Demographic Factors												
Males												
0-1	89	55	84.9	67	73	53	7.2	13.5	75	60	4.3	12
2-3	118	74	80.9	57.2	112	76	8.5	18	112	74	5.3	15.4
4+	63	110	79.4	50.5	59	106	9.2	21.2	63	111	5.6	18.2
Females												
0-1	123	82	85.2	63.4	107	80	7.3	15.1	109	88	4.3	13.1
2-3	111	81	78.8	57.2	103	80	9.2	17.7	105	81	5.6	16.3
4+	36	76	80.2	48.0	34	75	8.6	22.7	36	76	5.8	18.5
Children												
0	59	50	85	63.5	50	47	7.2	14.7	50	51	4.2	13.0
1-3	131	90	80.6	54.9	121	90	8.3	19.8	122	91	5.3	15.0
4-6	67	58	82.3	57.7	60	58	8.8	17.4	64	60	5.0	16.0
7+	13	41	78.3	49.2	13	40	9.5	21.1	14	43	7.0	18.8
Total *Finca* Population												
0	15	0	89.4	NA	8	NA	6.5	NA	9	0	4.2	NA
1-5	85	69	83.6	62.9	77	66	7.1	15.3	78	74	4.4	13.1
6-11	136	87	80.5	57.0	125	87	8.9	18.4	129	87	5.3	15.8
12+	34	83	79.8	50.3	34	82	9.0	21	34	84	5.9	18.3
Duration of Residence												
0-5	63	28	89.9	66.5	43	27	6.1	12.1	44	28	2.9	12.9
6-10	87	122	81.5	58.9	84	120	8.1	17.7	89	126	4.9	14.5
10+	120	89	77.9	49.8	117	88	9.2	21.3	117	91	6.1	18.5

Variable Description	Frequency		*Finca* Area In Forest (%)		Frequency		*Finca* Area In Crops (%)		Frequency		*Finca* Area In Pasture (%)	
	1990 (n=270)	1999 (n=239)	1990	1999	1990 (n=244)	1999 (n=235)	1990	1999	1990 (n=250)	1999 (n=245)	1990	1999
Demographic Factors (cont'd)												
Subdivisions												
1	241	125	82.3	60.9	214	122	8.1	16.7	221	130	4.9	13.9
2	24	50	78.1	56.4	25	50	10.1	18.4	24	52	6.3	16.5
>2	5	64	81.6	47.8	5	63	8.1	21.8	5	63	6	19.8
Socioeconomic Factors												
Off-farm employment (person mo.)												
0	185	76	80.4	60.1	170	76	8.6	16.5	176	82	5.4	14.7
0.1-1	6	2	88	74.0	5	2	6.9	6.4	5	2	4.6	13.1
2-6	39	27	85.3	59.3	32	29	7.4	15.7	34	29	4.4	17.1
7-12	26	49	85.3	62.1	25	49	7.0	16.5	22	49	3.7	13.5
13+	14	85	83.2	48.4	12	79	8.9	22.8	13	83	5.0	17.9
Hired Labor (person mo.)												
0	76	92	83.8	65.0	67	91	8.4	13.7	64	93	4.8	13.5
0.1-1	30	55	81.8	57.7	26	53	9.3	16.9	30	54	5.1	15.9
2-6	72	43	81.4	47.3	66	44	7.6	23.5	68	45	4.6	18.4
7-12	33	14	80.4	39.6	31	15	8.4	28.5	31	17	5.7	18.6
13+	59	35	80.8	49.5	54	32	8.4	22.6	57	36	5.7	17.1
Electricity												
No	214	119	82.5	60.8	197	119	7.9	15.9	203	124	4.8	14.9
Yes	37	62	74.9	52.9	34	59	11	21.5	34	62	6.9	16.5

Variable Description	Frequency		*Finca* Area In Forest (%)		Frequency		*Finca* Area In Crops (%)		Frequency		*Finca* Area In Pasture (%)	
	1990 (n=270)	1999 (n=239)	1990	1999	1990 (n=244)	1999 (n=235)	1990	1999	1990 (n=250)	1999 (n=245)	1990	1999
Socioeconomic Factors (cont'd)												
Title or Cert.												
No	1	49	98.6	67.1	2	50	10.2	11.6	1	23	.47	16.0
Yes	269	190	81.8	53.6	242	185	8.3	20.3	249	208	5.1	15.7
Biophysical Factors												
Black Soil												
No	93	103	86.7	64.5	79	103	6.7	14.5	81	108	3.7	13.4
Yes	177	136	79.3	50.2	165	32	9	21.4	169	137	5.8	17.7
Topography												
No	155	130	85.7	63.7	132	128	7.2	14.9	136	134	3.9	13.7
Yes	115	108	76.6	47.6	112	106	9.6	22.7	114	110	6.4	18.3
Geographic Factors												
Access												
No	139	109	86.6	65.4	115	108	7.1	13.6	123	110	4.0	13.8
Yes	131	130	76.9	48.8	129	127	9.3	22.5	127	135	6.1	17.5
Bus												
No	186	140	85	59.7	153	136	7	16.6	162	140	3.9	15
Yes	84	99	74.9	51.7	84	99	10.6	20.9	79	105	7.1	17
Ranchera												
No	137	36	84.7	56.6	116	33	7	17	127	36	4.1	16.8
Yes	133	203	78.9	56.4	128	202	9.4	18.6	123	209	6	15.7
Distance to sawmill (km)												
0-10	49	96	72.8	50.9	47	95	11.5	19.7	45	102	7.3	18.2
11-20	69	60	84.2	55.8	64	58	8.1	20	64	61	4.5	15.7
21-30	51	31	85.3	75.4	44	32	7.7	11	44	32	4.9	9.6
31-40	23	28	84.2	55.1	22	26	6.2	18.8	23	26	3	14.7
40+	78	24	82.5	56.7	67	24	7.3	18.7	74	24	4.9	15.7

Variable Description	Frequency		*Finca* Area In Forest (%)		Frequency		*Finca* Area In Crops (%)		Frequency		*Finca* Area In Pasture (%)	
	1990 (n=270)	1999 (n=239)	1990	1999	1990 (n=244)	1999 (n=235)	1990	1999	1990 (n=250)	1999 (n=245)	1990	1999
Geographic Factors												
Distance to rice husker (km)												
0-10	66	74	75.1	51.5	64	72	10.5	20.3	62	80	7	17.4
11-20	105	116	80.2	54.6	101	112	8.6	19.4	104	115	5.3	16.5
21-30	32	19	88.9	72.6	33	20	5.3	12.4	31	20	3.2	10.8
31-40	12	14	80.2	70.5	11	15	8.5	13	11	14	5	10.9
40+	55	16	89.4	60.1	35	16	6	15.6	42	16	3.1	14
Distance to coffee roaster (km)												
0-10	65	138	78.4	58.6	62	137	9.9	17	60	144	5.7	15.5
11-20	111	62	80.6	49.5	106	61	8.7	22.3	107	63	5.5	18.1
21-30	26	18	92.3	72.9	17	19	6	13	20	19	3.4	10.1
31-40	12	7	80.2	64.6	45	7	7.4	14.4	46	17	5.4	12.6
40+	55	14	89.4	39.7	14	11	3.4	26.7	17	12	1.5	19
Distance to market (km)												
0-10	29	69	80.1	47.3	27	67	8.6	22	25	74	5.6	18.3
11-20	32	99	77.3	53.3	31	95	10.3	20	32	98	5.6	17
21-30	11	38	87.4	68	11	38	7.2	13.1	10	38	3.2	12.1
31-40	23	14	76.4	70.5	23	15	10.4	13.1	22	14	6.2	10.9
40+	175	19	83.4	70.2	152	20	7.8	12.8	161	21	4.9	11.8

5.7.3. **Regression Modelling: Landscape Composition**

Table 5.9 provides results of the cross-sectional regression models run for the LULC classes -- forest, crops, and pasture. The relationship of demographic variables to the dependent variables (i.e., percentage of landscape in forest, crops, or pasture) is as expected by theory. The *year finca established* variable is significantly and positively related to forest in 1990 ($\alpha = .05$), while the relationship to pasture is significant and negative in both 1990 ($\alpha = .01$) and 1999 ($\alpha = .01$). These relationships indicate that *fincas* established more recently are associated with more forest and less crop and pasture land; the older a *finca*, the more crop and pasture and less forest is expected. *Total population of the finca* is significantly and negatively associated with forest cover in 1990 ($\alpha = .01$) and 1999 ($\alpha = .01$); this variable displays a significant and positive relationship to crops and pasture in 1990 ($\alpha = .01$) and to pasture in 1999 ($\alpha = .01$). As population increases through time, whether through natural increase (e.g., marriage, birth) or in-migration, additional forest areas are cleared in favor of establishing pasture and crop lands.

Socioeconomic variables significant in the 1990 and 1999 models include both *off-farm employment* and *hired labor*. *Off-farm employment* shows a significant positive relationship to the percent of the *finca* in forest in 1990 ($\alpha = .01$), as in Pichón (1997a), Pichón and Bilsborrow (1999) and others since. *Off-farm employment* exhibits a significant and negative relationship to the percent of the *finca* in cropland in 1990 ($\alpha = .01$) and pasture in 1990 ($\alpha = .01$) and 1999 ($\alpha = .01$). These relationships indicate the role of off-farm employment in mitigating forest loss, as labor previously available to the *finca* is devoted to off-farm endeavors. The relationship of *off-farm employment* to cropland in 1999, however, is significant and positive ($\alpha = .1$). This suggests the possibility that off-

Table 5.9. *Finca*-level models describing landcover composition for 1990 and 1999.

Variable Description	*PLand: Forest*		*PLand: Crops*		*PLand: Pasture*	
	1990 (n=270)	1999 (n=239)	1990 (n=244)	1999 (n=235)	1990 (n=250)	1999 (n=245)
Intercept	-112849	-473	19.7	261	42.2	305
Demographic Factors						
Total *Finca* Population	-67.18*** (21.3)	-.350*** (.129)	.040*** (.013)	.078 (.070)	.033*** (.008)	.191*** (.049)
Year *Finca* Established	60.8** (26.4)	.268 (.180)	-.008 (.014)	-.124 (.099)	-.020** (.009)	-.146** (.067)
Socioeconomic Factors						
Off-farm employment	54.8*** (9.0)	-.030 (.030)	-.024*** (.008)	.032* (.017)	-.022*** (.006)	-.024*** (.008)
Hired Labor	-16.8 (122)	-5.09*** (.874)	-.036 (.068)	3.19*** (.799)	-.001 (.032)	.779** (.351)
Biophysical Factors						
Black Soil	-357.6 (239.8)	-1.73 (2.52)	.099 (.126)	.030 (1.32)	.146 (.113)	.657 (.886)
Topography	-930.1*** (337.7)	-7.87** (3.09)	.305* (.179)	4.58*** (1.51)	.383*** (.113)	1.82 (1.25)
Geographic Factors						
Access	-587.5 (418.9)	-6.59*** (2.23)	.236 (.142)	3.92*** (1.19)	.229** (.101)	1.01 (.937)
Transportation	-311 (230.7)	-.329* (.194)	.094*** (.036)	.197* (.115)	.107*** (.023)	.102 (.077)
Distance to sawmill	20.5** (8.9)	.047 (.131)	-.016*** (.004)	-.036 (.059)	-.011*** (.003)	-.052 (.052)
Distance to market	-.22 (3.8)	.401*** (.128)	-.002 (.002)	-.141** (.070)	.000 (.001)	-.111*** (.038)
Distance to nearest comm.	65.3 (47.4)	.192 (.523)	-.011 (.031)	-.173 (.295)	-.033* (.018)	-.063 (.170)
Nearest comm. population	.010 (.050)	.0003 (.000)	7.89×10^{-6} (.000)	9.18×10^{-5} (.000)	2.33×10^{-5} (.000)	1.18×10^{-4} (.000)
R-squared	.38	.56	.23	.51	.45	.41
No. clusters	41	40	39	39	41	40

variables significant at ***.01 level, ** .05 level, * .1 level

farm employment earnings are being used to expand cropped areas. *Hired labor* exhibits a significant and negative relationship to the percent of the *finca* in forest in 1999 ($\alpha = .01$), while showing a significant and positive relationship to the percent of the *finca* in cropland ($\alpha = .01$) and pasture ($\alpha = .01$) in 1999. Hired labor is thus shown to decrease the proportion of land in forest, while expanding the area devoted to crops and pasture. As hired labor had become more rare by 1999, its impact on large farms is more evident.

Of the biophysical variables, *black soil* has a negative relationship to forested area, and a positive relationship to area in cropland or pasture. The relationship of black soils to forest is not surprising, given that black soils are richer in organic matter and would be expected to grow crops with less use of inputs. *Topography*, specifically flat land, is significantly and negatively related to forest in 1990 ($\alpha = .01$) and 1999 ($\alpha = .05$), while exhibiting significant and positive relationship to cropland ($\alpha = .1$) and pasture ($\alpha = .01$) in 1990 and to pasture in 1999 ($\alpha = .01$). Flat land is reasonably associated with less land in forest, also for reasons related to agricultural suitability, as flatter areas would be the first cleared for agriculture. The greater the proportion of a *finca* with flat topography, the more land area is suited to cropping.

A number of the geographic variables are significant predictors of the percent of the *finca* in various LULC classes. *Road access* to the *finca* is negatively related to the percent of the *finca* in forest in both 1990 and 1999, significantly so in 1999 ($\alpha = .01$), and is positively related to the percent of the *finca* in crops and pasture, significantly so for pasture in 1990 ($\alpha = .05$) and crops in 1999 ($\alpha = .01$). The relationship of road access to the LULC variables indicates the importance of year-round vehicle access to the *finca* for transportation of wood, crops, or cattle to the market, thus encouraging expansion of crops and pasture at the expense of forested area. *Transportation* exhibited a negative relationship to proportion of the *finca* in forest, significant in 1990($\alpha = .1$), and a significant and positive relationship to the proportion in crops in 1990 ($\alpha = .01$) and 1999 ($\alpha = .1$) and to the proportion in pasture in 1990 ($\alpha = .01$). The association of increased availability of transportation options with decreased forest cover and increased crop and pasture land serves as an indicator of the importance of bus and *ranchera* services in transporting goods to market.

Other geographic variables focused on the role distance to outlets for farm products, such as wood and crops or animals, plays in predicting the percentage of forest, crops, or pasture on the farm. Distance to the nearest sawmill is positively related to the area in forest, significantly so in 1990 ($\alpha = .05$), and significantly and negatively related to area in crops ($\alpha = .01$) and pasture ($\alpha = .01$) in 1990. As the distance to the nearest sawmill increases, there are greater costs associated with transport of cleared wood, and, therefore, less interest in clearing forested areas to acquire income from the timber. The relationship of distance to the nearest crop/animal market is significantly and positively related to forested area in 1999 ($\alpha = .01$) and significantly and negatively related to area in crops ($\alpha = .05$) and pasture ($\alpha = .01$) in 1999. These relationships show that as distance to communities in which sawmills or crop/animal markets are located increases, forested area generally increases, as the cost to transport goods to market goes up; area in crops or pasture decreases for the same reason. In addition, these relationships highlight the shifting importance of wood and agricultural products. The significance of the distance to sawmill variable in 1990 but not in 1999 illustrates the decreasing importance of sawmills over time, as fewer trees are left to cut. Crop and animal markets become more important over time, however, because of the shift to commercial production over time. Population of the nearest community is not a significant predictor of proportion of the *finca* in forest, crops, or pasture. While contrary to expectations, this may be a signal that nearest community population does not exert as strong an influence as communities with agricultural infrastructure, which on the whole are larger communities.

An examination of the coefficients for dependent and independent variables in 1990 and 1999 show that the direction of the relationships is, in general, the same for both years.

Independent variables for which the sign changed between 1990 and 1999 were not significant predictors of the percent of the *finca* landscape in forest, crops, or pasture. This suggests that the processes associated with the variables in this model exhibit stationarity between 1990 and 1999.

5.7.4. **Regression Modelling: Landscape Configuration**

Table 5.10 provides results for the cross-sectional regression models in which pattern metrics representing landscape configuration (i.e., *patch density* (*PD*) and *landscape shape index* (*LSI*)) served as the dependent variables. Demographic variables that exhibit significant relationships with these landscape configuration metrics include *total finca population* and *year finca established*. *Total finca population* shares a significant and positive relationship with both PD and LSI at $\alpha = .01$ in 1990 as well as 1999. A larger *finca* population, with greater numbers of mouths to feed as well as a potentially larger labor pool, would increase the complexity of a *finca's* vegetative landscape. As more land is cleared to expand area in crops and pasture, these clearings not only increase the existing number of patches of crops or pasture, but of forest as well, as previously larger patches of forest are divided by agricultural expansion. The *year finca established* variable exhibits a significant and negative relationship to PD in 1990 ($\alpha = .05$) and 1999 ($\alpha = .01$) as well as LSI in 1990 ($\alpha = .05$) and 1999 ($\alpha = .01$). The relationship of PD to the year of establishment indicates that the more recently a *finca* has been established, the fewer patches it exhibits. The less patchy vegetation is on the *finca*, the greater likelihood that forest areas are better connected. In turn, the less patchy a *finca* landscape is, the less landscape complexity exists; landscape complexity is thus lower on more recently established *fincas* as well. These relationships are in line with the order of events suggested by household and farm life cycle theory, as the number of patches on the *finca* landscape as well as landscape complexity would understandably increase with the agricultural expansion associated with a growing family.

Table 5.10. *Finca*-level models describing landscape configuration in1990 and 1999.

Variable Description	PD		LSI	
	1990 (n=266)	1999 (n=238)	1990 (n=266)	1999 (n=238)
Intercept	230.9	3159.8	21.5	82.9
Demographic Factors				
Total *Finca* Population	.107*** (.031)	1.76*** (.502)	.010*** (.003)	.046*** (.011)
Year *Finca* Established	-.113*** (.043)	-.1.51*** (.605)	-.010** (.004)	.039*** (.015)
Socioeconomic Factors				
Off-farm employment	-.058*** (.015)	-.138 (.088)	-.007*** (.001)	-.004 (.003)
Hired Labor	-.062 (.114)	7.10** (2.73)	.013 (.022)	.299*** (.066)
Biophysical Factors				
Black Soil	.629** (.310)	13.45** (7.33)	.081** (.037)	.384** (.197)
Topography	.980** (.436)	18.21** (9.24)	.127** (.055)	.525** (.239)
Geographic Factors				
Access	.874*** (.334)	21.56*** (6.23)	.083** (.049)	582** (.184)
Transportation	.346*** (.124)	.628 (.565)	.052*** (.012)	.029** (.013)
Distance to sawmill	-.028*** (.010)	-.014 (.329)	-.004*** (.001)	-.011 (.011)
Distance to market	-.008 (.006)	-1.00*** (.328)	-.0007 (.0005)	-.031*** (.007)
Distance to nearest comm.	-.136** (.055)	-1.34 (1.85)	-.011 (.007)	-.025 (.034)
Nearest comm. population	-.003 (.005)	-.057 (.052)	-.0009 (.0006)	-.004** (.001)
R-squared	.56	.50	.50	.60
No. clusters	39	39	39	39

variables significant at ***.01 level, ** .05 level, *.1 level

Socioeconomic variables significant in both the 1990 and 1999 models include off-farm employment and title. *Off-farm employment* showed a significant and negative relationship to PD and LSI at $\alpha = .01$ in 1990; the relationship to both variables is negative but non-significant in 1999. The relationship of off-farm employment to patch density and the landscape shape index is associated with the diversion of labor to off-farm endeavors. With less labor working the *finca* to clear new areas for agriculture, patch density and landscape complexity decrease. *Hired labor* exhibits a generally positive relationship to these metrics of landscape configuration; the relationship of hired labor to both PD and LSI is significant in 1999 ($\alpha = .01$). Hired labor thus works in a manner opposite to off-farm employment, expanding the pool of labor and making possible the expansion of agriculture; as the number of patches cleared for agriculture increase, landscape shape complexity does as well.

The biophysical variables *black soil* and flat topography (*topography*) are both significantly and positively related to both PD and LSI in 1990 and 1999 ($\alpha = .05$). Since both black soil and flat topography encourage agricultural expansion, the positive relationship between these variables and the pattern metrics is as expected. The expansion of agriculture related to either fertile soils or flat topography would result in greater numbers of patches, which would thus produce a landscape with greater shape complexity.

Several of the geographic variables show themselves to be significant predictors of PD and LSI values. *Access* exhibits a significant and positive relationship to PD in 1990 and 1999 at $\alpha = .01$, and to LSI in 1990 as well as 1999 at $\alpha = .05$. *Transportation* shares a significant and positive relationship with both metrics in 1990 ($\alpha = .01$) and with LSI in 1999 ($\alpha = .05$). The greater accessibility to markets represented by vehicle access to the *finca* or bus/*ranchera* transportation in the nearest town encourages agricultural expansion, which is associated with increasing numbers of patches on the *finca* landscape as well as increasing complexity of those patches.

The pattern metrics exhibit significant and negative relationships to a number of the distance variables. *Distance to nearest sawmill* is so related to both PD ($\alpha = .01$) and LSI ($\alpha = .05$) in 1990, while *distance to nearest market* exhibits a significant and negative relationship to both PD ($\alpha = .01$) and LSI ($\alpha = .01$) in 1999. These negative relationships are associated with the decrease in land cleared for agriculture with distance from these market communities. *Distance to nearest community* is negatively related to both PD and LSI, significantly so for PD in 1990 ($\alpha = .05$). As the distance to the nearest community increases, there is less impetus to clear land for provision of farm products to that community, thereby reducing the number of patches cleared and, accordingly, landscape shape complexity. *Nearest community population* exhibits a positive relationship to PD and a negative relationship with LSI; neither of these relationships is significant. These relationships may point to agricultural expansion on *fincas* as they aim to meet the needs of an expanding local population; as agricultural expands and cropped land coalesces, landscape shape complexity would be reduced.

5.8. **Conclusion**

This modeling effort illustrates a number of issues. The consistency of the direction of relationships between 1990 and 1999 among the dependent variables describing landscape configuration and the independent variables point to stationarity in the relationships modeled. While the NEA has been seen to be a complex, dynamic system in terms of the LULC change observed, the relationships illustrated here describing landscape configuration do not seem to illustrate such dynamism. The relationships between the independent variables describing landscape composition and the independent variables do, however, show some variability in the directions of the relationships modeled.

In addition, this work illustrates the importance of using remote sensing imagery to model LULC. Despite the utility of remote sensing as a dependent variable, shortcomings are recognized. For example, there is often a lack of accuracy assessment for some of the images in a time-series. In this case, there is a lack of accuracy assessment data for images of the NEA prior to 1999. The lack of accuracy assessment information has influenced this work through the remote sensing classification that was chosen, as fewer classes are generally associated with higher accuracy. While work that uses survey data on LULC as the dependent variable may discriminate between forest, pasture, and annual as well as perennial crops, this remote sensing work is not able to discriminate between crop types. Additionally, there are issues associated with the ability to discriminate between forest and tree crops such as coffee and cacao. However, given that this work's use of the remote sensing as the dependent variable shows relationships similar to those that exist in models in which LULC data were generated from the household surveys, it seems the next step would be to compare remote sensing and survey responses concerning LULC to evaluate the extent to which significant differences exist. Knowledge of the strength of the relationship between our survey and remote sensing data is important. Given that we have been able to obtain imagery of the NEA for time points between major survey data collections, such knowledge allows us to better evaluate the *finca*-level LULC change information provided by images collected between major survey data collections.

This work contributes to work modeling LULC in the Northern Ecuadorian Amazon as well as the larger land change science community. This work, seated at the intersection of people, place, and environment, serves as a reminder that the integration of multiple data types, from household to community surveys, to remote sensing time series data as well as variables derived though use of geographic information systems, continues to provide useful insights when applied to questions of land cover change. In addition, given the pursuit of agent-based modeling by some project members, this work provides the basis with which information about communities could begin to be included as agents affecting land cover change.

Though this work provides a number of contributions, improvements could still be made. First, it is necessary to note that three of the variables used in the models are not at the *finca*-level; the bus and *ranchera* variables, as well as population of the nearest community are variables associated with the community nearest each *finca*. Results of models might thus be improved if a multilevel model were implemented. In addition, given the significance of the transportation data as predictors of LULC proportion and pattern, a next step might be to further elucidate how access to transportation affects LULC. Access of farms to transportation may be further described by integrating data collected from the NEA's bus and *ranchera* companies concerning the existence of service and its frequency, thus better discriminating among *fincas,* as those with better transportation access, whether served by multiple companies or with higher trip frequency, have more options and greater ease in getting their products to market.

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CHAPTER 6

CONCLUSION

The goal of this chapter is to synthesize this research as a whole and to provide conclusions. This final chapter will not only provide a synthesis of the foregoing chapters but will also identify future research directions. This chapter will, therefore, describe what has been learned from this study and what still needs to be done.

6.1. **Research Aims Revisited**

This study sought to examine land cover pattern and change processes from the dual perspectives of the community and the *finca* to better understand land cover change in the frontier environment of the NEA. The primary objective of this research was to develop a better understanding of how community characteristics, linkages among communities, and feedbacks between communities and households affect change in forest, agriculture, and urban LULC in the NEA. Three research aims were set out in Chapter 1:

1. *Examine the spatial distribution, characteristics, and connectedness of communities in the NEA, as well as the linkages among communities and between communities and households.*
2. *Characterize landscape composition and dynamics of land cover change at the community level using remote sensing and spatial analysis methods.*

3. *Model the influence of household and community-level variables on land use and land cover change at the finca level.*

The goal in structuring these research aims was to characterize communities in the NEA as well as to illustrate LULC changes in this region at multiple scales (*finca*- and community-level). The first research aim expanded our knowledge about communities as individuals and as types, or classes of communities, and illustrated the connections among communities and between households and communities. The second research aim used the information gained from classifying communities in the examination of the pattern and extent of LULC change around surveyed communities. The third research aim modeled *finca*-level LULC change, incorporating community data among the explanatory variables.

6.2. **Main Findings**

Chapter 3 focused on three research questions. These research questions examined how the survey communities are arrayed in space and time; whether surveyed communities show similarities that allow them to be sorted into groups; functional relationships that exist between households and communities as well as among communities in the NEA; and how these functional relationships change over time. Analysis of spatial and temporal patterns as well as the similarities and differences among communities revealed several relationships.

First, the temporal and spatial distribution of surveyed communities illustrated the expansion of population into and throughout the region. Only a handful (n=5) of surveyed communities existed prior to the discovery of oil in the region. With the discovery of oil, expansion of road infrastructure, and spontaneous migration to the region, the number of established communities increased rapidly in the late 1960s and throughout the 1970s, with more than half (n=36) of the 59 surveyed communities becoming established within that timeframe. The establishment of communities was initially concentrated along the northern tier of the study area, along the road connecting Lago Agrio to Tena (and ultimately Quito), then expanded southward along the Lago-Coca road and eastward along the road connecting Jivino Verde and Shushufindi. Communities established in the 1980s and 1990s tended to be located with increasing distance from these major regional roads. Tracing the establishment of major communities in the NEA over space and time is helpful from the perspective of understanding settlement of the NEA as a "moving frontier" of the sort described by Webb (2003) – the frontier's boundary was transient and time-dependent as people advanced into unsettled or sparsely populated areas to claim lands.

Second, hierarchical cluster analysis was shown to be an effective means of classifying surveyed communities. Average linkage cluster analysis generated results that placed communities in the NEA along a "development continuum." The results produced by the cluster analysis were found to not only be reasonable, given experience and direct observation in the study area, but also provided a very good solution, as shown through cophenetic correlation analysis (0.85). The classes suggested by the cluster analysis (e.g., most developed, intermediate level of development, and least developed) are helpful in a number of ways. Given the multidimensionality of the dataset, the "development continuum" is an idea much more easily grasped than the individual variables that produced the clusters. In addition, the "development continuum" classification lends itself naturally to use in examining the classes in other scenarios. For example, these classes may be used in future research to model the LULC impacts of different types of communities.

Third, functional relationships among NEA communities were shown to operate in a manner expected according to central place theory, with higher order communities providing the widest variety of goods and services. Lower order communities are related to these higher order communities through transportation linkages provided by buses and *rancheras*. Highest order communities provide access to 1) administrative services (i.e., civil register) and, in the case of Coca and Lago Agrio, monetary distributions from the Ecuadorian government, 2) the greatest range of health services, both public and private, 3) education beyond primary school, and 4) agricultural infrastructure (sawmills, rice huskers, coffee roasters, and crop/animal markets). The characterization of higher order versus lower order communities is supported by household survey data from 1990 and 1999, wherein responses concerning location of purchases, higher education, and medical treatment point to those communities offering a diversity of goods and services. The relationships illustrated among these communities in the NEA supports the validity of applying central place theory in this study area. In addition, examination of the range of goods and services in higher order versus lower order communities is helpful from a policy perspective. For example, examination of the various types of infrastructure (i.e., market, education, transportation, healthcare) highlighted communities that were not as well-served and thus could assist policymakers in targeting extension of services.

Chapter 4 focused on research questions examining whether significant differences in land cover patterns existed as a function of 1) distance from communities, 2) different types of communities (i.e., age, level of development), and 3) time. Regarding distance from communities, results revealed that across all image years forest cover increased with distance, while agriculture decreased with distance and pasture increased initially with distance from the central buffer, then decreased. Across all image years and all spatial buffers, less developed communities were associated with greater proportions of forest, while the most developed communities were associated with the highest proportions of agriculture. Pasture land exists in similar proportions around different community types.

Examination of communities by age class, across all image years and buffers, revealed that the proportion of forest is highest for the most recently established communities. The proportion of agriculture is noticeably higher in communities established between 1950 and 1979 than in communities established in the 1980s and 1990s. The oldest communities (i.e., those established in the 1960s) maintain lower proportions of forest through time than communities established in the 1970s and 1980s.

Analysis of trends in the proportions of land in forest, agriculture, and pasture in the image time-series revealed a number of relationships. All images illustrated that the proportion of agriculture decreased with distance from community, though the proportion of agriculture in each successive image in the time-series increased. Pasture also generally increased in proportion throughout the time-series and showed higher proportions in the spatial buffers closest to communities, decreasing slightly with distance. Forest cover, understandably, decreased in proportion in each image year, while showing increased proportions with distance from communities.

The patterns depicted in the analyses undertaken in Chapter 4 illustrate several important concepts. First, distance is an important predictor of land cover. This, is of course, an expected outcome, given the number of studies that have pointed to the importance of distance as a factor affecting LULC in the NEA (Pan and Bilsborrow 2005, Pan et al. 2004, Pan 2003, Pichón and Bilsborrow 1999, Pichón 1997a, Pichón 1997b). This research, however, examined distance in a different manner, using buffers, and with a different focus, on LULC in the areas surrounding communities rather than on the *finca*. In addition, this research highlights that, despite the differences in proportion of various cover types in the areas surrounding different types of communities, each of the community types displays a similar relationship with the forest, agriculture, and pasture land cover classes with distance from the community. This is particularly helpful in understanding how LULC around various types of communities is likely to change over time. Similar lessons apply to the patterns exhibited by communities of varying age; while clear differences exist in the proportion of different land cover types, land cover patterns around communities exhibit the same trends with distance.

Chapter 5 described models of LULC patterns across time and space at the *finca*-level, while incorporating community-level effects, by employing cross-sectional multivariate linear models that adjust for clustering of observations within communities. The cross-sectional models showed that demographic, socioeconomic, biophysical, and geographic variables have all played a significant role in shaping the composition and configuration of *finca* LULC in the NEA. The geographical variables presented in the models offered a new perspective on modeling LULC in the NEA and thus are the focus of the following discussion. Geographic variables are shown to be significant predictors of landscape composition and configuration; they included vehicle access, existence of bus and *ranchera* transportation, and distance to various types of agricultural infrastructure (e.g., sawmill, crop/animal market). Road *access* to the *finca* is significantly and negatively related to the percent of the *finca* in forest and is significantly and positively related to the percent of the *finca* in crops and pasture. *Access* exhibits a significant and positive relationship to patch density and the landscape shape index. *Transportation* has a significant and negative relationship to forest and a significant and positive relationship to crops and pasture. *Transportation* also shares a significant and positive relationship with patch density and the landscape shape index. *Distance to sawmill* and *distance to market* both exhibited significant and positive relationships to area in forest, significant and negative relationships to area in crops and pasture, and significant and negative relationships to both patch density and the landscape shape index. Distance to nearest community and nearest community population also exhibited a significant and negative relationship to patch density and the landscape shape index.

6.3. **Applications and Contributions**

The research presented in this dissertation provides several contributions. Chapter 2 provides an in-depth background on the people and the environment in the NEA. As such, it can serve as a useful primer for people interested in working in this region. The characterization of communities in the NEA in Chapter 3 assists in understanding how the region is geographically and hierarchically organized, providing insights into how communities in the study area are related. The cluster analysis, used in conjunction with household survey data from 1990 and 1999, provides a richly textured picture of how communities in the NEA are related to one another. In addition, the combination of the cluster analysis with the household survey data provide confirmation of the usefulness of central place theory in the NEA.

The research presented in Chapter 3 not only provides new insight and validates theory, but it also underpins future modeling efforts, particularly in the development of rules for cellular automata (CA) or agent-based models, since different rules concerning land cover change can be developed for communities in the various clusters. This work also may be applied in relation to policy, since analyses examining clusters of particular types of infrastructure (i.e., market, education, transportation, medical) highlight clusters of communities that are not well-served. Communities with low levels of infrastructure could, thus, be targeted for extension of services.

Chapter 4 contributes to our understanding of the NEA in a variety of ways as well. This chapter provides a measure of the impacts of communities in the Northern Ecuadorian Amazon on their surrounding landscape over time and validates agricultural location theory. In addition, this work illustrates how communities impact the landscape in similar ways as they age, and at different intensities depending upon their level of development. Beyond the specifics of the research questions examined, the work presented in Chapter 4 speaks to the issue of direct and indirect impacts of communities on surrounding areas. While direct impacts of communities are seen through the expansion of urban LULC, indirect effects are assessed through examination of the patterns of forest, agriculture, and pasture in the areas surrounding communities. Given that the Northern Ecuadorian Amazon is an area whose trajectory is one of "incipient urbanization," the historical perspective this research work provides concerning LULC around NEA communities is important for future decision-making. One would expect populated places in the NEA to continue to grow, given the relative lack of available land to settle. That said, knowledge about how communities have historically impacted their surroundings will be helpful as policymakers decide whether and how to preserve forested areas.

Chapter 5 extends the treatment of geographic effects on farm-level LULC change. Variables used in this work, such as distance to elements of agricultural infrastructure (e.g. sawmills and crop/animal markets), transportation, and the population of the nearest community, were not previously integrated into LULC models for the NEA. This work contributes to our understanding of the NEA by providing a new dimension to describe communities in the NEA and enriching analytical work at the household level through greater understanding of community characteristics coupled with knowledge of household-community linkages. The research also provides insights for future comparison of differences among community clusters on variables not included in the analysis, such as land cover dynamics. In addition, knowledge about the influence of communities on *finca*-level LULC provides information on which to base rules for the spatial simulation of LULC dynamics using cellular automata and agent-based approaches.

Multiple aspects of this work represent contributions to the Land Change Science community. Examining the impact of communities on the surrounding landscape contributes to an area of land change science focusing on gradient analyses. Gradient analyses are represented in a limited number of publications (Luck and Wu 2002, Seto et al. 2005, Wu et al. 2006, Xie et al. 2006, Yu and Ng 2007, Weng 2007) that generally focus on a single urban area. The work characterizing changes in the area surrounding communities in the NEA thus fills a gap, as it assesses LULC and LULC changes around multiple communities that vary in size and age, and additionally, examines a developing country context in which urbanization is likely to play a growing role in LULC change in coming years. A second aspect of this work that contributes to Land Change Science is the modeling work that couples human and natural systems. While the human components of the system are integrated into the models through demographic, socioeconomic, and geographic variables selected, the natural system is represented in the use of biophysical variables as well as through landscape pattern metrics that describe landscape composition and configuration.

6.4. **Challenges Addressed in Research**

6.4.1. **Linking People and the Environment**

Methodological issues associated with human-environment research exist in integrating spatial and social science data, namely in effectively linking people to the landscape (Geoghegan at al. 1998, Entwisle et al. 1998, Rindfuss et al. 2002, Rindfuss et al. 2003a, Rindfuss et al. 2004, Walsh et al. 2004), choosing appropriate spatial and temporal data resolutions (Rindfuss and Stern 1998), and protecting confidentiality of human subjects (Rindfuss and Stern 1998; Rindfuss et al. 2003a, Van Wey et al. 2005), while taking care to integrate the wider contextual issues that face local actors (Chowdhury et al. 2006). This work addresses a number of these methodological issues. In the case of farm-level LULC, the links between people and the landscape were made by first choosing to follow the *finca* land parcels through time and the people associated with them through time. The issue of subdivision of the original farm, or *finca madre,* made this issue of linkage even more interesting. *Fincas* were followed through time by using boundary data from the GIS to clip images in the remote sensing time-series; this choice exemplifies the use of remote sensing data (pixels) at an aggregated level. Data describing the decision-makers associated with these images was obtained by aggregating household surveys for all farm subdivisions to the *finca* level. In the case of community-level LULC, the link between people and the landscape was not explicitly explored, but could be in the future. The link in this case is at the census sector level, one level above the community level. This is the lowest level for which Ecuadorian census data is available and allows for population and socioeconomic variables to be related to LULC.

Choice of appropriate spatial and temporal data resolutions for this research was dictated by the research questions as well as the availability of data (i.e., household and community surveys). In characterizing NEA communities through time, the temporal resolution of the research was dictated by the number of reasonably cloud-free images of the NEA. Using *finca*-level composition and configuration as the dependent variables and a suite of independent variables selected primarily from the 1990 and 1999 household surveys required the use of images that are closest in date to the time of the household surveys. While sufficient to track changes in land cover, the spatial resolution of the available imagery, 79 meters for pre-1985 images in the time-series and 30 meters thereafter, resulted in the decision to resample imagery to a higher resolution. As a result, the images used in analyzing LULC around communities were resampled to the 1 m level, as were the images of the *fincas.*

6.4.2. **Remote Sensing Accuracy Assessment**

The lack of a formal accuracy assessment for some of the images in a time-series presents a challenge, though not one uncommon to scientists working with time series data. This study lacks a formal accuracy assessment for images of the NEA prior to 1999. The lack of a formal accuracy assessment has influenced this work through the remote sensing classification that was chosen, as fewer classes are generally associated with higher accuracy.

The use of the remote sensing measures as the dependent variable shows relationships similar to those that exist in models of LULC that were generated from the household surveys. This has prompted the intent to compare remote sensing and survey responses concerning LULC to evaluate the extent to which significant differences exist. Knowledge of the strength of the relationship between the survey and the remote sensing data can be used to assess its accuracy to a greater extent than previously possible.

6.5. **Implications for Future Research**

One starts a project with research questions. The process of research inevitably generates more research questions. A number of research possibilities arose from the study, as the actual research prompted additional questions and new directions for research. For example, the work described in Chapter 3 regarding how communities are arrayed in time and space, as well as of their similarities, provides the background for and opportunity to examine LULC change at other levels, such as the parroquia, canton, or province. While some LULC change work has been done at the parroquia-level (i.e., Mena et al. 2006), the work described here concerns relationships among communities as well as an assessment of communities of differing levels of development, which adds richness and depth to examinations of LULC change. Additional avenues for research arise from the issue of communities of varying levels of development. Because there is an expectation that the more-developed communities will produce greater landscape change through their linkages to surrounding rural areas, future work will utilize results of the cluster analysis in conjunction with pattern metric data derived from remote sensing images to group communities by level of development and assess whether significant differences in land cover exist between clusters.

Chapter 4 provided a starting point for describing LULC and for examining LULC change around communities. Patterns around these communities should, therefore, be explored in additional ways, most importantly in terms of the primary roads associated with each community. Spatial buffers around roadways at the depth of typical farms (2000 m) would provide a measure not only of the patterns generated by farms in proximity to these communities, but also a way of examining patterns at various distances from the main roads in the Northern Ecuadorian Amazon (i.e., Lago-Quito, Lago-Coca, Jivino Verde-Shushufindi).

Chapter 5 expanded our knowledge of the impact of community-level variables on *finca*-level LULC. However, improvements could still be made. First, it is necessary to note that three of the variables used in the models are not at the *finca*-level; the bus and *ranchera* variables, as well as population of the nearest community are variables associated with the community nearest each *finca*. Results of models might thus be improved if a multilevel model were implemented. In addition, given the significance of the transportation data as predictors of LULC proportion and pattern, a next step might be to further elucidate how access to transportation affects LULC. Access of farms to transportation may be further described by integrating data collected from the NEA's bus and *ranchera* companies concerning the existence of service and its frequency, thus better discriminating among *fincas,* as those with better transportation access, whether served by multiple companies or with higher trip frequency, have more options and greater ease in getting their products to market.

While a number of potential future directions for research stem directly from this dissertation, other interests have developed as a result of coursework or have been prompted by developments in the land change science community. For example, research interests have developed in working on questions of LULC change related to national parks as well as indigenous territories in the NEA. Given the importance of these areas in preserving biodiversity as well as cultural integrity, it remains important to track changes in these areas though time. Another area of research that is of interest is that of land change science community's dialogue concerning sustainability, resilience, and adaptation. Given the recent higher profile of these issues, it seems reasonable that the Ecuador project begin to integrate these concepts into its next wave of household-level survey data collection with the explicit intent of understanding human behavior, the evolution of social and ecological systems, and the feedbacks and space-time lags of human-environment interactions.

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1990

Table A.1. Correlation table for variables selected for use in modeling landscape composition and configuration in 1990.

	Males	Children	Total *Finca* Pop.	Year *Finca* Est.	Subdiv.	Off-farm empl.	Hired Labor	Elec.	Title	Black soil	Topo.	Access	Trans.
Males	1.00												
Children	0.40	1.00											
Total *Finca* Pop.	0.80	0.83	1.00										
Year *Finca* Est.	-0.10	0.01	-0.05	1.00									
Subdivisions	0.55	0.39	0.58	-0.04	1.00								
Off-farm employment	0.29	0.16	0.31	-0.04	0.28	1.00							
Hired Labor	0.19	0.13	0.19	-0.15	0.25	0.10	1.00						
Electricity	-0.03	-0.12	-0.04	-0.16	-0.13	0.21	0.16	1.00					
Title	-0.22	-0.17	-0.25	0.00	-0.46	-0.15	-0.06	0.08	1.00				
Black soil	0.10	0.13	0.18	-0.17	0.14	0.05	0.16	0.13	0.03	1.00			
Topography	0.19	-0.10	0.07	-0.16	0.08	0.09	0.16	0.15	0.04	0.38	1.00		
Access	0.11	-0.01	0.08	-0.31	-0.09	0.05	0.12	0.23	0.08	0.07	0.13	1.00	
Transportation	0.09	-0.07	0.04	-0.22	-0.05	0.09	-0.02	0.12	0.12	0.10	0.21	0.50	1.00
Dist. to sawmill	0.03	0.00	0.00	0.33	0.00	-0.01	-0.07	-0.17	-0.07	-0.05	0.09	-0.12	-0.29
Dist. to rice husker	-0.16	-0.05	-0.15	0.44	-0.13	-0.03	-0.17	-0.20	-0.06	-0.28	-0.29	-0.18	-0.26
Dist. to coffee roaster	0.01	-0.03	-0.05	0.34	0.04	-0.09	-0.01	-0.15	-0.15	-0.11	0.02	-0.12	-0.49
Dist. to market	-0.08	-0.05	-0.11	0.34	-0.07	-0.09	-0.13	-0.18	-0.08	-0.17	-0.09	-0.11	-0.17
Dist. to nearest comm.	-0.13	-0.05	-0.12	0.33	-0.06	-0.03	-0.19	-0.18	-0.05	-0.14	-0.18	-0.34	0.09
Nearest comm. pop.	0.04	0.07	0.08	-0.01	0.14	0.11	0.14	0.04	-0.05	0.12	-0.09	0.10	0.37

Table A.1. (cont'd)

	Dist. to sawmill	Dist. to rice husker	Dist. to coffee roaster	Dist. to market	Dist. to near comm.	Near. comm. pop.
Dist. to sawmill	1.00					
Dist. to rice husker	0.31	1.00				
Dist. to coffee roaster	0.71	0.45	1.00			
Dist. to market	0.44	0.78	0.61	1.00		
Dist. to nearest comm.	-0.01	0.42	0.00	0.27	1.00	
Nearest comm. pop.	-0.28	-0.18	-0.35	-0.20	0.26	1.00

1999

Table A.2. Correlation table for variables selected for use in modeling landscape composition and configuration in 1999.

	Males	Children	Total *Finca* Pop.	Year *Finca* Est.	Subdiv.	Off-farm empl.	Hired Labor	Elec.	Title	Black soil	Topo.	Access	Trans.
Males	1.00												
Children	0.62	1.00											
Total *Finca* Pop.	0.88	0.90	1.00										
Year *Finca* Est.	-0.21	-0.15	-0.20	1.00									
Subdivisions	0.74	0.67	0.78	-0.12	1.00								
Off-farm employment	0.39	0.28	0.38	-0.16	0.33	1.00							
Hired Labor	0.05	-0.03	0.02	-0.05	0.03	0.09	1.00						
Electricity	-0.07	-0.10	-0.08	-0.02	-0.19	0.01	0.09	1.00					
Title	0.07	-0.05	0.01	-0.23	-0.02	-0.02	0.24	0.16	1.00				
Black soil	0.18	0.24	0.24	-0.13	0.24	0.18	0.21	0.06	0.10	1.00			
Topography	0.18	0.15	0.20	-0.09	0.25	0.19	0.17	-0.03	0.17	0.47	1.00		
Access	0.18	0.06	0.14	-0.31	0.08	0.24	0.26	0.18	0.34	0.06	0.10	1.00	
Transportation	0.23	0.06	0.18	-0.04	0.18	0.39	0.17	0.06	0.13	0.25	0.32	0.24	1.00
Dist. to sawmill	-0.18	-0.07	-0.15	0.36	-0.14	0.02	-0.04	-0.06	-0.26	0.10	0.10	-0.17	-0.19
Dist. to rice husker	-0.20	-0.10	-0.18	0.46	-0.18	-0.19	-0.11	-0.07	-0.29	-0.06	-0.05	-0.17	-0.20
Dist. to coffee roaster	-0.11	-0.09	-0.13	0.17	-0.15	0.05	0.07	0.05	-0.16	-0.15	-0.02	0.13	-0.04
Dist. to market	-0.15	-0.09	-0.15	0.29	-0.09	-0.21	-0.10	-0.15	-0.23	-0.12	-0.10	-0.17	-0.18
Dist. to nearest comm.	-0.10	-0.17	-0.16	0.29	-0.08	-0.19	-0.18	-0.03	-0.17	-0.20	-0.25	-0.33	0.12
Nearest comm. pop.	0.18	0.04	0.13	0.01	0.11	0.21	0.09	0.02	0.04	-0.04	-0.13	0.03	0.40

Table A.2. (cont'd)

	Dist. to sawmill	Dist. to rice husker	Dist. to coffee roaster	Dist. to market	Dist. to near comm.	Near. comm. pop.
Dist. to sawmill	1.00					
Dist. to rice husker	0.77	1.00				
Dist. to coffee roaster	0.48	0.51	1.00			
Dist. to market	0.45	0.62	0.27	1.00		
Dist. to nearest comm.	-0.07	0.16	-0.06	0.14	1.00	
Nearest comm. pop.	-0.34	-0.40	-0.24	-0.37	0.23	1.00