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From the Household to the Community: A Resource Demand and Land-Use Model of Indigenous Production in Western Amazonia

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From the Household to the Community: A Resource Demand and Land-Use Model of Indigenous Production in Western Amazonia

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Dedication

To the people of the Amazon

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This study takes a spatial perspective to analyze traditional land-use and production systems in humid tropical environments, with emphasis on the agricultural dimension. The setting is the Pastaza River Basin in the Ecuadorian Amazon and the Achuar and Shiwiar indigenous groups are used to highlight the elements of these systems. This dissertation relies on land use/land cover change and agricultural change theories to analyze indigenous land use systems. The study uses empirical data to examine the linkages between decision making, the demand for land resources, and landscape change. Results suggest that the transition from nomadic-dispersed to permanent-nucleic villages leads to the implementation of a land-use zoning system that responds to changes in resource availability. This system can be represented by a concentric land-use-zones model that depicts an efficient distribution of land resources

around service infrastructure such as landing strips, health centers, or schools. Overall, the demand for land resources varies with changes in household composition. At the beginning of the household's life cycle, the demand for farmed land is relatively low because the family's food requirements are minimal. As households grow, the demand increases and agriculture expands. As young adults leave the house for any reason, the demand for cultivated land decreases and the extent of agricultural land use contracts. In addition, the demand for land resources is associated with ecological conditions of the habitats in which production occurs and with distance to the community. Areas with good soils have smaller agricultural plots than areas with poor soils. People living in poor-soil environments manage larger fields but produce less food per unit of area than households with good soils. The probability of an area of becoming agriculture increases in sites farther away from existing cultivation fields, service infrastructure, and homes since areas closer to these features have already been used and are recuperating as fallows. Additionally, people are cultivating in areas that are relatively steeper than older agricultural fields. These findings suggest that indigenous people are expanding agriculture into areas with adverse pedologic and topographic conditions, which may be an indication of overall scarcity of land resources for food production.

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Chapter One

Introduction and Context

1. Introduction

Understanding the ways that land cover changes with changes in land use has long been a pursuit of geography, agricultural economics, archaeology, and related disciplines (Butzer, 1982; Redman, 1999; Turner II, 2002). Many researchers have analyzed land cover change resulting from food production activities as it is significant for the planet's system by virtue of the sheer magnitude of agricultural land use. Ramankutty *et al*., (2002) estimated that almost 12 percent of the potentially vegetated surface of the Earth (about 18 million km^2) is under some form of cultivation. However, a large part of the land surface is unsuitable for cultivation, due to limitations in the length of the growing season, precipitation, soil characteristics, or topography. Humans have overcome these limitations through the use of technology (e.g. irrigation, fertilization, terracing). In certain areas of the world, where accessibility to technology is constrained by high costs or lack of incentives, production systems have experienced small variations over time (Lawrence & Schlesinger, 2001). This study focuses on the analysis of traditional production systems and land cover change in tropical lowlands. This research combines survey, statistical, and spatial modeling approaches to analyze the spatial dimensions of traditional production systems and utilizes the Achuar and Shiwiar indigenous groups to exemplify the elements of western Amazonian systems.

Recent research indicates that agricultural expansion, intensification, and the consequent land cover change are implicated in environmental problems ranging from local to global scale, and nowhere are these problems more severe than in tropical regions (Barraclough & Ghimire, 2000; Walker, 2004). Much of this evidence comes from the analysis of peasant farmers in relatively new settlements at tropical forest frontiers, who often have been considered the main agents of environmental change (Wood, 1983; Walker *et al*., 2000; Walker, 2004). It is also generally accepted that indigenous peoples inhabit many, if not the great majority, of the less disturbed tropical forests (Zimmerman *et al*., 2001; Fearnside, 2003), but are currently experiencing rapid socio-cultural, demographic, and economic transformations (Descola, 1981; Lu, 1999; Holt *et al.*, 2004; McSweeny & Arps, 2005). As indigenous peoples in the tropics slowly integrate into national and international economies, and their social and cultural conditions consequently change, it is expected that their resource use strategies will adjust to these changes as well. It is likely that these alterations will increase the demand for food resources, which could ultimately cause resource scarcity or depletion, and end up affecting the well-being of local populations.

If indigenous populations continue to grow and pressure on natural resources increases, production systems will most likely experience changes in order to satisfy food demands of the growing numbers. Research on the evolution of production systems has focused on theories that explain changes on agricultural land use either in the form of intensification or extensification. Intensification refers to gains in production obtained primarily by increasing yields in areas already under cultivation. Extensification refers to gains in production obtained primarily by expanding the area under cultivation on areas that were previously unused. Two schools of thought have guided the discussion on this topic. The first was introduced by Malthus in 1798, and is based on the premise that agricultural extensification is the most obvious response to changes in population density. The problem arises as population pressure outstrips food supply because population grows exponentially and food supply increases arithmetically. This situation leads to the collapse of the food production system as the carrying capacity of the environment reaches its limit due to land scarcity problems. Once the system reaches its carrying capacity, human populations face starvation, war, or lack of employment opportunities in agriculture, in addition to a consequent pressure for migration to other rural or urban areas (Ehrlich & Holdren, 1988; Ehrlich & Ehrlich, 1990; Kates, 1995). The second concept was introduced by Boserup in 1965. She contended that population growth increases agricultural production in the form of intensification as innovation and technological shifts occur and allow for growing population numbers. This means that the carrying capacity of the food production system is not fixed and can be modified as technology is innovated and people adapt their systems to hardship conditions. Thus, population growth may be a determinant of agricultural change and not necessarily of resource depletion or settlement relocation.

Other researchers have found both Malthusian and Boserupian concepts too narrow, and have showed that changes in agricultural systems are explained not only by disparities in demographic conditions and technology, but also by factors such as integration to markets (Godoy *et al.*, 2001), institutional changes (Brookfield, 1972; Binswanger & McIntire, 1987), and the historical-political contexts of production (Rudel, Bates, & Machinguiashi, 2002). In the presence of markets, people may change production strategies to intensify production or extraction of tropical forest flora and fauna to satisfy the external demand (Padoch, 1985; Humphries, 1993; Behrens, Baksh, & Mothes, 1994; Henrich, 1997; Sierra *et al*., 1999). When the availability of resources diminishes, subsistence societies may change the institutions that regulate the access to land to guarantee a relatively equitable distribution of resources (Binswanger & McIntire, 1987). These changes are generally influenced by local, national, and regional development policies and linked to historical events (Rudel *et al.,* 2002). However, when markets are almost inexistent and the primary purpose of production is to provide nourishment for local populations, agricultural production may be linked almost exclusively to demographic factors (Nietschman, 1973; Netting, 1983; Turner, Hanham, & Portararo, 1977). In these cases, Chayanovian theory can help to elucidate how demographic factors affect decisions on land allocation for agricultural land use (Thorner, Kerblay, & Smith, 1986). Chayanovian theory examines the relationships between changes over time in household composition and age, and the resulting patterns of land use. This study builds on these theories to analyze the relationships between agricultural production and the socio-demographic contexts of indigenous societies.

Most land use studies and theories rely on land rent maximization theory of von Thünen and Ricardo to explain changes in land cover (Mertens & Lambin, 2000; Walker, 2003). In these models, any parcel of land, given its attributes and location, is assumed to be allocated to the use that earns the highest rent, which implies that production needs to be intensified or expanded to maximize profit. Additionally, current land use and land cover change (LULCC) theories in the tropics mainly focus on the demand for land in colonization areas and on migrant peasant farmers that are held in fixed and well-delimited farms or fields, in which production is a hybridization of subsistence and market-oriented goals (DeShazo & DeShazo, 1995; Pichón, 1997; Pfaff, 1999; Walker, 2003). Such theories allow investigation of the influence that various policy measures such as colonization and land legalization have on land allocation choices under private property schemes (Lambin, 1997; Pichón, 1997; Kaimowitz & Angelsen, 1998; Brondizio *et al*., 2002). Most observers agree that these policies generally result in high demand for land as people attempt to safeguard legal ownership on frontier lands (Southgate, Sierra, & Brown, 1991; Angelsen, Shitindi, & Aarresttad, 1996; Rock, 1996). As populations in frontier lands grow, so does the demand for land for agricultural purposes (Pichón, 1997; Perz, 2002; McCracken *et al.* 2002). When the demand increases, forest lands that are closer to accessibility infrastructure, urban markets, and villages are more likely to be incorporated into the production system (Sader &Joyce, 1988; Ludeke *et al*., 1990; Chomitz & Gray, 1996; Nelson, 2001). In general, it can be argued that the roles that institutions, infrastructure development, land tenure security, and demographics play in LULCC in colonization areas are fairly well understood.

However, less agreement exists among researchers on the role that the demand for land resources plays on land cover change in indigenous lands in the humid tropics. The evidence that shows that theories based on colonization fronts will also represent the conditions found in indigenous territories is limited. The conditions found in colonist areas are different than those conditions found in most indigenous territories where land is communally administered, production areas are temporary, dynamic, may overlap, and the actual goal may not be to obtain the highest rent (i.e. maximization), but may be to satisfy the nutritional needs of the population. Some studies suggest that indigenous groups clear large forested areas when the demand for agricultural products increases due to shifts in the purpose of production (i.e. from subsistence to market oriented) (Henrich, 1997; Humphries, 1993). Other authors conclude that indigenous groups do not demand extensive areas for cultivation purposes as long low population densities are maintained (Brookfield, 1972; Netting, 1993), people enjoy secure rights of use to the land (Hyde, Amacher & Magrath, 1995; Rudel *et al.*, 2002), and the goal is mainly subsistence (Godoy, 2001). Some researchers suggest that the demand for land resources and the intensity of agriculture are associated with the type of environment where production occurs and with changes in settlement patterns (Lathrap, 1970; Meggers, 1971; Descola, 1981; Denevan, 1996; Denevan, 2001). This research contributes to this discussion by providing empirical evidence on the factors that influence the demand for land resources in indigenous territories in Western Amazonia. Unlike past approaches examining indigenous land use systems and similar issues, in which analyses are mostly based on surveys and ethnographic descriptions, this study addresses the demand for land and food resources through the study of agricultural land use within a spatially explicit context. This study integrates up-to-date detailed spatial, socioeconomic, and demographic information to advance the understanding of the spatial dimensions of traditional land use systems in tropical humid environments. In doing so, this research departs from the theoretical improvisation and ethnographic descriptions that have characterized much of the anthropological work done in tropical humid environments of Latin America.

2. Theoretical overview

The current socioeconomic and demographic states of the majority of Amazonian indigenous groups are the product of a continuous exchange between native and non-native Amazonians over time. Thus, contemporary Amazonia should be recognized as a cultural landscape resulting from continuous social and human-environment interactions. This dissertation lies at the intersection of two main areas of research. The first area of research is a theoretical framework on traditional land use and agricultural systems, which introduces concepts and typologies compatible with Amazonian societies. While Amazonian landscapes are recognized as dynamic spaces in continuous change resulting from the continuous socialization of nature, theory on agricultural systems in tropical areas helps to explain the structural and physical characteristics of their production systems. The second field of research is a theoretical overview of LULCC, with emphasis on agricultural expansion, which complements the theoretical baseline to derive the hypotheses that guide this research. The current paradigm of LULCC theory in the Amazon region attempts to explain the relationships between socioeconomic, biophysical, demographic, and political-institutional variables and landscape change. While these theories have allowed partial unraveling of the complexity of LULCC in tropical regions, they have mainly been based on deforestation in colonization areas, where agents of change are generally external. Such theories may not be appropriate for indigenous areas where land use and agricultural production depends mostly on endogenous factors such as household dynamics and, to a lesser degree, on environmental conditions. As agriculture appears to be expanding in indigenous territories, this study builds on this framework and on empirical data to examine the spatial characteristics of indigenous agricultural production at household and community levels.

3. General objective and scope

The general objective of this study is to advance the understanding of contemporary indigenous production systems in traditional societies in lowland tropical regions. This investigation primarily concentrates on the spatial characteristics of the main components of indigenous productions systems, with emphasis on agriculture. The main focus of this study lies on the relationships between agricultural land use, demographics, and biophysical parameters as they occur among several groups of tropical subsistence horticulturalists.

4. Specific objectives

The specific objectives of this study are oriented toward answering three general research questions:

1) What are the effects of changes in settlement patterns on the spatial manifestation of production systems in indigenous areas in the humid tropics? To answer this question, this research will document the spatial dimension of contemporary indigenous production systems in tropical humid environments. This objective will be pursued through the development of a descriptive land use model using empirical data on indigenous productions systems in forest-based societies of Western Amazonia. The hypothesis is that although settlement patterns conditions in Western Amazonia have shifted from dispersed-nomadic to nucleic-permanent living arrangements, native people have adapted their production systems to these changes and maintained the basic

elements of the traditional system. However, the extent of domestic management areas has probably decreased due to changes in resource availability and competition for land resources around accessibility infrastructure.

2) What are the structural characteristics of cultivation systems of contemporary subsistence groups in tropical lowlands that are at early stages of the transition to a market-oriented economy? To answer this question, this study will assess the structural characteristics of agricultural production in order to characterize the demand for land resources and agricultural intensity in subsistence production systems in tropical lowlands. For this purpose, this study will statistically analyze and compare cultivation systems in two biophysically different regions in the Ecuadorian side of the Pastaza River Basin: the inter-fluvial and riverine environments. The underlying hypothesis is that indigenous groups with similar cultural, socio-economic, and technological characteristics have most likely developed cultivation systems that respond to these conditions in a similar way (i.e. swidden and shifting management). However, differences in land use patterns and structure may exit, which could be associated with local ecological conditions and with people's demand for land resources.

3) What are the factors that affect the demand for land resources in indigenous and subsistence-based societies in tropical lowlands? To address this issue, this study will evaluate the relationships between agriculture and the socio-demographic and biophysical contexts of contemporary indigenous societies. The linkages will be sought through a spatially explicit land use model that will be built upon LULCC and agricultural change theory, and that will use inputs of empirical data. The model intends to improve the

understanding of land use systems in indigenous areas through the integration of spatial and socio-economic information at a household level, for the purpose of predicting changes in areas where data is unavailable or incomplete. The initial hypothesis is that the factors that influence the demand for land in indigenous areas in tropical lowlands is driven by variations in biophysical factors, such as soils and slope, demographic aspects, such as population pressure, and spatial conditions such as distance to existing agricultural areas and proximity to accessibility infrastructure.

5. Significance

This study focuses on indigenous peoples and land cover change caused by agricultural land use. Choosing indigenous peoples to study agricultural expansion does not necessarily mean that agricultural encroachment in forested areas of indigenous lands is currently an environmental threat. In fact, Zimmerman *et al*. (2001) pointed out that legally recognized indigenous reserves of Amazonia span tens of millions of hectares (approximately 20% of the Amazon basin) of intact forest ecosystems, placing aboriginal issues at the forefront of biodiversity conservation. This study focuses on indigenous peoples for two important reasons: First, agricultural expansion driven by indigenous agents has received less attention than agricultural growth in areas controlled by peasant farmers and colonists. Second, although agricultural expansion in indigenous territories may not be a current environmental threat, it may become one in the future as national health programs are applied and indigenous populations increase, management practices and cultures change, markets become more available, and populations face land shortages (Godoy, 2001). Logging or forest clearing caused by agricultural extensification in indigenous lands may not result in large areas of forest loss at any one time. However, over time and at current rates of population growth, agricultural expansion could potentially increase forest fragmentation and the loss of forest-dependent species. As indigenous people gain greater sovereignty over their territories, they will ultimately benefit by taking steps to lower internal pressure on their forests. Restricting pioneer farmers and cattle ranchers from cutting forests was yesterday’s problem; curbing indigenous people form mismanaging their natural resources will likely be at the top of tomorrow’s policy’s agenda.

This study examines agricultural intensification at the household level in lowland tropical areas, and investigates the linkages between household decision making and production. Unlike many studies of LULCC and agricultural systems, this research is significant because it is based on direct *in-situ* measurements of land use and land cover. Most analyses of LULCC and agricultural systems generally rely on socioeconomic surveys alone, or are linked to georeferenced spatial data with coarse resolutions. In these studies, quantitative information on the extent of households’ land uses is generally derived from socioeconomic surveys and not directly from on-site measurements or from remotely sensed data, due to the lack of spatial detail. This situation forces researchers to depend mostly on informants that may or may not provide adequate information. Conversely, research completed during this study overcomes the aforementioned limitations by obtaining direct field measurements and by accurately mapping land use areas with the aid of up-to-date high resolution aerial images and the global positioning system (GPS). This procedure allows capturing local spatial variability to adequately classify land uses at the household level.

Finally, this research is noteworthy due to the geographical location of the study area. The lower watershed of the Pastaza River Basin in the Ecuadorian Amazon (PRBEA) encompasses a significant area of tropical forest of approximately 12,000 km^2, where several groups of long-term Amazonian residents, such as the Shuar, Achuar, Shiwiar, Canelos Kichwa, Andoas, and Zápara, coexist. This work is of particular importance because it provides previously unrecorded spatial and socio-economic information of this culturally and biologically diverse region. More importantly, it has been recognized that indigenous groups living in the area are facing rapid cultural transformations due to changing socioeconomic and demographic conditions in the entire region. However, it is not clear what these changes are and how they affect people's choices on land allocation and resource use.

This study provides empirical quantitative evidence on the spatial and socioeconomic nature of landscape transformation in the Amazon region. This dissertation is a spatial and socio-economic study of indigenous production systems with emphasis on the agricultural element, and utilizes two sub-ethnic groups of the Jívaro linguistic group of the lower Pastaza River Basin (i.e. the Achuar and Shiwiar) to guide the discussion. Subsequent chapters include theoretical discussions on agricultural systems and LULCC, a physical and historical description of the study area and the subject populations, research methodology, results of the analysis of indigenous production systems, discussion of the results, and conclusions.

Chapter Two

Indigenous Production Systems

1. Introduction

Cultural ecologists have evaluated the diverse range of management practices, cultivars, and social relations that constitute indigenous production systems, as well as the intricate agro-ecological knowledge that underlies them (Posey & Balée, 1989). Though an important source of hypotheses for further research, many of these evaluations come from ethnographies that make it difficult to generalize results because of the different methods use for collecting, analyzing, and presenting information (Godoy, 2001). Anthropologists have described in detail the stresses (and less often the benefits) produced by the integration of Indian societies to national economies of lowland Latin America. However, they have paid less attention to developing theories, systematizing data to test hypotheses, and generalizing about the structural characteristics of production systems in societies that are in the transition from subsistence to a market oriented economy. Recent approaches that have used not only ethnographically grounded fieldwork but also quantitative data on where, what, how much, or how often forest and agricultural items are produced, have provided important insights towards elucidating the structural characteristics of indigenous production systems and how they have changed over time (Behrens *et al*. 1994; Godoy, Brokaw, & Wilkie, 1995; Sierra *et al*,. 1999; Godoy, 2001; Vadez *et al*. 2004).

From the revision of literature, two characteristics of production systems are distinguished, which constitute the premises behind this research. First, indigenous land uses and agricultural systems are not static but dynamic. This condition is due to several factors such as ecosystem dynamics and to historical factors which have caused massive changes in demography and settlement patterns since the European invasion of the Americas (Davis & Wali, 1994). Indigenous peoples have continuously created new and modified existing land and resource-use practices to ensure their physical and cultural survival under conditions of warfare, conquest, disease, slavery, and displacement (Denevan, 1996). Additionally, as technology diffuses and households participate in a market economy, their economic opportunities increase and the demand for annual crops changes from an increase in income and population (Netting, 1993). These conditions may trigger changes in production systems as they evolve locally (i.e. within the same geographic area or environment) to fit particular characteristics of human populations (e.g. size, social complexity), satisfy the external demand for agricultural products, and adapt to environmental and technological constraints (e.g. scarce agricultural land or lack of agricultural inputs) (Boserup, 1965; Brookefield, 1972; Thapa & Rasul, 2005).

Second, any production system and corresponding land uses will be strongly related to the structural makeup of the culture of the society that employs that system. The interrelationships between land, plants, domestic animals, technology, productive inputs of energy and people all determine the levels of production and create cultural landscapes. Thus, researchers could expect a link between the cultural context and social institutions of lowland forest dwellers and their land use practices. Any type of production system typology should take into account the socio-cultural drivers as well as the economic and technological ones (Berkes, Colding, & Folke, 2000; Martinez, 1994;

Posey & Balée, 1989). This study focuses on subsistence production systems and treats them as dynamic arrangements, where landscape patterns reflect not only households' decisions on resource use that are constrained by technology and the environment, but also by cultural and historical aspects of the societies in which these systems evolve.

This chapter begins with a review of literature regarding the characteristics and dimensions of food production systems in subsistence based societies. Next, a discussion is presented of how and why production systems evolve with emphasis on the agricultural dimension. Subsequently, this chapter revises some theories on the physical expression of agriculture and highlights the importance of analyzing the spatial dimension. Finally, a classification typology for the study of agriculture is presented, which is used as an aid for the characterization of agriculture in tropical lowlands.

2. Characteristics of food production systems in subsistence-based societies

The analysis of food production systems centers on the economy of domestic units. It is household production that provides the main proximate driver of landscape change, serving as the nexus between the objectives of the household and the use of land (Turner II, Meyer, & Skole, 1994; Walker & Homma, 1996). Consequently, the key to understanding subsistence-based production systems at the household level lies in understanding how households utilize land for food production or extraction. Most indigenous groups of the tropics practice a mixed subsistence economy based upon horticulture, wild plant gathering, hunting and fishing. These mixed subsistence systems rely on simple technologies and an extensive knowledge base which allows for the extraction of natural resources from an essentially fragile environment (Davis & Wali, 1994).

In most indigenous tropical forest-dwelling societies, the household economy is marked by a pronounced division of labor by sex, although economic or other needs may justify breaking the traditional norms regarding this division (Beckerman, 1987). Labor generally encompasses two distinct but complementary work processes: shifting swidden horticulture, a quasi-exclusive female domain, and hunting and fishing for big fish, an exclusive male domain (Burton & White, 1984; Beckerman, 1987; Descola, 1994; Coomes & Burt, 1997). Hence, the analysis of traditional modes of production and land uses should clearly distinguish separate spaces, where these two processes occur. First, the labor process of men, which can be considered as an activity of predation (i.e. clearing forest, killing game, and fishing) within a natural ecosystem; and second, the labor process of women that can be perceived as the transformation of nature (i.e. horticulture and food preparation), within an artificial ecosystem. These two processes and spaces intersect on a third occupancy element that amalgamates the domestic unit: the housing area. The house is explicitly conceived as a normative form of social grouping and residency (Harner, 1972; Descola, 1987). In subsistence economies, the residential unit corresponds to an autonomous domestic production and consumption group. Whether a domestic unit is integrated to nucleated village or not, it is ultimately responsible for the transformation of the natural setting. The traditional household is self-sufficient with regard to their horticultural and protein supply; it exercises autonomous control over its resources, its means of production, and its products (Beckerman, 1987).

2.1 The agricultural and cattle-raising elements

The agricultural dimension encompasses the agricultural and, more recently, cattle-raising activities, in addition to the land allocated for the production of cultivated foods and animal species. Subsistence cultivation systems in the tropics involve an enormous diversity of rational and permanent cropping systems and remain of fundamental importance for the economy of several indigenous groups in tropical America (Charlton, 1987). As shifting swidden cultivation appears to be one of the most widespread agricultural systems in indigenous areas in tropical regions (Amelung & Diehl, 1992; Sirén, 2007), attention should be placed on the characteristics of this system and its practitioners to address the issues related to landscape change.

Shifting cultivation is a farming system that begins with the slash and mulch or burn (i.e. swidden) of a patch of primary or secondary forest and normally implies the existence of a cropping cycle component. Cutting and burning patches of forest give the cultivator rapid access to nutrients via wood ash (Charlton, 1987). A society practicing shifting cultivation traditionally maintains the effective functioning of the system and its own self-sufficiency by absorbing unused land and letting other areas recuperate as fallow to address the problems of short-term fertility decline as well as weed and pest proliferation (Ewel, 1986). The extent of clearing depends on the techniques used by the farmers and the overall demographic and environmental circumstances that relate to the length of the fallow periods between farming cycles. At low population densities, shifting swidden cultivation involves the clearing of only a minimal proportion of the forest each year. Traditional swidden fields are quite small by the standards of many agricultural systems, the plurality of them being less or equal to 1 ha (Beckerman, 1987). Shifting cultivation begins with intensive management practices (i.e. frequent cleaning) using traditional tools, progresses to increasingly less intensive management (i.e. rare and only partial weeding), and finally ends with the eventual regeneration of largely natural growth. Production of the plot obviously changes as well; tree crops replace the roots, grains, and semiperennial fruits that are harvested in the first several years (Harris, 1971; Denevan, 1971; Smole, 1976; Eden, 1980; Liebman & Dyck, 1993).

In a shifting cultivation system, small landholders prefer to expand production to maximize labor output (Turner *et al*., 1977). For this purpose, land availability is an essential factor required to accommodate increasing populations and to permit fallow or rest periods that are an important component of the land use cycle; the fallow period must be sufficiently long to re-establish soil fertility for another cycle of use. Under conditions of low population pressure, fallows can be left to grow for such a long time that old agricultural plots become basically indistinguishable from the primary forest (Myers, 1990; Descola, 1994). When additional land is no longer available for incorporation into the system, the fallow period length is reduced, soil fertility decreases, crop yields drop during the cultivation portion of the cycle, and the entire system is in jeopardy (Charlton, 1987).

The choice of a family agricultural plot includes consideration of conditions such as soils, slope, vegetation characteristics, and proximity to the house (Boster, 1983; Descola, 1994; Godoy, 2001). Alluvial soils in flat areas are usually, but not always, of higher fertility than non-riverine soils on hilly terrain. This tendency is probably enough to explain most of the preference for them. People generally prefer areas with bush forest or small trees since clearing is easier and requires less input than areas covered with large trees. Most swiddeners have a field, commonly the major field, located close to the residential area. Even peoples who locate their main fields at some distance from their dwellings usually maintain a small “house garden” within a few meters of their home (Lathrap, 1977). A number of researchers agree that the maximum distance people are willing to walk to a plot is about 7 km (Carneiro, 1961; Isacsson, 1975; Aspelin, 1976). Distances may be even greater for fields accessible by canoe (von Hildebrand, 1975).

In several Amazonian societies, the responsibility for making the choice and clearing the plot falls exclusively on the male, as the head of the domestic unit (Beckerman, 1987; Descola, 1994). After an area has been cleared and cleaned, the new plot is exclusively the domain of women. Women activities in the new agricultural area represent a gradient of intervention from total ecosystem transformation, which occurs in the swidden plot, to transplanting or planting in existing vegetation formations, to merely protecting spontaneous, valuable species via weeding. This gradient of manipulation is well documented for the Brazilian Caboclos at the mouth of the estuary (Brondizio, 1996; Brondizio *et al.*, 1994), the Huastec Mayan Indians (Alcorn, 1983), and for indigenous Amazonian groups such as the Achuar, Shuar, and Bora (Harner, 1984; Denevan *et al.*, 1984; Descola, 1994).

From the point of view of control over resources and means of production, horticultural or cattle ranching labor processes in subsistence based and market oriented societies, remain within the sphere of the domestic unit (Beckerman, 1987). In male dominated subsistence societies, agricultural fields and pastures generally belong to the male household head who confers implicit rights of usufruct to the women of the household (Alberti, 1986). For example, Descola (1994) pointed out that among the Jívaro Achuar there is no concept of jurisdiction of property of non-transformed land; only the products of labor are subsumed under a rule of possession. The clearing is part of the household domain, owned and controlled by the household head. The agricultural plot itself belongs to the women who work it but the pastures remain male spaces, although women can use some of the cleared land if new areas for agricultural production are needed.

2.2 The foraging element

Foraging refers to the collection of wildlife (i.e. animal and plant species) for subsistence (DeSouza-Mazurek *et al.*, 2000). Wildlife species are a critical part of the diet of most people living in Amazonia's rain forest habitats (Peres, 1990; Bodmer, 1994; Alvard, 1994; Alvard *et al.*, 1997). In fact, some researchers have suggested that foraging could have sustained tropical lowlands societies for centuries without the need to depend on cultivated foods (Bahuchet, McKey, & DeGarine, 1991; Brosius, 1991; Dweyer & Minnegal, 1991; Endicott &Bellwood, 1991; Stearman, 1991). These studies argued that an indigenous production system lacks necessary dependence upon the agricultural element with which it co-occurs and can be connected with a system of carbohydrate procurement that is not agricultural. Thus, subsistence of contemporary rain forest foraging peoples, in which extensive relationships with sedentary farmers appear to be universal, may be a somewhat distorted reflection of their subsistence patterns in the preagricultural past (Bahuchet *et al.*, 1991). Whatever form food production took, the issue is not so much whether Amazonian forest-dwellers cultivated or not, or whether they could have survived without any source of cultivated produce or not. What does matter is the recognition of the importance of both the cultivation and foraging components in current indigenous land use systems.

Foraging areas are dynamic zones that change according to variations in the availability of game and forest resources, and in the distribution of human populations (Good, 1989; DeSouza-Mazurek *et al*., 2000). As Amazonian people become more sedentary and the availability of more efficient hunting weapons increases (Milliken *et al*, 1992; Stearman & Redford, 1995; Leeuwenberg, 1997), it is likely that hunting pressure will intensify resulting in the decline of wildlife populations and hunting yields. Hunters who live in permanent villages are expected to have lower yields per unit effort than those who relocate more frequently (DeSouza-Mazurek *et al.*, 2000). Information from the literature indicates that most hunting occurs near villages (Hames, 1980; Fragoso, 1991; Alvard, 1994; Hill *et al*, 1997; Mazurek, 1997). For instance, Descola (1987) pointed out that in dispersed settlement patterns in the upper Pastaza basin, gathering zones were generally found approximately within 1 or 2 km from temporary house gatherings. These areas were well known spaces and constituted an extension of the domestic management unit. While the areas surrounding the houses and agricultural areas correspond to gathering zones, hunting areas are generally located beyond these areas and extend out between 5 and 7 km. In forest regions of the Brazilian Amazon, most hunting occurs within 10 km of a village (Fragoso, Silvius, & Villa-Lobos, 2000). Beyond 10 or

15 km from villages, areas are lightly hunted. In general, areas close to settlements are used more frequently for hunting than more distant ones but tend to have lower capture per unit of effort than remote hunting sites (Hames, 1980; Alvard, 1994; Fragoso, 1998). Capture per unit of effort is usually higher in more remote and lightly hunted areas than in areas close to settlements in Amazonia (Vickers, 1980; Bodmer *et al*, 1994; Alvard *et al.*, 1997).

Some studies that investigated the effects of distance from the village on wildlife harvesting in Amazonia have been done in areas where hunting trips are single day events and where people go hunting by foot (Vickers, 1991; Alvard, 1994; Avlard *et al.*, 1997). These studies have concluded that generally hunting yields increased with distance from the settlement (e.g. Hames & Vickers, 1982, or Alvard, 1994). Species composition of the catch can also change with distance from the village (Hames & Vickers, 1982). Preferred species may become rare near settlements when compared to distant hunting sites. However, some species of large rodents such as *guantas* (*Cuniculus paca*) or *guatusas* (*Dasyprocta punctata*) and artiodactyls are more abundant in the persistently hunted area closer to settlements compared with the infrequently hunted area (Bodmer *et al.*, 1994). Hunting pressure also varies depending on species. Large mammals such as tapirs, peccaries, and monkeys are among the most harvested followed by bird and reptile species (Redford & Robinson, 1987; Vickers, 1991; Alvard, 1993).

The majority of the Amerindians in Amazonia rely on fish, rather than game, as their principal source of animal protein (Dufour, 1990). The relative importance of each activity (i.e. hunting or fishing) varies according to the ecotype and settlement type. In blackwater areas where rivers are small, such as in northwestern Amazonia, fish can be considered part of the forest ecosystem, because non-predatory fish feed primarily on forest products (Knöppel, 1970). Tukanoan Indians recognize the importance of forests to fish (Dufour, 1981; Chernela, 1985) since some areas, especially inundated forests, are an important feeding ground for fish. In several Amazonian countries, indigenous peoples have protected them from deforestation (Chernela, 1985).

The collection of animal and plant species is also an important activity of the household. Indigenous people in the Amazon are known for the collection of small vertebrates, such as frogs, as well as invertebrates. The use of insects for food is widespread (Posey, 1978; Dufour, 1987). The more commonly collected and consumed insects appear to be ants, termites, and larvae of both *Coleoptera* and *Lepidoptera* (Dufour, 1990; Descola, 1994). Tukanoans harvest ants and termites at low but constant rates. Palm grubs (Curculionidae) are a managed resouce: palms are cut with the expectation that they will be invaded by weevils and the larvae can be harvested at a later date. Amerindians also collect a wide range of plants and plant products as food and for use in housing, tool manufacture, craft production, and medicine (Dufour, 1990). The role of collected plant foods in the diet ranges from trail snacks and emergency foods to important sources of nutrients Palm products are one of the most critical forest resources for indigenous peoples throughout the Amazon region of South America (Bodley & Benson, 1979; Denevan & Padoch, 1987; Henderson, 1995).

In the labor process of hunting, fishing, and collection the domestic unit usually controls the resources and the means of production within the core of the natural ecosystem which forms its territory. Nevertheless, in contrast to the processes of horticultural and cattle ranching, the maintenance of optimal low-density man-animal ratios within a hunting territory depends not only on the domestic unit but also on the mechanisms of territorial partition and settlement processes (Cashdan, 1983). Control over the hunting territory by a domestic unit depends most of all on the maintenance of overall communal territoriality. Maintenance of the domestic unit's hunting territory is then ultimately dependent, through a whole series of social mediations and agreements, on the institutionalization of implicit rules that regulate access to game resources (Casimir, 1992; Descola, 1994).

3. The evolution of food production systems

There is a considerable body of literature on how and why food production systems change. Researchers continue to explore the possible reasons why people shifted from exclusively foraging systems to farming arrangements in the first place. Theories on this issue have used population pressure (Redding, 1988), climatic change, technological innovation, the elaboration of social networks, and the appearance (through various mechanisms) of new plant varieties (Layton *et al.*, 1991), or social inequality and competitive feasting among hunting groups (Hayden, 1990, 1992) to explain such a shift. Even though this is a matter of ongoing research and debate, other scientists have focused their attention almost exclusively on what comes next, once cultivation has been adopted: the evolution of agricultural production systems (Alcorn, 1989; Toledo 1990; Warner, 1991).

Regardless of the theoretical underpinning and type of system in question, population growth and density frequently enjoy notoriety in land use and land cover change studies that attempt explaining changes in food production systems (Keys & McConnell, 2005). Indeed, two framing concepts have been typically used to analyze the relationship between agricultural change and population growth. The first approach was introduced in 1798 by Malthus is his work *An Essay on the Principle of Population*, in which he claimed that population growth in England would soon outstrip food supply because population grew exponentially and food supply increased arithmetically. The second concept was introduced by Boserup in 1965 in her book, *The Conditions of Agricultural Growth*. She contended that population growth increased agricultural production in the form of agricultural intensification as innovation and technological shifts occurred and allowed for the growing population. Lee (1986) and Turner & Ali (1996) suggest that Malthus and Boserup may complement rather than contradict each other. They share various assumptions about the relationships among population, technology, and resources use but differ in their views of the origin of technology. Malthus implies that technology is exogenous in that its development is not necessarily linked into the population-resource condition. Boserup grounds this development directly into that condition; technological change is endogenous to it.

The Malthusian idea points out that environmental alterations, in general, and changes humans bring to food production systems, in particular, approach tipping points that promise to slide humanity into starvation and conflict. Under this scenario, the state of technology determines the levels of cropping intensity. Thus, agricultural extensification is the most obvious and only response to the employment of traditional technology and to changes in population. Once an agricultural system reaches its carrying capacity, human populations face starvation, war, or lack of employment opportunities in agriculture, in addition to a consequent pressure for migration to other areas. This situation will indisputably lead to environmental alterations that promise to threaten people's survival (Ehrlich & Holdren, 1988; Ehrlich & Ehrlich, 1990; Kates, 1995).

For Boserup, food production systems evolve from extensive to intensive forms of resource management and could be better explained as the result of differences in population growth and the capacity of technological innovation. Increases in population stimulate increases food production. This can be achieved not only by extensification (i.e. increasing the area under cultivation but keeping yields constant) but also by intensification (i.e. increasing yields and keeping the area constant), with the adoption or development of new technologies. Generally, extensification can be seen as a measurement of labor efficiency in a system and only occurs where available land is abundant, as under this situation the return to increased labor inputs will tend to be higher on new land than on land that is already under cultivation. Increases in population and, thus, in the amount of labor, allow extending agricultural area. An extensive agricultural system may be an efficient way of land management since increases in labor input reduces the time required for clearing larger areas. As the land frontier is reached, and marginal land is brought into cultivation, the returns to labor from extension of area decrease. The result is a shift to an intensive strategy. In other words, land scarcity arising from steadily growing population forces landholders to move gradually from extensive to intensive types of agricultural systems, such as from forest fallow to annual cropping and from rotational to settled types of agricultural systems. Several researchers have studied this type of evolution and specifically pointed out the positive linkages between population growth and agricultural intensity (Ruthenberg, 1980; Pingali, Bigot, & Biswanger, 1987; Tiffen *et al.*, 1994; Smith *et al*, 1994). Figure 2.1 depicts both Malthus and Boserup theses respecting the association between population growth and agricultural change.

Because population growth is common in regions experiencing agricultural change, especially the shift from mainly subsistence to market oriented production, it adds little explanation to how and why changes occur. In fact, the general existence of population growth and movement in these regions can confound interpretation, as it frequently is the only shared trait across separate regions (Keys & McConnell, 2005). Thus, explanations arise that point to population as the primary cause of agricultural intensification and gloss over other candidate causes, such as affluence and technology at the regional level, and environmental, market or inter-ethnic relationships, and cultural factors at the local level.

Some authors have suggested that people produce for social prestige (Descola, 1994; Brookfield, 1972), which implies that some agriculturalists produce far more food than is required for human sustenance alone, investing it in commercial exchanges and in maintaining important social relationships between social groups. Brookfield & Hart (1971) suggested that production depends on the capacities and ambitions of a determined group and its social rank in the community. This means that agricultural intensification may emerge not only as a response to population pressure, but also as part

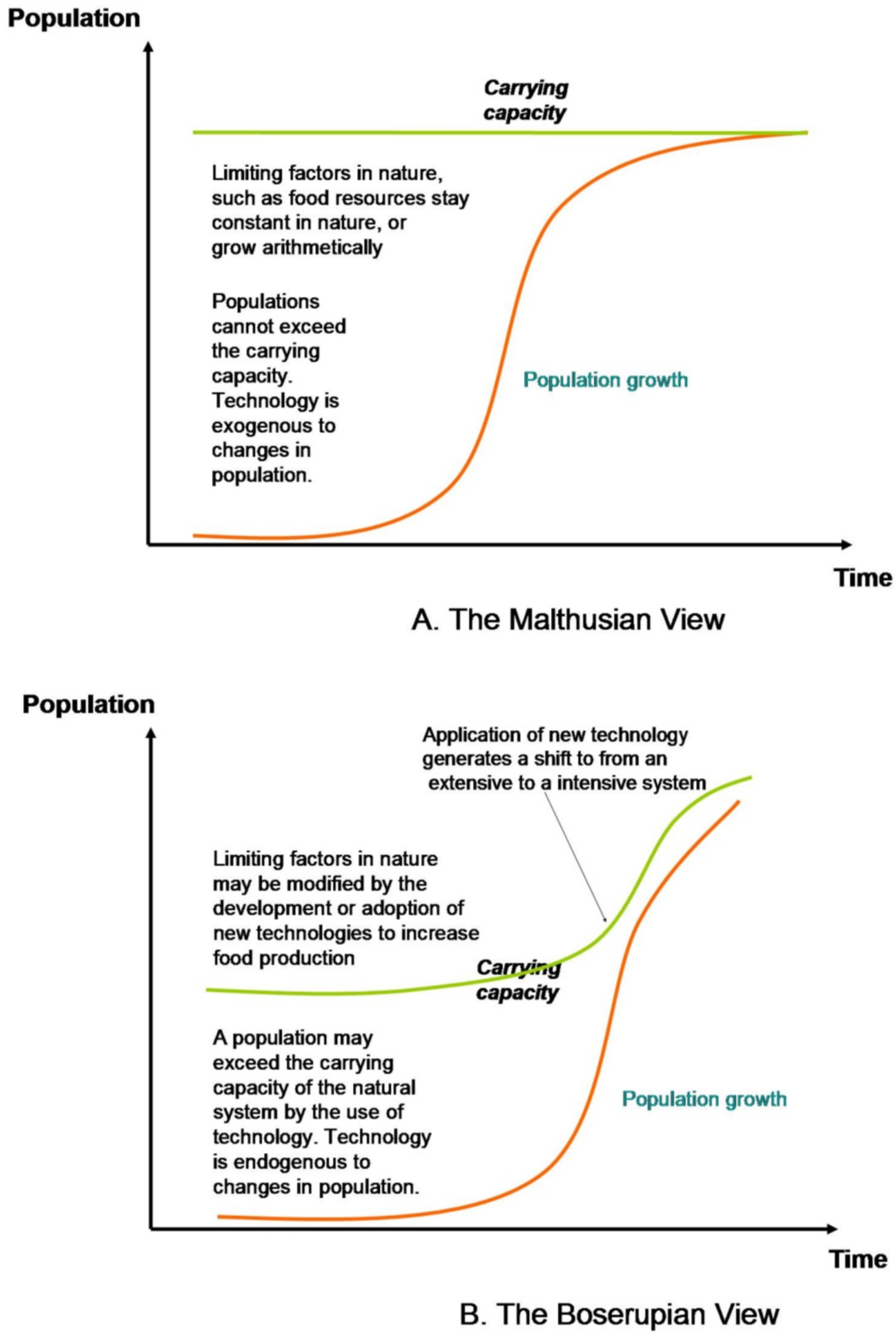


Figure 2.1: Two framing concepts typically used to analyze the relationship between agricultural change and population growth: a) Malthus' view, and b) Boserup's perspective.

of a search for social relationships and political empowerment.

Cultural ecologists such as Brookfield (1972), Turner II &Brush (1987), and Ali (1995) and consider agricultural output to be a function of constraints imposed by the physical environment, and the human capabilities to reduce and modify those constraints. Like human factors, biophysical factors bound agricultural systems. Precipitation, soils conditions, topographic characteristics, temperature, and water supplies constrain how landholders use the land. However, people's adaptive capacities may become a main source of agricultural innovation as technology allows alteration of the environmental factors given sufficient knowledge and/or capital. Where technology is precarious and land and labor are available, people will adopt the most efficient production system that responds to these characteristics, such is the case of shifting swidden cultivation.

In the views of others, such as Lipton (1968) or Binswanger & McIntire (1987), knowledge and skill are essential, but not enough for adoption of improved agricultural systems. Despite being knowledgeable and skilled, poor landholders cannot apply the inputs required, such as improved seeds, inorganic fertilizers, and irrigation, due to poor institutional services or structural constraints imposed by institutions. Institutions mean the ways that people organize their activities, including both formal rules and rules-in-use that govern people's differential access to and enjoyment of the benefits of natural resources for agro-silvo-pastoral and other productive and aesthetic purposes (Ostrom, 1990; Dietz *et al*., 2003). Institutions either facilitate or hinder land use change, as do shifts in culturally related aspirations and desires (Datoo, 1978; Grigg, 1979; Meertens, Ndege, & Enserink, 1995). Hayami & Ruttan (1971), Ramaswamy & Sanders (1992), and McMillan *et al.*, (1998) therefore, consider the development of agricultural systems as a combined function of institutions and technology, because institutions not only govern the processes by which scientific and technical knowledge is created but also facilitate the application of new technology (Sanders *et al*., 1996).

According to Schultz (1964), traditional cultivators will not be able to develop other forms of agricultural systems unless they have access to or create improved technologies, inputs, and markets through well established institutions. This idea implies that innovation is exogenous to the production system and challenges Boserup's thesis. At regional or national levels, land tenure security and prices of agricultural products, which are shaped by national laws and agricultural policy, significantly influence landholders profit margins and agricultural decisions (Lele & Stone, 1989; Ehui, Williams, & Swallow, 1995). Insecure land tenure not only acts as a constraint to investment, but also deprives farmers to access formal credit, inputs, and other institutional services required for more intensive agricultural practices. As a result, land holders are often forced to continue subsistence agricultural practices (Ehui *et al*, 1995; Feder, Onchan, & Chalamwong, 1998; Thapa & Rasul, 2005; Thapa, 1998). However, as population pressure increase and production systems evolve from less to more intensive land uses, the demand for more secure rights to specific pieces of land or other resources generally increase (Boserup, 1965; Demsetz, 1967; Binswanger & McIntire, 1987; Platteau, 1996). This demand may be accommodated within customary land tenure systems by allowing households long term use and inheritance rights of use and usufruct of specific resources. Land leasing and sharecropping may arise, allowing an efficient use of available factors of production, which may differ across households. Where capital intensification is occurring, increased demands for credit increase the demand for mortgage land. Customary rights to mortgage or even sell land may evolve (Platteau, 1996). Customary land rights may evolve from communal to more private forms without external intervention; although it is often assumed that formal land titling arrangements are necessary for this process to occur (Pender, 1999).

The increasing availability of commodity markets combined with an escalating desire of market goods could trigger changes in traditional patterns of subsistence and resource use (Henrich, 1997). When agricultural products turn into a commodity, the economic opportunities of people change, not only due to the proximity and intervention of markets but also to changes in the cultural behavior of societies (Brookfield, 1972; Descola, 1987; Humphries, 1993; Henrich, 1997). Such changes may occur as slow evolutionary processes that evolve incrementally at the timescale of decades or more, or as fast changes that are abrupt and occur as perturbations affecting human-environment systems suddenly (Lambin *et al.* 2003). Some societies at an early stage of market integration change very slowly from low productive activities with low returns to more intensive ones with higher returns. Indeed, in the absence of markets, indigenous households will produce primarily for subsistence, but in their presence they may intensify resource use, diversify production, or even deplete resources (Henrich, 1997; Sierra *et al*, 1999). The degree of agricultural intensity in subsistence households is, in the end, a function of both long-run and short-run phenomena, including patterns of historical accumulation, the wealth position of the group, and domestic cycle stages affecting the availability of labor, which determines how much and how often households produce (Walker & Homma, 1996; Coomes & Burt, 1997).

The integration of subsistence households into a market economy and the consequent rise in income could not only intensify agricultural production but also could potentially cause changes in subsistence strategies and dietary practices (Alcorn, 1984; Panayotou, 1992; Godoy *et al.*, 1995). These changes could happen in consumption and in the costs of production. Changes in consumption could arise from changes in income or from changes in the price of substitutes for forest products. Higher income could increase consumption of non-traditional products and reduce subsistence production. Economic development could also deflect consumption away from subsistence products by lowering the price of commercial agricultural products. Commercial production of peanuts and rice, for example, could increase the supply of these products and turn consumption away from traditional products such as manioc, plantain, and forest goods. Changes in the costs of production could also affect subsistence strategies. For instance, by lowering the costs of production of non-traditional products through the introduction of new technology more food can be produced, which could decrease the consumption of traditional products. However, empirical evidence supporting the idea that economic development could change subsistence strategies and dietary practices has been somewhat ambiguous. Some authors have shown that market participation was not necessarily accompanied by a decline in subsistence production (Sierra *et al.* 1999; Rudel *et al*., 2002; Vadez *et al.*, 2004). However other authors have shown that shifts to commercial agriculture were accompanied by a decline in subsistence production and deterioration of the traditional diet among subsistence groups (Alcorn, 1984; Godoy *et al.,* 1995). In general, from the review of literature it can be argued that the relationships between independent (e.g. labor, income, terrain conditions) and dependent variables (e.g. yields of production or cultivated area) have ranged from strong to non-existent.

4. The spatial manifestation of agricultural production

Land use is a concept that refers to the manner in which biophysical attributes of the land are handled, and the cultural components defining the manipulation. The concept of land cover refers to the biophysical state of the earth's surface and immediate subsurface (Porro, 2005), while landscape is treated as the perspective and physical "manifestation of the relation among humans and the environment" (Crumley, 1994, p. 6). Yet, the concept of land use assumes various fields of research and paradigmatic orientations.

Beginning at least with Von Thünen in 1842, agricultural land use has long been regarded as a key aspect in numerous explanations of landscape change (Turner & Doolittle, 1978; Turner *et al.*, 1977). Von Thünen examined the intensity (viewed in terms of production or yield per unit area and time) and the spatial dimension (i.e. extent and shape) of agriculture according to the distance to market centers (Symons, 1978; Visser, 1980; Thapa & Rasul, 2005**).** According to this theory, the spatial extent and intensity of agriculture decrease with increasing distance to markets, because longer distance leads to reduced profit margins for farmers by incurring higher transportation costs. In this theory, agricultural systems are found to be distributed around a single, "isolated" market place in the form of land use intensity rings (Lambin *et al.,* 2001).

Although this explanation provided a basis for understanding the spatial manifestation of agriculture on land cover, it treats change as if it was essentially linear, fixed, or permanent for the system in question and does not primarily concern the dynamic process of intensification. This theory does not recognize that agriculture may take forms of extensification or intensification, and that agricultural areas may show cyclic patterns of expansion and contraction. The cyclic behavior of agricultural change can spatially manifest in the form of expansion and contraction, not necessarily concentrated around markets. This is an important characteristic of many indigenous agricultural systems, in which production is mainly for subsistence.

Differences in spatial agricultural patterns can be explained by differences in the levels of production. Doolittle (1987) suggested that initially, landholders practice extensive or labor-efficient agriculture. As production pressure increases for any reason (e.g. increase in population), agriculture is expanded throughout the land without technological change. When demands can no longer be met in this way, agriculture is intensified on land already under cultivation or expanded to other areas. As demand for cash crops and food decreases for any political, economic, or historical reason, the contraction of agricultural lands of varying quality follows a sequence opposite that of expansion. Because they require greater inputs to produce comparable yields, lands of low quality are taken out of production prior to lands of optimal quality where intensification occurs (Brookfield, 1972). Thus, agricultural areas may expand and contract across time and space, depending on endogenous and exogenous factors (e.g. household composition and influence of markets) affecting resources and the environment in different ways. Some systems will be more intensive and will require less land (e.g. plow agriculture); others will be more extensive and require more area (e.g. shifting swidden cultivation).

Differences in the spatial characteristics of agricultural land use can be explained by biophysical variations of the regions where a production system is applied. For instance, specialists in Amerindian cultures of the Amazon Basin recognize the diversity of ecosystems in this apparently homogenous vast region. Preliminary work by Camargo (1948, 1958), and Sioli (1950, 1954, 1957) in the Brazilian Amazon clearly distinguished between the ecological characteristics of riverine habitats or floodplains and the upland forest or interfluve regions. This fundamental duality of the Amazonian biotypes will be later expressed by the use of a diversity of terms: *várzea / terra firme* (Meggers, 1971), *várzea / ete* (Hegen, 1966), riverine habitat / inter-fluvial habitat (Lathrap 1968, 1970) or flood plain / tropical forest (Roosevelt, 1980).

This study follows the approaches by Hegen (1966), Lathrap (1968), and Denevan (1970) and takes into account a plurality of ecological conditions to characterize the main types of habitats in Western Amazonia. The specific differences between these two ecotypes entail important geomorphologic and ecologic variations: riverine habitats are characterized by alluvial valleys and recent floodplain which are rich in volcanic sediments from the Andes. This biotope is characterized by the presence meandering white-water rivers, from which alluvial terraces emerge. The riverine habitat is distinguished by the high degree of fertility of alluvial soils, a concentrated fauna of large mammals, and rich aquatic resources. But this type of landscape is not limited to the middle and lower watersheds of the Amazon Basin: this type of habitat also characterize the upper basin of the Amazon from the Putumayo River between Ecuador and Colombia to the Ucayali River in Peru (Lathrap, 1970). The interfluvial environment contrasts in every sense with the riverine habitat. The soils in this type of habitat are poor with high contents of iron and aluminum. Terrain is irregular with the presence of mesas and hills and characterized by high, non-floodable, and relatively unfertile terraces. In terms of fauna, interfluves are characterized by the absence of large aquatic mammals, few fish, very dispersed and predominantly tree-dwelling land fauna (Ross, 1976). Amerindian populations seem to have adapted to these particular geomorphological and ecological conditions over centuries of occupation. The distinctive characteristics of the two ecotypes account for important differences in the horticultural productivity of pioneering slash-and-mulch or burn cultivation (Descola, 1987).

In pre-contact times, intensive agriculture in nucleated settlements was well underway in several regions of the Amazon, especially in *várzea* or riverine regions where soils are considered to be better suited for cultivation (Denevan, 1996; Erickson, 2000; Heckenberger *et al.*, 2003). However, during colonial and post-colonial times such systems could have undergone important changes. Amazonian populations fell drastically after the first contact with Europeans in the sixteenth century due to disease, warfare, and slavery (Meggers, 1992; Heckengerger *et al.*, 2003). It has been suggested that indigenous populations today are a vestige of what they once were (Denevan, 1976, 1996, 2001). Thus, under today's very low population density conditions, Amerindian subsistence production systems, including swidden cultivation, described in the ethnographic record became a remnant of their former range of variation and intensity (Beckerman, 1987). The somewhat forced nomadic condition of indigenous groups in combination with their reduced populations resulted in highly mobile and low intensity cultivation systems, in which agricultural areas were scattered in space (Myers, 1992).

Indeed, agriculture was not intensive in most parts of the Amazon region, specifically in the inter-fluvial habitat, which accounts for more than 95% of the Amazon basin (Meggers, 1971), for two reasons: 1) soils in these areas cannot support continuous intensive agriculture without external inputs (Zarin, Duchesne, & Hiraoka, 1998), and 2) it is becoming clear that a large capital investment in the form of labor and technology was not possible due to reduced human populations, isolation, and the lack of cultivable land in areas of the Amazon basin not occupied by Europeans (Bergman 1980; Parker *et al*., 1983; de Jong, 1988). Land use patterns associated with Amazonian cultivation systems were characterized by intermittent plots of agriculture and succession forest; patches of cleared land disappearing and reappearing across space and time.

With the suppression of slavery and inter -and intra- tribal wars, and the proliferation of regional health programs in several tropical areas around the world, many indigenous populations are growing rapidly (McSweeny & Arps, 2005). If they are to continue generating their own food supply, they must increase their agricultural production. One way to do this is to expand land use (i.e. clear more area) in order to increase the agricultural output. This option may be feasible when the quality and quantity of land is the adequate to sustain the growing populations. When land scarcity problems arise, however, farmers may shorten fallow periods to avoid problems regarding land competition, although this may lead to other problems such as soil exhaustion and increasing pest and weed infestation (Charlton, 1987).

As most indigenous people nowadays live in permanent settlements and it becomes increasingly difficult to find unutilized land, people may be forced to travel longer distances in the search for good soils. However, the travel cost to distant old-growth forest may be so high that people may prefer to instead clear recent fallows closer to settlements, which could minimize transportation costs but also reduce productivity (Sirén, 2007). Specific spatial patterns associated with these processes may emerge that clearly distinguish between similar agricultural systems and management practices.

When people face land scarcity problems, competition for land among landholders may also occur. When deciding upon whether or not to clear a particular piece of land at a particular time, the landholder must consider the risk that, if he does not clear it now, someone else may do so in the future based on a customary right (i.e. a claim resulting from a long series of habitual or customary actions). Such implicit competition may lead to the shortening of fallow periods in older agricultural plots or may force landholders to travel long distances in the search for agricultural land. To avoid these problems, landholders may adopt new technologies to intensify agriculture in already cleared plots or modify local institutions to regain control over forest resources and access to land (Boserup, 1965; Angelsen, 1997).

5. A classification typology for the study of agricultural systems

The study of agricultural land use can be done in several ways and following different approaches. Even the simplest agricultural unit comprises a large number of components and types of relations among them that may require several lines of inquiry to obtain a good understanding of them. One sensible response to this complexity is to use a classification typology that may help to dissect agriculture into component parts and types of associations in order to understand the intricate interactions between human societies and the environment.

Several authors have offered theoretical schemes for the classification of cultivation systems. Ruthenberg & Andreae (1982) proposed a classification scheme following the cropping system approach. This classification scheme is based on the analysis of the highest yield of the farming area, which represents the main output of the system. Doppler (1994) developed a classification for farming systems based on the economic characteristics of landholdings according to household objectives and needs (i.e. market or subsistence oriented), and included features of resource use and of non-farm activities. Although these classification schemes complement each other and are important frameworks to study cultivation systems, they treat each component individually and neglect the interconnections between system components, which limit their applicability to particular cases and areas.

Turner and Brush (1987) offer a general universal classification scheme applicable to all cultivation systems, regardless of environmental, cultural, or socioeconomic conditions. This scheme is based on three key dimensions of farming systems: 1) technological type, 2) output intensity, and 3) production type. Each dimension reflects a particular aspect of agricultural production. Changes in one of these components will trigger changes to the other two and to the system as a whole.

The technological component refers to the inputs (e.g. chemicals, machinery, tools) and infrastructure (e.g. transportation networks) used in agricultural production. Technology schemes focus on one or a set of techniques and procedures used on a cultivar or suite of cultivars. In its broadest use, reference is made to the categories of traditional (paleotechnic) and modern (neotechnic) technologies used in horticulture/vegeculture (fruits, tubers, roots, vegetables) and agriculture (grains). More specific technological types include swidden or slash-and-burn/mulch cultivation (denoting a cut, burn/mulch, and fallow procedure, terrace cultivation, and irrigation agriculture). Technologies vary locally or regionally primarily by the degree of commodity production involved. Even within a single system, two technologies may exist: one for subsistence production and one for market production. Both traditional and modern technologies are employed to help alleviate environmental constraints and to sustain rather high levels of output.

Output intensity refers to yield or production per unit area and time (Turner & Brush, 1987). Output intensity can be measured by monetary value, calories, or weight, and the measurement used depends on the type of production and cultivars in question. A widely used measurement is weight/area/time (e.g. kg/ha/year, lb/m^2/weak, or variations thereof). Boserup (1965) refers to agricultural output intensity as the frequency with which a parcel of land is cultivated, and employs the crop-fallow cycle to measure that frequency. For example, a system in which the land is cultivated for one year and fallowed for 10 consecutive years has a crop-fallow ratio of 1:10. A crop-fallow cycle of

1:1 (one year of cropping to one year of fallowing) is considered to have fifty percent intensity since each cropping unit is cultivated once every other year. A cycle of 1:0 is taken to have one-hundred percent intensity since each cropping unit is cultivated once every year with no fal1ow. Boserup's definition of agricultural intensity does not consider cropping techniques, labor, or productivity, although these characteristics relate to agricultural intensity.

Different technologies lead to a diversity of output intensities, which then define the type of production. Production can be either for consumption (i.e. subsistence) or commercialization (i.e. market-oriented) or a combination of both. Less developed economies generally are subsistence-based at first and then develop a "commercialization or market" orientation, often referred to as the "money economy" (Datta Chaudhury, & Adhikari, 1993). Some researchers recognize a "native market economy" stage between the market and subsistence economies (Enke, 1963; Miracle, 1968). Sometimes distinctions are made between pure "subsistence" producers and producers who have both "subsistence" and "non-subsistence" production, but such producers are nearly always identified as part of the "subsistence" economy.

The level of consumption, the proportion of marketed production, the motivations that prompt farmers to produce output to be marketed, and the rate of change of production techniques are all used in the literature in varying combinations to define "subsistence" farmers (Turner & Brush, 1987; Turner *et al.*, 1977; Miracle, 1968). In discussions of problems of economic development, one of the concepts related to the nature of production -frequently simply the proportion of production marketed- is usually implied. The least ambiguous and analytically most useful concept is pure "subsistence" defined as complete self sufficiency by the individual or the household. If pure subsistence prevails, production techniques can change somewhat with the introduction of new crops or tools, for instance. Such innovations may result in output increments that are large relative to the existing level of production. However, it is unlikely that there will be frequent or continuous changes in technology. It will be impossible to improve labor efficiency significantly through specialization, and it will be difficult for knowledge and materiel needed for increases in productivity to flow from one producing unit to another (Turner & Brush, 1987). Moreover, producing units will be cut off from external pressures and incentives for increases in productivity. Once farmers begin to sell or barter output, distinguishing between them becomes difficult conceptually and empirically. Hence, it is not surprising that there is no common scale for measuring degrees of subsistence and that in practice all small farmers with any production that is not sold tend to be called "subsistence" farmers.

Using this typology as a common measuring scale, it is possible to classify production systems at different levels of development and compare them (Figure 2.1). For instance, among the most common agricultural forms of indigenous agriculture in Amazonia that have been described in the literature are cyclic agroforestry or swidden-fallow management systems (Padoch *et al.*, 1985; Beckerman, 1987; Denevan & Padoch, 1987; Fujisaka, Hurtado, & Uribe, 1996; Coomes, Grimard, & Burt, 2000). These systems usually employ traditional technology, have low intensity, and serve to sustain the nutritional needs of the practitioners of the system, although this is not always the

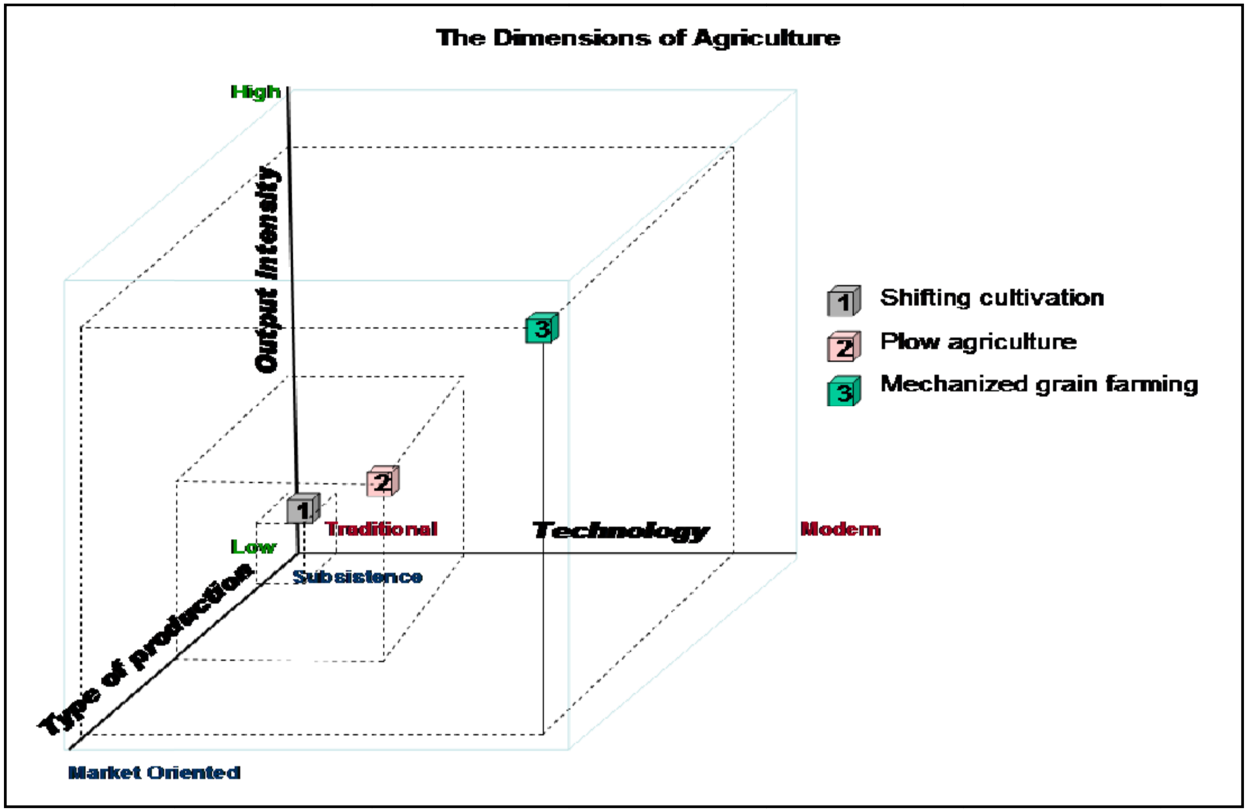


Figure 2.2: Dimensions of agricultural systems. Examples of farming systems and their position on the agricultural change continuum:

1. Shifting cultivation: This is a low intensity, traditional, and subsistence oriented production system practiced in most tropical regions of Latin America, Africa, and Indonesia.
2. Plow agriculture: This system requires the utilization of tools (i.e. plow and/or cattle) to turn up the soil and prepare for planting. Output intensity is expected to be higher than shifting subsistence cultivation but is still considered a traditional farming system. Production may or may not be market oriented. Examples of regions where plow agricultural systems are used are the colder and direr Asiatic farming regions, river valleys of the Middle East, parts of Europe and Africa, and mountain highlands of Latin America.
3. Mechanized grain farming: This is a market oriented farming system. It requires modern technology to produce commercial amounts of food. Examples of regions where this type of agricultural system is used are: Australia, Great Plains of the United States, the steppes of Ukraine, the pampas of Argentina. (source: modified from Grigg, 1974).

case for the whole Amazon basin and other tropical lowlands (see for example, Netting, 1993; Humphries, 1993; Netting & Stone, 1996; Connelly & Chaiken, 2000; Potter, 2001). Other systems lie on the opposite side of the spectrum and employ modern technology, employ intensive management practices, and mostly produce for the markets. Examples of these systems include mechanized grain farming or any other form of farming that involves large fields and/or numbers of animals, large resource inputs (pesticides, fertilizers, etc.), and a high level of mechanization (Turner & Brush, 1987).

This research uses this classification system as a framework to analyze agricultural systems in tropical lowlands, with emphasis on indigenous production in Western Amazonia. This typology facilitates the understanding of agriculture in the region since it provides a baseline that integrates the socioeconomic, political, environmental, and technological elements of the systems in question. In this way, comparisons with other systems are possible and broader assessments of various themes, such as agricultural change, are not hindered.

Chapter Three

Modeling Land Use and Land Cover Change

1. Introduction

Agricultural expansion has been noted as the major proximate cause of land cover change, having been estimated to account for about 90 percent of all forest clearing in the tropics (Chichilnisky, 1994). Our understanding of the relationships between agricultural land use and land cover has improved in the past few decades, which has helped to advance certain objectives of the global change community, such as the ability to predict land use and land cover change (LULCC) (Parker *et al*., 2003). However, this body of knowledge is still incomplete and studies are needed that are representative of a whole range of regions and human groups, including a broad diversity of land use strategies.

Changes in land cover are caused by factors that often interact with each other in intricate ways, making it difficult to separate cause and effect (Kaimowitz & Angelsen, 1988; Geist & Lambin, 2002). As is the case with most environmental issues, these changes are tightly linked to human actions (Lambin *et al.,* 2001). To understand them, both human and physical contexts need to be considered simultaneously, though this is not a simple task (Gilruth *et al.*, 1995). The understanding of LULCC requires creating direct links between spatially explicit land cover information, as derived from remote sensing, and information on land use change processes for developing new methods and models which merge landscape data with data on human behaviors. Though extremely complex, the analysis of these behaviors and of the contexts in which they are presented can be grouped based on common patterns in broadly similar environments. In the case of tropical lowlands, typical social behaviors and patterns of land cover change could be grouped into two major categories: the colonist and the long-term resident footprints.

This chapter presents a literature review of the main theories that claim to explain changes in land cover and land use. Section Two presents the theoretical context used in this study for the analysis of the factors that lead to the conversion from forest cover to agricultural land use. Section Three summarizes the methodological approaches used in the analysis of LULCC.

2. A theoretical framework for the analysis of land use and land cover change

Most LULCC studies and reviews focusing on tropical lowlands have mainly concentrated on the role of colonists and their practices as main agents and drivers of environmental change (see reviews by Kaimowitz &Angelsen, 1998; Geist &Lambin, 2001; Irwin & Geoghegan, 2001). The literature generally recognizes the existence of proximate causes and underlying driving forces of LULCC. Proximate causes are human activities or immediate actions at the local level, such as agricultural expansion, that originate from intended land use and directly impact land cover. Underlying driving forces are fundamental social processes, such as human population dynamics or agricultural policies that underpin the proximate causes and either operate at the local level or have an indirect impact from the national or global level. Figure 3.1 summarizes the main sets of proximate factors and underlying forces associated with LULCC in tropical regions. This figure shows that theories and models that claim to explain land cover change in colonization fronts in tropical lowlands may be grouped according to one

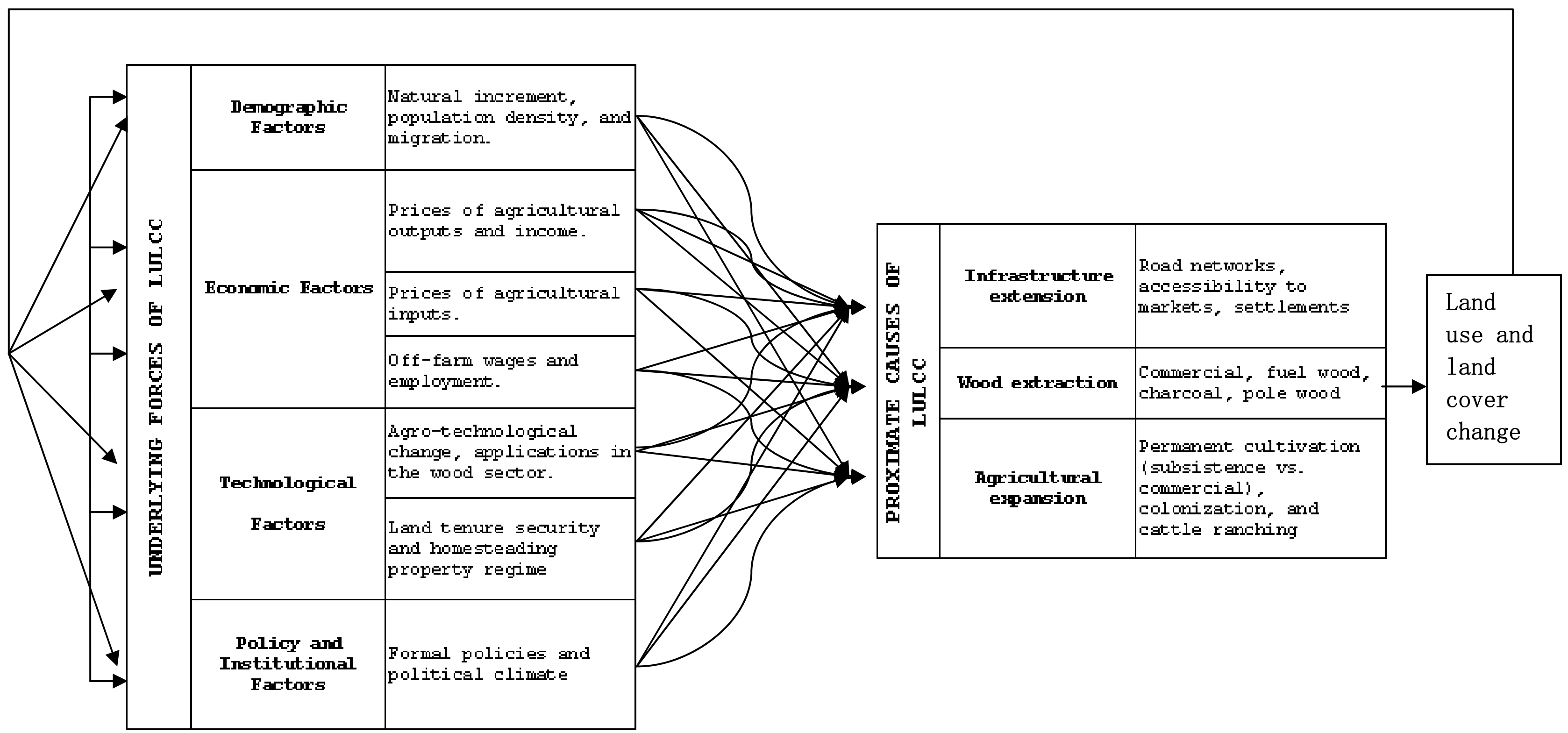


Figure 3.1: Underlying and proximate causes of LULCC in tropical regions (based on Geist & Lambin, 2002). No single or key variable, such as technological or demographic change, unilaterally affects land cover. Feedbacks and interactions between proximate and underlying driving forces best explain LULCC. Black arrows represent the interconnections between underlying forces and proximate causes of landscape change.

of the following sets of variables: demographic, socio-economic, technological, and political-institutional (Geist & Lambin, 2002; Brondizio *et al*., 2002). But interconnections between these variables should be always expected and no one-factor approach could claim to explain all the variation in land use and land cover change.

Tables 3.1 and 3.2 summarize the underlying and proximate causes of LULCC respectively, and highlight the direction of the relationship between independent variables and changes in land cover. McCraken *et al.* (2002) and Pichón *et al*. (2002) proposed that demographic characteristics, such as population growth and migration in colonization frontiers, lead to particular combinations of agricultural activities and land uses. In these cases, theories that link demographic characteristics of households to the extent of agriculture can help to elucidate how changes in population relate to the demand for land for agricultural purposes. This is the case of Chayanovian theory. Chayanov stated that “the force of the influence of consumer demands is so great that the worker, under pressure from a growing consumer demand, develops his output in strict accordance with growing number of consumers” (Chayanov 1986; 78, quoted in Netting, 1993; 305). Chayanov's thesis, drawn from detailed village studies in Russia, argued that the “drudgery of labor” in peasant production was such that farm households did not seek to produce as much as was possible —as in profit maximization —but sought a more restrained and less elastic goal, to provision the household. This theory suggests that demographic conditions of households, such as the age of the head of the household and the ratio between consumers and producers, determine how much people produce (Thorner, Kerblay, & Smith, 1986; Turner II & Shajaat, 1996; Mena *et al.,* 2006). The

Table 3.1: Summary of underlying causes of LULCC in tropical regions

UNDERLYING FORCE		***DIRECTION OF THE RELATIONSHIP***
Demographic Factors	Natural increment, population density, migration	*Increase (Positive)*
Economic Factors	Prices of agricultural outputs and income	*Increase (Positive)*
	Prices of agricultural inputs	*Indeterminate (Neutral)*
	Off-farm wages and employment	*Reduce (Negative)*
Technological Factors	Agro-technological change, applications in the wood sector	*Indeterminate (Neutral)*
Policy and Institutional Factors	Land tenure security and homesteading property regime	*Indeterminate (Neutral)*
	Formal policies and political climate	*Indeterminate (Neutral)*
Other Factors	Cultural and social attitudes	*Indeterminate (Neutral)*

Table 3.2: Summary of proximate causes of LULCC in tropical regions

PROXIMATE CAUSE		***DIRECTION OF THE RELATIONSHIP***
Infrastructure extension	Road networks, accessibility to markets, and extension of settlements.	*Increase (Positive)*
Wood extraction	Commercial, fuel wood, charcoal, and pole wood.	*Increase (Positive)*
Agricultural expansion	Permanent cultivation, colonization, and cattle ranching.	*Increase (Positive)*

"Household's Life Cycle" approach looks at the relationship between changes over time in household composition and age and the resulting patterns of land use (Figures 3.2). Specifically, the approach looks at how farmed land increases or decreases in relation to internal household dynamics (e.g. household's age) (Figure 3.2a) or the ratio between consumers and producers (Figure 3.2b). Some authors use this approach to assess the importance of the effects of demographic processes, especially age and sex, on land use and farm labor supply in colonization areas of the Amazon (Walker & Homma, 1996; Marquette, 1998; McCracken *et al*., 2002; Perz, 2002; Walker *et al*., 2002; Moran, Siqueira, & Brondizio, 2003). The household life cycle refers only to aspects of the household that change with the age of the head: from having no children to small children, adolescent children, young adults, and finally children leaving the household or marrying. In the case of subsistence agriculturalists, as is the case of most indigenous populations in the tropics, one can expect that changes in population affect the extent of farmed land (Lambin *et al.,* 2001). However, there has been limited work on the effect of demographic factors, especially life-cycle factors, on land management of forest-based societies in tropical America.

Other authors who have looked into economic factors that lead LULCC suggest that higher prices for agricultural products stimulate land cover change and intensify agriculture. Farmers shift resources into land preparation when prices of agricultural products are high and receive higher incomes (Panayotou & Sungsuwan, 1994; Deininger & Minten, 1996; Barbier & Burgess, 1996; Cropper *et al*., 1997). Higher prices of agricultural inputs (e.g. fertilizers) lead farmers to adopt more extensive

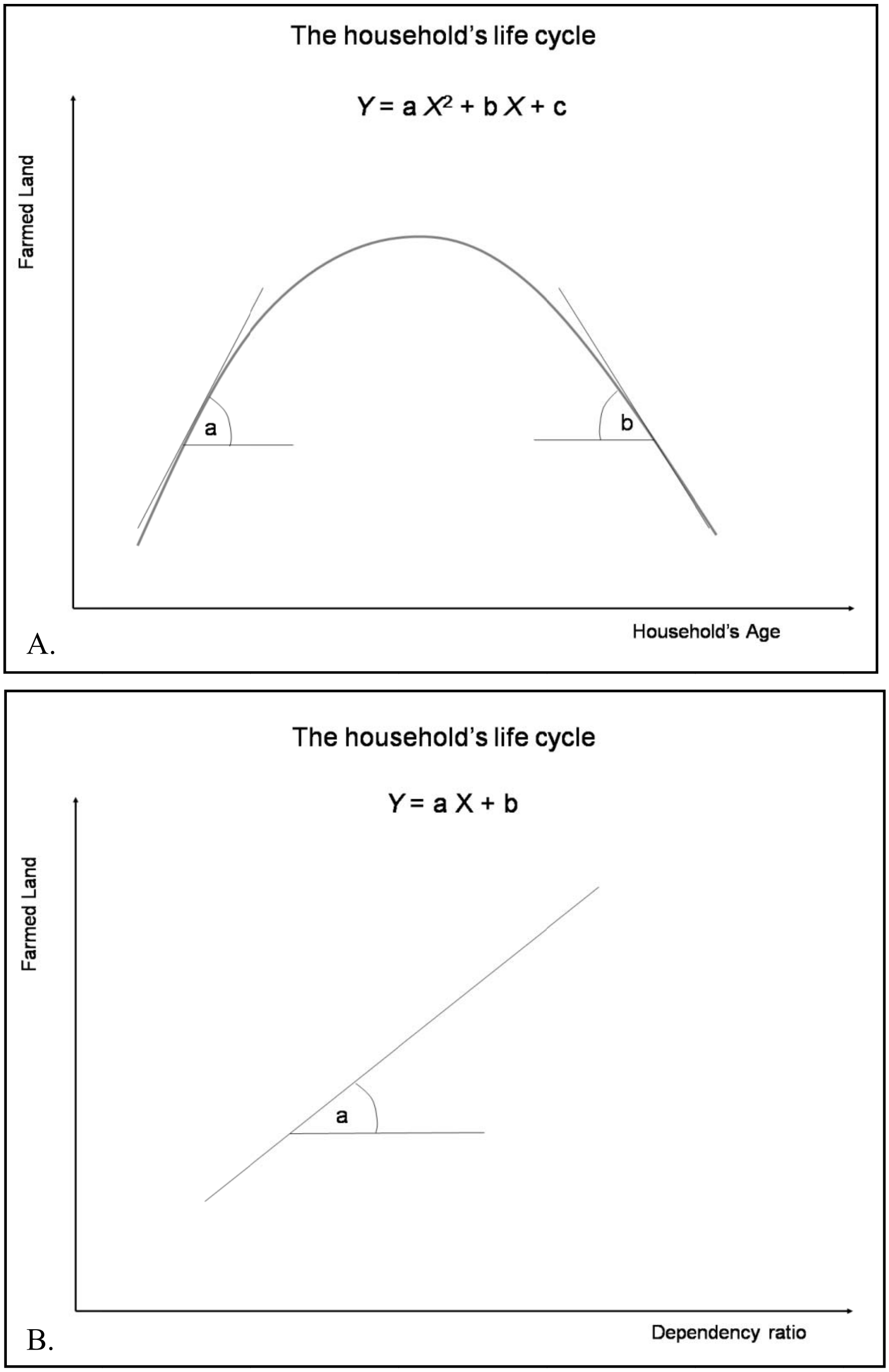


Figure 3.2: The household's life cycle approach. A) The model depicts the variation in farmed land in relation to the age of the household. B) Another common approach is to use the relationship between consumers and producers (i.e. dependency ratio) to evaluate the amount of farmed land. The land demanded by households depends on the relation between consumers and producers.

production systems than use more land. On the other hand, higher the costs associated with increased agricultural inputs make agriculture less profitable and can lead to a reduction in the amount of agricultural land (Holden, 1993; Mwanawina & Sankhayan, 1996; Barbier & Burgess, 1996; Aune *et al*., 1996). Among the most significant findings is that off-farm employment and wages reduce the amount of forest clearing and subsequent land preparation for agriculture. This is because agriculture and forestry activates become more costly (Holden, 1993; Ruben, Kruseman, & Hengsdijk, 1994; Bluffstone, 1995; Godoy, Wilkie, & Fanks, 1997; Pichón, 1997).

Some authors have argued that technological factors promote or hinder LULCC (Larson, 1991; Brown, Jepson, & Price, 2004). Technological changes that increase productivity without significantly altering labor or capital requirements can be expected to increase land cover change and intensify land use (Southgate, 1990; Pacheco, 2002). However if technology is more labor intensive, expensive, or requires extra labor farmers may opt to focus their resources on existing farmland and stop clearing land (Holden, 1993; Grainger *et al*., 2003).

Institutional factors such as formal policies to redistribute land (e.g. agrarian reforms and colonization programs), political climate (e.g. governmental management), or property rights (e.g. land races or titling) may influence the rates of LULCC (Mendelsohn & Balick, 1995; Geist &Lambin, 2002). In the absence of well-defined land tenure security, forest clearing often becomes a way to claim land rights (Rudel, 1995). Once land rights are granted, land cover change rates tend to slow down (Angelsen, 1999; Nelson *et al*., 2001). However some empirical evidence suggests that secure tenure encourages investment by making it less risky. If the investment involves clearing land in the forest, land cover may be rapidly converted to agricultural areas (Anderson & Hill, 1990; Southgate *et al*., 1991; Mendelsohn, 1994; Barbier & Burgess, 1996). Some studies indicate that the quality of governance is an important determinant of LULCC (Turner *et al*., 2001; Moran *et al*., 2002; Simmons, 2002; Klepeis, 2003). Policy failure and environmental mismanagement are often related to increased forest clearing. However, governments or managers start and stop their environmental policies. Therefore, changes in governmental policies may accelerate or decelerate changes in land use and land cover (Alvarez & Naughton-Treves, 2003; Wunder & Sunderlin, 2004).

Most studies that look at the proximate causes of LULCC in tropical regions usually consider variables that can be grouped into three main sets: Infrastructure extension, wood extraction or deforestation, and agricultural expansion (Geist & Lambin, 2002). Many authors suggest that greater infrastructure development and better access to markets and forest areas accelerates LULCC (Ludeke *et al*., 1990; Southgate, 1990; Chomitz & Gray, 1996; Mertens & Lambin, 1997; Nelson & Hellerstein, 1997; Mertens *et al*., 2002). LULCC is more likely to occur in areas that are closer to urban areas and markets in physical distance and traveling time, as transportation costs are reduced (Ludeke *et al.,* 1990, Crews-Meyer, 1999; Rudel, 2000; Southworth & Tucker, 2001). Small forest patches are generally more accessible than large compact patches and forests in coastal countries and islands are more accessible than those in continental countries, except in the case of forests in protected reserves (Rosero-Bixby & Palloni, 1998; Pfaff, 1999; Nelson, Harris, & Sone, 2001).

Some authors have suggested that either labor or capital-intensive logging causes LULCC (Capistrano, 1994; Barbier & Burgess, 1996; Deacon, 1995). However, if correctly managed, forest plantations can reduce the pressure on natural forests (Barros & Uhl, 1995). Since logging is usually related to timber prices, higher prices for timber are likely to promote deforestation by making logging more profitable (Wunder, 1996; Sierra, 2001). Higher timber values also increase the net benefits of clearing land and encourage LULCC (Burgess, 1993; Gullison & Losos, 1993).

Other researchers have discussed how the natural settings of forest areas and their vicinities either help to promote or control activities that may lead to the expansion of agriculture (Brondizio *et al.,* 2002; Rudel, 1993). Previous studies that looked at the effects of environmental factors on agricultural land use usually rely on spatially referenced explanatory variables on land use to find linkages between cause and effect of LULCC. Some researchers have shown that people are more likely to expand agriculture when suitable areas are physically closer to roads, and railroads, as it takes less time to reach them (Ludeke, Maggio, & Reid, 1990; Liu, Iverson, & Brown, 1993; Chomitz &Gray, 1996; Mamingi *et al*., 1996; Deininger & Minten, 1996; Rosero-Bixby & Palloni, 1996). Similarly, areas with better soils and topographic conditions (i.e. flat, fertile, and adequately drained) and drier climates (Sadder & Joyce, 1988; Gastellu-Etchegorry & Sinulingga, 1988; Chomitz & Gray, 1996; Rosero-Bixby & Palloni, 1996) have a higher chance of being cleared as the demand for land resources increase. Forest fragments are more at risk than old growth forests in large continuous areas, and those close to the forest edges are especially vulnerable to be cleared for agricultural purposes (Liu, Iverson, & Brown, 1993; Brown, Inverson, & Lugo, 1993; Mertens & Lambin, 1997). Since land cover change processes have a great deal of inertia, areas close to previously cleared locations are more likely to be used for agriculture or cattle ranching (Mertens &Lambin, 1997).

The transition from subsistence to commercial agriculture may have different effects on LULCC (Ranjan & Upadhyay, 1999; Mertens *et al*., 2002). This kind of transition can apply as slow evolutionary processes that evolve incrementally at the timescale of decades or more and can cause minimum change on forest cover, or as fast changes that are abrupt and occur as perturbations affecting human-environment systems suddenly, drastically accelerating LULCC (Lambin *et al*. 2003). Some societies at an early stage of market integration prefer extensive agriculture which is an efficient production mechanism that involves low technological investment. Agricultural extensification and large-scale land cover conversion to pastures for cattle ranching lead to rapid landscape change (Behrens *et al*., 1994; Bulte & van Soest, 1996; Walker, 1999; Walker *et al*., 2000; Seidl, Da Silva, & Moraes, 2001). When agricultural production cannot sustain the growing populations by the implementation of an extensive land use system, a shift from low productive activities (i.e. lower yields) with low returns to more intensive ones (i.e. higher yields) with higher returns may occur. If this is the case, forest clearing for agricultural purposes may stop since gains in production could be obtained from intensification in already cultivated fields.

From the revision of literature, it can be argued that the factors that the roles that institutions, infrastructure development, land tenure security, and demographics play in

LULCC in colonization areas are fairly well understood. However, researchers have paid less attention to the conversion of forest to agricultural land use in areas managed and controlled by indigenous populations. Although agricultural expansion in indigenous territories is not necessarily a current environmental threat, it may become one in the future as national health programs are applied and indigenous populations increase, management practices and cultures change, markets become more available, and populations are affected by land shortages. This study is aimed at filling this gap in research and examines how indigenous households' decisions on land allocation respond to endogenous and exogenous factors influencing the demand for land resources. It is expected that LULCC in indigenous areas with low participation in the market is mainly controlled by demographic factors, proximity to accessibility infrastructure such as landing strips, and biophysical conditions such as soil quality and topographic conditions.

3. Common approaches for the study of land use and land cover change

Most of the theory and literature reviewed on LULCC is based on the use of models (Mertens & Lambin, 2000). This section examines the most frequent LULCC modeling approaches. Two general approaches are identified: non-spatial models and spatially explicit approaches. Non-spatial land use change models generally lack spatially referenced information. Thus, a difficulty in applying these models to land use change studies lies in their inability to deal with spatial variability (Huang, Cai, & Peng, 2007). Spatial land use change models, on the other hand, can successfully predict the quantity of change, with the location of land use change over long periods, and directly include spatial concepts such as location or distance in the form of algebraic expressions or behavioral rules.

3.1 Non-spatial models of land use and land cover change

Non-spatial models of LULCC generally follow an econometric approach. In econometric approaches to LULCC, the supply and demand functions of the land market, which is assumed to be competitive, are estimated. Most economic modeling of land use changes originates from the land rent theories of von Thünen and Ricardo (Mertens & Lambin, 2000). Models of urban and peri-urban land allocation are much more developed than their rural counterpart (Riebsame, Meyer, & Turner II, 1994). Any parcel of land, given its attributes and location, is assumed to be allocated to the use that earns the highest rent. Such models allow investigation of the influence of various policy measures on land allocation choices (Lambin, 1997). The recent appearance of spatial econometrics to model LULCC has provided a successful technique to combine econometric and spatial theory for the analysis of regional cross-sectional and panel data (Anselin, 1988; Munroe, Southworth, & Tucker, 2001).

Microeconomic models usually assume that the agents whose behavior is described within the model have the capacity to make informed predictions and plans, and that they are risk minimizers and profit maximizers (Fischer *et al*., 1996). After exploring all options available to them, individuals make rational decisions based on available information, obligations, and expectations (social as well as economic), so as to balance anticipated returns and risks (Vanclay, 1995). Given the inherent unpredictability of some of the socioeconomic forces driving land use changes, economic models often adopt a normative approach; they describe how land use changes occur under ideal circumstances.

Equation-based models are mathematical in some way, but some are especially so, in that they rely on equations that seek a static or equilibrium solution. The most common mathematical models are sets of equations based on theories of population growth and diffusion that specify cumulative LULCC over time (Sklar & Costanza, 1991). More complex models, often grounded in economic theory, employ simultaneous joint equations (Kaimowitz & Angelsen, 1998). One variant of such models is based on linear programming (Weinberg, Kling, & Wilen, 1993; Howitt, 1995).

System models represent stocks and flows of information, material, or energy as sets of differential equations linked through intermediary functions and data structures (Gilbert & Troitzsch, 1999). Time is broken into discrete steps to allow feedback. Human and ecological interactions can be represented within these models, but they depend on explicit enumerations of causes and functional representation, and they accommodate spatial relationships with extreme difficulty (Baker, 1989; Sklar & Costanza, 1991).

3.2 Spatial models of land use and land cover change

Until a few years ago, mathematical and computational capacity limited the operation of spatially explicit techniques to study human and ecological interactions (Parker *et al.*, 2003). Presently, the development of advanced computer-based spatially explicit modeling tools such as geographic information systems (GIS) has opened new possibilities to link social and ecological systems. These relatively new approaches can help to incorporate the key variables of both the environment and the human individuals or institutions that shape the landscape. In this review, I will concentrate on two commonly used approaches used in LULCC studies. Their combination may help to overcome limitations in the availability of multi-temporal spatial data.

3.2.1 Cellular automata

Modeling, especially if done in a spatially explicit manner, is a valid procedure for the exploration of alternative pathways into the future, for conducting experiments that test our understanding of key processes, and for describing human-environment interactions in quantitative terms (Lambin *et al*., 2000). Spatially explicit approaches to study LULCC, such as cellular automata (CA) models, have been successfully applied to predict LULCC in different contexts. Among the advantages of using CA to model spatial dynamic phenomena are its intrinsic geographic nature (Tobler 1979), its relative simplicity to model complex systems (Phipps and Langlois 1997), and its capacity to mirror how human-environment systems work (Batty 1997).

In CA, each cell exists in one of a finite set of states, and future states depend on transition rules based on a local spatio-temporal neighborhood. In a two dimensional CA, neighborhoods can be of the von Neumann or Moore types. The von Neumann neighborhood is the smallest symmetric aligned arrangement of cells, which does not consider diagonal connections with neighboring cells. The Moore neighborhood is a 3 x 3 matrix with the output cell in the center. It considers diagonal connections with neighboring cells. A CA system is homogenous in the sense that the set of possible states is the same for each cell and the same transition rule applies to each cell. Time advances in discrete steps, and updates may be synchronous or asynchronous (Hegselmann 1998).

In a synchronous CA, the state of each cell is calculated at each time step, but held in a temporary store until all states have been calculated. Then the cells are all updated to their new state simultaneously. Asynchronous CA models can be of two kinds: random and ordered. In random asynchronous models, cells are updated in no particular order after their state has been calculated. In ordered asynchronous models, there is some pattern to the order of updating (Comforth *et al.*, 2003).

CA models of land use change phenomena have mainly been applied to urban sprawl, socio-spatial dynamics, segregation, gentrification, and location analysis (White, 1998). The popularity of urban CA is in part due to weaknesses in the existing stock of urban models (Torrens & O'Sullivan, 2001), but is also owed to the abundance of spatially referenced data and the several advantageous properties offered by CA. Among the advantages of using CA in land use change phenomena are their intrinsically geographic nature (Tobler, 1979), their relative simplicity to model complex systems (Phipps & Langlois, 1997), and their capacity to mirror how human-environment systems work (Batty, 2001). However, a CA approach may not be suitable where limited multi-temporal land use and land cover data exist, which hinders a proper formulation of data-driven decision rules that control the interaction of cells and their neighborhoods. In these cases, the combination of a deterministic CA approach and spatial models that combine linear statistical techniques and spatial analysis may be an alternative (De Almeida *et al.*, 2003).

3.2.2 Logistic multiple regression

The combination of logistic multiple regression (LMR), and deterministic CA, within a GIS framework is an interesting option that may help to overcome the problem of limited multi-temporal land use and land cover data. LMR is designed to estimate the parameters of a multivariate explanatory model in situations in which the dependent variable is categorical, and the independent variables are continuous or categorical. LMR is more appropriate than discriminant analysis if some independent variables, such as soils quality, are qualitative in nature (Press & Wilson, 1978). LMR identifies the role and intensity of the explanatory variables (X_n) in the prediction of the probability of one state of the dependent variable, which is defined as a categorical variable Y. Suppose X is a vector of explanatory variables and P_a is the response probability to be modeled with, in the case of a dichotomous dependent variable, $P_a = Pr(Y = 1| X)$, with Y = 0 meaning the absence of an event and Y = 1 meaning the presence of that event (e.g. the presence or absence of agriculture in a particular area). Linear logistic regression has the form:

$$\text{Logit } (P_{a\,(x,y)}) = \ln[P_{a(x,y)} / (1 - P_{a(x,y)})] = La$$

$$La = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n \qquad (2)$$

Where α is the intertcept and β_n are slope parameters. The probability values can thus be quantitatively expressed in terms of explanatory variables by:

$$P_{a(x,y)} = \frac{e^{(\alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \ldots + \beta nXn)}}{1 + e^{(\alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \ldots + \beta nXn)}} \qquad (3)$$

Where $P_{a(x,y)}$ is the probability of a location with coordinates (X, Y) of containing an event and expressed as a function of odd ratios. Odds ratios are usually used to facilitate model interpretation (Menard, 1995; Stokes *et al.,* 1995) (Figure 3.3). The odds ratio is a measure of association that approximates how much more likely (or unlikely) it is for the outcome to be present for a set of values of independent variables (Hosmer & Lemeshow, 1989). The probability, the odds, and the logit are three different ways of expressing the same thing (Menard, 1995). The estimated odds values are computed as the exponential of the parameter estimate values (Hosmer &Lemshow, 1989; Agresti 1990):

$$\text{Odds}\ [P_{a(x,y)}] = e^{(\alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \dots + \beta nXn)} \quad (4)$$

The predictive ability of a logistic regression model is evaluated from the table of maximum likelihood estimate, which contains the maximum likelihood estimate of the parameter, the estimated standard error of the parameter estimate, the Wald chi-square statistic, and the significance probability for the parameter estimate. Positive values of parameters indicate that larger values of the explanatory variables increase the likelihood of agricultural land use, while negative values indicate the opposite. The Wald statistic is the square of the ratio of the coefficient to its standard error, and is an alternative assessment which is commonly used to test the significance of the individual logistic regression coefficients for each independent variable. If significance level (p value) of the Wald statistic is less than a significance level then the parameter is useful to the model. In the case of logistic models, the goodness-of-fit measure is defined as the ratio of maximized log likelihood (p^2). Although p^2 ranges in value from 0 to 1, it has a theoretical maximum value of less than 1, even for a "perfect" model. Thus, it should not be judged by the standards of what is normally considered a "good fit" in conventional

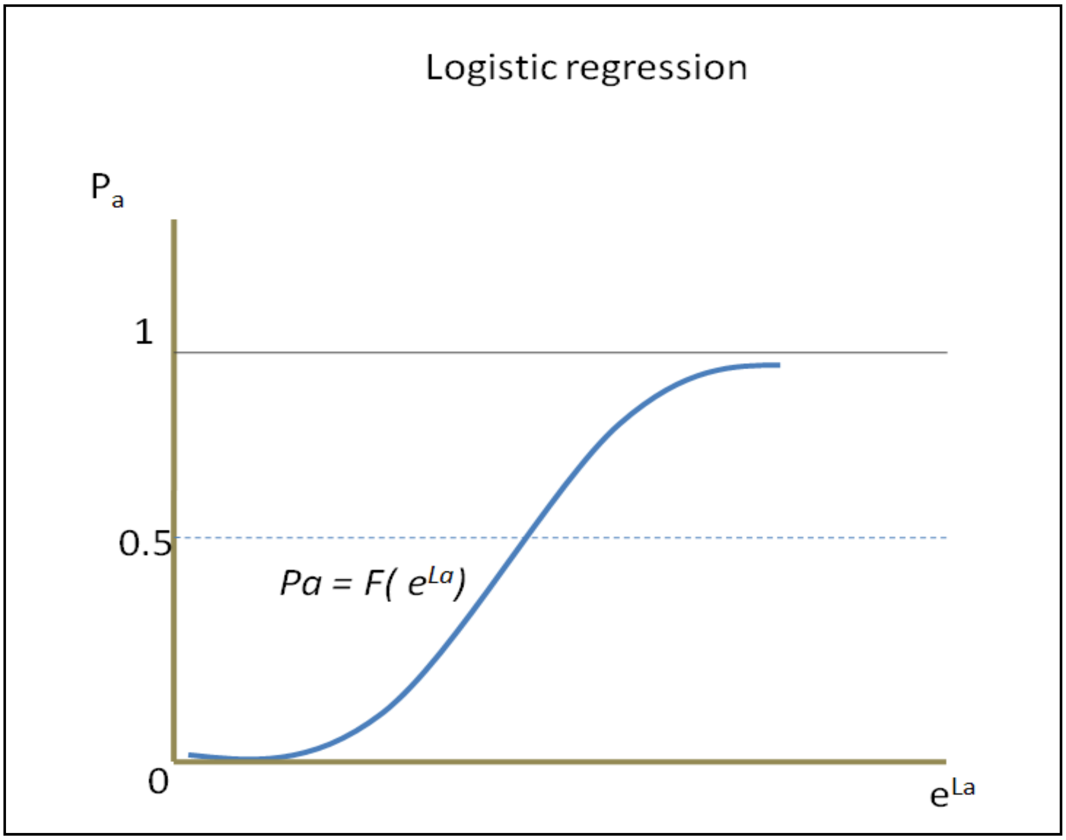


Figure 3.3: The logistic regression model, where P_a is a function of the odds (i.e. e^{La}) and logit (i.e. La). The odds ratio is expressed as $e^{La} / 1 + e^{La}$, *La* is the logit model $\alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \dots + \beta nXn$. βn are the logistic regression coefficients and Xn the independent variables.

regression analysis (Wrigley, 1985).Values between 0.2 and 0.4 should be taken to represent a very good fit of the model (Domencich & McFadden, 1975). For this reason, the Nagelkerke's R^2 is generally reported. This value is an adjusted version of the Cox & Snell R-square that adjusts the scale of the statistic to cover the full range from 0 to 1.

The LMR technique yields coefficients for each independent variable based on a sample of data. These coefficients are interpreted as weights in an algorithm that generates a map depicting the probability of a particular location to change to a certain state or to remain in the same one. LMR has been successfully used in wildlife habitat studies (Pereira & Itami, 1991; Narumalani *et al*., 1997; Bian & West, 1997) and land use and land cover change analyses (Ludeke *et al*., 1990; Chomitz & Gray, 1996; Mertens & Lambin, 2000; Huang *et al*., 2007).

The combination of LMR and GIS routines allows a relatively simple implementation of spatially explicit models of LUCC, given the power, wide acceptance, and relative ease of use of both statistics and GIS. The combination of LMR and GIS may be useful for the development and analysis of LULCC scenarios and supplement existing LULCC research (Mertens & Lambin, 2000). This approach overcomes limitations in the availability of data, especially the lack of multi-temporal spatial information consistent with the scale of analysis. This study follows this approach to study agricultural expansion and the associated LULCC in traditional communities in tropical lowlands.

Chapter Four

Study Area and Research Subjects

1. Introduction

This study focuses on the lower watershed of the Pastaza River Basin in the Ecuadorian Amazon (PRBEA). The Pastaza River Basin on the Ecuadorian side occupies approximately 20 percent of the Pastaza megafan, an area of 60,000 km^2 that is considered by some to be the largest alluvial fan in the world (Räsänen *et al*., 1992). It includes sections of the provinces of Tungurahua, Pastaza, and Morona Santiago. The two main urban centers in the lower watershed, Puyo and Macas, are the capital cities of Pastaza and Morona Santiago, respectively (Figure 4.1). According to the 2001 national agricultural census (INEC, 2003), forest cover in the Amazonian provinces was about 61 percent. Pasture dominated the use of cleared land (taking up about 90 percent of the farmed area), followed by perennial crops (6.5 percent), and secondary vegetation (3.5 percent). These provinces have approximately 180,000 inhabitants, of which 62 percent live in rural areas and 45 percent are indigenous peoples. The estimated annual population growth rate in these two provinces is 2.6 percent. The indigenous groups that live in the area are the Shuar, which is possibly the largest, with approximately 46,000 people, the Kichwa with approximately 28,000 (INEC, 2003), the Achuar with an estimated population of 6,000 (NAE, 2007), the Shiwiar with 1,200 people (NASHIE, 2007), Zápara with 200, and Andoas with 150 (INEC, 2003). Figure 4.2 shows a map of the distribution of indigenous groups in the PRBEA and the proportions of their

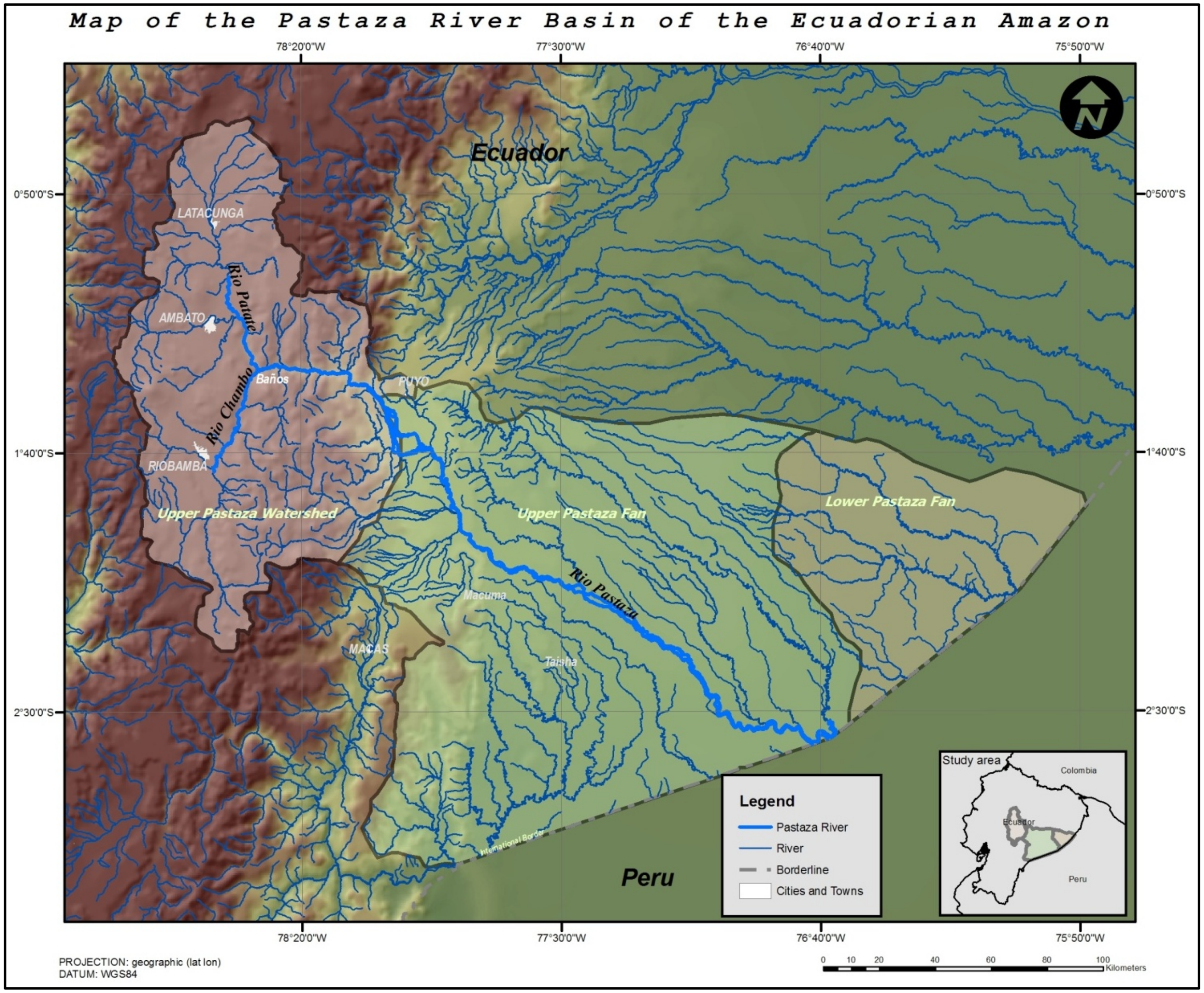


Figure 4.1: The physical context of the study area. The upper and lower Pastaza fan in the Ecuadoirna Amazon. Source: Bès de Berc *et al*., 2005.

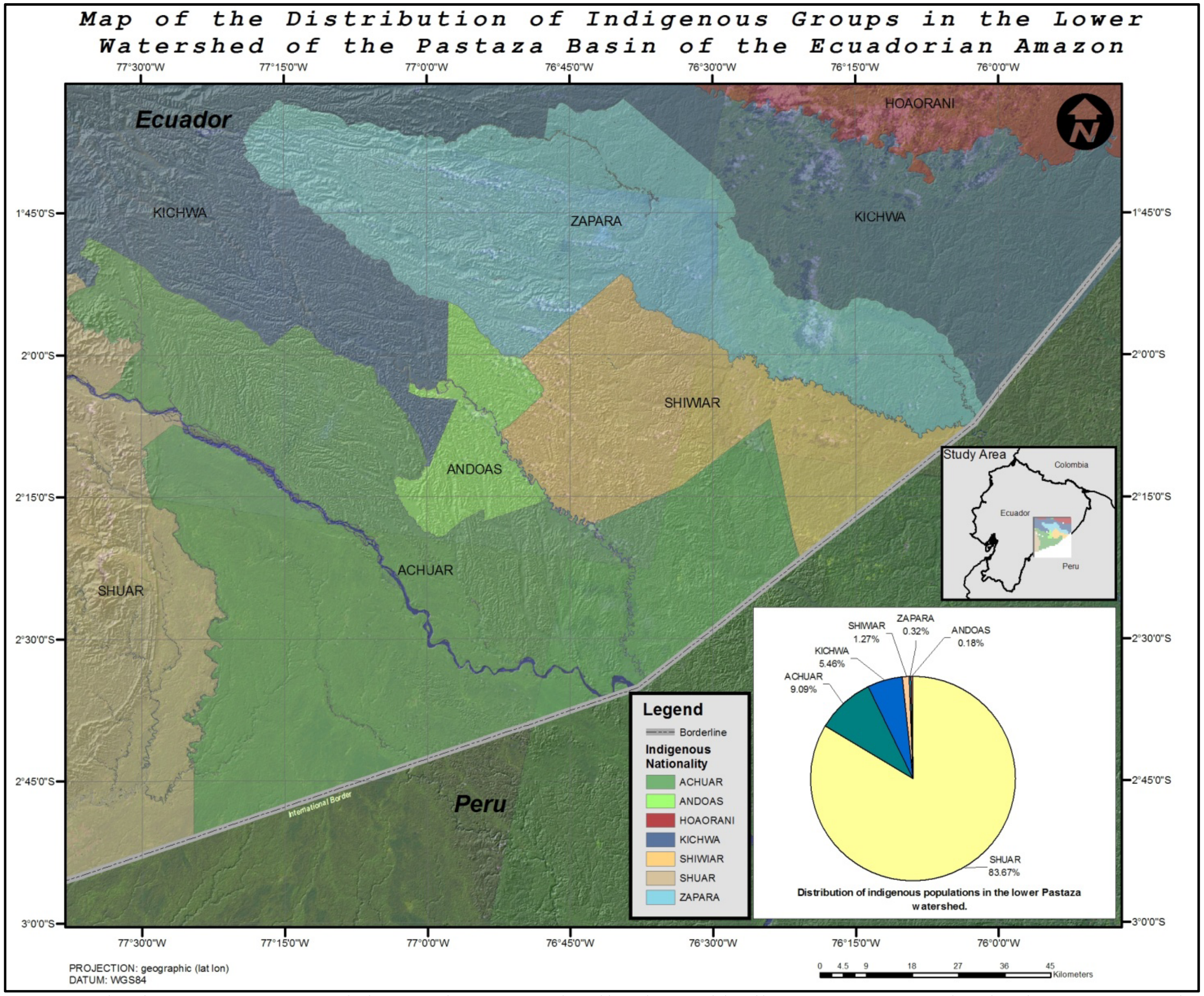


Figure 4.2: The human context of the study area. Distribution of indigenous groups in the lower watershed of the Pastaza basine in the Ecuadorian Amazon. Source: various sources, compiled by R. Sierra, 2006.

populations in relation to the total number of indigenous inhabitants. This study concentrates on the Achuar and Shiwiar groups.

It is important to note that both the Achuar and Shiwiar belong to the Achuar dialectic group which is part of the Jívaro linguistic family. The Jívaro are probably one of the largest and most homogenous indigenous groups of the Amazon basin (Descola, 1987), and their spatial distribution covers different ecozones of the Pastaza river basin. Other dialectical groups that belong to the Jívaro linguistic family are the Shuar, Huambisas, and Aguaruna (Figure 4.3).

One of the first historical descriptions of the Achuar group was made by a Dominican missionary called Alfredo Germani. Germani compiled a group of narratives and diaries from his fellow missionaries and wrote the book "*Pueblo de Fuertes*" [People of the Strong Ones] (Germani, 1984). In this manuscript, he reports that in 1775 the Dominican missionaries of the Canelos area encountered a small group of Achuar families, which they were unable to convert to Christianity. These families came from an area called Sáasaim, in the southern region of the Pastaza River valley. Germani also describes a series of violent encounters between the Canelos Kichwa and some Achuar coming from the Huasaga, Ipiak, and Wampuik Rivers area around the year 1797, which resulted in the expulsion of the Canelos of middle basin of the Pastaza River and their relocation along the Bobonaza River. According to Germani, during the late 1700s the Achuar moved to the south and southwest, pushing the Candoshi southwards towards the Marañon River and the Huambisa westwards to the Morona River (Bolla, 1993). Since

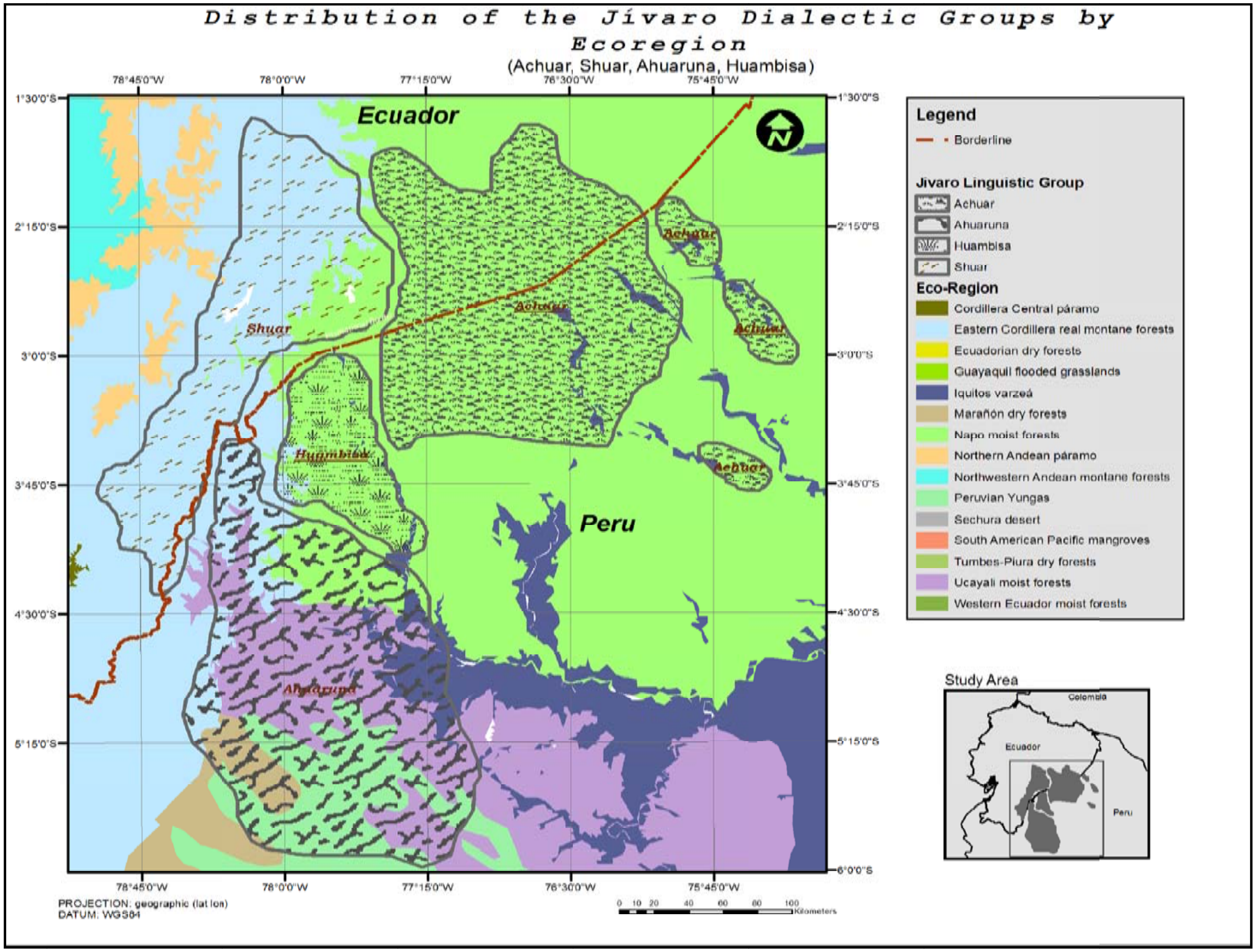


Figure 4.3: Distribution of the Jivaroan dialectic groups and their occupancy ecosystems. Source: Descola, 1987 and Olson *et al*., 2001.

then, this group has occupied the lower watershed of the Pastaza River Basin almost exclusively (Descola, 1994).

In the case of the Shiwiar, their mixture origins explain why the literature has referred to this group as "Achuar", "Kichwa", or simply as "Jívaro" (Fast, 1976; Uriarte, 1976; Chirif, & Mora, 1977; Fung, 1981). Despite the strong Kichwa influence on the Shiwiar, in which the bi-linguistic component Quechua-Jívaro is very common, and where the values and the social system has some similarities with the Kichwas, the Shiwiar still maintain strong Achuar customs, traditions, and life styles. For instance, the architecture, production strategies, and clothing belong completely to the Achuar culture. The usual trend in this region is that the Quechua language and its ethnic identity gain terrain at the expense of other ethnic and linguistic categories. This process of "emergent ethnicity" (Whitten, 1976) goes far back even before the arrival of the Europeans and the introduction of the Quechua as the *lingua franca* in the Amazon region. This is a role Quechua still plays, making communication possible among members of different ethno-linguistic groups (Hudelson, 1987). However, this historical trend of the adoption of the Quechua and the ethnic identity linked to it seems to be an exception among the Shiwiar and has taken the inverse process. In this case, the members of this ethnic group have adopted the Jívaro-Achuar language and its ethnic identity as theirs. The result of this process has been the development of a dual standard identity (Seymour-Smith, 1988). In this system of dual values, they maintain a native Jívaroan identity in the community, but at the same time they identify themselves with the *mestizo* culture and the values linked to the non-native world.

2. Spatial, cultural, and socioeconomic transformations in the Pastaza River Basin

After the war between Ecuador and Peru in 1941 and the signing of the *Protocolo de Río de Janeiro* in 1942, the Jívaroan region was divided in two. In the Peruvian part, the penetration of non-indigenous elements was more successful than in the Ecuadorian side. A new form of non-indigenous implantation was common in Peru, which does not have an equivalent on the Ecuadorian side (Descola, 1988). This is the case of the *patrón*, a mestizo or white trader permanently established in some sort of forest concession, which he partially exploited with the aid of indigenous labor. The system was based on voluntary but unequal interchange: the Jívaro gave the *patrón* wood as payment for manufactured goods such as machetes, axes, or shot guns. The debt was almost inextinguishable since it was always reactivated by new acquisitions (Seymour-Smith, 1988).

The acquisition of manufactured goods, especially shot guns and machetes, through the Peruvian *patrones* and indigenous trade networks, turned the period 1940–1960 into a violent one in the Jivaroan history (Steel, 1999). These tools became much desired goods and feuds to obtain them were so intense that they threatened the group's continued survival. According to Taylor (1981), from 1940 to about 1960 more than 50 percent of adult Achuar males died in intra tribal feuds and raids against the Shuar. Bennett-Ross (1980, 1984) reports similarly staggering numbers: from lists of deaths obtained from her informants in the early 1970s, she estimates that 59 percent of deaths of adult males in the preceding decade resulted from warfare. The Achuar themselves sensed that the violence was getting out of hand and subsequently referred to the 1940–1960 period as the time when they were "literally ending" (Taylor, 1981). Discussing this period, Taylor (1981: pp. 651–52) states that "the intensity of the killing was apparently well beyond anything the traditional pattern of warfare could account for".

Another form of non-indigenous penetration in the Jívaro territory was oil prospection by large multi-national companies. In Ecuador, attempts to discover oil began in the 1930s were the oil company Shell opened a landing strip in Taisha for prospecting purposes. In the 1970s, the company Amoco also prospected for oil in the northern part of the Bobonaza River. Nevertheless, neither Shell nor Amoco found any conclusive evidence of the existence of oil and abandoned the area. Taisha now serves as a military base and has a *mestizo* colony with a couple of hundred inhabitants.

Oil prospecting in the Jívaroan territory in Peru only took place because indigenous peoples were already "pacified" by Protestant missionaries of the Summer Linguistic Institute (SLI). The SLI put into practice a classic procedure based on the old Spanish reductions or *reducciones*, when the missionaries were confronted by nomad and dispersed populations. They encouraged the Jívaro to group around small plazas, forming small villages, clustered around the landing strips used by the organization's aircrafts. The missionaries did not reside in these recently founded villages but rather lived in exclusive missions located in the lower Huasaga area. From their headquarters, the missionaries visited regularly the different indigenous villages, also called *centros*, establishing trade networks, which substituted those implanted by the *patrones*. As a consequence, the influence of Peruvian traders declined, while the authority of the SLI missionaries increased (Descola, 1994).

The penetration of the missionaries among the Ecuadorian Achuar took a different shape. First of all, the Achuar from Ecuador energetically rejected any attempt of accessing their territory by non-indigenous people until the late 1960s. Only between 1968 and 1970 were Catholic and Protestant missionaries able to establish the first peaceful contacts with the Ecuadorian Achuar, followed by several evangelization attempts. Salesian missionaries, who already worked with the Jívaro Shuar in the nineteenth century, established one mission in Macas and another later in the upper Huasaga River. North American Protestant missionaries from the Gospel Missionary Union (GMU) established a mission in Macuma in 1940 (Taylor, 1981).

The Catholic and Protestant missionary groups differed immensely from one another, not only in terms of their theological dissensions, but also in their evangelization methods and "styles" (ibid.). The Protestants of the GMU, similarly to their colleagues of the SLI, had an important infrastructure from the beginning (i.e. single-engine aircrafts and radio communication systems), which influenced their way of approaching the Achuar. The "pacification" techniques were similar to those of the SLI: settlement of houses in small villages, clustered around a landing strip, and the implantation of Shuar instructors already converted to Christianity. Some of these villages received cattle from the GMU, and the missionaries were responsible of the commercialization of meat in Macas or Puyo (i.e. the main regional markets).

The Salesian style differed drastically from their Protestant competitors. In the early 1960s a young generation of Italian missionaries harshly criticized the conservative and paternalist approach of the older generation of missionaries, and for the first time gave the Jívaro the opportunity to lead their own political and religious organization. In pastoral terms, the new attitude of these missionaries involved a more direct and active participation in the daily lives of the Achuar families. Hence, Jívaro culture and organization began to be drastically reshaped (Harner, 1972). For instance, in 1964 the *Federación de Centros Shuar* was founded by initiative of the young missionaries, primarily to enable the Jívaro Shuar to establish legal ownership of their land (Salazar, 1981; Bottasso, 1984; Neumann, 1994). At that time, Ecuador enacted its first land-reform law and augmented it in 1973 and 1977. The reforms set up administrative mechanisms to redistribute land but also established programs to expedite colonization of "unoccupied lands" (Rudel *et al*., 2002). To show that their land was "developed", a necessary condition for ownership under new Ecuadorian laws, the Shuar and some Achuar turned to small scale cattle ranching (Salazar, 1981; Hendricks, 1993; Neumann, 1994). Additionally, Shuar neighborhoods were encouraged to form property-owning administrative units also called *centros*, which grouped several families around an airstrip or central plaza usually containing a school, chapel, and health clinic (Salazar, 1981). Groups of *centros* were organized into *asociaciones*, which were united into the federation, with elected officials at each level of the hierarchy (ibid.). A similar emergence of *centros* and political organization took place among the Achuar and Shiwiar in the 1970s (Descola, 1981; Taylor, 1981).

According to the Ecuadorian Jívaro themselves, the prospect of acquiring cattle as a source of revenue was the main incentive for settling in *centros* and accepting the tutorship of the missions (Taylor, 1981). By year 1980, the *centros* were encouraged to form communal *grupos de desarrollo ganadero* (groups of cattle ranching development), and a large injection of credit extended by the *Federación de Centros* Shuar allowed them to acquire pasture seeds and large quantities of cattle. At that time, the estimated number of cattle heads in the Achuar territory was about 200, most of them concentrated in the two oldest *centros*, Pumpuentza and Wichim. Despite the federation's cooperative character, most cattle were and still are individually owned. Household heads cleared relatively extensive tracts of rain forest and became small-scale cattle ranchers as well (Taylor, 1981). Until the late 1980s, cattle were in fact the main source of cash among the Achuar (Descola, 1994). Pasture lands for cattle ranching became a new form of land use in the Jívaro territory. This activity contributed to the sedentary character of today's nucleated settlements since, unlike the swidden agricultural plots or *chacras*, a pasture become permanent once it was established (Descola, 1987). The introduction of cattle ranching caused the clearing of new land and the conversion of old *chacras* into pastures.

During the 1970s and 1980s wage labor was sporadic and limited. Only a handful of Achuar went to work in the coastal and highland provinces, but mainly in the two main regional cities of Puyo and Macas. Most of them returned to their communities after a year and resumed their traditional lifestyle (Descola, 1987; Taylor, 1981). The money thus earned was sometimes invested in cattle, but far more often in consumer goods such as radios and clothes that were rapidly reinvested in the traditional trade circuits. Thus, wage labor has not resulted in capital accumulation either for the Jívaro Achuar or Shiwiar.

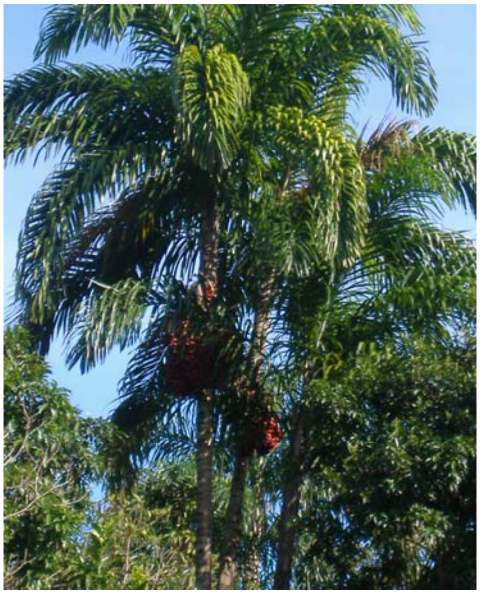
The Jívaro showed clear signs of acculturation during the 1990s. With radio-assisted bilingual schools in virtually every *centro*, levels of educational achievement rose rapidly (Cimento, 2006; personal communication). The introduction of formal schooling implied direct effects on work processes, on space organization, and on traditional modes of socialization. For instance, before the formation of *centros*, the Jívaro society was dispersed and lived temporarily (e.g. 3 – 4 years) in endogamous family units consisting of groupings of 6 – 12 houses separated by several kilometers (Descola, 1987). With the formation of *centros*, the modern arrangement of human occupation in the Achuar and Shiwiar areas is now characterized by the construction of residential units around landing strips.

Presently, residential units still preserve the characteristic of traditional dwellings although there is evidence of the usage of foreign materials such as tin roofs, metal nails, and concrete. Nevertheless, contemporary residential units in general comprise two important traditional spaces: the house and the immediate cleared area adjacent to it also referred to as "the exterior" (Figure 4.4). The exterior of a Jívaro house is carefully cleared for several reasons such as to minimize the risk of encountering snakes or facilitate access to residences. Modern Achuar and Shiwiar households sometimes adorn these areas with native or introduced ornamental plants, medicinal plants, fruit trees, or *chonta* palms (*Aiphanes aculeate*) (Figure 4.5). In modern villages, families generally

A. Aerial photograph of a residential unit in the community of Sawastian. (Year 2006)

B. Horizontal photograph of the same residential unit (Year 2003). Note: The house in this photograph is the same as the one in the aerial image with a quadrangular shape.

Figure 4.4: Physical characteristics of residential areas. Residential units in the PRBEA can be divided in two areas: the house and the immediate cleared area adjacent to it, generally free of vegetation. Photos by S. López and R. Beard.



A. *chonta* palms (*Aiphanes aculeate*)

B. *Papaya (Carica papaya)*

C. *Frutipan* (*Artocarpus altilis)*

D. Ornamental plants

Figure 4.5: Examples of plant species commonly found in the exterior areas of Achuar and Shiwiar residential units. Photos by S. López and R. Beard.

place these two spatial units over flat terrain and close to a river or to small stream to provide water for consumption or bathing.

The Achuar and Shiwiar traditional houses have almost identical architecture and are constructions of nearly elliptical shape, generally without external walls and with a thatched roof of up to a height of up to 5 m (Figure 4.6). Typical palms used for roof thatching include *kampanak* (*Hyospathe sp*.), *turuji* (*Hyospathe tessmannii*), *chaapi* (*Phythelepas sp*.), and *kuunt* (*Wettinia maynensis*). *Kampanak* and *chaapi* palms are at times specifically cultivated in gardens in some areas for this purpose. The most frequent materials used as the main structure of the house are two palms species*: tuntuam (Iriartea sp*.) and *ampaki (Iriartea verticosa Mart*.). Figure 4.7 shows examples of the most common palm species used in construction in the Achuar and Shiwiar territories.

Presently, the lowlands Jivaro still rely heavily on hunting and fishing for the acquisition of protein. With the introduction of shotguns since the 1940s and 1950s, men now prefer to hunt with them when ammunition is available. If not, blowguns are still used but to a lesser degree. All Jívaro men know how to use the blowgun with great skill, and many also know how to construct one. However, curare dart poison (i.e. poison extracted from certain frog species or plants used on traditional darts) is typically bought or traded from the Peruvian Jívaro.

Some Jívaro male household heads sometimes build hunting huts in areas that are located five to10 km away from their main residence, however this practice is not commonly observed in current settlements anymore. These huts usually served as shelters

Figure 4.6: Architectural characteristics of Jívaro traditional houses: A) A Shiwiar house in the community of Kurintza. Note the divided space where the bedroom is. This particular feature was not found in any of the visited Achuar communities. B) An old house being repaired in the Achuar community of Kupit. Note the four vertical sticks to support the roof. C) A new house being built in the community of Sawastian. Note the bottom-up thatching process to make the roof. Photos by S. López and R. Beard.

when hunting trips last for more than one day, which is currently very occasional. According to Descola (1987) a household could manage a hunting area between forty and forty-five square kilometers, which could easily provide regular amounts of game for one or two hunters. These conditions may have changed in recent decades due to changes in settlement patterns and limitations in the availability of game species.

The last decade of the twentieth century is marked by fast changes in commerce and trade behavior in the Jivaro territory (Bolla, 2003). For instance, Catholic and Protestant missionaries began to establish local sources of manufactured goods within or within the vicinity of each *centro,* in the form of cooperative *tiendas*, or small shops. These shops provided the Achuar and Shiwiar with consumer goods such as clothing, radios, batteries, and production tools such as machetes, fishing tackle, and hunting implements. Consumer goods and traditional exchange values were altered because of these new forms of commerce. Additionally, the circulation of cash, fairly plentiful in some Achuar *centros* because of cattle or sporadic off-farm labor, also affected traditional trade networks. Further, in 1996, a few Achuar communities began to participate in pilot production projects led by *Fundación Chankuap,* a Salesian non-profit organization settled in Macas. The objective of this foundation was to support the indigenous families in the production and commercialization of handicrafts and agricultural products (Fundación Chankuap, 1996). The effects of the new cash economy on traditional trade networks, as far as the author knows, have not yet been evaluated; however, Achuar leaders appear to be aware of the socioeconomic and cultural effect

Figure 4.7: Examples of palms used for the construction of traditional houses in the Jívaro area. A) An aerial view of a *kampanak* palm (*Hyospathe sp*.) plantation in the Achuar community of Wasakentza. B) A *chaapi* palm (*Phythelepas sp.)* planted in the surrounding area of a house in the Achuar community of Kupit. C) *Pambil* palm or *tuntuam* (*Iriartea sp*.) used in the main structure of houses. Photo by S. López and R. Beard

implied by articulation to the national market economy (personal communication with Achuar leaders in 2006).

3. The Achuar and their current territorial occupancy

Presently, the Ecuadorian Achuar are represented by the *Nacionalidad Achuar del Ecuador* (NAE), which was legally recognized by the Development Counsel of the Indigenous Nationalities and Communities of Ecuador (CODENPE) in 2005. NAE consists of nine grassroots associations and 64 communities, and embraces approximately 6,000 people (NAE, 2007). The estimated annual growth rate for the Achuar is approximately 5 percent. The estimated population density in NAE's territory is 0.86 persons / km^2. This organization has its headquarters in Puyo, where the Achuar leaders live and work. NAE's territory extends between the parallels 1°45' South and 2° 50' South, on the border with Peru, and the meridians 77° 38' West and 76° 20' West, which comprise an area of approximately 700,000 ha (Figure 4.8).

A similar organization was created in Peru in 2000 called *Federación de la Nacionalidad Achuar del Perú* (FENAP), which includes two grassroots organizations, represents 77 communities, and embraces approximately 10,000 people (La Torre Lopez, 1998). After the signing of a peace treaty between Ecuador and Peru in 1998, a bi-national organization was formed called the Bi-national Coordinating Committee of the Achuar Nationality of Ecuador and Peru (COBNAEP).

NAE's territory is characterized by gentle depressions corresponding to old fluvial terraces of the Pastaza River. These depressions are permanently inundated and

Figure 4.8: Map of the Achuar territory. Source: NAE, 2006.

covered almost uniformly by extensive patches of *Mauritia flexuosa* palms, called *moretes* o *aguajes* in the upper Amazon or *moriches* in Venezuela. This vegetation type is usually referred to as *moretal* or *aguajal* (Sierra, 1999) and constitutes a typical biotope of Amazonian deltas and riverine areas. Interestingly, the word “Achuar” is the contraction of the words “Achu”, which is the Jívaro word to describe the *morete* or *aguaje* palm, and “Shuar”, which means people. Therefore, Achuar stands for “the people of the *morete* palm”.

The Achuar occupy a region drained by a large fluvial system; this fluvial network flows downstream, across relatively flat slopes from the northeast to the southeast where it feeds the Marañon River. Within this fluvial system, three distinct ecotypes exist. The distinctive features of each are due to the different types of soils drained by the hydrographic network. These biophysical differences serve as a baseline to characterize the Achuaran land occupancy. Figure 4.9 and Table 4.1 show the distribution of *centros* in relation to the types of geomorphologic features and soils found in the area. Table 4.2 describes the soil and geomorphologic information associated with Figure 4.9 and Table 4.1. The Achuar occupy low terraces in the great alluvial basins where aggrading rivers flow such as the Pastaza River and some of its tributaries such as the Copataza, Capahuari, Kapawi, Huasaga and Bobonaza Rivers. These terraces present alluvial volcanic soils (Fluventic Tropaquepts), or black soils that have a high potential fertility. These areas correspond to the units K in Figure 4.5 and belong to the riverine habitat. According to Descola (1987), their physical and chemical characteristics make

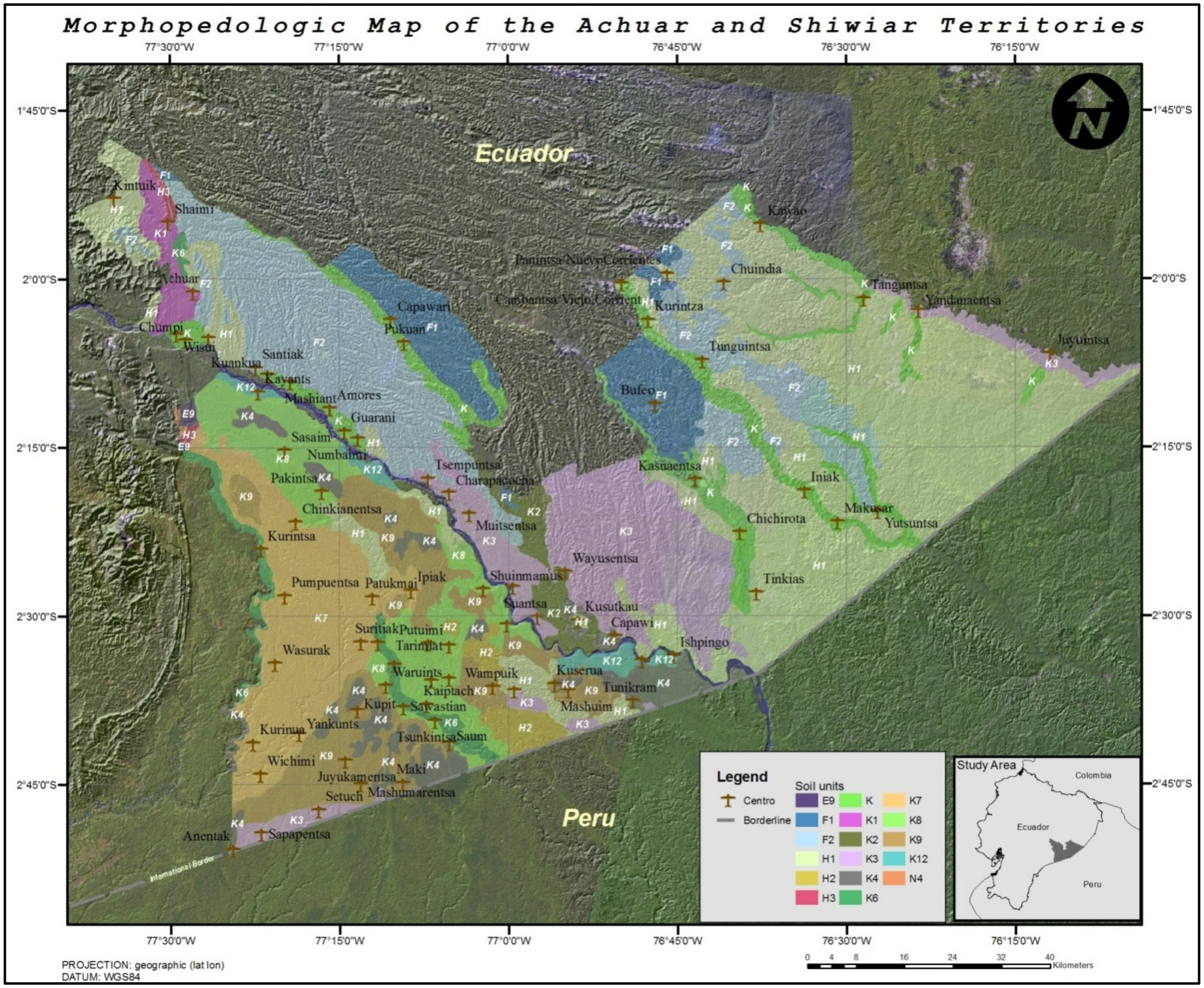


Figure 4.9: Morphopedologic characteristics of the Achuar and Shiwiar territories .Source: Custode, 1983

Table 4.1: Name, location, types of soils, and geomorphology of the Achuar and Shiwiar *centros*.

	Name	Coordinates		Morphopedologic units												
	CENTRO	Lat	Lon	H1	F1	F2	K	K1	K2	K3	K4	K6	K7	K8	K9	K12
Achuar Centros	Achuar	-2.025315	-77.466961	.	.	.	x	.	.	.	.	.	.	.	.	.
	Amores	-2.198200	-77.264930	x	.	.	.	.	.	.	.	.	.	.	.	.
	Anentak	-2.853352	-77.408522	.	.	.	.	.	.	.	.	.	.	.	x	.
	Apachentsa	-2.518922	-77.003757	.	.	.	.	.	.	.	.	.	.	.	x	.
	Capawari	-2.067067	-77.175264	.	.	.	x	.	.	.	.	.	.	.	.	.
	Capawi	-2.536786	-76.843532	.	.	.	.	.	.	x	.	.	.	.	.	.
	Charapacocha	-2.323398	-77.089028	.	.	.	.	.	.	x	.	.	.	.	.	.
	Chichirota	-2.382573	-76.658581	.	.	.	.	.	.	.	x	.	.	.	.	.
	Chinkianentsa	-2.367402	-77.315576	.	.	.	.	.	.	.	.	.	x	.	.	.
	Chumpi	-2.097424	-77.478854	.	.	.	x	.	.	.	.	.	.	.	.	.
	Copataza	-2.093138	-77.444606	.	.	.	x	.	.	.	.	.	.	.	.	.
	Guarani	-2.232228	-77.243674	.	.	.	x	.	.	.	.	.	.	.	.	.
	Guasaga Viejo	-2.578924	-77.170409	.	.	.	.	.	.	.	.	.	.	.	x	.
	Iniak	-2.320892	-76.563123	.	.	.	x	.	.	.	.	.	.	.	.	.
	Ipiak	-2.468721	-77.145818	.	.	.	.	.	.	.	.	.	x	.	.	.
	Ishpingo	-2.565872	-76.757338	.	.	.	.	.	.	.	x	.	.	.	.	.
	Juyukamentsa	-2.720632	-77.243105	.	.	.	.	.	.	.	.	.	.	.	x	.
	Kaiptach	-2.638287	-77.12268	.	.	.	.	.	.	.	.	x	.	.	.	.
	Kasuaentsa	-2.304386	-76.725043	.	.	.	x	.	.	.	.	.	.	.	.	.
	Kayants	-2.174410	-77.371256	.	.	.	.	.	.	.	.	.	.	x	.	.
	Kintuik	-1.886929	-77.584383	.	.	.	.	.	.	.	.	x	.	.	.	.
	Kuankua	-2.148296	-77.356782	.	.	.	x	.	.	.	.	.	.	.	.	.
	Kuchintsa	-2.602372	-77.11565	.	.	.	.	.	.	x	.	.	.	.	.	.
	Kupit	-2.646033	-77.225504	.	.	.	.	.	.	.	.	.	.	.	x	.
	Kurintsa	-2.407609	-77.367291	.	.	.	.	.	.	.	.	.	x	.	.	.
	Kurinua	-2.695285	-77.379721	.	.	.	.	.	.	.	.	.	.	.	x	.
	Kuserua	-2.60786	-76.93296	x	.	.	.	.	.	.	.	.	.	.	.	.
	Kusutkau	-2.513187	-76.898326	x	.	.	.	.	.	.	.	.	.	.	.	.
	Maki	-2.754364	-77.157663	.	.	.	.	.	.	.	.	.	.	.	x	.
	Makusar	-2.367065	-76.514052	.	.	.	x	.	.	.	.	.	.	.	.	.
	Mamantsa	-2.616711	-76.992845	.	.	.	.	.	.	.	.	.	.	.	x	.
	Mashiant	-2.159100	-77.323891	.	.	x	.	.	.	.	.	.	.	.	.	.
	Mashuim	-2.616995	-76.912853	.	.	.	.	.	.	.	.	.	.	.	.	x
	Mashumarentsa	-2.756011	-77.220161	.	.	.	.	.	.	.	.	.	.	.	x	.
	Muitsentsa	-2.355280	-77.059675	.	.	.	x	.	.	.	.	.	.	.	.	.
	Numbaimi	-2.242920	-77.224115	.	.	.	x	.	.	.	.	.	.	.	.	.
	Pakintsa	-2.321922	-77.277224	.	.	.	.	.	.	.	x	.	.	.	.	.
	Patukmai	-2.478356	-77.202366	.	.	.	.	.	.	.	.	.	.	.	.	x
	Pukuan	-2.100804	-77.155608	.	.	.	.	x	.	.	.	.	.	.	.	.

Table 4.1 (cont.):

	Name	Coordinates		Morphopedologic units												
	CENTRO	**Lat**	**Lon**	**H1**	**F1**	**F2**	**K**	**K1**	**K2**	**K3**	**K4**	**K6**	**K7**	**K12**	**K8**	**K9**
Achuar Centros	Pumpuentsa	-2.476902	-77.33255	.	.	.	.	.	.	.	.	x	.	.	.	.
	Putuimi	-2.547617	-77.120325	.	.	.	.	.	.	.	.	.	.	.	x	.
	Santiak	-2.138157	-77.375113	.	.	.	.	.	.	.	.	.	x	.	.	.
	Sapapentsa	-2.828844	-77.366948	.	.	.	.	.	.	.	.	.	x	.	.	.
	Sasaim	-2.260724	-77.332335	.	.	.	.	.	.	.	.	.	.	x	.	.
	Saum	-2.695306	-77.088661	.	.	.	.	.	.	.	.	.	x	.	.	.
	Sawastian	-2.641819	-77.157212	.	.	.	x	.	.	.	.	.	.	.	.	.
	Setuch	-2.794576	-77.282637	.	.	.	.	.	.	x	.	.	.	.	.	.
	Shaimi	-1.921987	-77.504538	.	x	.	.	.	.	.	.	.	.	.	.	.
	Sharamentsa	-2.463325	-76.994707	.	.	.	.	.	.	x	.	.	.	.	.	.
	Shuinmamus	-2.467321	-77.039051	.	.	.	.	.	.	x	.	.	.	.	.	.
	Suantsa	-2.508304	-76.958655	.	.	.	.	x	.	.	.	.	.	.	.	.
	Surik Nuevo	-2.599856	-77.089408	.	.	.	.	.	.	.	.	.	.	.	x	.
	Suritiak	-2.545648	-77.219689	.	.	.	.	.	.	x	.	.	.	.	.	.
	Tarimiat	-2.550733	-77.08906	.	.	.	.	.	.	.	.	.	.	.	.	x
	Tinkias	-2.472181	-76.634907	x	.	.	.	.	.	.	.	.	.	.	.	.
	Tsempuntsa	-2.302744	-77.120289	.	.	.	.	.	.	x	.	.	.	.	.	.
	Tsunkintsa	-2.662293	-77.110540	.	.	.	.	.	.	.	.	.	.	x	.	.
	Tunikram	-2.633202	-76.81717	.	.	.	.	.	.	.	x	.	.	.	.	.
	Wachirpas	-2.572508	-76.804032	.	.	.	.	.	.	.	x	.	.	.	.	.
	Wampuik	-2.611888	-77.024985	.	.	.	.	.	.	.	.	.	.	.	x	.
	Waruints	-2.610249	-77.182758	.	.	.	.	.	.	.	.	.	.	x	.	.
	Wasakentsa	-2.546758	-77.194893	.	.	.	.	.	.	.	.	x	.	.	.	.
	Wasurak	-2.577148	-77.346605	.	.	.	.	.	.	.	.	.	x	.	.	.
	Wayusentsa	-2.441422	-76.916872	.	.	.	.	.	x	.	.	.	.	.	.	.
	Wichimi	-2.74173	-77.368573	.	.	.	.	.	.	.	.	.	x	.	.	.
	Wisui	-2.087876	-77.492089	.	.	.	x	.	.	.	.	.	.	.	.	.
	Yankunts	-2.681664	-77.310930	.	.	.	.	.	.	.	.	.	x	.	.	.
	Yutsuntsa	-2.351454	-76.455133	.	.	.	x	.	.	.	.	.	.	.	.	.
Shiwiar Centros	Bufeo	-2.191863	-76.784327	.	.	.	x	.	.	.	.	.	.	.	.	.
	Cambantsa	-2.012843	-76.833811	x	.	.	.	.	.	.	.	.	.	.	.	.
	Chuindia	-2.011689	-76.682078	.	.	.	.	.	.	x	.	.	.	.	.	.
	Juyuintsa	-2.117423	-76.199406	.	.	.	.	.	.	x	.	.	.	.	.	.
	Kawao	-1.925321	-76.12823	.	.	.	x	.	.	.	.	.	.	.	.	.
	Kurintsa	-2.067276	-76.794563	.	.	.	x	.	.	.	.	.	.	.	.	.
	Panintsa	-1.998568	-76.765964	.	.	.	.	.	.	x	.	.	.	.	.	.
	Tanguntsa	-2.035663	-76.475212	.	.	.	x	.	.	.	.	.	.	.	.	.
	Tunguintsa	-2.126977	-76.714534	.	.	x	.	.	.	.	.	.	.	.	.	.
	Yandanaentsa	-2.053146	-76.394491	.	.	.	x	.	.	.	.	.	.	.	.	.

Table 4.2: Classification scheme used in the pedological characterization of the Achuar and Shiwiar territories. Use this table as reference to Figure 4 and Table 4.1.

SOIL ID	*SOIL TYPE*	*GEOMORPHOLOGIC FEATURES*	*CHARACTERISTIC*
N4	Typic DYSTROPEPTS (red soils)	Foothills topography and irregular hills	Less deep lime and clay red soils; low fertility and high aluminum content
E9	Oxic DYSTROPEPTS HAPLORTHOX (red and brown soils)	Old alluvial fans and dissected floodplains. Terraces and cliffs.	Deep clayey soils, with low fertility, and very high aluminum content
F1	Oxic DYSTROPEPTS (red and brown soils) and HAPLORTHOX	Deeply dissected mesas	Very deep clayey soils with very low fertility (brown soils), low fertility (red soils), and toxic aluminum
F2	Oxic or Typic DYSTROPEPTS (red soils)	Irregular topography derived from mesas.	Very deep clayey soils
H1	Oxic or Typic DYSTROPEPTS (red soils)	Hills	Shallow clayey and loamy soils, with low fertility and toxic aluminum
H2	Oxic or Typic DYSTROPEPTS (red soils) and TROPAQUEPTS	Hills surrounded by swamps	Shallow red clayey and loamy soils, with low fertility and toxic aluminum. Variable fertility with a superficial phreatic layer
H3	ORTHENTS and Oxic DYSTROPEPTS	Chevrons	Sandy soils, with low or no fertility
K1	DYSTROPEPTS EUTROPEPTS	Medium level alluvial terraces	Soils with variable fertility, generally fertile
K2	Aquic DYSTROPEPTS TROPAQUEPTS	Low alluvial terraces	Soils with high water content or "gley"
K3	TROPAQUEPTS	Floodplains and depressions	Complex of soils with variable fertility and superficial phreatic layer
K4	Hydric TROFIBRISTS	Depressions and oxbow lakes	Poor drainage, multiple limitations with organic matter
K6	Aquic DYSTROPEPTS and Fluventic TROPAQUEPTS	Terraces of the Cangaime, Huasaga, and Macuma Rivers	Low fertility, with toxic aluminum; high fertility and high phreatic layer

Table 4.2 (cont.):

SOIL ID	***SOIL TYPE***	***GEOMORPHOLOGIC FEATURES***	***CHARACTERISTIC***
K7	Oxic HAPLORTHOX Typic and Aquic DYSTROPEPTS (pardos) TROPAQUEPTS	Flat and slightly hilly floodplains drained by creeks	Soils with variable characteristics depending on their thickness; some are deep and clayey, with low fertility and toxic aluminum; others are thinner and siltier with medium fertility and limited drainage
K8	Oxic HAPLORTHOX Typic and Aquic DYSTROPEPTS (pardos) TROPAQUEPTS	Flat floodplains with imperfect drainage	Soils with variable characteristics depending on their thickness; some are deep and clayey, with low fertility and toxic aluminum; others are thinner and siltier with medium fertility and limited drainage
K9	K4 and K6 COMPLEX	Mixed features of K4 and K6	See K4 and K6
K12	Aquic HYDRANDEPTS (upstream)	Terraces of the Pastaza and Upano Rivers	Soils generally deep and loose with imperfect drainage and risk of flooding
K	Complex of K units	Complex of terraces with different levels	Characterisitcs of K soils units.

them the best soils in the entire Achuar region: the pH is not overly acid ranging from 5.5 and 6.5, the interchangeable aluminum rate is low, and their content of organic matter is high. However, poor drainage conditions become an important constraint for agriculture. The vegetation found in these areas corresponds to the ‘Amazon lowland white-water inundated evergreen tropical forests’ category of the classification by Sierra (1999) for the Ecuadorian mainland. Figure 4.10 and Table 4.3 show the distribution of *centros* in relation to the vegetation types found in the region.

The Achuar also occupy the high terraces of the rivers originated in the mesas system such as the upper Capahuari River and its tributaries, upper Bobonaza River, upper Copataza River, and upper Corrientes River. These are composed of red soils of ferralytic origin (Typic or Oxic Dystropepts) with high aluminum content or of a mixture of red soils and sandy soils produced by the erosion of the hills and mesas. These two latter types of soils have a very low potential fertility (Custode, 1983). These areas correspond to the units F and H in Figure 4.5 and belong to the inter-fluvial habitat. The vegetation type found in this area corresponds to the ‘Amazon lowland evergreen forests’ category (Sierra, 1999) on hilly terrain. Finally, they also occupy a third category of geomorphologic features that are included in the same group for simplification purposes: the recent alluvial terraces and swampy alluvial floodplains. Although these two areas are geomorphologically different, the soils of both are almost identical (Custode, 1983). The vegetation type found on the flat areas of recent alluvial terraces also corresponds to the ‘Amazon lowland evergreen forests’ category. The most typical geomorphologic features of these alluvial floodplains are large inundated depressions. These depressions can be

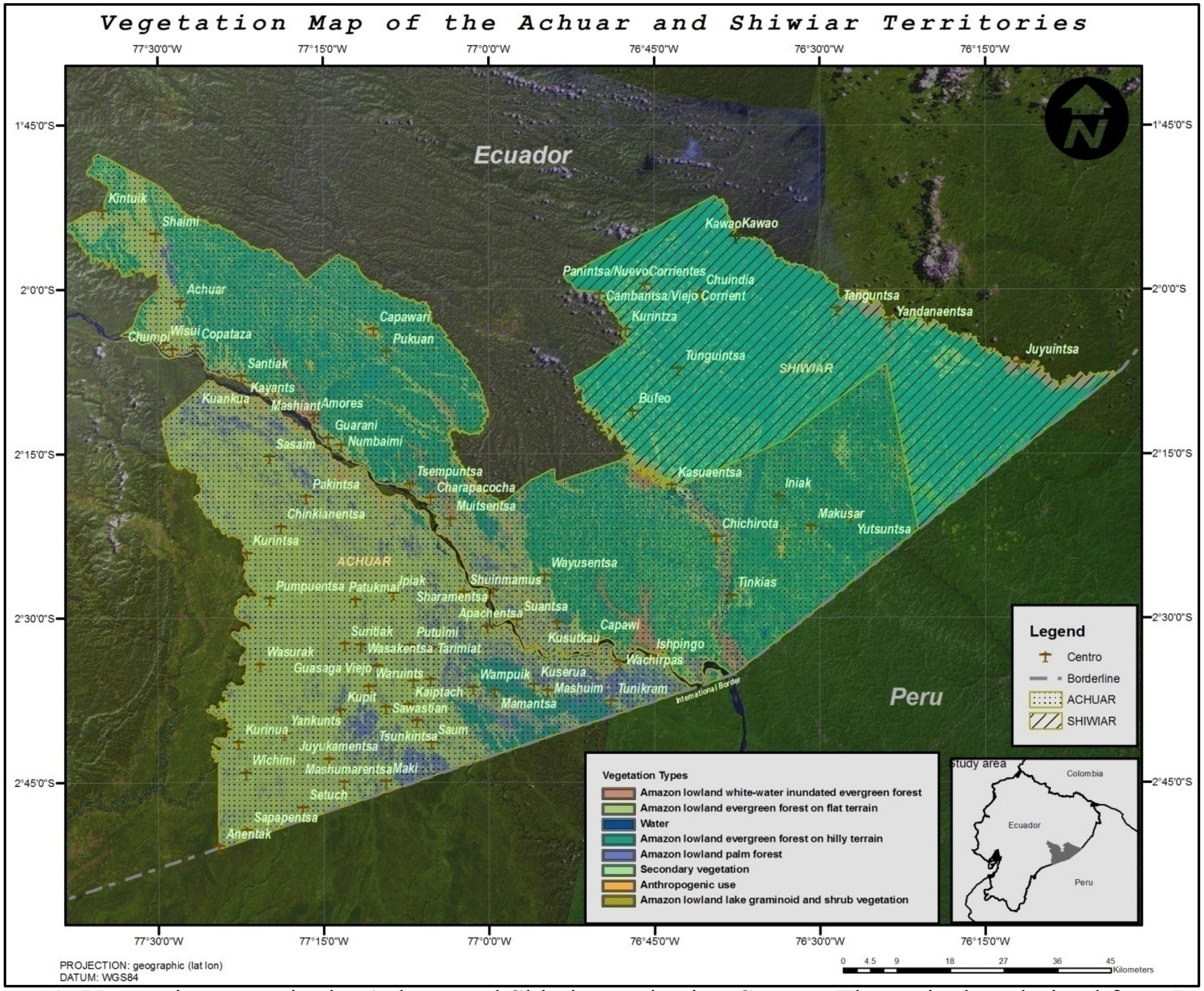


Figure 4.10: Vegetation types in the Achuar and Shiwiar territories. Source: Thematic data derived from Landsat ETM satellite data. Paths 9 and 8, Rows 61 and 62, Years 2000-2002. Classification scheme based on Sierra, 1999.

Table 4.3: Distribution of *centros* in relation to the vegetation types found in the region

	Name	Lat	Lon	Amazon lowland white-water inundated evergreen forest	Amazon lowland evergreen forest on flat terrain	Amazon lowland evergreen forest on hilly terrain
Achuar Centro	Achuar	-2.025315	-77.466961	.	X	.
	Amores	-2.1982	-77.26493	X	.	.
	Anentak	-2.853352	-77.408522	.	X	.
	Apachentsa	-2.518922	-77.003757	.	X	.
	Capawari	-2.067067	-77.175264	.	X	.
	Capawi	-2.536786	-76.843532	.	X	.
	Charapacoch	-2.323398	-77.089028	.	X	.
	Chichirota	-2.382573	-76.658581	.	X	.
	Chinkianentsa	-2.367402	-77.315576	.	X	.
	Chumpi	-2.097424	-77.478854	.	X	.
	Copataza	-2.093138	-77.444606	.	X	.
	Guarani	-2.232228	-77.243674	.	X	.
	Guasaga Viej	-2.578924	-77.170409	.	X	.
	Iniak	-2.320892	-76.563123	.	.	X
	Ipiak	-2.468721	-77.145818	.	X	.
	Ishpingo	-2.565872	-76.757338	X	.	.
	Juyukaments	-2.720632	-77.243105	.	X	.
	Kaiptach	-2.638287	-77.12268	.	X	.
	Kasuaentsa	-2.304386	-76.725043	X	.	
	Kayants	-2.17441	-77.371256	.	X	.
	Kintuik	-1.886929	-77.584383	.	X	.
	Kuankua	-2.148296	-77.356782	.	X	.
	Kuchintsa	-2.602372	-77.11565	.	X	.
	Kupit	-2.646033	-77.225504	.	X	.
	Kurintsa	-2.407609	-77.367291	.	X	.
	Kurinua	-2.695285	-77.379721	.	X	.
	Kuserua	-2.60786	-76.93296	.	X	.
	Kusutkau	-2.513187	-76.898326	.	X	.
	Maki	-2.754364	-77.157663	.	X	.
	Makusar	-2.367065	-76.514052	.	.	X
	Mamantsa	-2.616711	-76.992845	.	X	.
	Mashiant	-2.1591	-77.323891	.	X	.
	Mashuim	-2.616995	-76.912853	.	X	.
	Mashumarent	-2.756011	-77.220161	.	X	.
	Muitsentsa	-2.35528	-77.059675	.	X	.
	Numbaimi	-2.24292	-77.224115	X	.	.
	Pakintsa	-2.321922	-77.277224	.	X	.
	Patukmai	-2.478356	-77.202366	.	X	.
	Pukuan	-2.100804	-77.155608	.	.	X

Table 4.3 (cont.):

	Name	Lat	Lon	Amazon lowland white-water inundated evergreen forest	Amazon lowland evergreen forest on flat terrain	Amazon lowland evergreen forest on hilly terrain
Achuar Centro	Pumpuentsa	-2.476902	-77.33255	.	X	.
	Putuimi	-2.547617	-77.120325	.	X	.
	Santiak	-2.138157	-77.375113	.	X	.
	Sapapentsa	-2.828844	-77.366948	.	X	.
	Sasaim	-2.260724	-77.332335	.	X	.
	Saum	-2.695306	-77.088661	.	X	.
	Sawastian	-2.641819	-77.157212	.	X	.
	Setuch	-2.794576	-77.282637	.	X	.
	Shaimi	-1.921987	-77.504538	.	X	.
	Sharamentsa	-2.463325	-76.994707	.	X	.
	Shuinmamus	-2.467321	-77.039051	.	X	.
	Suantsa	-2.508304	-76.958655	.	X	.
	Surik Nuevo	-2.599856	-77.089408	.	X	.
	Suritiak	-2.545648	-77.219689	.	X	.
	Tarimiat	-2.550733	-77.08906	.	X	.
	Tinkias	-2.472181	-76.634907	.	.	X
	Tsempuntsa	-2.302744	-77.120289	.	X	.
	Tsunkintsa	-2.662293	-77.11054	.	X	.
	Tunikram	-2.633202	-76.81717	.	X	.
	Wachirpas	-2.572508	-76.804032	X	.	.
	Wampuik	-2.611888	-77.024985	X	.	.
	Waruints	-2.610249	-77.182758	X	.	.
	Wasakentsa	-2.546758	-77.194893	.	X	.
	Wasurak	-2.577148	-77.346605	.	X	.
	Wayusentsa	-2.441422	-76.916872	.	.	X
	Wichimi	-2.74173	-77.368573	.	X	.
	Wisui	-2.087876	-77.492089	.	X	.
	Yankunts	-2.681664	-77.31093	.	X	.
	Yutsuntsa	-2.351454	-76.455133	.	.	X
Shiwiar Centro	Bufeo	-2.191863	-76.784327	.	.	X
	Cambantsa/V	-2.012843	-76.833811	.	.	X
	Chuindia	-2.011689	-76.682078	.	.	X
	Juyuintsa	-2.117423	-76.199406	X	.	.
	Kawao	-1.925321	-76.12823	X	.	.
	Kurintza	-2.067276	-76.794563	.	.	X
	Panintsa/Nue	-1.998568	-76.765964	.	.	X
	Tanguntsa	-2.035663	-76.475212	X	.	.
	Tunguintsa	-2.126977	-76.714534	.	.	X
	Yandanaents	-2.053146	-76.394491	X	.	.

located far away from a river. In fact, these swampy areas are depressions with impermeable clayey bottom floors where water accumulates. Usually, the soils are Tropofibrist, and very rich in organic matter, which supports the growth of hydromorphic vegetation, where the *morete* palm dominates. These areas correspond to the ‘Amazon lowland palm forest’ category and belong to the riverine environment.

The Andes play a determinant role in modifying the general atmospheric circulation of the low inter-tropical pressures, by maintaining dense masses of humid air on the east flank of the PRBEA. The increase of temperatures and the decrease in precipitation progress in an inverse and regular fashion along an altitudinal axis. As elevation in the Achuar territory decreases towards the east from 500 masl to less than 200 masl, the average annual temperature increases from 20.3 ° to 23.9 °. Mean annual temperature in the whole region oscillates between 24 and 25 °C. Daily mean minimum annual temperature varies between 19 and 20 °C, while a maximum temperature oscillates between 29.8 and 31 °C. Relative humidity varies less, however it tends to decrease during the hottest months (85 percent) and increase during the cooler months (90 percent). There are two seasons, not markedly different in terms of temperature, but unalike in relation to precipitation regimes. The rainy season appears between March and July, whereas precipitation is less between September and February, with a noticeable decrease in December. August is a transitional month and can either prolong the rainy season, or inaugurate an earlier dry season (Descola, 1994).

4. The Shiwiar and their current territorial occupancy

The Shiwiar experienced a similar organizational process like the one that took place with the Achuar. In December of 1999, Shiwiar was officially recognized as a nationality in the seventh congress of the *Confederación de Nacionalidades Indígenas del Ecuador* (CONAIE). Originally the Shiwiar created the *Organización the la Nación Shiwiar de Pastaza del Ecuador* (ONSHIPAE), but later changed the name to *Nacionalidad Shiwiar del Ecuador* (NASHIE). Currently, NASHIE represents 1,200 Shiwiar who are distributed in nine *centros* (NASHIE, 2006). The annual population growth rate among the Shiwiar is approximately 5.6 percent. Two *centros*, Bufeo and Kurintza, contain more than 50 percent of the total population. There are four main Shiwiar communities in Peru with a total population of approximately 1,200 inhabitants (La Torre López, 1998).

The Shiwiar territory in the PRBEA comprises an area of approximately 230,000 ha. Population density in NASHIE's territory is 0.54 persons / km^2. It extends between the parallels 1°50' South and 2°36' South, and between the meridians 76°52' West and 76°2' West. Elevation decreases towards the East and Southeast, ranging from 370 masl on the Northwestern side of the territory, along the Bobonaza and Corrientes Rivers, to 200 masl in the Southeast towards the Conambo River and the border with Peru (Figure 4.11). Interestingly, the word Shiwiar means "the ones on the other side" (Bolla, 2003). The Shiwiar are in fact those who live on the northern side of the Pastaza River. The Shiwiar separated from the southern Achuar in the late 1700s and settled along the Bobonaza, Corrientes, and Conambo Rivers (ibid.).

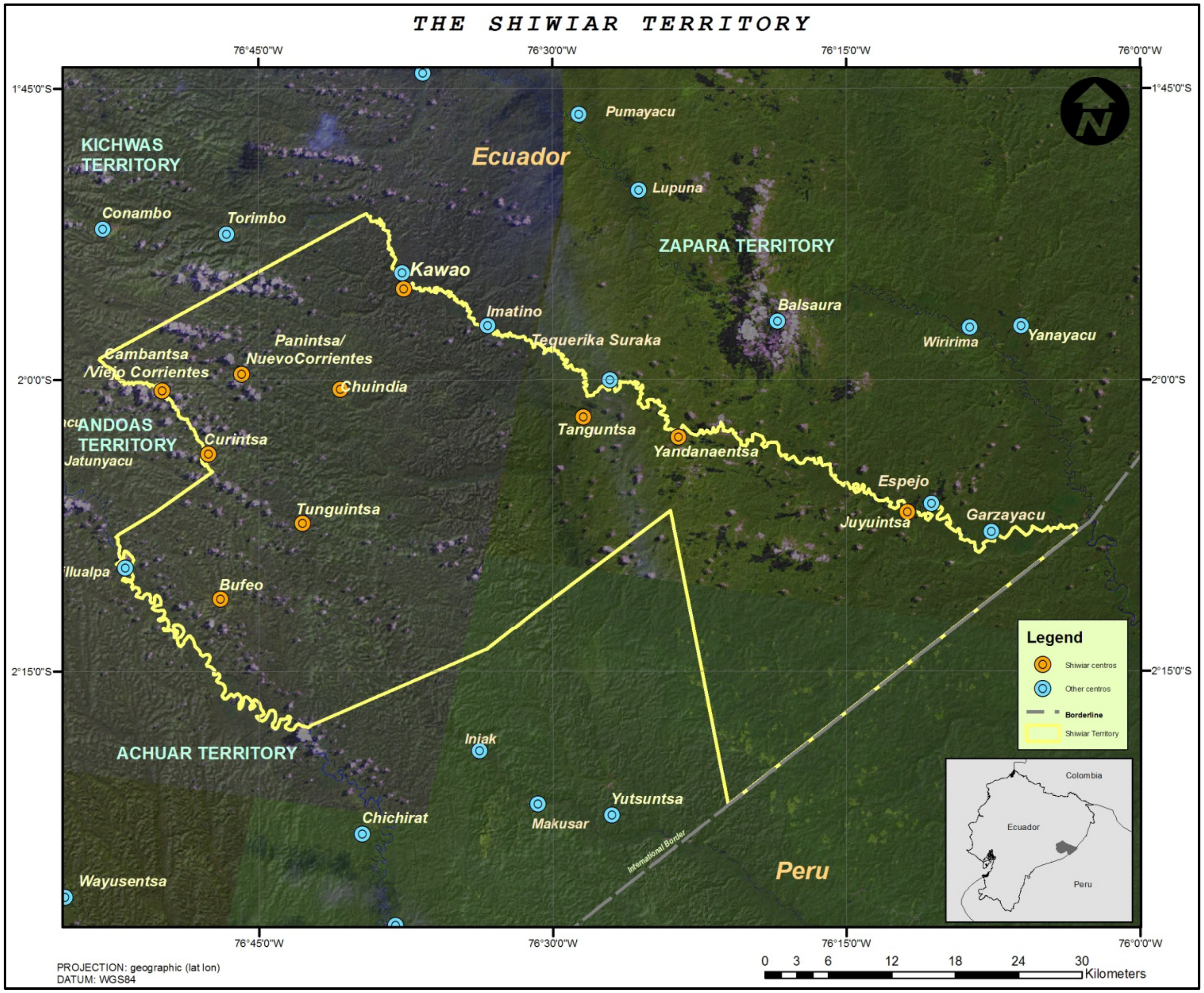


Figure 4.11: Map of the Shiwiar territory. Source: NASHIE, 2006.

The Ecuadorian Shiwiar occupy two distinctive geomorphologic features and associated ecotypes. The first one corresponds to the high inter-fluvial alluvial terraces of the Corrientes, Bobonaza, and Conambo Rivers characterized by the presence of mesas and hills. The soils are Typic or Oxic Dystropepts, generally red sandy soils with low fertility and with high aluminum content, not suited for intensive agriculture (Descola, 1994), and characterized by an imperfect drainage system. The vegetation type of these areas corresponds to the 'low land evergreen tropical forest' category (Sierra, 1999) on hilly areas. They also occupy the recent and lower alluvial terraces of the Bobonaza, Corrientes, and Conambo Rivers. These terraces are Vitrandepts, Dystrandepts, and Aquic Dystropepts soils. Despite their high fertility, low aluminum content, and rich organic matter content, the freatic layer in these areas is usually too high to allow for intensive agriculture. The vegetation type found in these areas belongs to the 'low land evergreen tropical forest floodable by white waters' category of the classification by Sierra (1999). Temperature and precipitation regimes are similar to those of the Achuar territory and typical of the equatorial Andean-Amazonian foothills.

Chapter Five

Data Collection

1. Introduction

Data collection is one of the most time-consuming and expensive, yet important tasks in any kind of geographic research. Because of the spatial scope taken in this dissertation, the study uses a range of spatially explicit methods for the creation, construction, and capture of data. These methods include the extraction and collection of data in the field and from primary and secondary sources. Primary sources include digital aerial photographs, satellite imagery, GPS measurements, and georeferenced socio-economic surveys. Secondary sources encompass topographic maps and thematic spatial information such as geomorphologic and soils maps. Building upon theoretical frameworks and up-to-date spatial and georeferenced socioeconomic data, the goal of this study is to characterize tropical lowland food production systems and examine agricultural growth. This characterization is based on the analysis of: 1) the spatial characteristics of traditional land use systems, 2) the structural characteristics of agricultural systems, and 3) the factors that explain agricultural expansion in two distinctive environments of the Amazon region: the riverine and inter-fluvial habitats; the evaluation presupposes that agricultural intensity and land use and land cover characteristics are a reflection of landholders' decisions and that these, in turn, reflect production conditions of traditional systems.

This chapter presents the methods used in this dissertation for the collection of data for the analysis of indigenous production systems in the Pastaza region. The study focuses on the Jívaro case since this group is representative of traditional indigenous populations in western Amazonia. Section Two discusses the characteristics of the sample and subsamples used in this study for the characterization of indigenous production systems. Section Three describes the methods used for the collection of data and construction of databases.

2. The sample

Godoy *et al*. (2001) suggested that an appropriate approach for analyzing resource use systems in the context of early stages of market integration would be to study two culturally comparable sets human groups living in similar cultural environments but with different socioeconomic and ecological characteristics. Similar cultural backgrounds allow normalizing for potential variation in resource use patterns. This study followed this approach and collected and analyzed data that are representative of two groups that share similar cultural backgrounds but have, to some extent, experienced different socio-economic development probably due to dissimilar ecological conditions and historical trajectories in the recent past.

Data in this study fall into two levels of aggregation or detail: the village or *centro* category (i.e. coarse resolution), and the household category (i.e. fine resolution). At the village level, data were obtained from seven lowland Jivaroan *centros*. Two of these villages, Bufeo and Kurintza, are Shiwiar. The rest, Wasakentza, Kupit, Sawastian, Tsunkintza, and Yuntsuntza, are Achuar (Figure 5.1). These villages are, in general, representative of typical occupancy settings of Amazonian lowland societies. Specifically, Yuntsuntza, Kurintza, and Bufeo are representative of *centros* that occupy

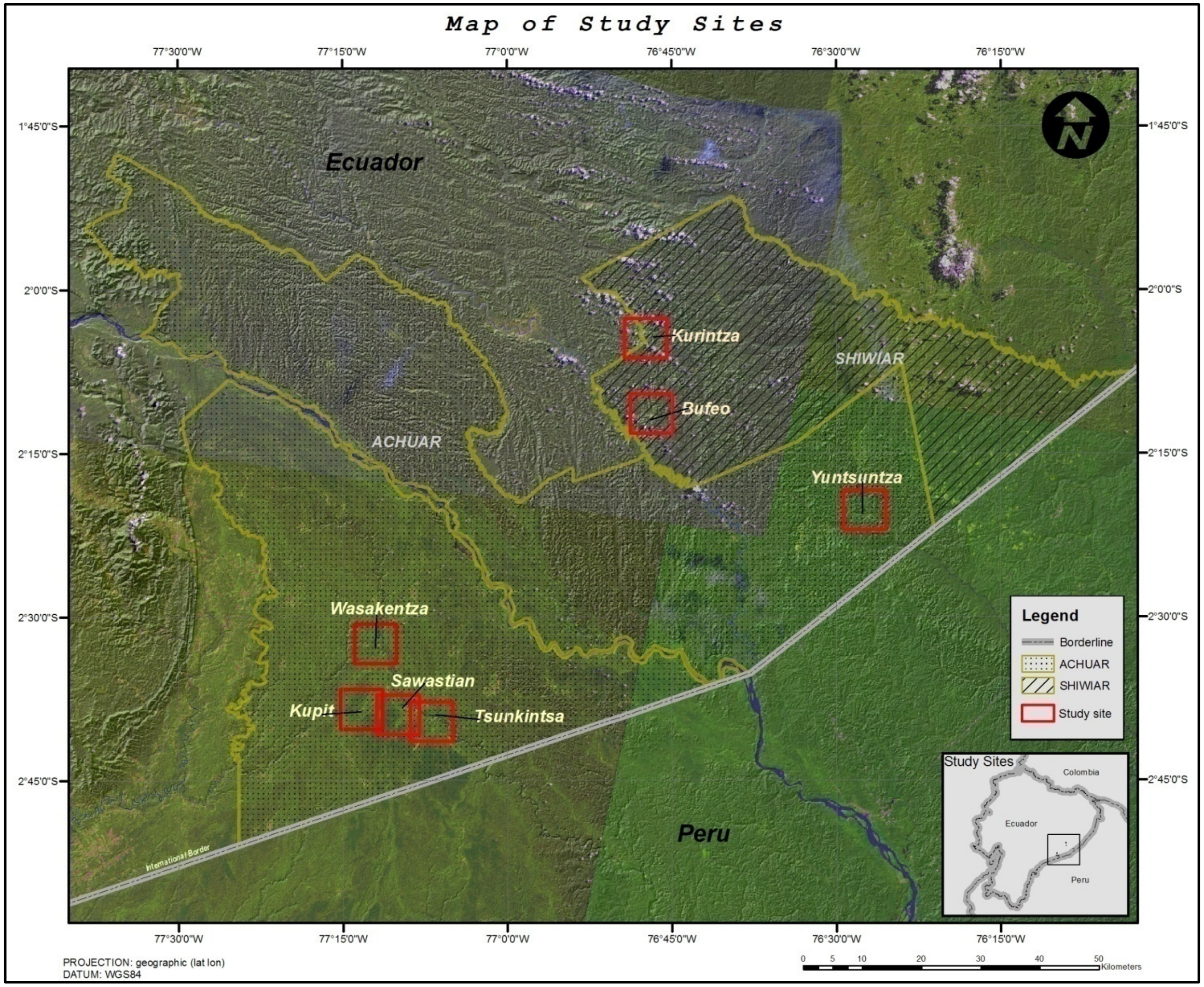


Figure 5.1: Location of the study sites in the Achuar and Shiwiar territories.

the older and high inter-fluvial alluvial terraces of the Corrientes, Bobonaza, and Conambo Rivers. Kurintza and Bufeo account for 22 percent of the Shiwiar villages and their inhabitants account for 55 percent of the total Ecuadorian Shiwiar population. Kupit, Sawastian, and Tsunkintza are representative of the *centros* that occupy the recent riverine alluvial terraces of the south of the Pastaza River. Wasakentza is a special case. Although it is considered an Achuar *centro*, most of the communal area is managed and controlled by a Catholic mission, which was established in the late 1970s by Salesian priests. In the Wasakentza study area, another *centro* called Suritiak was recently established. Although the author of this document did not conduct field work in this community, it was also mapped since it was part of Wasakentza's area of influence. The selected Achuar villages account approximately for 8 percent of all the Achuar *centros* and their inhabitants represent 6 percent of the total Achuar population. Table 5.1 summarizes information about year of establishment, total number of households, number of families that participated in this study, and the ecological region of the sample *centros*. At the household level, data for analysis were obtained from a series of datasets. Spatial data were obtained from a set of 101 households. This set can be divided in two. The first set (N=55) is representative of the northern area of the PRBEA. The second set (N = 46) is representative of households found in the southern PRBEA. These datasets were used for the spatial characterization of traditional agricultural systems. Socio-economic and demographic attributes were linked to a set of 55 households. From this set, 30 domestic units belong to the northern PRBEA and 25 to the southern PRBEA. This dataset was used in the analysis of agricultural extensification and intensification.

Table 5.1: Shiwiar and Achuar communities that participated in the 2006 land use study.

Centro	Territory	Formation Year	Total Number of Families	Number of Families that participated in the study	Ecological region
Bufeo	Shiwiar	1975	31	19	Older high inter-fluvial alluvial terraces. North of the Pastaza River
Kurintza	Shiwiar	1979	23	23	Older high inter-fluvial alluvial terraces. North of the Pastaza River
Yuntsuntza	Achuar	1989	13	13	Older high inter-fluvial alluvial terraces. North of the Pastaza River
Wasakentza	Achuar	1978	5	4	Recent lower alluvial terraces. South of the Pastaza River
Kupit	Achuar	1998	7	6	Recent lower alluvial terraces. South of the Pastaza River
Sawastian	Achuar	1996	12	12	Recent lower alluvial terraces. South of the Pastaza River
Tsunkintza	Achuar	1997	11	11	Recent lower alluvial terraces. South of the Pastaza River

3. Methods used in the process of data collection

Household level data for this study were obtained from four sources: 1) Georeferenced aerial digital photos and video, 2) short questionnaires conducted by the author on land ownership, management practices, and cultivars, 3) socioeconomic interviews conducted by members of EcoCiencia, a local nongovernmental organization, and the Center for Environmental Research in Latin America of the University of Texas at Austin , and 4) official cartographic data on rivers and terrain conditions. Figure 5.2 shows a flowchart of the data management and collection procedure.

Spatial data on agriculture, pasture, and housing areas of the 101 households were derived from georeferenced digital videography and photography and verified in the field with GPS and direct observations. Georeferenced digital videography and photography were acquired between October 2005 and January 2006 using a digital still camera and a camcorder mounted on an aircraft. An area of 6 x 6 km was covered for each community with 32 flight lines separated by 180 m intervals. Flyovers were done at a flight height of 500 m above the ground. GPS and a video mapping system were used for the collection of positional information of aerial videos and digital still images (Figure 5.3). A GPS base station was established in Puyo, the capital city of the Pastaza Province and located approximately 150 km away from the sample communities. The station was placed at the following coordinates: -1.48465921 latitude, -78.00311344 longitude, and 958.9042 m above sea level. Images were geometrically corrected and rectified using differentially corrected GPS data and a third order polynomial transformation in a GIS. Seven preliminary photomosaics of residential, agricultural, and pasture areas were created with

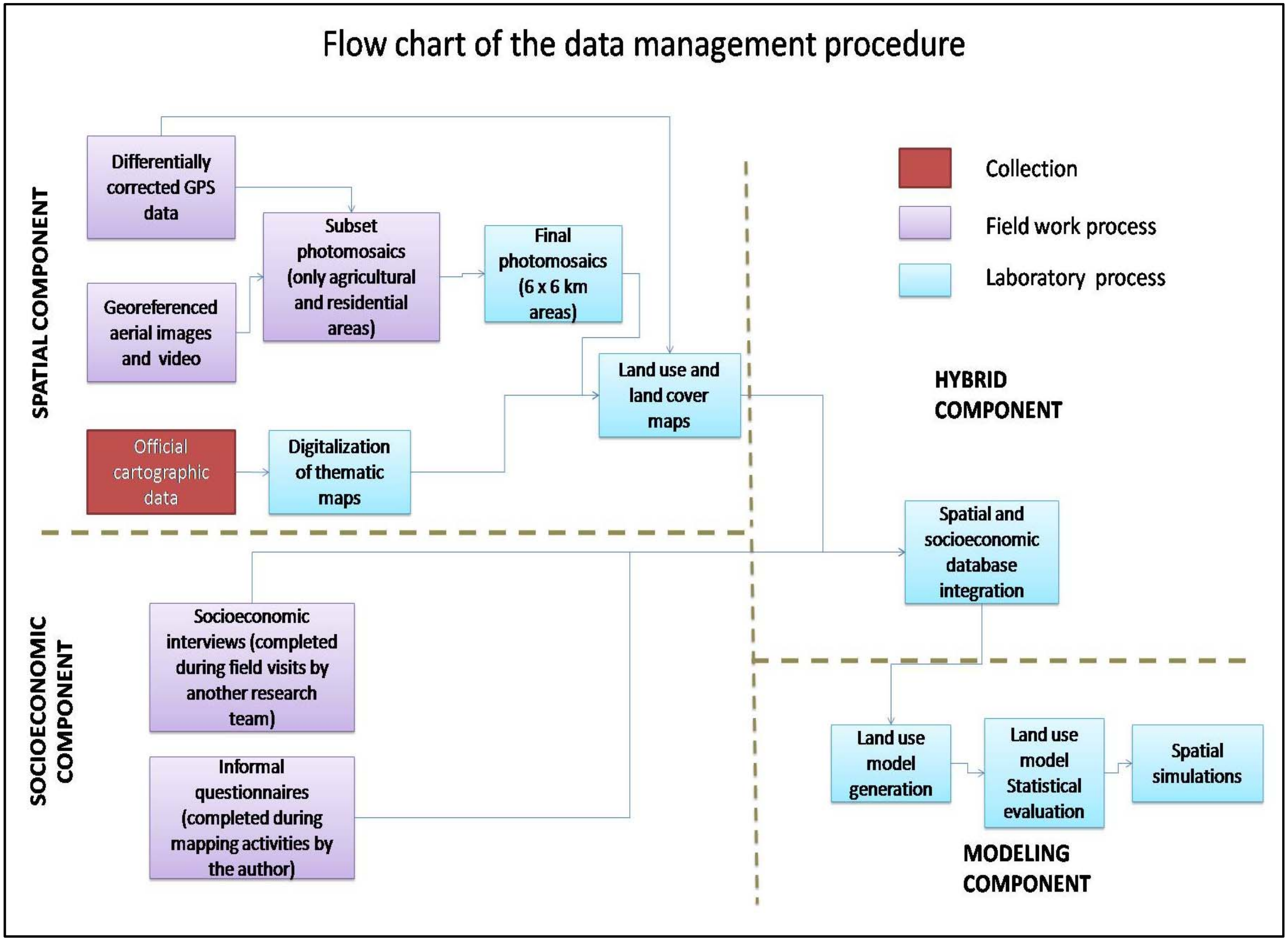


Figure 5.2: Flowchart of the data management procedure. In this study, the process of data collection and management has four main components: spatial, socioeconomic, hybrid, and modeling components.

a spatial resolution of 0.10 meters. The root-mean square errors (RMSE) of the photomosaics ranged between 10 and 15 m. These mosaics were used in the field in a GIS environment for the interpretation of land use and land cover units.

Preliminary field visits to the Jívaro territory were done between 2003 and 2005. These visits enabled the research team to establish important personal connections with key local institutions, gain an overall sense of the dimensions of the region and localities, collect preliminary spatial and socioeconomic data, and generate preliminary hypotheses. Quantitative information on resource use was collected during four field visits in 2006. Each visit consisted of periods of approximately three weeks each. Field work consisted of visiting every household of each of the seven *centros*. It is important to note that approximately 13 percent of the total number of households was not included in the sample either because the family did not want to participate in the study or the members were not present during the survey. Each management unit was composed of a residential, agricultural and pasture, and hunting areas. Location and composition information was recorded for each household.

A GPS device was used to map the extent and location of each agricultural and pasture areas. The mapping was done by walking along the boundaries of the agricultural plots or *chacras* and pastures, and by collecting GPS waypoints with information on agricultural products (Figure 5.4). At least one main hunting trail was mapped per family. Hunting trails were mapped with the aid of GPS, and by following hunters along their most common hunting routes (Figure 5.5). Information on the location where the hunt took place and games species was recorded to measure how far hunters moved away from

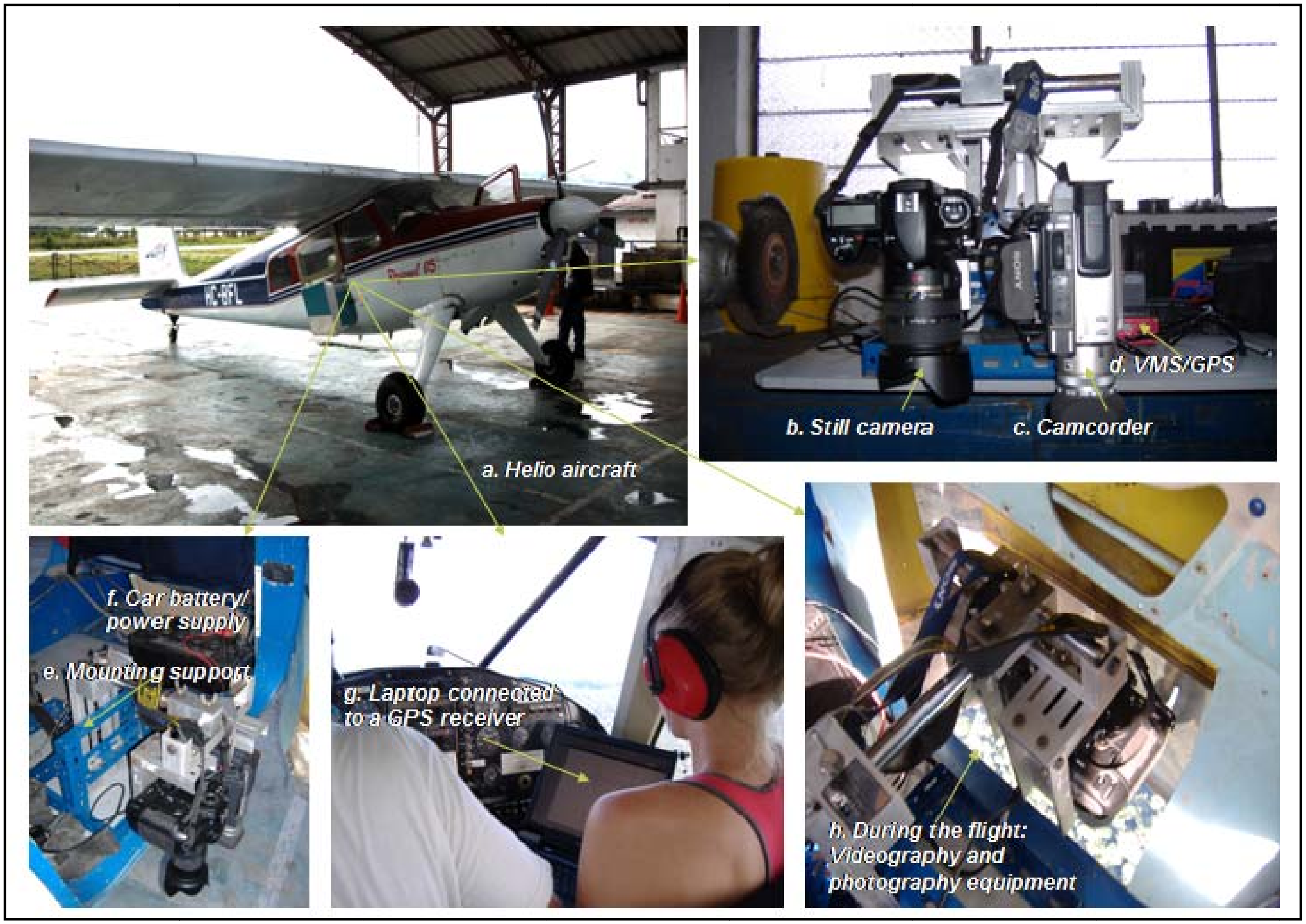


Figure 5.3: Videography and photography equipment used for the collection of georeferenced aerial images: a) A Helio-type aircraft with a customized door used for the collection of remotely sensed data, b) still camera, c) camcorder, d)Video Mapping System (VMS) and GPS used to assign positional information to the video and still images, e) mounting support, f) car battery used for power supply, g) laptop connected to a GPS used to locate flight lines, h) Photo from the inside of the aircraft during a flight.

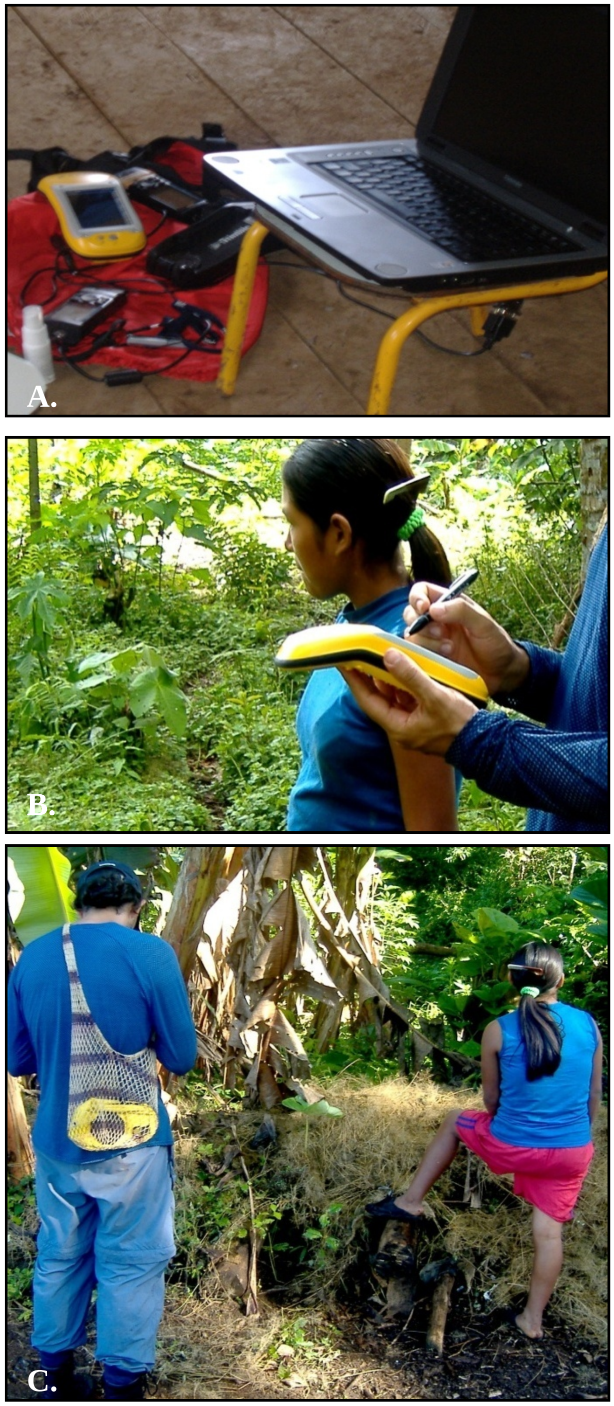


Figure 5.4: Members of the research team mapped agricultural plots via GPS. A) GPS and laptop used for *in-situ* mapping of agricultural plots and management areas. B) A member of the research team collects information about ownership of a plot in a GPS. C) A member of the research team maps the border of an agricultural plot. Photos by R. Beard.

Figure 5.5: Members of the research team followed hunters with GPS receivers to map the location of hunting trails, areas, and species. A) Hunting trail crosses an old-growth forest stand. B) The hunting trail crosses a patch of secondary forest. Photos by S. López.

the main hunting trail to look for game. In addition, short informal questionnaires on crop cycles and agricultural practices were completed during the mapping activities. Demographic and socioeconomic information (i.e. family size, age, gender, yields of production, types of products, education level. etc) was collected during the same time by another research team from the *Fundación Ecuatoriana de Estudios Ecológicos* (EcoCiencia). This information was linked to the attributes of 55 of the 101 households. After the field visits, photomosaics were completed for the seven selected communities (Figures 5.6 to 5.12). With the aid of differentially corrected ground control points, the mosaics RMSE were reduced to approximately 5 m. The final mosaics were used for the interpretation of land use and land cover of 101 domestic units and the surrounding environments. The interpretation was made via screen digitizing in a GIS environment and verified using the information obtained during field visits. Two levels of information were derived from the aerial digital mosaics. The first level includes eleven general land cover and land use categories. Each class represents distinctive dominant land use conditions recognized by landholders: 1) lowland evergreen tropical forest on flat and hilly terrain, 2) riverine evergreen forest inundated by white waters, 3) herbaceous vegetation, 4) inundated palm forest, 5) secondary vegetation, 6) water, 7) polyculture agriculture, 8) monoculture agriculture, 9) pasture, 10) infrastructure, and 11) residential.

The first four classes include primary forests and natural vegetation with little or no human intervention. Secondary vegetation refers to both areas of dense undergrowth with some emergent trees and to vegetation that develops after the clearing of forests. This category also includes old pastures and agricultural areas that have been left

Figure 5.6: RGB mosaic of the Achuar *centro* Yuntsuntza

Figure 5.7: RGB mosaic of the Achuar *centro* Tsunkintza

Figure 5.8: RGB mosaic of the Achuar *centro* Sawastian

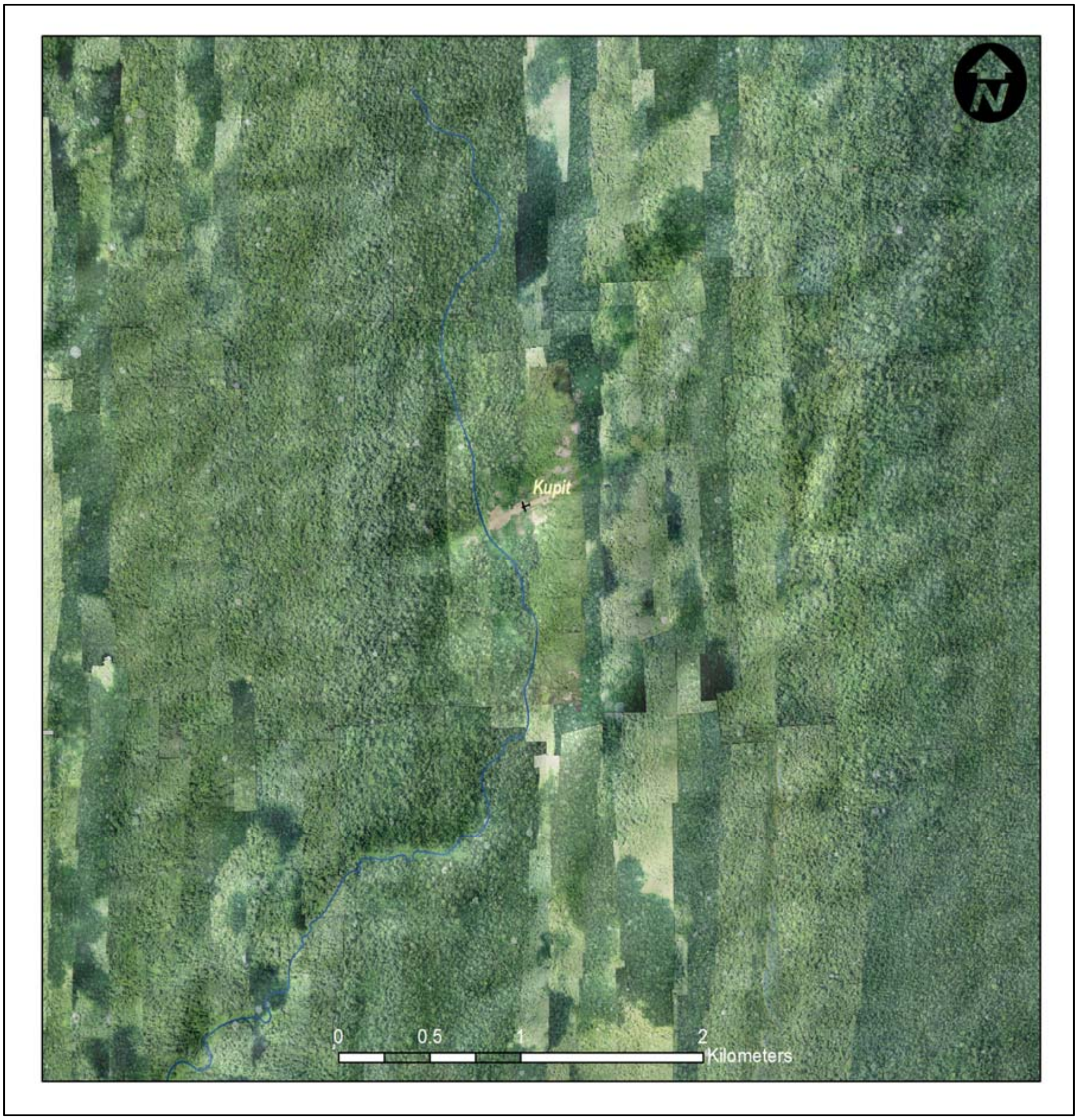


Figure 5.9: RGB mosaic of the Achuar *centro* Kupit

Figure 5.10: RGB mosaic of the Achuar *centros* Wasakentza and Suritiak

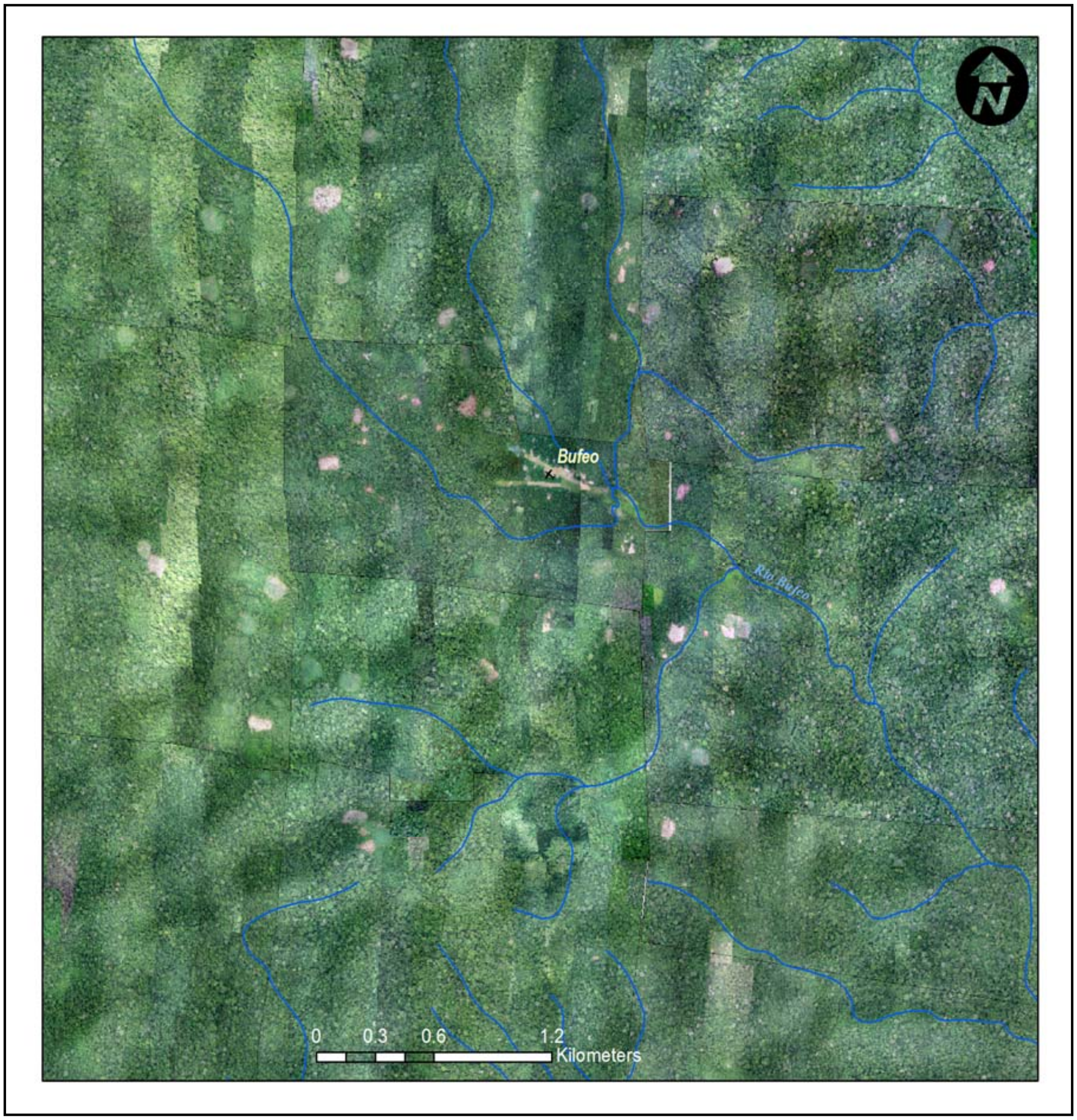


Figure 5.11: RGB mosaic of the Shiwiar *centro* Bufeo

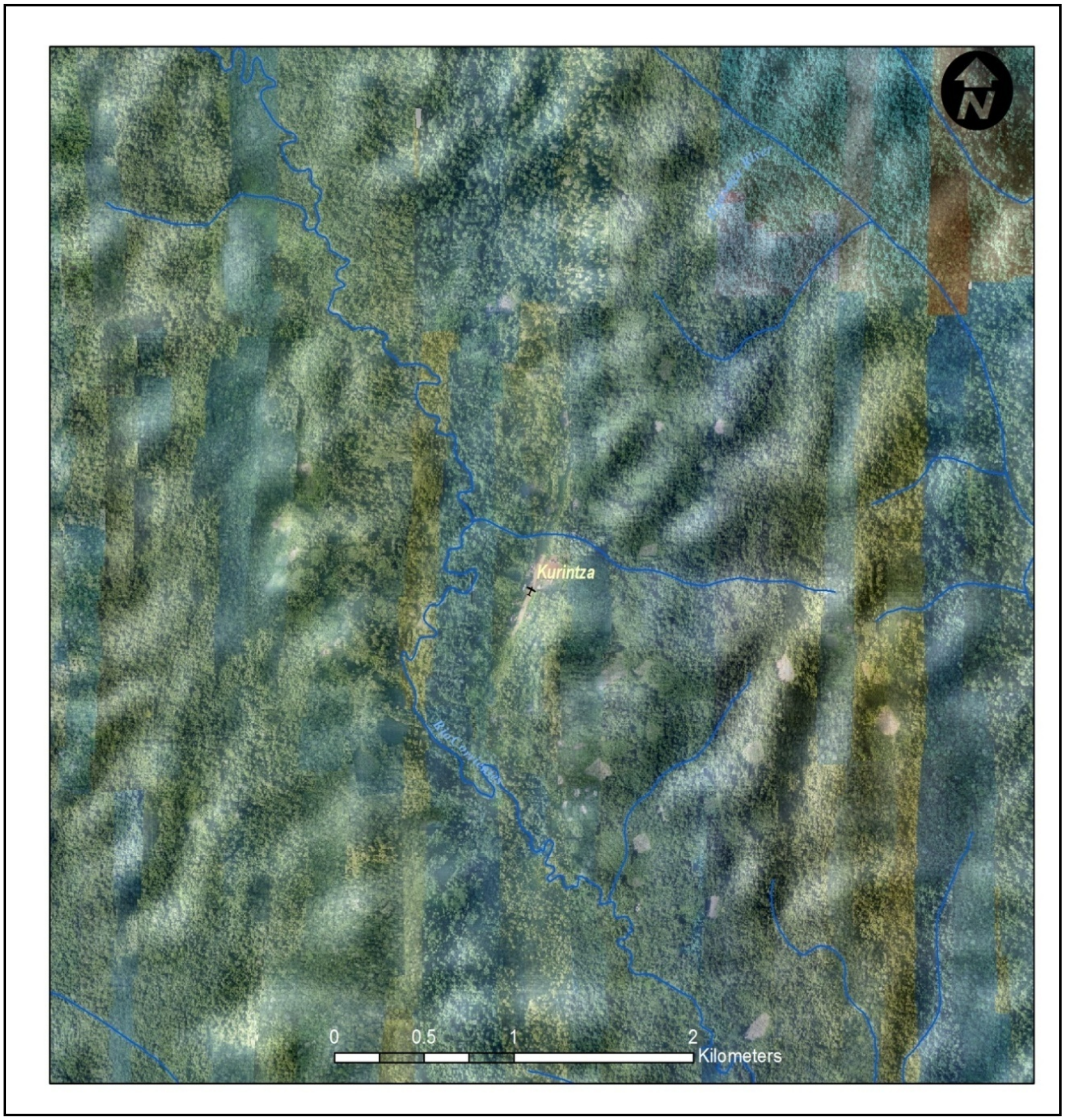


Figure 5.12: RGB mosaic of the Shiwiar *centro* Kurintza

abandoned for a decade or two. The distinction between monoculture and polyculture agriculture is necessary to differentiate two types of agricultural practices. Polyculture agriculture refers to those *chacras* in which more than one product is cultivated. Monoculture agriculture refers to single-crop agriculture or plantations. Water refers to any type of water body such as lakes or rivers. Pasture corresponds to pasturelands used for cattle ranching that can be either natural or planted. The infrastructure class includes transportation, communication, education, and any other type of communal asset. The residential class encompasses houses and the immediate open space next to them not used for agriculture. Hunting and foraging areas consist of secondary and primary forest used for collecting forest products and hunting. These areas were delimited by applying a buffer of 150 meters to each side of the hunting trails mapped using the GPS. This threshold is roughly the average distance from the main trail to where hunters go to look for game.

The second level presents a more detailed description of the features of the *chacras* and residential areas. While land cover classes remained the same, agricultural and residential areas were split into smaller polygons representing the dominant use of that polygon. In those cases where more than one agricultural product was found but the boundaries were not clearly defined, the ratio between the dominant product and the secondary product was expressed as a new class. For example, if plantain was the dominant product (i.e. > 50% of the polygon), and cacao plants occupied a smaller area in the same polygon, the relationship was expressed by the category “Plantain / Cacao”. If cacao dominated the polygon, the class name changed to “Cacao / Plantain” (Figure

5.13). This detailed categorization helped to separate farming areas into commercial and subsistence agriculture. Residential areas were split into house and residential land. House is the polygon representing the actual house and residential land is the cleared land immediately next to the house not necessarily used for agriculture but which could contain some ornamental plants or fruit trees. The database also includes information about land ownership.

Topographic and soils maps were obtained from the Ecuadorian Military Geographic Institute (IGM) and the Environmental Ministry and then digitized to characterize terrain conditions. Elevation contour lines were digitized for each community. Digital elevation models with a resolution of 25 m were created for each study site using the Topogrid application in ArcInfo WorkStation. Slope and soil information was then integrated into the spatial database to characterize terrain conditions in each domestic management area.

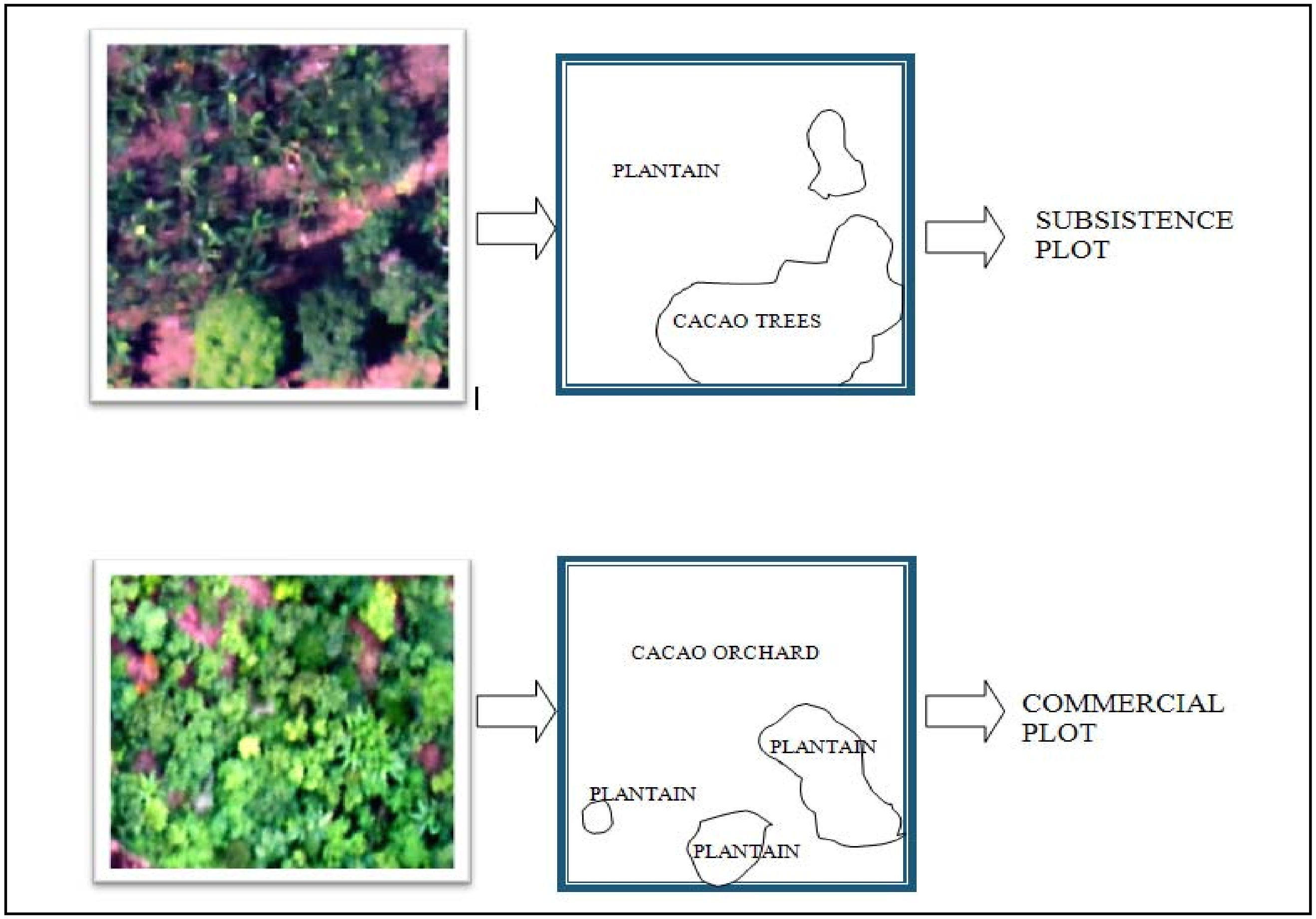


Figure 5.13: Interpretation of two agricultural plots. A) A subsistence agricultural plot where plantain occupies more than 50% of the area. B) A commercial plot where cacao occupies more than 50% of the area.

Chapter Six

Methodological Approaches for the Analysis of Indigenous Production Systems

1. Introduction

The methods used in this study for processing and analysis of data draw upon the questions and hypotheses stated at the outset of this document. The information collected in this study was processed within a geographic information system (GIS) framework, linking household survey data and land use and land cover information collected in the field via global positioning systems (GPS) and derived from the visual interpretation of georeferenced aerial digital photomosaics . This combination of field-based study with remote sensing provides a powerful methodology deployed with increasing frequency to investigate processes of environmental change (Liverman *et al.,* 1998; Walsh & Crews-Meyer, 2002; Fox *et al.,* 2002; Gutman *et al.* 2004; Boucek & Moran, 2004; Entwisle & Stern, 2005).

The analysis of data in this dissertation involves a series of approaches ranging from descriptive maps to statistical models that attempt to explain changes in landscape patterns due to variations in social organization and ecological/spatial conditions. This chapter focuses specifically on the application and implementation of these approaches for the analysis of traditional production systems in the PRBEA. Section Two presents the methodology used in the descriptive evaluation of the spatial configuration of current indigenous production systems. Section Three discusses the methodology used in the analytical evaluation of indigenous production with emphasis on the agricultural component.

2. Descriptive analysis of traditional production systems

The first two general research questions of this study refer to the spatial and structural characteristics of food production systems in tropical lowlands (i.e. what and where people produce, how much, and how often). It was expected that ecological and demographic differences between regions of the Amazon Basin affect the way people allocate resources and also plays an important role in defining the characteristics of the production system in use. People adjust their resource management practices to fit particular biophysical (Brookfield & Padoch, 1994; Gunderson, Holling, & Light, 1995; Berkes, Colding, & Folke, 2000) and demographic conditions (Brookefield & Brown, 1963; Boserup, 1965; Turner et al, 1977; Allen, 2001). This premise implies that the structural attributes of production systems, such as the fallow and cropping periods or hunting cycles, may present local variations even if the technological, cultural, and socioeconomic attributes of the people who employ these systems are similar. Further, the premise presupposes differences in cultivation intensity and in the spatial patterns that result from the application of particular management practices. Some tropical lowland areas may be characterized by more intensive systems and other areas by more extensive ones. Each type of system may show a distinctive footprint that may help to understand the processes associated with the system in use.

Traditional production systems in the PRBEA were characterized using two complementary approaches: 1) a descriptive assessment of the spatial dimension of the components of traditional production systems, and 2) a comparative estimation of the extent and intensity of agriculture in the northern and southern regions of the PRBEA. The first approach draws on the analysis of the distribution and spatial characteristics of land use zones (i.e. residential, agricultural/cattle-raising, and hunting zones) within the context of the transition from nomadic-dispersed settlements to permanent-nucleic settlements. The analysis is based on t-test comparisons to establish differences and similarities between the northern and southern PRBEA. This kind of analysis is used for the characterization of spatial dimension of production systems in the inter-fluvial and riverine environments. The second approach draws on the analysis of the structural characteristics of agricultural production. A simple analysis of labor efficiency defined in this study as the average cultivated area per person was used to characterize the extent of agriculture. Two measurements of agricultural intensity were used to characterize the level of production: 1) annual agricultural yield per unit of area, and 2) the ratio between time of production and fallow period. Agricultural yield per unit of area was obtained from the socio-economic surveys by summing the amount in kg of the main subsistence products (i.e. manioc and plantain) collected in one week. This number was extrapolated to one year to obtain a yearly consumption yield per household and then divided by the total subsistence agricultural area in ha obtained from the interpretation of the aerial photographs. The ratio between time of production and fallow period was calculated based on information obtained from questionnaires during the mapping activities. For example, if the crop/fallow ratio of a particular management area was 1:10 (i.e. one year of production and ten years of fallow) the percentage of agricultural intensity was 1/11 or nine percent. If the ratio was 2:10, the level of intensity was 1/6 or seventeen percent.

Groups that maintain lengthy periods of cultivation and short periods of fallow, such as a 10:1 cycle, are considered to have a degree of intensity of one hundred percent. This assumption is necessary because most scholars refer to such systems as permanent or annual cultivation. Again, the two-sample t test procedure was used to compare means of the crop/fallow ratios and measurements of agricultural output per unit of area between the two regions of the PRBEA.

3. Modeling indigenous land use systems

The analysis of the extent and intensity of agriculture provides insights on the structural characteristics of the indigenous production. However, it limits the understanding of the effects of endogenous and exogenous factors that affect those characteristics. The third general research question stimulates the search for connections between agricultural growth and spatial and non-spatial factors that affect how people allocate land. The analysis of the factors that determine the conversion from forest to agriculture in indigenous tropical lowlands was made using two complementary approaches. The first draws on the analysis of the household's life cycle and focuses mainly on the relationships between demographic conditions of households, such as the age of the head of the household and the ratio of producers to consumers to investigate their influence on the demand for land resources. The second approach uses a combination of bivariate and multivariate analyses to evaluate a series of explanatory variables to predict the extent of agricultural land use and the probability of an area for conversion to agriculture. The results of these analyses are the basis for the prediction of agricultural expansion by means of a spatially explicit land use model.

3.1 The household's life cycle approach

Chayanovian theory may help provide further insights on the effects of household demographics on the extent of cultivated land. This theory suggests that the composition of the household developmental cycle, proxied by variables such as the number of consumers relative to the number of producers (i.e. the dependency ratio) dictates the extent of farmed land. The amount of cultivated land varies according to household needs. Higher rates of agricultural growth occur at early stages of household settlement. As households age, these rates decrease since there is already enough land put into production that helps to satisfy the nutritional needs of the family. As households age, some land is taken out of production as children get married and abandon the household. Parents may redistribute land among their children or simply produce less, in which case the extent of the household's farmed area decreases. These effects might be most evident in sites that are physically isolated, and therefore separated from exogenous factors such as markets or technological innovations. In periods of low household labor availability (e.g., early in the family life cycle when couples have young children, as well as later after adult children marry and move away), households tend to adopt agricultural practices suitable to the relatively low availability of household labor, such as clearing forest mainly to grow annual food crops or switching land use to cattle. In periods of higher availability of labor, as is the case of the presence of teenage children or young adults, household members may engage in extensive or labor-efficient agricultural practices to sustain the household's demand for food. Hence, the influence of consumer demands may force a household to produce in strict accordance with growing or diminishing number of consumers.

The relationship between household characteristics and farmed area was assessed using a sample of 55 domestic units. For this evaluation, the study focused on the household's life cycle and used the dependency ratio and household age to explain variations in farmed land. Households were grouped by age groups and an average amount of cultivated land was calculated per group to depict the relationship between household age and accumulated cultivation land. The dependency ratio was calculated by adding the number of consumers (i.e. household members $\leq$ 14 years old plus household members $\geq$ 64 years old), dividing it by the number of producers (i.e. 14 years old < household member < 64 years old), and obtaining an average value for each age group. It was expected that the relationship between consumers and producers will determine the amount of land demanded by a household. This relationship can be depicted by a linear model of the form:

$$Y = \alpha X + b \tag{1}$$

Where Y is the average farmed land by each age group. X is the dependency ratio. α is the slope of the equation and b is the intercept. It is expected that farmed land is positively correlated with the dependency ratio.

3.2 Mapping the probability of agricultural land use

Chayanovian theory contributes to the understanding of the effects of household demographics and family composition on farmed land, but it adds little explanation about other factors (i.e. exogenous to the household) that influence decisions on land allocation. Overall landscape variation is, in the end, the combinatory effect of multiple factors, and multiple households interacting with each other and the environment. Agricultural expansion at coarser levels of aggregation is expected to be associated not only with population pressure but also with the spatial context wherein agricultural production occurs. Differently from population dynamics, population pressure is defined as the ratio between family size and its principal cultivated area. The spatial context of production refers to the topological relationships between geographic features (e.g. cultivation fields, houses, or infrastructure) and to the biophysical characteristics of the natural setting.

Terrain conditions such as slope and soil quality affect the decision of converting an area to agriculture or leaving it as forest. Slope can be seen as a relative measure of on-site conversion costs. Areas with steep slopes increase the costs of conversion from forest to agricultural land use and therefore make steep areas less attractive than flat areas. Soil can be understood as a qualitative measurement of the existing ecological conditions. Landholders usually prefer areas with good soils since they are expected to have higher productivity and remain fertile for longer periods, which will reduce the need for labor input and clearing more land. However, if competition for land occurs as populations increase, landholders may be forced to clear larger areas with less suitable soils for agriculture or reduce fallow periods in old agricultural plots to increase production.

The time of travelling from agricultural plots to residential areas is also expected to influence the conversion likelihood from forest to agriculture. Travel time can be seen as a relative measurement of the costs of moving, independent from the costs of conversion. Lower travel times, such as those to agricultural areas close to residential areas, result in lower costs and greater incentives for land clearing for cultivation. Nevertheless, if cultivable land is limited, people may decide to walk longer distances despite the costs in order to provide for the household.

Distance of an area to accessibility infrastructure such as a landing strip may also influence people's decisions land use. Distance to landing strips can be interpreted as the cost of access to communal service areas. Soon after a landing strip is created and the village is settled, agricultural areas are most likely to be established in areas close to landing strips to minimize travelling costs to service areas (i.e. medical centers, communal houses, sport infrastructure, etc). However, since areas around landing strips were probably converted to agriculture soon after people settled, it is expected that areas farther away from a landing strip may be used after several years of settlement occupancy. Further, competition for land may be higher in areas close to the landing strip which could degenerate in conflict among households. This could stimulate longer trips in the search for available land in order to avoid social clashes.

The proximity to existing agricultural areas may also help to determine the conversion likelihood of a forest area into agriculture. Shorter distances to agricultural units may result in higher probabilities of conversion since placing a plot closer to existing ones may reduce overall travel time and transportation costs (i.e. closer agricultural areas reduce the costs of travelling) or conversion costs (i.e. slope conditions may be similar in areas closer to each other).

The first step in the analysis of the factors that determine the demand for agricultural resources was to evaluate the relationships, albeit bivariate, between the extent of agriculture and a series of potential explanatory variables. This kind of analysis is useful to show non-linearities and threshold effects that should be considered for formulating variables for the examination of the extent and occurrence of agricultural land use. The next step was to analyze the combinatory effect of the most important factors that explain the occurrence of cultivation. This can be done using a multivariate statistical approach that allows determining the contribution of each factor to the overall level of landscape variation. In this case, logistic multiple regression (LMR) was used to predict the conversion probability of an area to agricultural land use.

The analysis units for the estimation of the LMR coefficients were obtained by dividing the seven 6 x 6 km study areas into cells with a resolution of 20 m, which is approximately a fourth of the minimum mapped agricultural area. A convex polygon containing all the line segments of the outmost agricultural polygons was traced for six of the seven communities in a GIS to limit the area under agricultural production. These polygons were used to clip each 6 x 6 km study site. Although spatial autocorrelation is a significant concern, it can be minimized by avoiding the omission of key variables. Even when all relevant variables are included in the model, error terms (both heteroskedastic error and spatial dependence in the error term) may remain spatially autocorrelated, which will most likely cause inefficient estimates. Nevertheless, the advantage in LMR is that the parameter estimates will still remained unbiased (Nelson & Hellerstein, 1997). Two approaches were followed to minimize the problem of spatial autocorrelation: 1) the coding of cells to identify neighboring and non-neighboring cells, and 2) a stratified random procedure to select 80 percent (N= 2,948 cells) marked as non-neighbors in order to reduce the probability of selecting adjacent cells for parameter estimation. Selecting random observations decreases the probability of selecting adjacent or close, and therefore spatially auto-correlated, observations. These cells were used for parameter estimation and the other 20 percent were used to validate the statistical model.

For every sample observation or cell, the values of the dependent and independent variables were recorded. Several spatially explicit variables, generated using standard GIS analysis tools, were evaluated as determinants of agricultural expansion, and therefore influencing decisions on land management. LMR was performed using the Binary Logistic Regression function in the SPSS software. The LMR model is specified as follows:

$$\text{Logit}\,(P_{a\,(x,\,y)}) = \ln\,[P_{a(x,\,y)} \,/\, (1 - P_{a\,(x,\,y)})\,] = L_{a\,(x,\,y)} \tag{2}$$

$$L_{a\,(x,\,y)} = \alpha + \beta_1\text{Soil} + \beta_2\text{FamDen} + \beta_3\text{DstLdn} + \beta_4\text{NstNbr} + \beta_5\text{Slope} + \beta_6\text{CstDstHo} \tag{3}$$

Where $L_{a\,(x,\,y)}$ is the logit model can be thought of as the "propensity towards" agricultural land use at a location with coordinates (X, Y). α is the intercept and β_n are the regression coefficients that represent how variations of the predictor affect the probability of the presence or absence of agricultural land use. Soil is a dummy variable for the presence of "adequate" and "inadequate" soils for agriculture based on the classification system used by Custode (1983). FamDen is the total number of family members of a household divided by the number of cells of the principal area of cultivation. This value was used as an estimate of population pressure in each domestic management unit. DstLdn is the straight distance from the edge of the closest landing strip to any site. This variable is a measure of the interaction between accessibility infrastructure and forest areas. NstNbr is the nearest distance to *chacras* and it is a measure of the spatial interaction between forest areas and existing agricultural plots. Slope is a measure of on-site conversion costs and reflects the attractiveness of a place for conversion to agricultural land use. CstDstHo is the least accumulative cost in minutes from the centroid of each agricultural area to the edge of the residential area and is a relative measure of the costs of moving through different surfaces and terrain conditions.

CstDstHo was calculated using a weighted or cost distance procedure. A total travel time map was created taking into consideration landing strips and terrain conditions such as slope and topographic barriers. A total cost surface was created by adding partial costs:

$$\text{TotCst} = \text{CstS} + \text{CstTB}. \tag{4}$$

Where TotCst is the total cost in minutes representing the time per unit of distance for moving through a cell. CstS is a relative time cost calculated by the decay function:

$$\text{CstS} = 60 / \text{Vmax} * e^{-\text{slope}/25} \tag{5}$$

Where Vmax is a constant that represents the maximum speed a person can move through flat areas and is calculated empirically based on GPS data. Slope is the maximum rate of altitudinal change between each cell and its neighbors. Slope was derived from 25 m resolution digital elevation models and measured in degrees. CstTB is the cost in minutes of moving through wetlands and water bodies. Each water body and wetland area was assigned a relative time cost index based on an expected average travel speed. Firm land areas were assigned a cost of moving of 0.

The logit function can be expressed as a function of odds to facilitate model interpretation:

$$P_{a\,(x,\,y)} = e^{La(x,\,y)} / (1+e^{La(x,\,y)}) \tag{6}$$

$$P_{a\,(x,\,y)} = \frac{e^{(\alpha + \beta1Soil + \beta2FamDen + \beta3DstLdn + \beta4CstDstHo + \beta5NstNbr + \beta6Slope)}}{1 + e^{(\alpha + \beta1Soil + \beta2FamDen + \beta3DstLdn + \beta4CstDstHo + \beta5NstNbr + \beta6Slope)}} \tag{7}$$

Table 5.2 shows a description of the explanatory variables used in the logit model. A surface depicting the probability of a forest cell to change to agricultural use can be generated as land clearing in the near future is more likely to be controlled by the same factors that controlled most recent agricultural expansion. Applying LMR results to update values of the dependent variable in the form of a raster layer in a GIS allows generation of a grid representing the surface probability of future land cover changes using equation (7). This procedure was followed to generate a probability surface and asses agricultural land use patterns in the community that was not used in the calibration of the LMR model. The probability map of agricultural land use allows rigorous validation of the model since it can be compared to the actual agricultural land use map of this community. For this purpose, this surface was overlaid on the land use and land cover map derived from the interpretation of aerial images. This map only depicted those areas that are most likely to be affected by agricultural expansion and allowed setting an average probability threshold that can be used as the cutoff value to model agricultural land use patterns in future scenarios. It contains no indication as to when these land cover changes might take place, but it does suggest where future changes will occur if similar recent causal processes observed are maintained. The predicted probabilities of land

Table 6.1: Description of the explanatory variables used in the logit model.

Variable	Description
CstDistHo	*Travel time between residential and agricultural areas (in minutes)*
DstLdn	*Euclidean distance from agricultrual areas to landing strips (in m)*
Slope	*Terrain slope (in degrees)*
FamDen	*Population density (Number of household members per unit of agriculture)*
NstNbr	*Proximity to an agricultural area (in m)*
Soil	*Soil quality (Good = 1; Bad = 0)*
N = 2,948	

cover changes only become projections of future land cover changes if a dynamic mechanism is incorporated into the model. Such a dynamic model is based on the assumption that, in the short term, changes will continue to take place in the same way they did in the recent past and that the processes of land cover change, as estimated by the model's coefficients, are stationary.

3.3 Simulation of agricultural expansion

The simulation of agricultural expansion was done in a GIS environment using stationary coefficients obtained from equation (7) and implementing the LMR model using map algebra operations and Python programming language. Conceptually, the variables in the spatial model can be classified as dynamic or static. Dynamic variables are those that change over time (i.e. after iteration). Static variables remain the same after each iteration. Distance to the closest agricultural plot (NstNbr) and population density per unit of agricultural area (FamDen) are considered dynamic variables because these layers are updated after each iteration. New nearest distance rasters are calculated using a distance-to-nearest-feature application in the GIS. Distances are Euclidean and calculated from every single cell to the edges of the polygons of agricultural land use. Population increases using a constant growth rate (5.6 percent for the Achuar and Shiwiar groups). Slope (Se), Soils (Sl), and cost distance values (CstDst) remain constant after each iteration. Figure 5.14 shows a schematic diagram of the conceptual model.

The system employs an iterative mechanism that simulates a decision making process, in which key and random unknown factors affect personal decisions on whether or not to expand agriculture. Some events appear to be random because agricultural

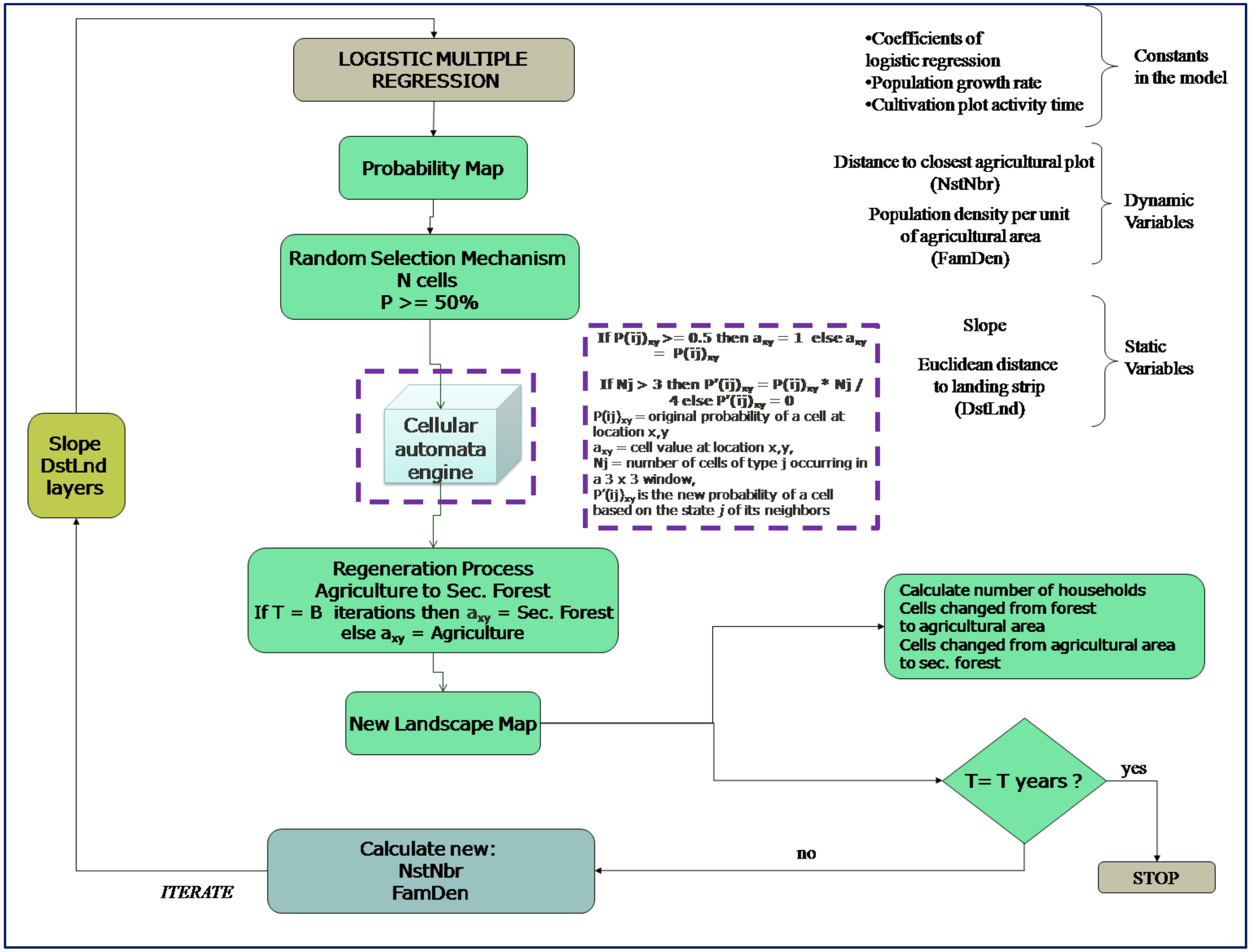


Figure 6.1: Conceptual spatially explicit land use and land cover change model.

expansion is a complex phenomenon and not all driving factors are known. Each iteration represents a time step of 1 year. The number of cells for the first iteration is chosen at random ranging from zero to a number representing a typical yearly amount of forest cleared by a number of households present at the beginning of the simulation. This guarantees that the largest amount of cells to pass from forest to agriculture after the first iteration is the average area cleared by one household in one year. In the next iterations, the number of cells to pass from forest to agriculture will depend on the number of agricultural areas needed to sustain the population present at a particular iteration. Once a non agriculture cell has passed to agricultural land use it will be masked out of the iteration process for an N number of iterations that account for an average fallow period. The actual transition from forest to agricultural land use is determined by a cellular automata (CA) mechanism that establishes which cells will change to agricultural land use based on the characteristics of its eight neighbors. The deterministic CA function can be expressed in following equations:

$$\text{If } P(ij)_{xy} >= 0.5 \text{ then } a_{xy} = 1 \text{ else } a_{xy} = P(ij)_{xy} \tag{8}$$

$$\text{If } Nj > 3 \text{ then } P'(ij)_{xy} = P(ij)_{xy} * Nj / 4 \text{ else } P'(ij)_{xy} = 0 \tag{9}$$

$P(ij)_{xy}$ is the original probability of a cell at location x,y of going from state i (non-agriculture) to state j (agriculture) calculated via LMR, a_{xy} is the cell value at location x,y, Nj corresponds to the number of cells of type j occurring in a 3 x 3 window, and $P'(ij)_{xy}$ is the new probability of a cell based on the state *j* of its neighbors (Figure 5.15). This is an iterative procedure and stops until there are no more transitions possible. These two equations work as an expanding mechanism that determines the shape of the final patch mosaic. The number of agricultural plots is estimated using a regression function of the form: $Y' = aX' + b$; where Y' is the amount of agricultural area. The amount of plots is calculated by dividing this amount by the average size of cultivation plots. a is the slope of the regression line, X' is the amount of people at that iteration, and b a constant. a and b were estimated using a sample of 55 households. The transition from agriculture to secondary vegetation occurs after T iterations. T is defined empirically and based on the information obtained from field questionnaires on fallow periods. The new landscape map contains information on agricultural area and secondary forest. A cumulative histogram is constructed after each iteration, representing the information about agricultural production (i.e. years of production after an agricultural site is abandoned) calibrated using information from *in situ* questionnaires. Additionally, the number of expected families after N years is also calculated. This information allows a "real-time" demographic and biophysical characterization of the landscape.

3.4 Validation of the statistical and spatially explicit land use models

Two types of validation procedures were applied in this study. The first one refers to the validation of the LMR model. In this case, two tests were used to evaluate the model's efficiency to adequately classify an observation into agriculture or non-agricultural area. The first test was done using an error matrix which calculates an overall accuracy of the model to classify cells based on their predicted probabilities and using a cutoff value of 0.5 (i.e. values larger or equal to 0.5 are classified as agriculture and lower values as non-agriculture). The test uses the cells that were employed to generate the model and the cells of a validation subset sample with those observations not used in the

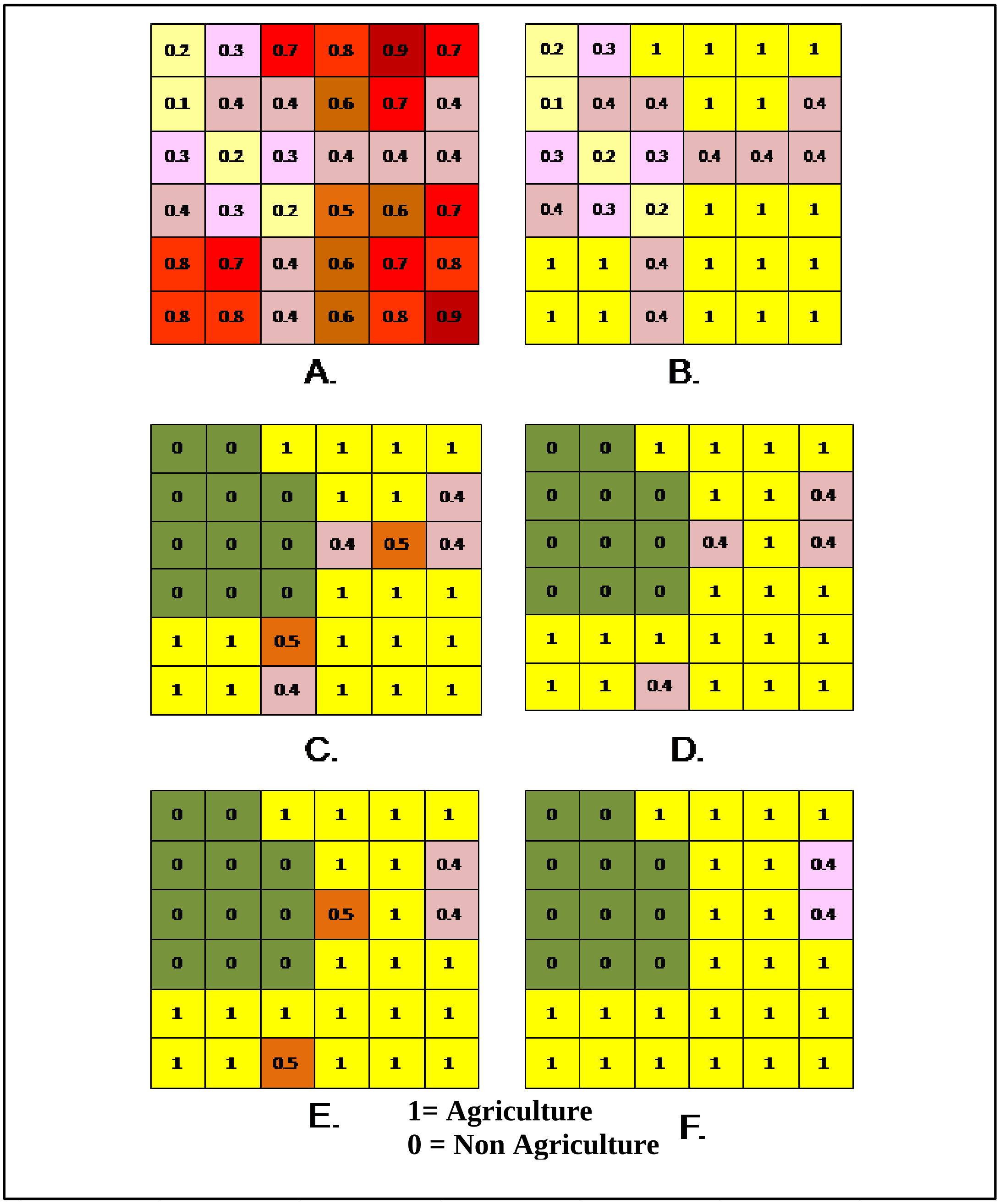


Figure 6.2: Probability maps before (A) and after (F) the convolution of the cellular automata engine. B, C, D and E show the intermediate steps in the transition process.

model. The second test was the construction of a Receiver Operating Characteristic (ROC) curve, which is a visual index of the accuracy of the model. The curve is plotted based on two dimensions. The sensitivity dimension refers to the probability that a "positive" case is correctly classified, and is plotted on the y-axis in an ROC curve. 1-sensitivity is the false negative rate. The specificity dimension is the probability that a "negative" case is correctly classified. 1-specificity is the false positive rate. The analysis of both sensitivity and 1-specificity allows determining the usefulness of a classification scheme and analyzing cutoff values in two-category classification schemes. In general, the further the curve lies above the reference line, the more accurate the model.

The spatially explicit simulation model was validated using information of *centro* Yuntsuntza, which was not included in the calibration of the LMR model. The initial scenario was that a landing strip was present when the village was founded and that two households with 5 members each arrived and settled around the landing strip at random locations. Fifty models of this scenario were done to obtain a robust representation for validation purposes. The final models represented an 18 year simulation since this was number of years that the village of Yuntsuntza has existed. The first type of validation procedure was done by aggregating the 50 simulated models to obtain a map depicting the probability of occurrence of agricultural land use at each location. A simple chi square procedure was done to determine if there was a statistically significant relationship between the predicted and observed distributions of cultivation areas. Additionally, five types of validation tests were employed to evaluate key landscape characteristics of the resulting simulations in relation to the actual land use in the area. The estimation of landscape metrics was done in FragStats V3.3 using the raster models generated in the GIS. These procedures consisted of:

1) Quantifying the proportion between the areas of predicted agricultural land use and the actual area of agricultural land use and measured by:

$$\frac{\text{Area of predicted agricultural area between Year 1 and Year 18}}{\text{Total agricultural area between 1989 and 2006}}$$

2) Quantifying the proportion between mean patch area of predicted land use and mean patch area in 2006 as measured by:

$$\frac{\text{Mean patch area of agricultural land use in Year 18}}{\text{Mean patch area of agricultural land use in Year 2006}}$$

3) Quantifying the proportion between patch density of agricultural areas (i.e. number of agricultural patches divided by 100 ha) predicted by the model using an average production time of 8 years (i.e. calculated for Yuntsuntza and derived from interviews) and the number of agricultural plots present in 2006, measured by:

$$\frac{\text{Density of predicted agricultural plots in Year 18}}{\text{Density of agricultural plots in Year 2006}}$$

4) Quantifying the proportion between Euclidean nearest neighbor distance of predicted agricultural plots in Year 18 and nearest distance of agricultural plots in Year 2006, as measured by:

$$\frac{\text{Mean nearest neighbor distance of predicted agricultural plots in Year 18}}{\text{Mean nearest neighbor distance of agricultural plots in Year 2006}}$$

5) Finally, quantifying the proportion between the perimeter-area fractal dimension in the simulated landscapes in Year 18 and the fractal dimension of the actual landscape in year 2006, as measure by:

$$\frac{\text{Perimeter-area fractal dimension of agricultural plots in Year 18}}{\text{Perimeter-area fractal dimension of agricultural plots in Year 2006}}$$

Error values in percentages were calculated for each validation procedure. These validation procedures allowed determining the performance of the land use model in simulating actual landscape characteristics.

Chapter Seven

A Land-use Zoning Model of Indigenous Production

1. Introduction

Production strategies are complex and tightly intertwined with the history of the people who developed or adapted those practices to the circumstances and conditions in which they live (Miles, Snow, & Meyer, 1978). Since the sixteenth century the Amazon region has seen considerable variation in several cultural features referred to as adaptive responses of indigenous peoples to changing socio-economic and demographic conditions (Posey & Baleé, 1989; Denevan, 2001). Adaptive responses to environmental constraints are expected to differ according to the ecological conditions of the particular people under study, which could limit generalizations across human populations in tropical lowland environments. However, some common responses of indigenous peoples in the Amazon region have been changes in settlement patterns, social organization (i.e. hierarchical to egalitarian), product choice (i.e. subsistence vs. market oriented), trade relations (e.g. credit, barter, and market exchange), among others (Coomes, 1992). From these features, changes from dispersed and semi-nomadic to nucleated and permanent settlements, are probably the factors that have directly led to lasting landscape transformations (Salazar, 1981; Descola, 1981).

This chapter presents a model of indigenous production, which helps to understand its spatial dimension. Section two discusses the implications of the transition from traditional dispersed settlements to modern nucleic residential arrangements in Western Amazonia. Section three focuses on the residential element of indigenous production. Section four presents the results of the analysis of the agricultural and cattle-raising elements of traditional production systems. Finally, section five presents the results of the analysis of the foraging element of contemporary traditional systems. I utilize the Jívaro case to exemplify these elements since this group is quite representative of indigenous peoples of western Amazonia.

2. An adaptive response to changes in settlement patterns: a land use zoning model of indigenous production.

The extent and patterns of production systems are closely entwined with the type of settlement and the environment where production occurs. Until the late 1960s, indigenous peoples in Western Amazonia such as the Jívaro, Huaorani, Campa, or Záparo were characterized by a pattern of dispersed settlements (Taylor, 1999). This form of settlement had existed in the western Amazon Basin long before the Spanish conquest, but only as an alternative alongside village-type habitats or big multifamily longhouses. These generally disappeared during the seventeenth century, giving way to dispersed settlements in isolated domestic units (ibid.). Residential and social atomization in turn led to a growing autonomy of local groups with respect to the natural setting. In dispersed residential arrangements, households exerted exclusive control over large areas. Under conditions of low population densities and large territories, domestic units continuously relocated throughout the region. In fact, Descola (1994) reported management areas between 20 and 40 square kilometers for a single household and settlements that lasted generally between one and three years.

In riverine habitats, households settled along river banks, generally on alluvial terraces (Descola, 1994). Intensive gathering and hunting occurred in areas that were beyond the extent of cultivation. In inter-fluvial areas, the settlement pattern was probably more scattered than in the riverine environment (Denevan, 2001). Gathering and hunting territories spread outwards in all directions from residential units. Figure 7.1 shows a land use model in dispersed and temporary settlements in the riverine and inter-fluvial habitats. In this model, distances between households i and j in the inter-fluvial biotope are larger than in the alluvial habitat due to differences in the placement of residential units. Descola (1994) suggested an average radius of five kilometers from the house to the outer edge of the hunting territory to determine the extent of the household's management area. This implies that houses in the inter-fluvial habitat were located at least 10 km away from each other (distance Y_{ij} in Figure 7.1). In the riverine habitat residential areas were established between three to five kilometers apart (distance X_{ij} in Figure 7.1). These differences indicate that the spatial distribution of houses in the inter-fluvial habitat was more dispersed than in the riverine biotope. The exception to the dispersed mode of occupation in both the riverine and inter-fluvial habitats occurred during wars, when multiple residencies gathered for the purpose of protection and defense against other groups. According to Taylor (1987), these temporary living arrangements consisted of a few families that shared the same house but produced and extracted food resources autonomously (Figure 7.2). Once the threat of war disappeared or conflicts among groups were solved, families returned to the dispersed arrangement.

The dispersed residential system that once characterized most indigenous groups

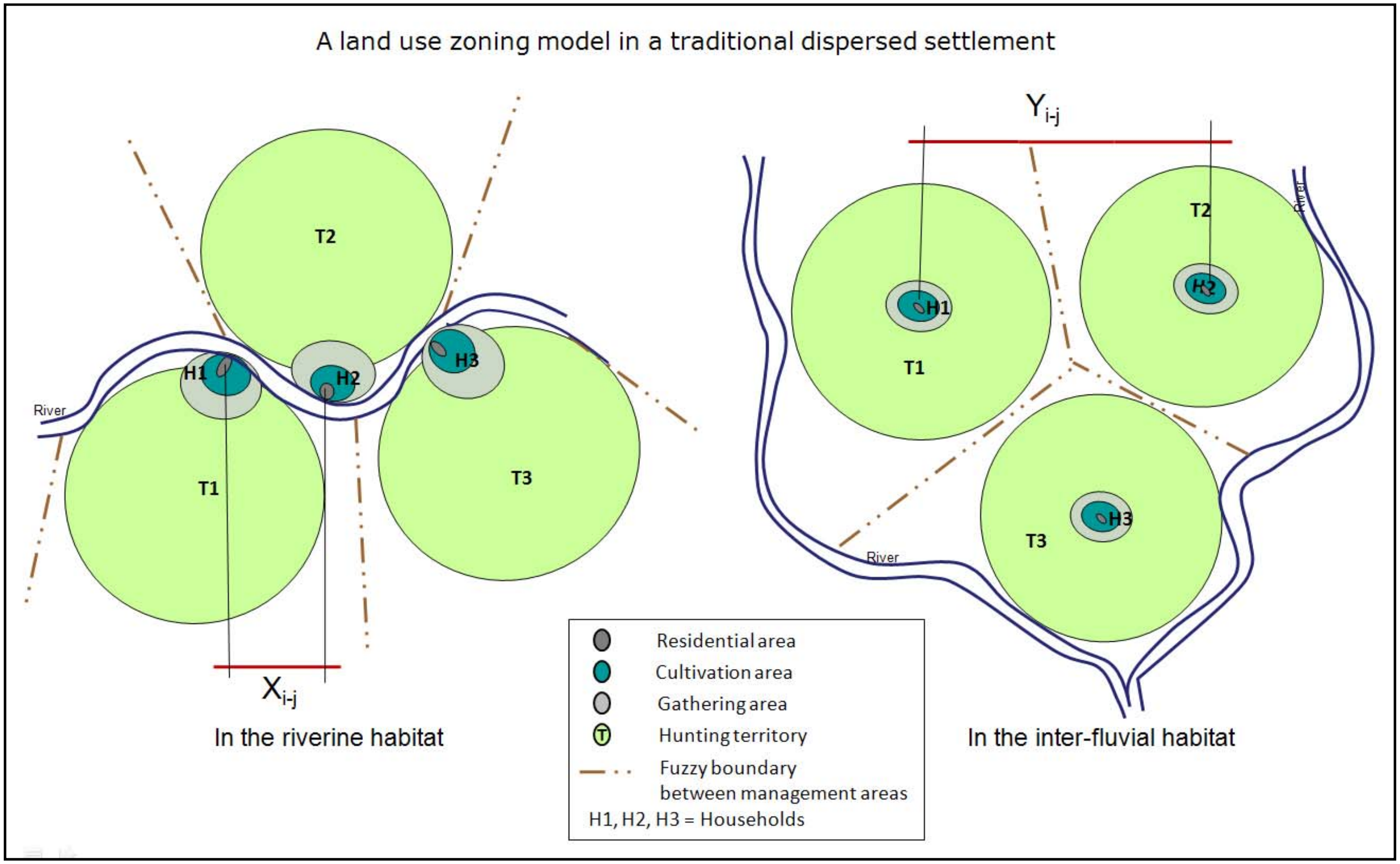


Figure 7.1: A land use model in dispersed and temporary settlements in the riverine and inter-fluvial habitats. Distance between households in the riverine model (X_{i-j}) are smaller than distances between households in the that inter-fluvial model (Y_{i-j}). Riverine settlements were probably more clustered than settlement in the inter-fluvial habitat.

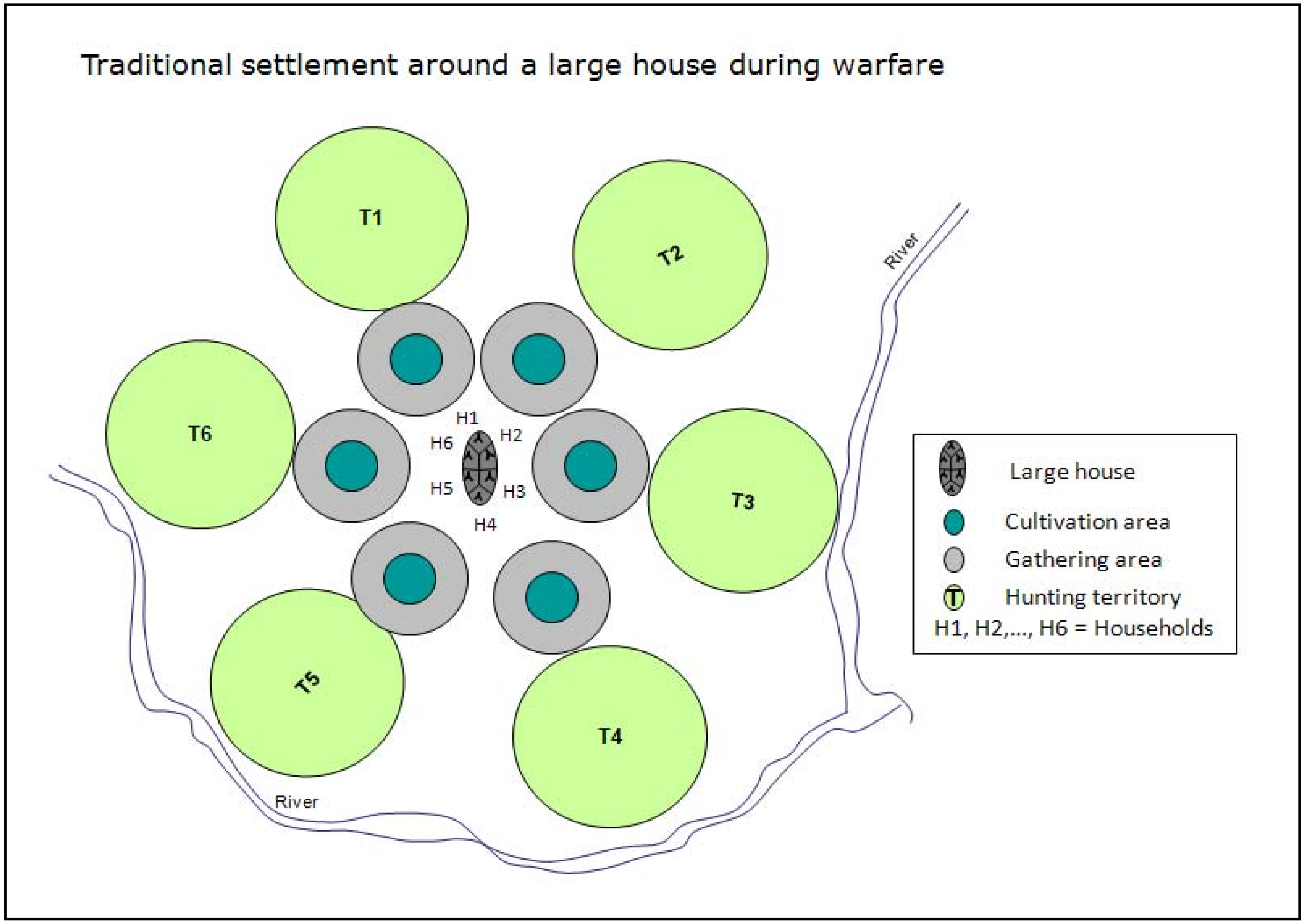


Figure 7.2: Temporary living arrangement during warfare. A few families shared the same house but produced and extracted food resources from independent spaces

of the western fringe of the Amazon region has almost disappeared and has been replaced by nucleated villages or *centros* (Taylor, 1999). The current nucleated settlement type has its origins in the reductions or *reducciones* introduced by the Spanish people in the Americas during the seventeenth and eighteenth centuries. In the 1960s, Evangelic and Catholic missionaries adopted a similar system to the reductions to group dispersed populations for evangelization purposes. They persuaded indigenous peoples to cluster around jungle airstrips and dedicate themselves to raising cattle and cultivating cash crops (Taylor, 1981; Salazar, 1981); activities that have contributed to the sedentary character of current settlements. Figure 7.3 shows an example of the proliferation of nucleated settlements in the PRBEA between 1927 and 2005.

Presently, the nucleation and sedentarization of villages is an important underlying cause of landscape transformation in indigenous territories of Western Amazonia. The proliferation of *centros* has contributed to the development of a zoning system that can be seen as an adaptive response to changes in resource availability due to sedentarization. Sedenarization, in turn, has probably originated changes in the institutions that regulate the access to land and forest resources. The analysis of the spatial distribution of production zones shows the emergence of a partition system that divides the space into "neighborhoods" or management areas (probably delimited in a fuzzy way by land marks such as large trees, creeks, hills) distributed around the airfield according to the location of residences and to kinship relationships among households (Figure 7.4). The spatial configuration of these management areas is such that any agricultural or pasture area in them will tend to be closer to the owner's residential area

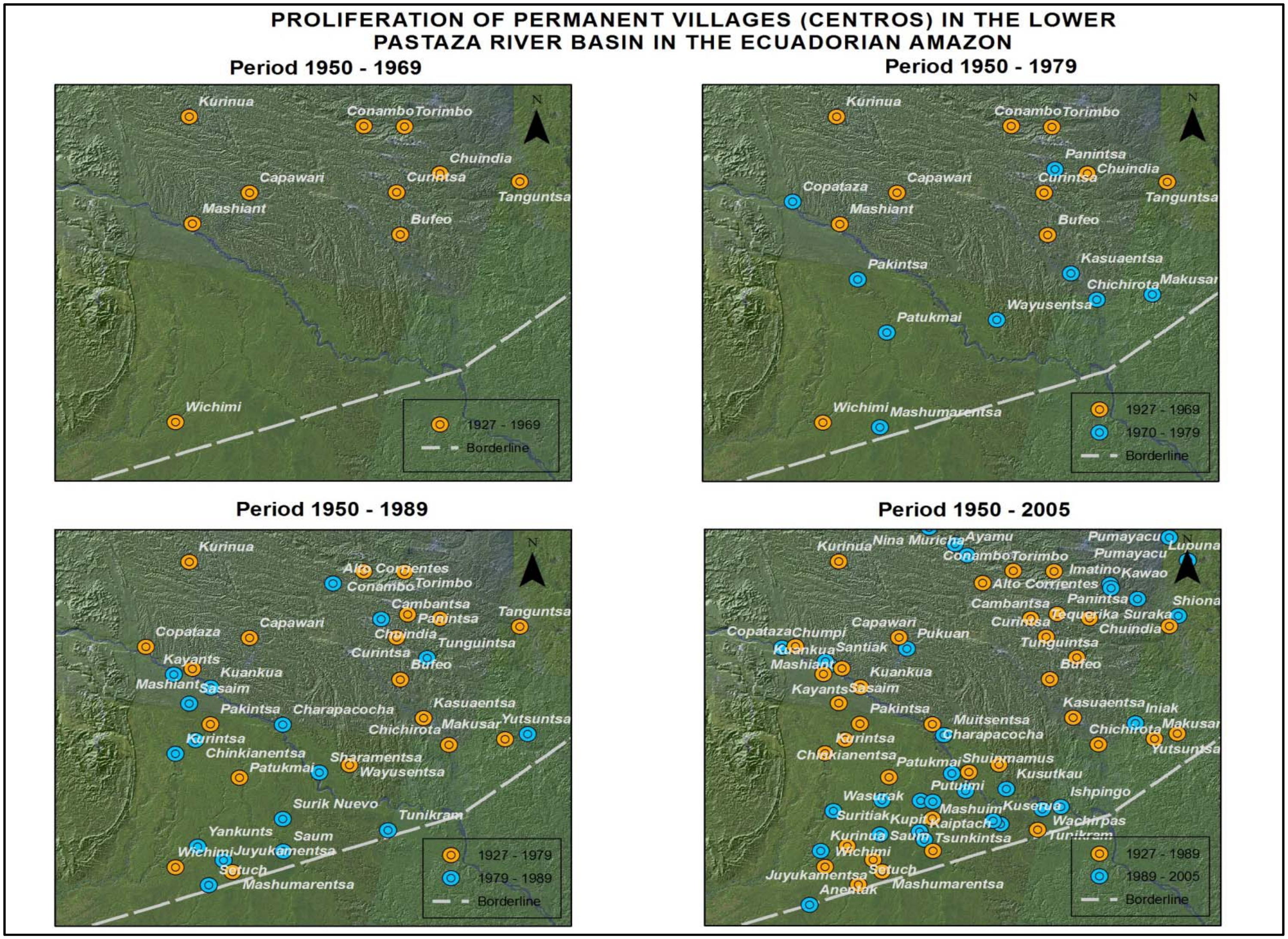


Figure 7.3: Proliferation of nucleated villages in the Achuar territory since the year 1950. (Source NAE, NASHIE, NAZAE, 2006)

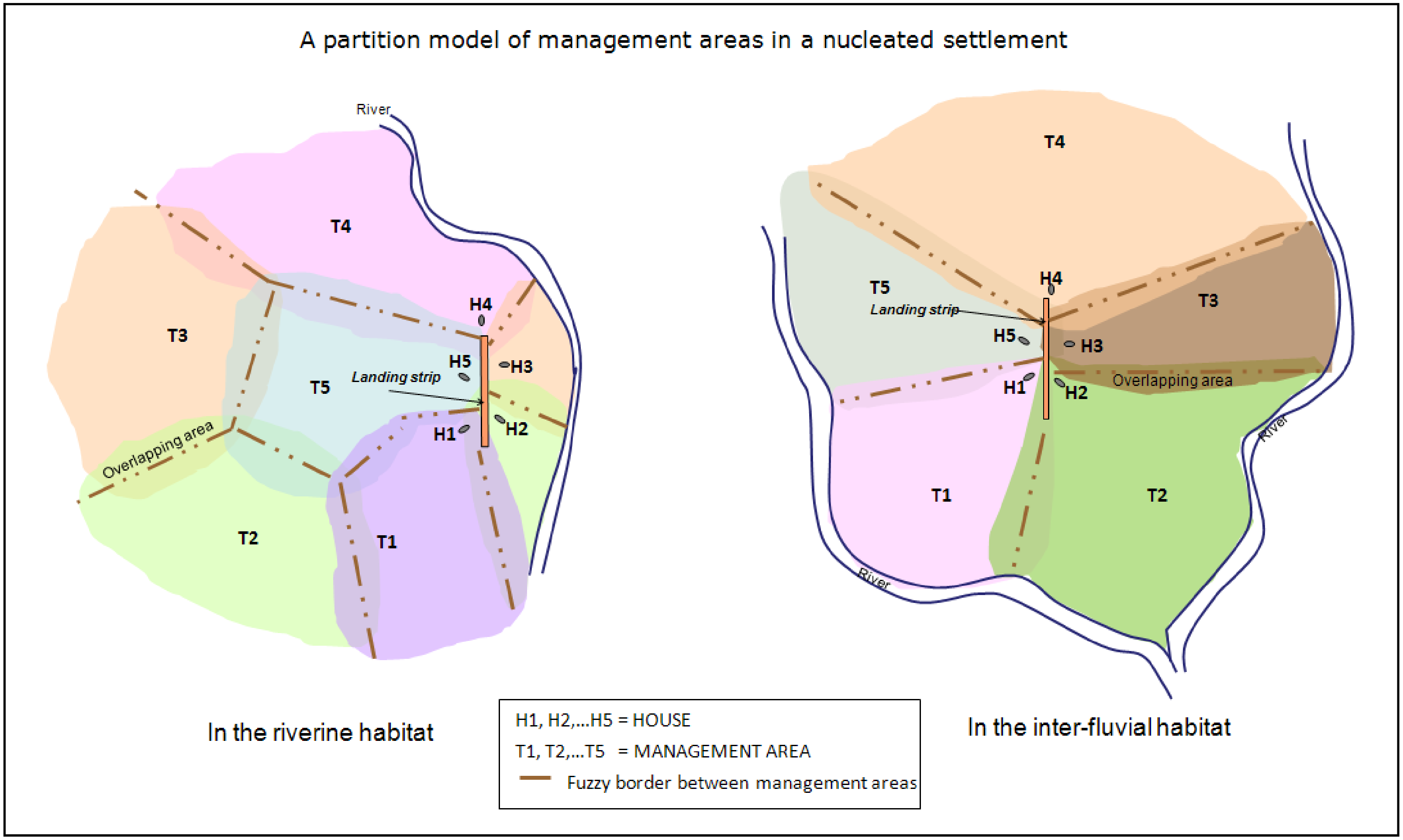


Figure 7.4: A partition system that divides the space into "neighborhoods" or management areas distributed around the airfield according to the location of residential units and to kinship relationships among households. The spatial configuration of these management areas is such that any agricultural or pasture area in them will tend to be closer to the owner's home than to any other residential area. Management areas may also overlap each other in a way that old-growth forest areas and water sources are not necessarily the exclusive property of one family alone and could be used by other families for resource extraction (e.g. occasional food gathering, hunting, or fishing).

than to any other residential area (polygons of different colors in Figure 7.4). However, management areas may also overlap each other in a way that old-growth forest areas and water sources are not necessarily the exclusive property of one family alone and could be used by other families for resource extraction (e.g. occasional food gathering, hunting, or fishing). On the other hand, clearing of old-growth forest for cultivation within an assigned management area gives the family exclusive rights of use and usufruct from that particular piece of communal land. With such a system, the community not only assigns resources in an efficient way but also confers the rights of use, production, and/or extraction of an area to families in a relative equitable way. This partition system also implies that clear institutions or behavioral rules are known and well understood by community members to avoid social clash. When families cannot get adequate land resources through the system or conflict arise due to population pressure and an overconcentration of families around airfields, agricultural intensification (Boserupian trajectory) or community fission and then relocation of households (Malthusian trajectory) may occur.

In the model, land use zones are depicted as concentric circles that spread outwards from the center of the community. Service infrastructure constitutes the center of the system that serves as the nucleus of productive activities. Figure 7.5 shows a representation of the zoning system in current riverine and inter-fluvial nucleated settlements. In riverine settlements, the space is constrained by the presence of water bodies such as large rivers that work as territorial barriers. Since the space between the river and the landing strip is limited, households closer to the river usually

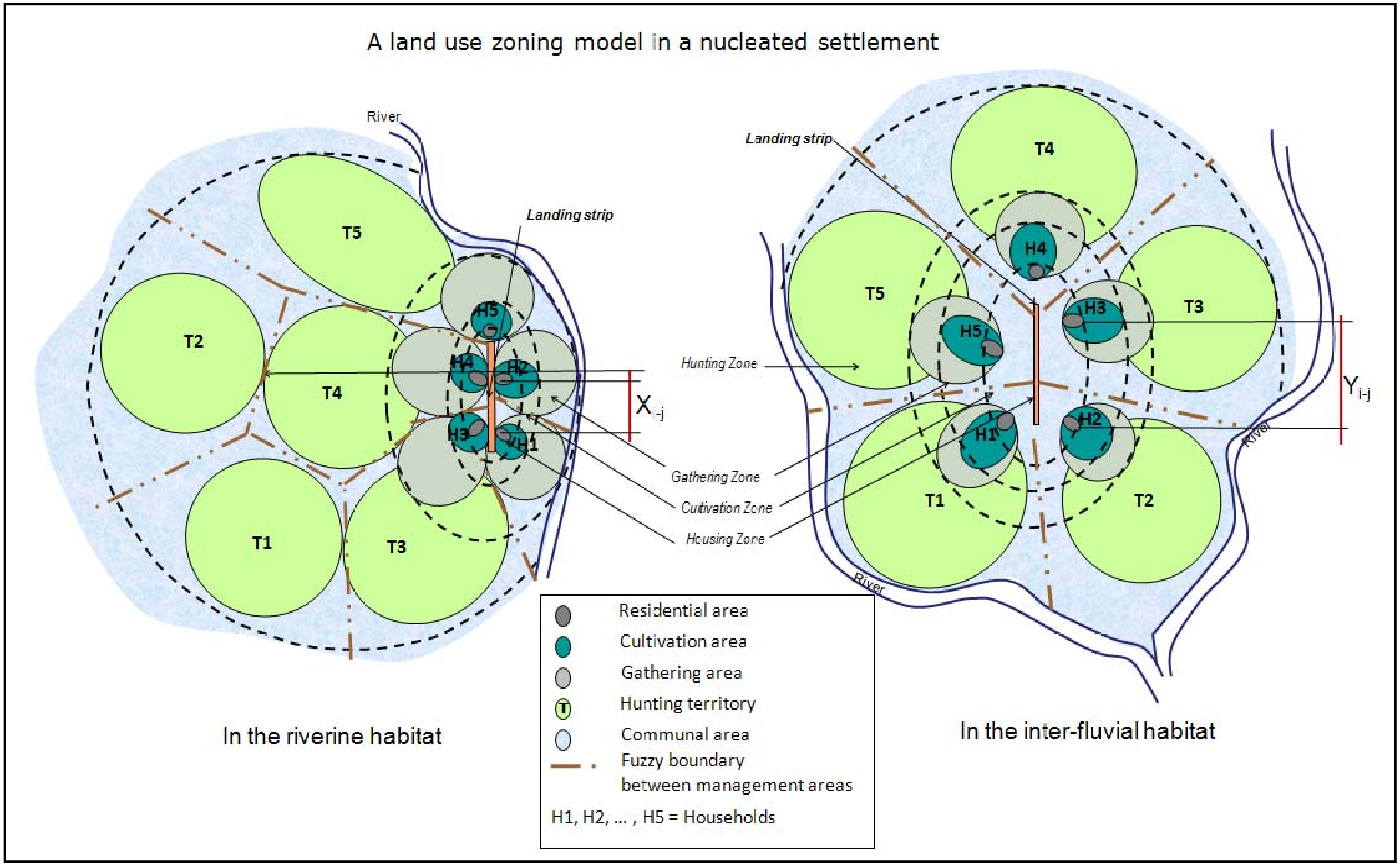


Figure 7.5: A land use zoning model in nucleated settlements in the riverine and inter-fluvial habitats. Distance between households in the riverine model (X_{1-2}) are smaller than distances between households in the that inter-fluvial model (Y_{1-2}). Riverine settlements are more clustered than inter-fluvial settlements.

manage hunting and/or gathering areas that are located on the other side of the airfield, on the opposite side of the residential area. In inter- fluvial villages, management areas generally expand outwards from the center of the village. Figure 7.6 contains a representative cross section of both biotopes and a horizontal representation of the different components of the land use zoning system. These figures show that housing areas are generally located adjacent to or nearby the airfield. Agriculture and pasture areas are situated close to residential areas, followed by intensive gathering and hunting zones that face outwards from the landing strip.

Table 7.1 summarizes the information obtained from the interpretation of aerial images on the spatial characteristics of production systems in the inter-fluvial and riverine biotopes. Results show that houses, cultivation areas, and pastures are significantly more clustered around the landing strips in the southern region than in the north. Additionally, cultivation areas and pastures in the alluvial terraces of the riverine system are closer to residential units than in the inter-fluvial environment. These patterns suggest that settlements and production zones in the inter-fluvial habitat are more dispersed than in the alluvial system. This finding provides a baseline for a distinctive characterization of land use systems according to the ecological context of production activities and supports the findings of other studies that suggest distinctive management strategies for riverine areas and inter-fluvial areas of the Amazon region (Lathrap, 1970; Meggers, 1971; Denevan, 2001). Land use and land cover maps of the seven subject communities (Figures 7.7 to 7.13) were used to quantitatively evaluate the spatial characteristics of production systems. Table 7.2 summarizes the statistical t-tests of the

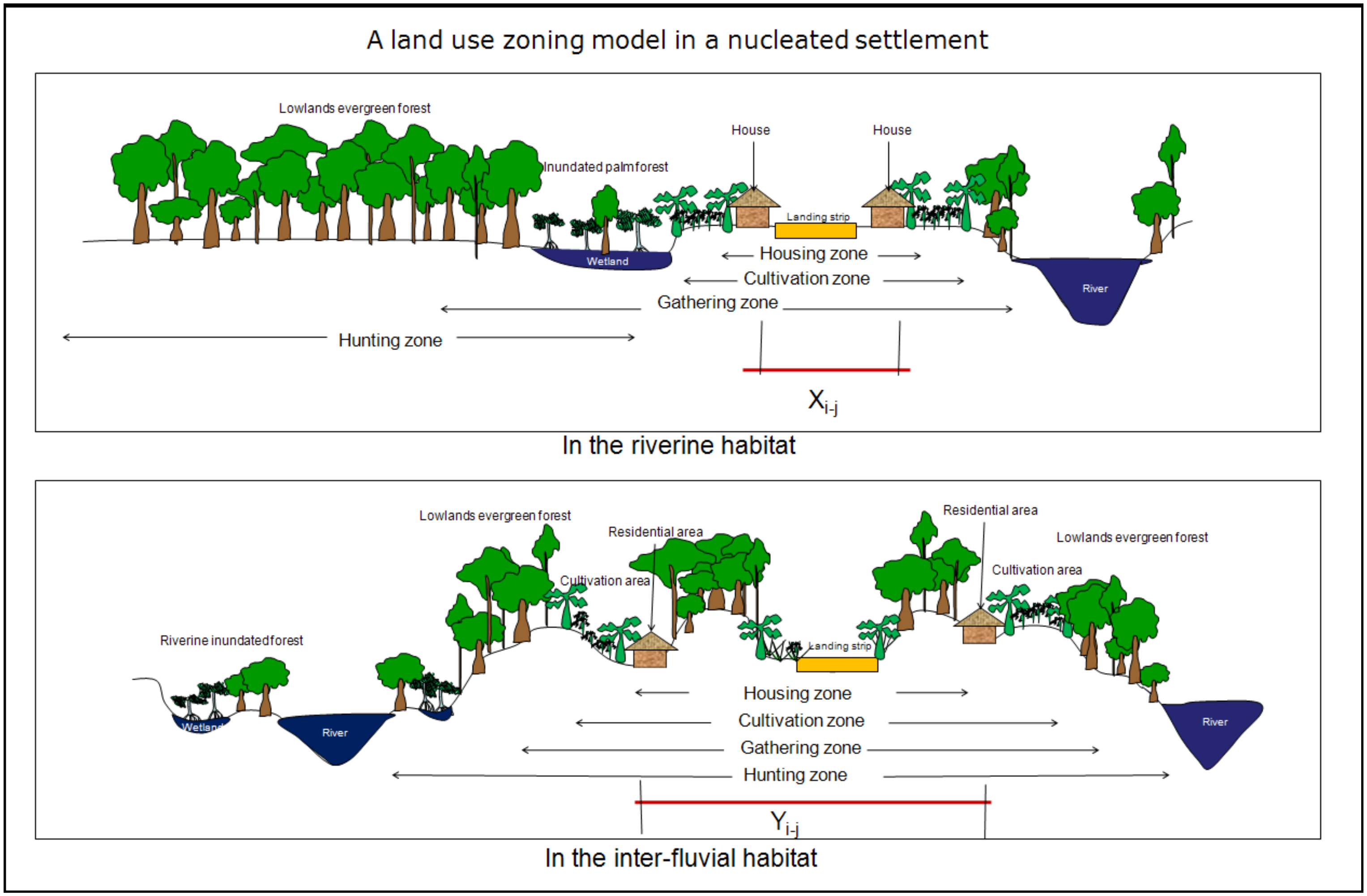


Figure 7.6: Representative cross sections of the riverine and inter-fluvial habitats in Western Amazonia. Note differences in topography between habitats. Distance between households in the riverine model (X_{i-j}) are smaller than distances between households in the that inter-fluvial model (Y_{i-j}). Riverine settlements are more clustered than in the inter-fluvial biotope.

Table 7.1: Descriptive statistics of the spatial configuration of traditional land use systems in the riverine (southern) and inter-fluvial (northern) habitats.

	Descriptive Statistics	*Northern PRBEA*	*Southern PRBEA*	*Levene's Test for Equality of Variances*		*t-test for Equality of Means*		
				F	***Sig.***	***t***	***df***	***P value***
Average distance from the center of a landing strip to residences (in Km)	**N**	54	35					
	Mean	0.66	0.22	21.68	0.00	4.08	87.00	0.00
	Std. Dev	0.60	0.22					
Average distance from the center of a landing strip to agropecuarian land use areas (in Km)	**N**	55	46					
	Mean	1.24	0.33	29.12	0.00	9.88	99.00	0.00
	Std. Dev	1	0.26					
Distance from the center of a landing strip to the end of hunting trails (in Km)	**N**	41	29					
	Mean	4.25	4.03	4.87	0.031	0.67	68	0.51
	Std. Dev	1.12	1.61					
Average distance from agropecuarian areas to residences (in Km)	**N**	116	100					
	Mean	0.57	0.14	53.82	0.00	7.74	214.00	0.00
	Std. Dev	1	0.18					

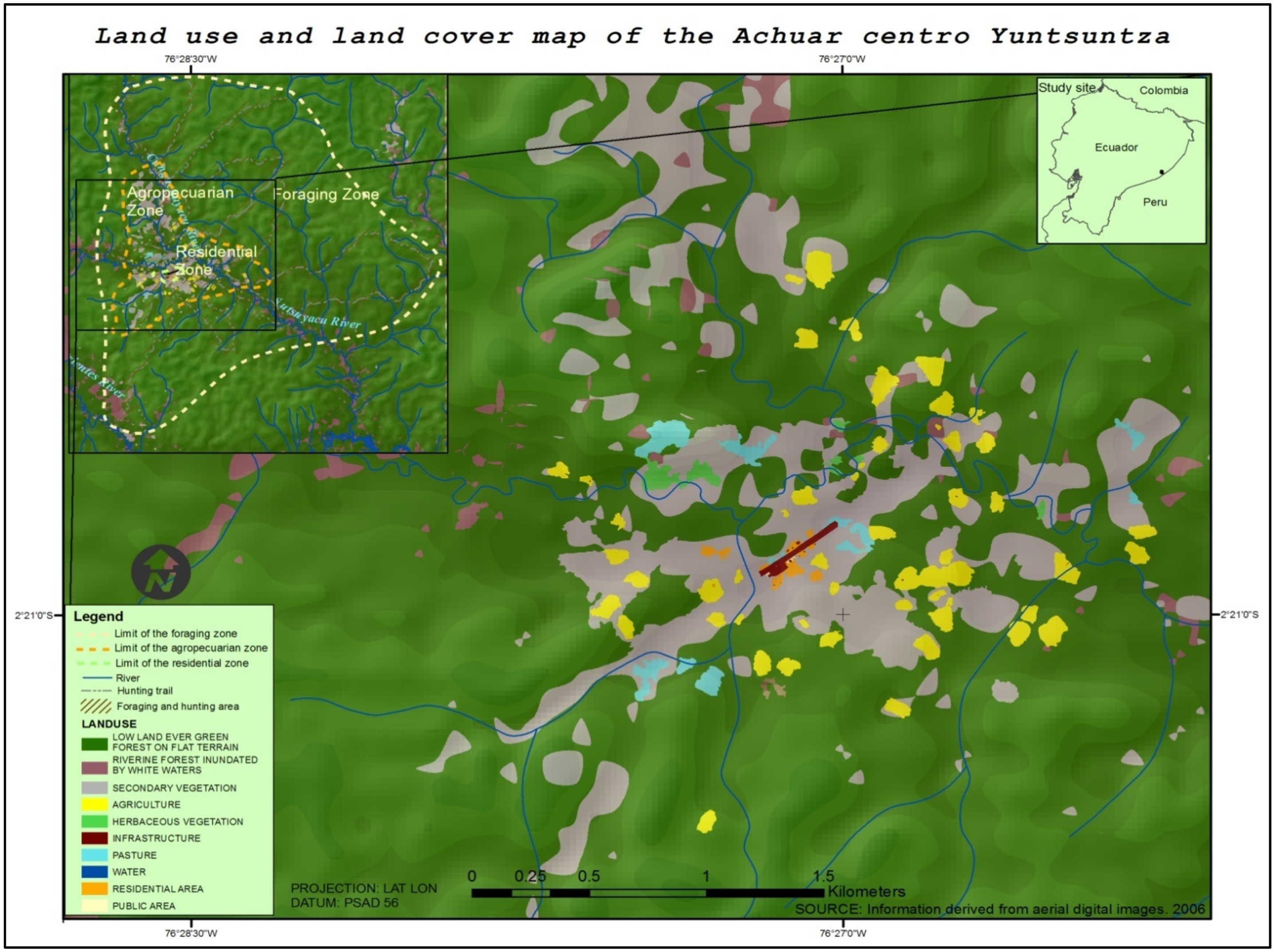


Figure 7.7: Land use and land cover map of the Achuar *centro* Yuntsuntza derived from the interpretation of aerial images.

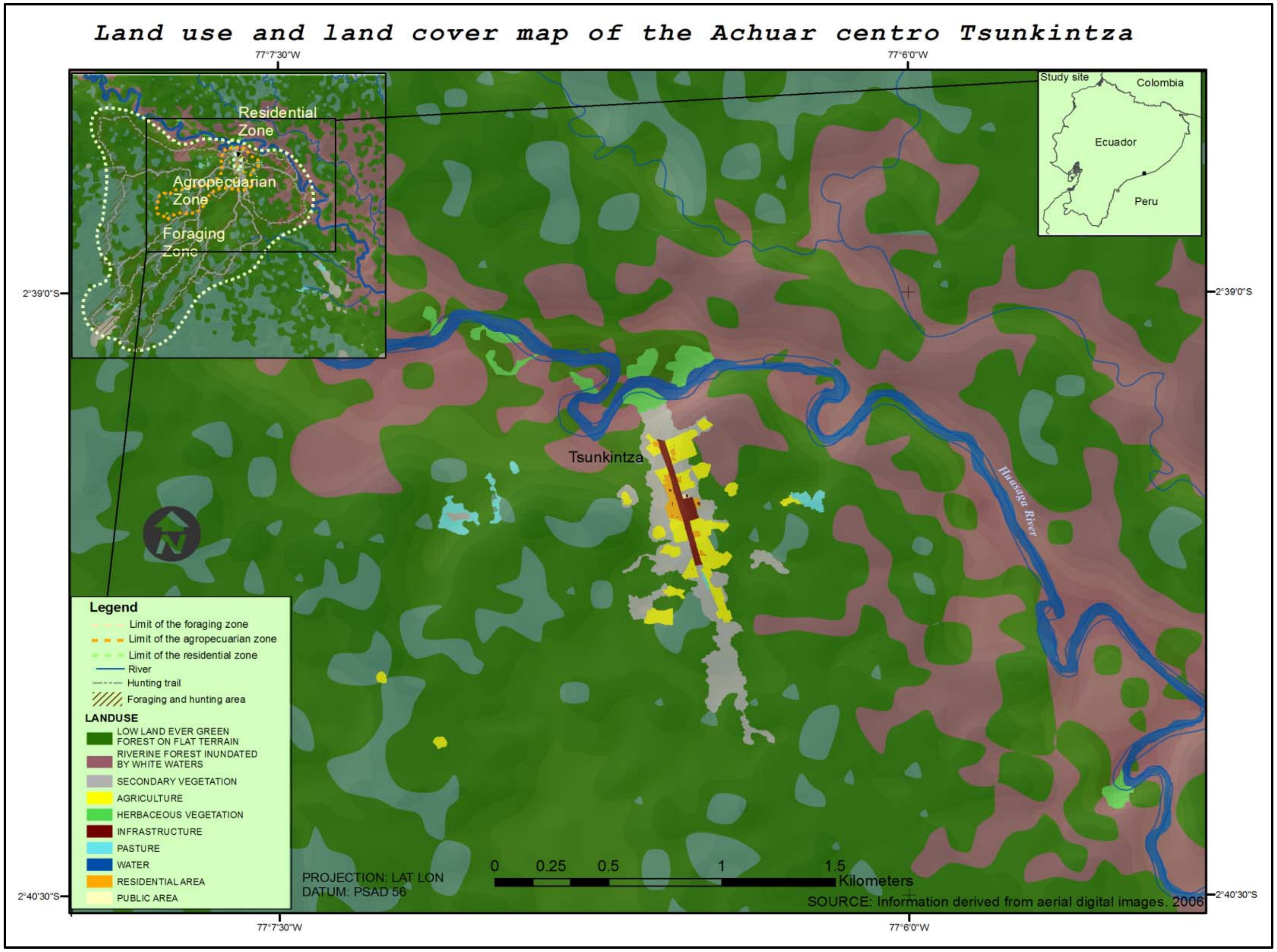


Figure 7.8: Land use and land cover map of the Achuar *centro* Tsunkintza derived from the interpretation of aerial images.

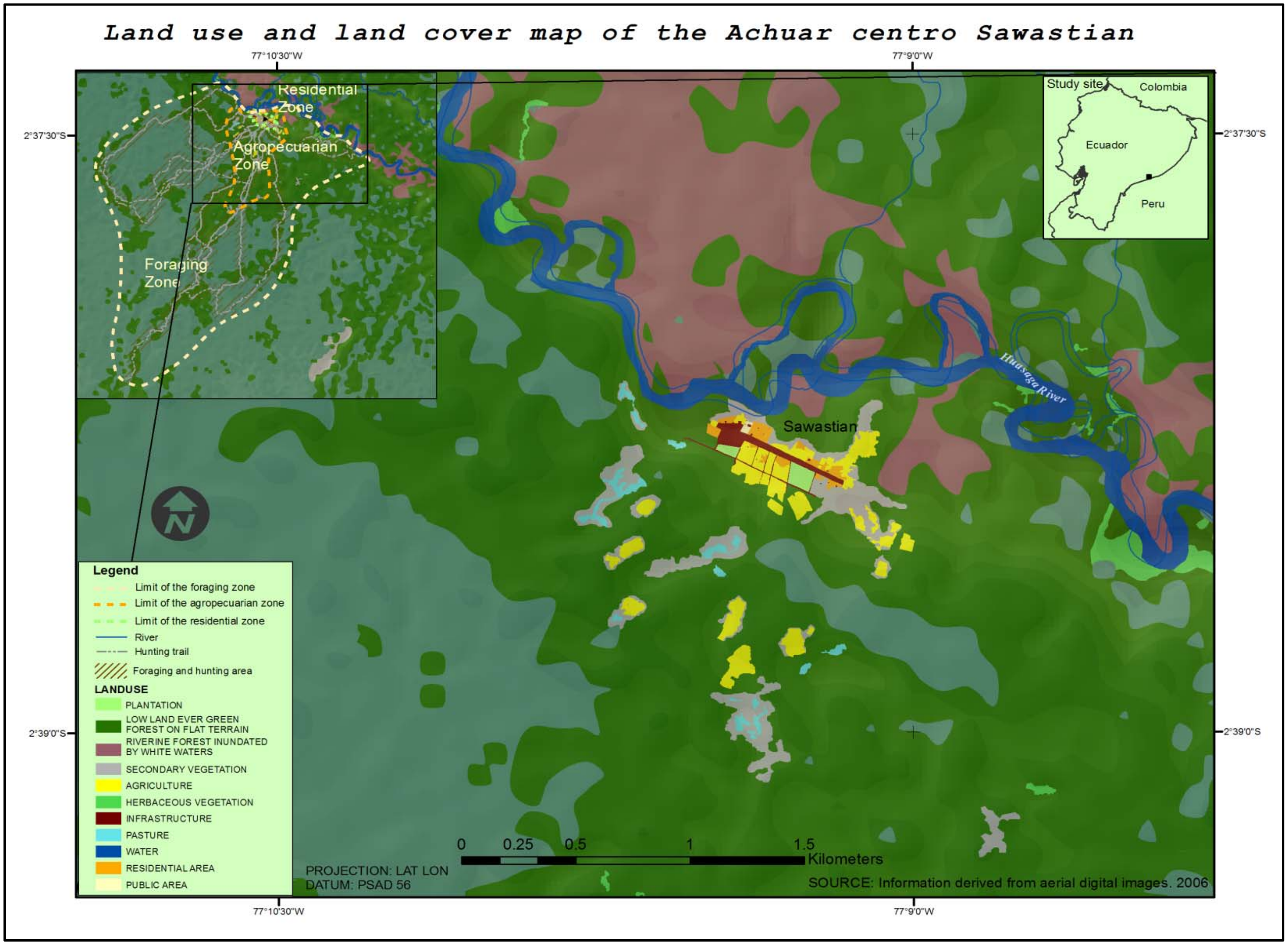


Figure 7.9: Land use and land cover map of the Achuar *centro* Sawastian derived from the interpretation of aerial images.

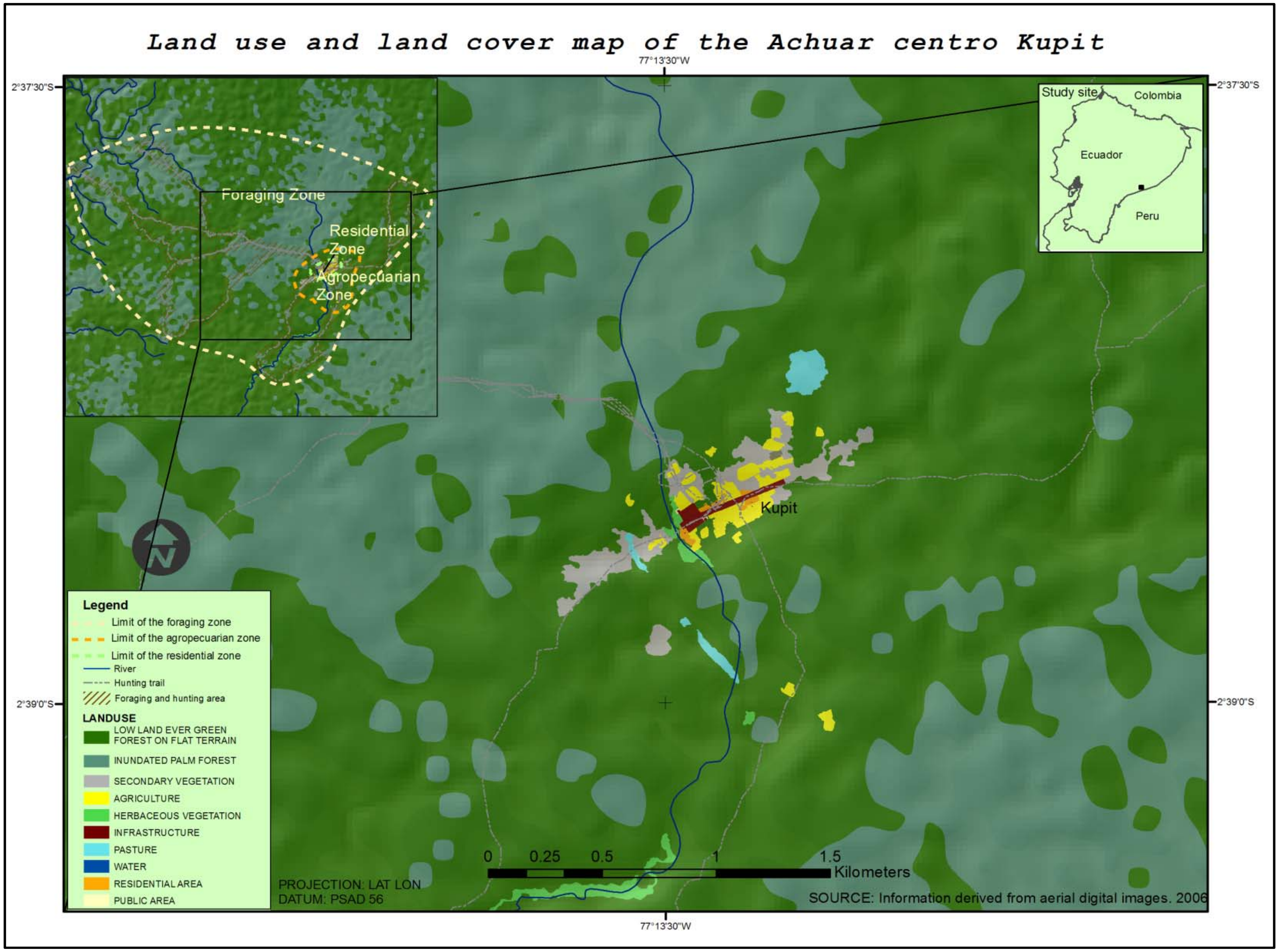


Figure 7.10: Land use and land cover map of the Achuar *centro* Kupit derived from the interpretation of aerial images.

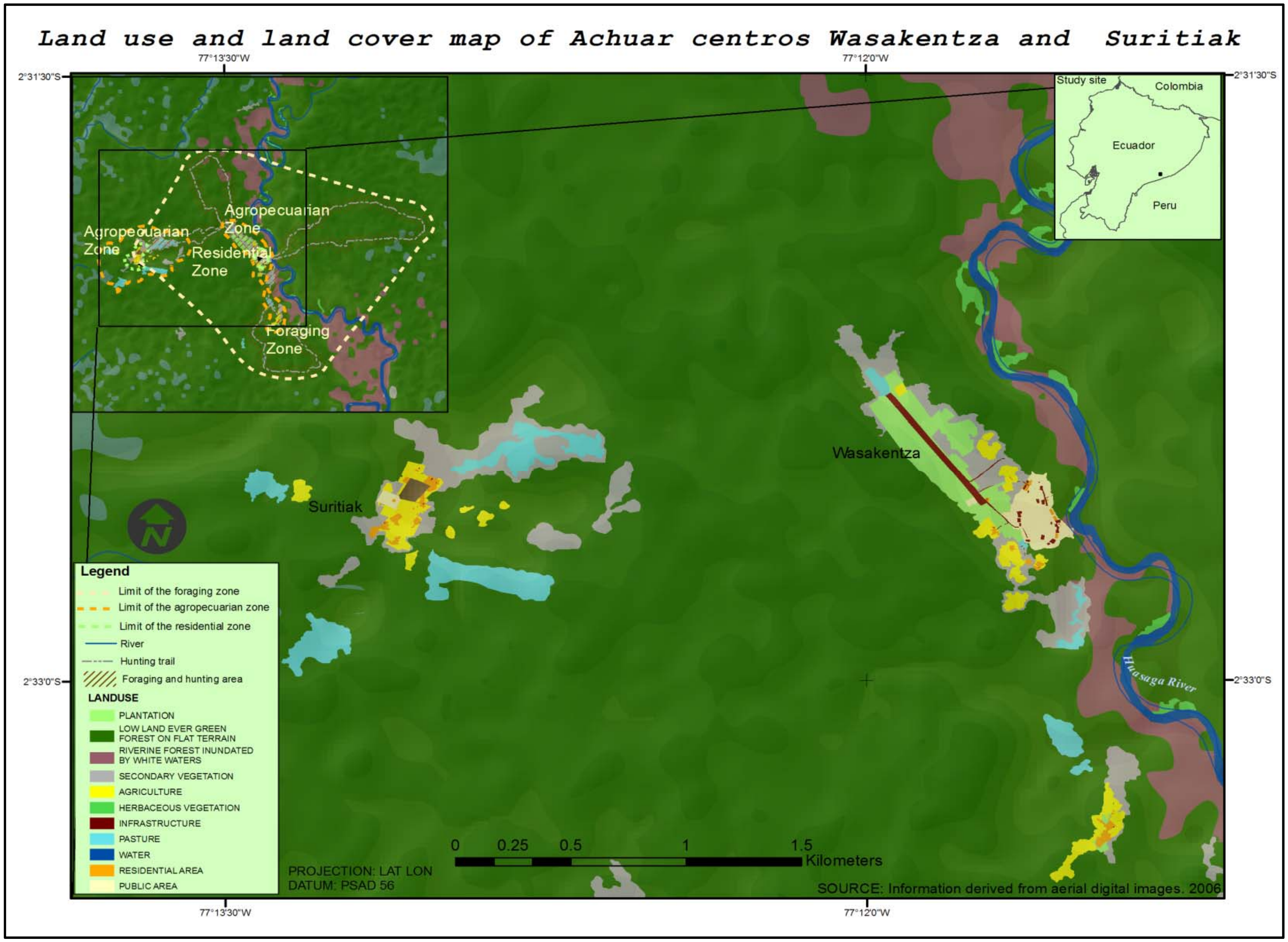


Figure 7.11: Land use and land cover map of the Achuar *centros* Wasakentza and Suritiak derived from the interpretation of aerial images.

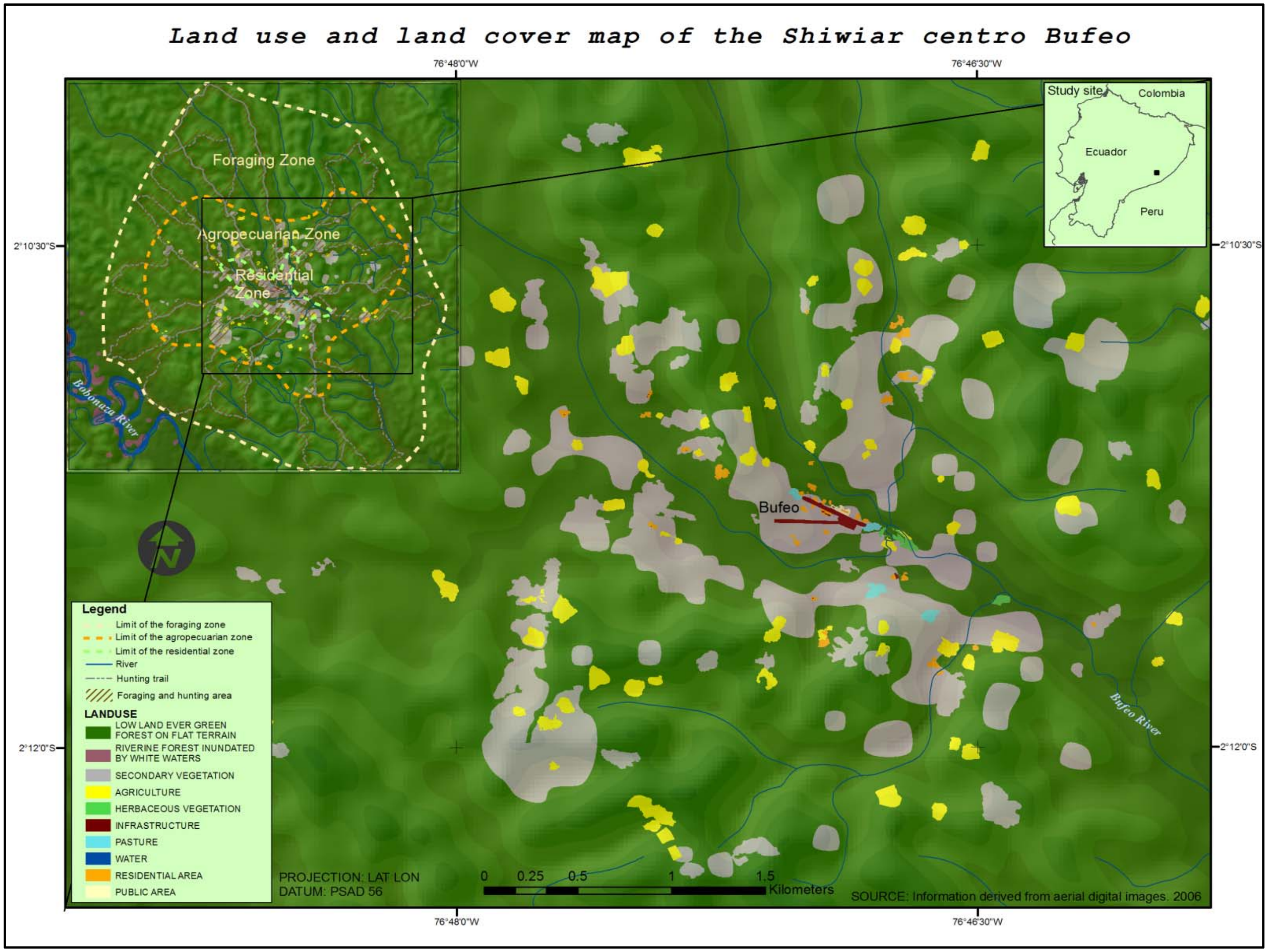


Figure 7.12: Land use and land cover map of the Shiwiar *centro* Bufeo derived from the interpretation of aerial images.

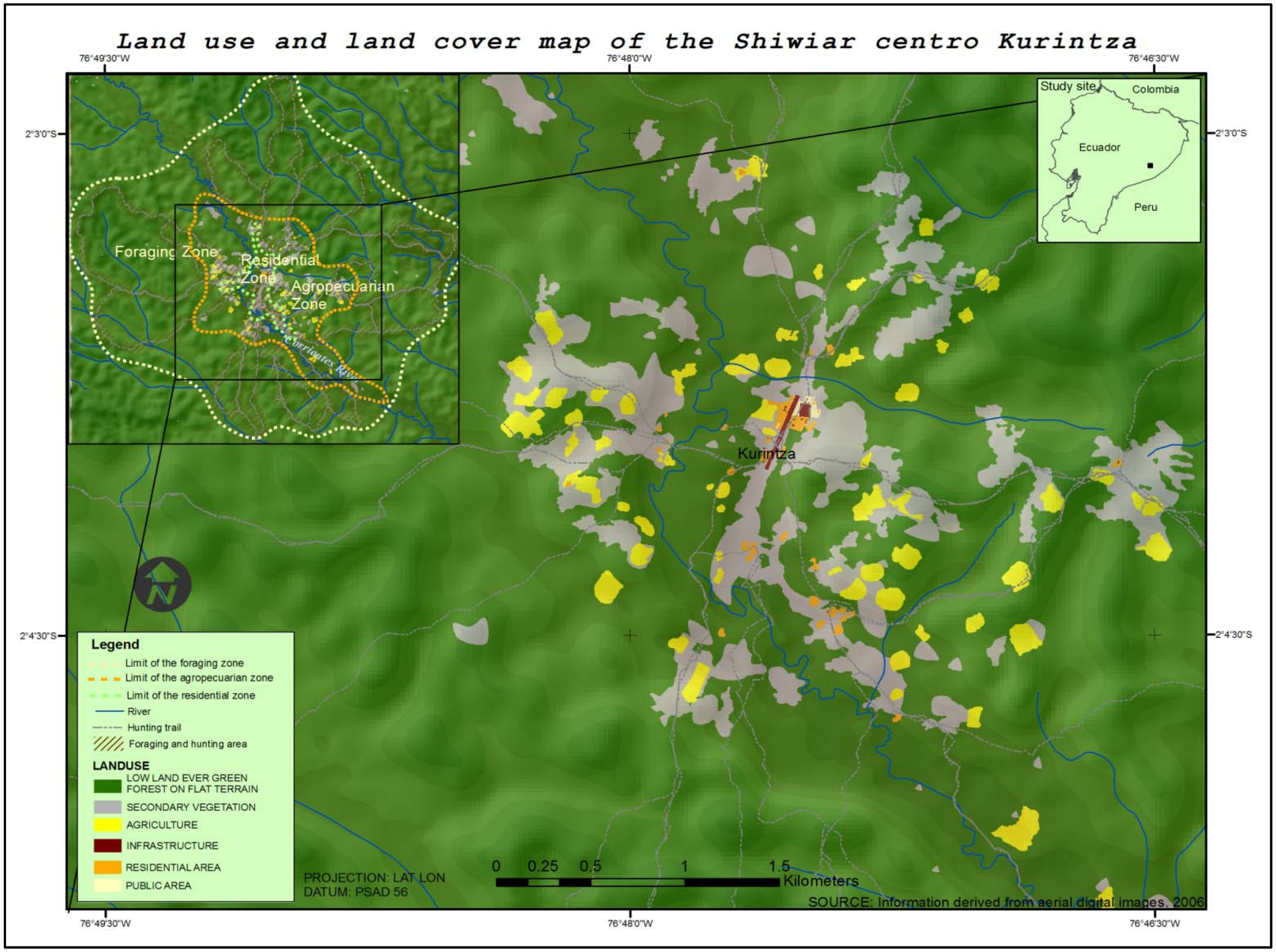


Figure 7.13: Land use and land cover map of the Shiwiar *centro* Kurintza derived from the interpretation of aerial

Table 7.2: Descriptive statistics of land use areas in the in the northern (inter-fluvial) and southern (riverine) PRBEA, and results of the statistical t-tests.

	Descriptive Statistics	Northern PRBEA	Southern PRBEA	Levene's Test for Equality of Variances		t-test for Equality of Means		
				F	*Sig.*	*t*	*df*	*P value*
Housing area per houshold (in m^2)	N	69	47	0.04	0.83	0.49	114.00	0.63
	Mean	1384	1266					
	Std. Dev	1227	1327					
Agricultural area per houshold (in ha)	N	55	46	1.84	0.00	-3.69	99.00	0.00
	Mean	1.68	1.03					
	Std. Dev	0.90	0.71					
Commercial agricultural area per houshold (in ha)	N	55	46	19.21	0.00	2.62	99.00	0.01
	Mean	0.01	0.08					
	Std. Dev	0.10	0.15					
Pasture area per household (in ha)	N	6	8	0.045	0.835	-0.37	12	0.72
	Mean	1.01	1.19					
	Std. Dev	0.85	0.78					
Hunting area per household (in ha)	N	45	32	0.361	0.55	-0.57	75	0.571
	Mean	242.00	254.00					
	Std. Dev	90.25	79.09					

evaluation of the spatial configuration of production systems in the riverine and inter-fluvial habitats. Results indicate that differences in size of residential units between the inter-fluvial and riverine households are not significant, which means that families in both regions are similar in size and space requirements. Indigenous households allocate, on average, 1,325 m^2 for this type of land use. In relation to the extent of agriculture, the size of cultivation areas is significantly different in both regions. Inter-fluvial households allocate 38 percent more land for cultivation land use than southern landholders. In general, an indigenous household allocates 1.36 ha for cultivation purposes. However, the analysis of commercial agricultural area shows different results. Southern households allocate 0.07more ha to commercial production than households in the northern region, which can be an indication of differences in levels of market integration. In fact, several communities in the Huasaga River basin have been involved in sporadic productive projects since the late 1990s (Chankuap Foundation, 1996). The extent of pasture areas is not significantly different between the northern and southern PRBEA. The average size per household of pasturelands in the region is approximately 1 ha. In general, cultivation areas and pastures account only for less than 1 percent of the total study area. Foraging areas (i.e. hunting and gathering) make up approximately 47 percent of it.

3. The residence: the core of indigenous production systems

The residential area constitutes the center of indigenous production systems. The residential area is generally occupied by one family, sometimes augmented by the presence of sons-in-law and other singular members of the husband's family or of his wife or wives. Descola (1987; p. 153) refers to these members as "satellite relatives".

However, the presence of these relatives is generally temporary. Each residential unit corresponds to a domestic autonomous production and consumption group. Whether a residential unit is aggregated to a nucleated village or lies in relative isolation, it is always the domestic unit that constitutes the immediate frame for the appropriation and alteration of land resources.

Data derived from the photomosaics and GPS measurements indicate that the average size of a Jívaro traditional house is 90 m^2, and although houses of up to 280 m^2 were found in the subject communities, these cases were rare. The average size of the cleared area adjacent to the house is 1,285 m^2. The average size of the overall residential area in the Achuar and Shiwiar territories is 1,375 m^2 with no significant differences among them. Descola (1987) associated large residential constructions (i.e. houses ≥ 280 m^2) with the existence of "great men". "Great men" were accomplished warriors who collected obligations from their neighbors by providing protection and agreeing to assist with the assassinations of enemies (Harner, 1972; Descola & Lory, 1982). Despite the fact that tribal wars have been entirely suppressed in the Jívaro territory and there is no need for several families to move into a single large house, some are still built by older members of the communities as a way to show their wealth or socio-economic status. Generally, large houses are occupied by households composed of a male household head and two or more wives.

4. The agricultural and cattle-raising elements of indigenous production

The agricultural and cattle-raising zone constitutes a space temporarily or permanently transformed by anthropogenic use. Several indigenous societies in tropical lowlands practice some kind of shifting horticulture that generally involves the slash-and-burning or mulching of primary or secondary forests. In some instances, a secondary forest can be so old that it may be difficult to differentiate it from old growth forests. The technique of clearing consists of a preliminary cleaning of the undergrowth and it is done by the male head and older sons of the household, followed by cutting of the small trees with a machete. Then, the large trees are felled so that they drag along the mass of the small trees in their fall. After a period of two or more months, depending on climatic conditions, the men and women of the domestic unit either begin the burning or leave the debris for mulching purposes. The men usually pile up the debris of dry branches for women to later stack them. Thereafter, the new plot is exclusively the domain of women. Women activities in the new *chacra* include transplanting, planting, and weeding. The exception to this exclusively female domain is the planting of certain crops such as cacao, peanuts, or maize which remain in effective control of men (although the harvesting is still done by women). Each married woman has her own plot, clearly delimited by trails and/or plantain fences (Figure 7.14). Each woman is only responsible for the crops, plantations, weeding, and harvesting of the plot. Hence, it is not appropriate in this study to analyze indigenous agricultural systems in the Pastaza region under the idea of communal exploitation.

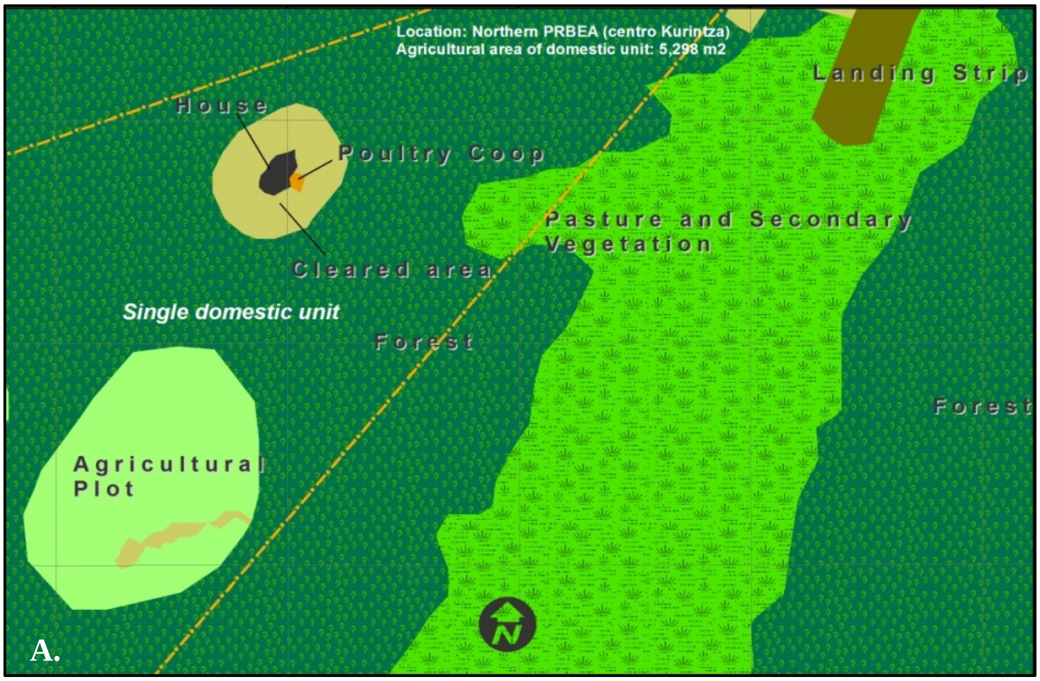
4.1 The spatial characteristics of horticultural production

In the southern region cultivation areas tend to be more clustered around the landing strip than in the northern area. In the southern region the mean distance from the center of the airfield to the edge of agricultural and pasture areas is 0.33 kilometers,

Figure 7.14: Example of a single family cultivation field in the community of Tsunkintza. A) An aerial view of a *chacra* clearly delimited by a plantain fence. B) A photograph of the owner of the same *chacra* in the center of the manioc crop.

whereas in the north it increases to 1.24 kilometers. Similarly, cultivation plots are generally closer to homes in the riverine environment than in the inter-fluvial habitat. In fact, the average time to reach an agricultural plot from the owner's residential area in the riverine area was 3.5 min, compared to 13 min in the northern region. Most exceptional cases were found in the northern environment where some *chacras* were located as far as 50 min away from the owner's residence. Generally, most *chacras* are located nearby the owner's residential space and can be reached within 15 minutes by foot. Figure 7.15a shows the typical footprint of a single domestic unit in the inter-fluvial biotope, in which one wife owns one agricultural parcel or *chacra.* In this typical pattern, the housing area is not immediately adjacent to the landing strip and the agricultural area is not adjacent to the housing area. Figure 7.15b shows the typical land use pattern of a single domestic unit in the riverine habitat. In this example, there are two wives in the household and each wife is responsible for her own agricultural plot. The housing area is located next to the landing strip and the cultivation area is adjacent to the residential area. These results indicate a more clustered pattern of *chacras* and residential units in the riverine habitat than in the inter-fluvial environment.

Figure 7.16 shows the areas and proportions of main crops managed by an average household in the lower Pastaza Basin. The graphic shows that the most important subsistence crops are, in order, manioc (*Manihot esculenta*) (80 percent of the total cultivation area), and plantain (*Musa spp.)* (10 percent of the household's cultivation extent). Manioc is planted in almost all fields, typically intercropped with a wide range of other crops such as *naranjilla* (*Solanum spp.)*, pineapple (*Ananas comosus*), sugar cane



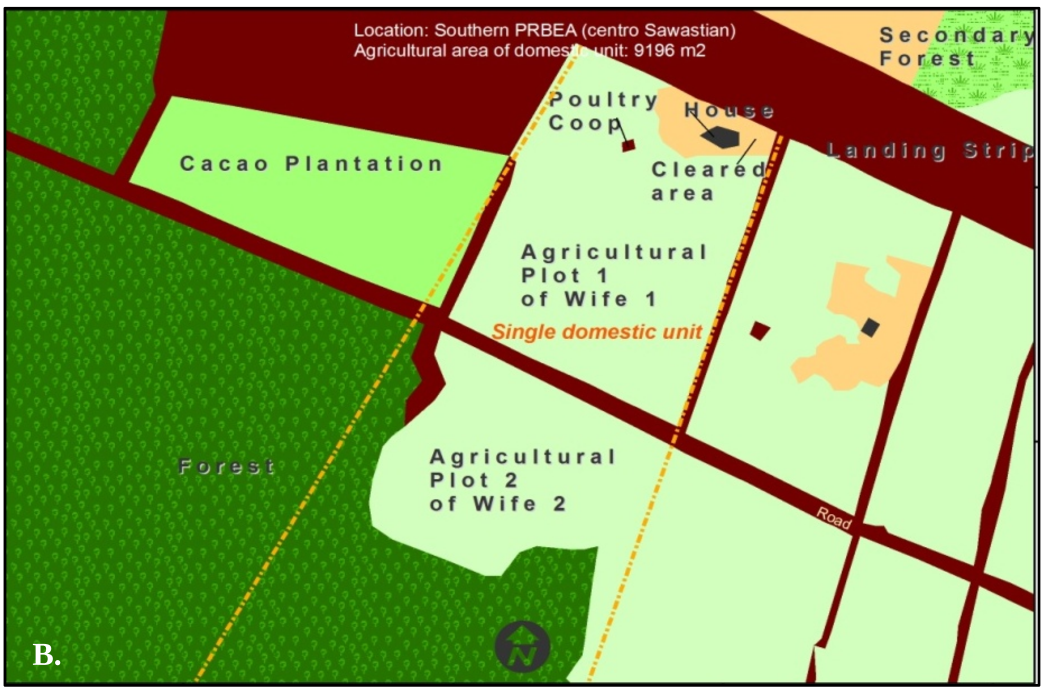


Figure 7.15: Typical land use patterns in recent nucleated settlements in Western Amazonia: A) A single domestic unit in the inter-fluvial habitat (northern PRBEA). Agricultural plots are generally located farther away from the landing strip, B) A single domestic unit in the riverine environment (southern PRBEA). Agricultural plots are located usually closer to residential areas and landing strips.

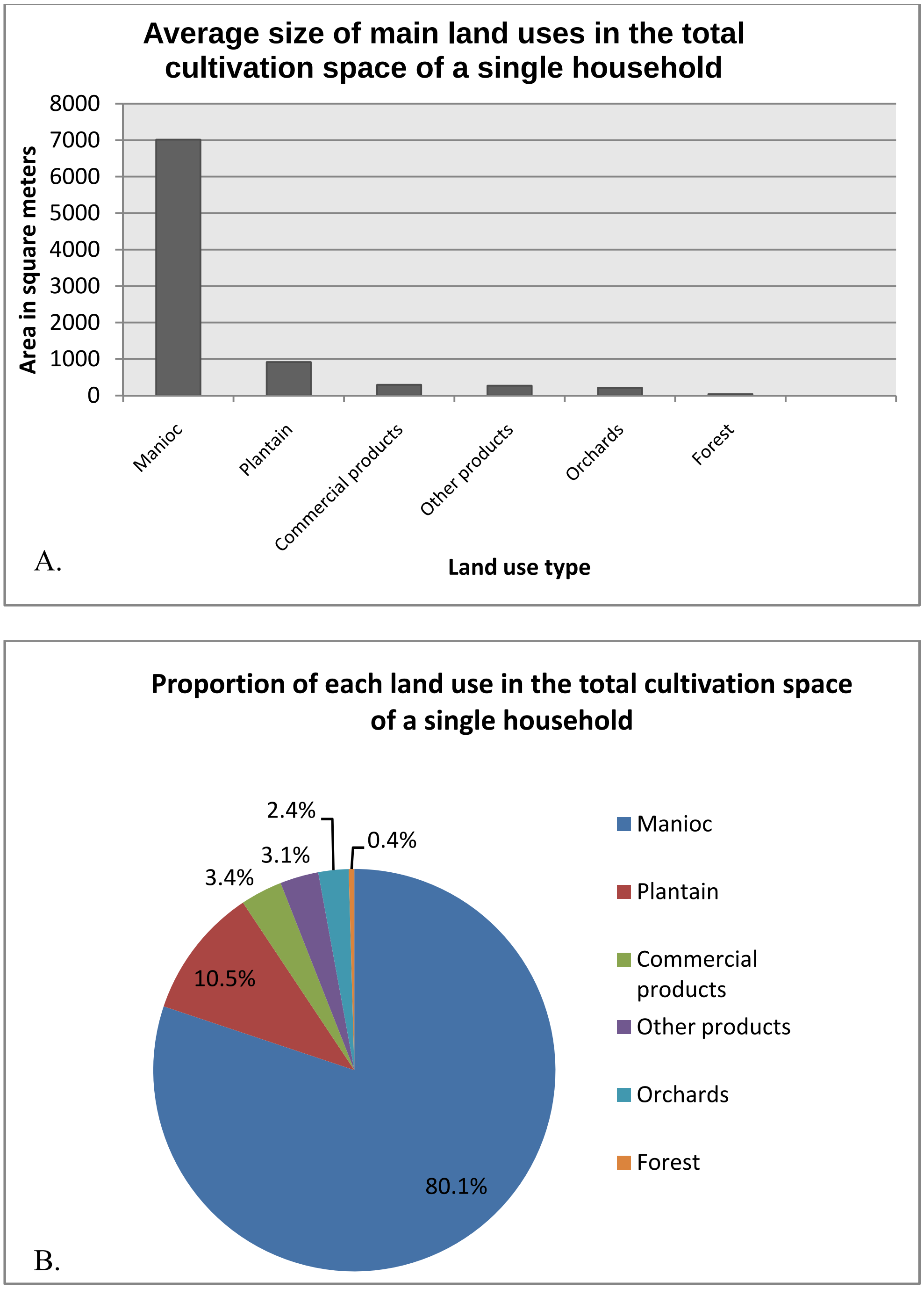


Figure 7.16: Main crops and land uses in the total cultivation space of an average household. A) Average size of land use and production areas. B) Proportional size of main land uses in relation to the total extent of cultivated land.

Saccharum spp.), sweet potato (*Ipomea batatas*), or maize (*Zea mays*). Some cultivation plots contain fruit trees such as orange (*Citrus sinensis*), banana (*Musa paradisiaca*), guaba (*Inga edulis*), or *fruti-pan* trees (*Artocarpus altilis*), but these occupy less than five percent of the household's cultivated area. Plantains are generally planted along the borders of the fields. Commercial crops account, on average, for 4.5 percent of the total cultivated area. The average household in the southern PRBEA allocates 8.10 percent of the available cultivated land for the production of commercial products, whereas the average household in the northern area only allocates 0.90 percent. In general, the average household allocates 50 percent of the commercial cultivation area to ground peanuts (*Arachis hypogea*), 43 percent to cacao (*Theobroma cacao*), 2 percent to achiote (*Bixa orellana*), and 5 percent to other products such as ginger (*Zinziber officinale*), hot pepper (*Capsicum sp*.), lemon grass (*Cymbopogon sp*.), among others (Figure 7.17). A characteristic of the system is that crops are harvested in succession. A similar attribute has been noted in other cultivation systems in the Corrientes and Bobonaza Rivers basin of the Ecuadorian Amazon (cf. Sirén, 2007). In the Pastaza River basin, a common succession is manioc-plantain; manioc harvested about 9 months up to a year, the age at which the plantains start to be harvested. Plantains are usually harvested two or three times and then fields are left for recuperation as fallows. In the riverine system, the average activity time of a cultivation plot is 3.7 years, whereas in the inter-fluvial area is 2.7 years, however this difference is not statistically significant. On the other hand, there is significant variation in the length of fallow period. In the riverine system fallows are on average 7 years, whereas in the inter-fluvial biotope the average fallow time is 20 years.

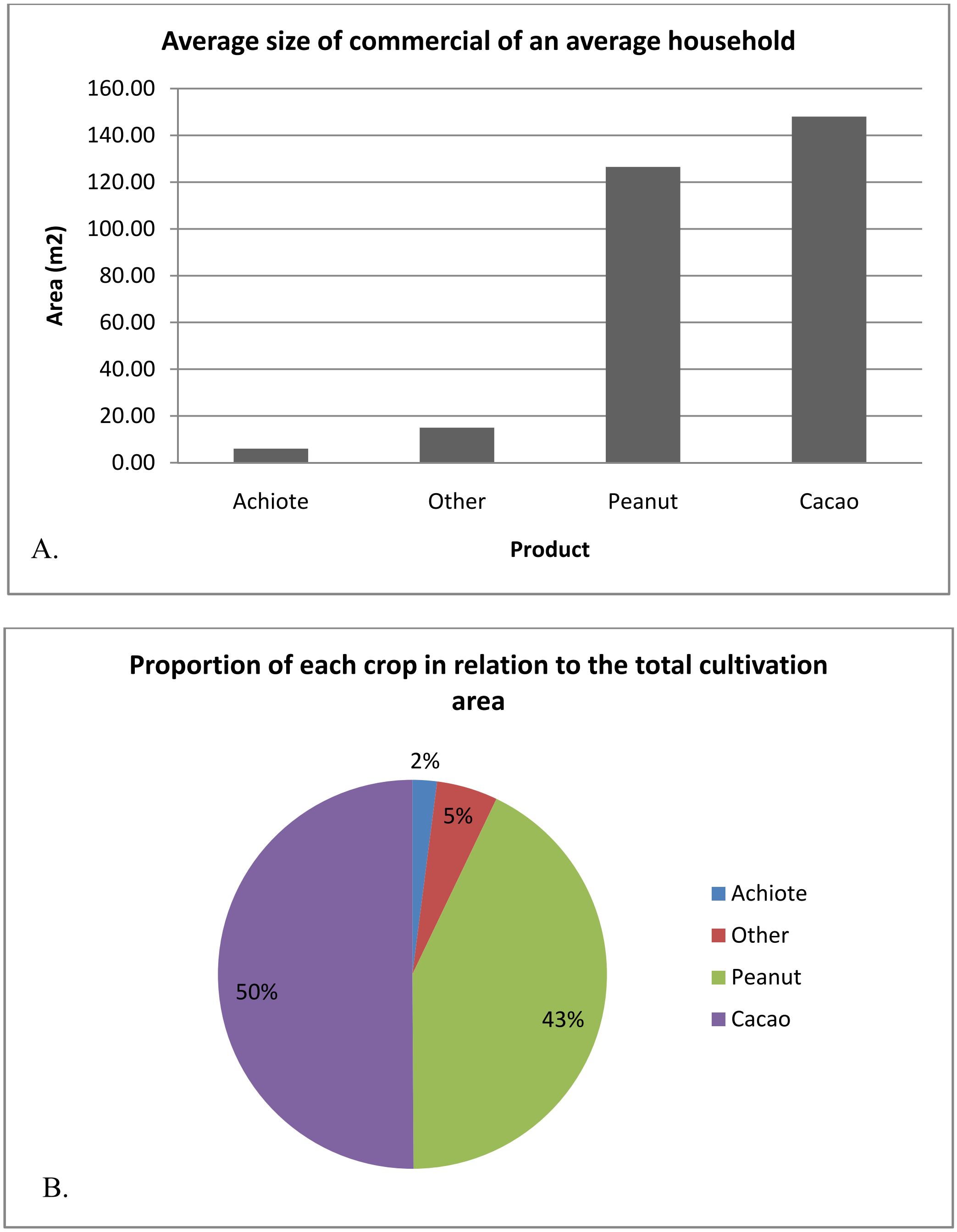


Figure 7.17: Size and proportion of commercial crops in an average cultivation area of a single household. A) Average size of main crops. B) Proportional extent of main commercial crops.

These differences may be explained by differences in soil quality and topography. According to the data, the average slope of *chacras* in the northern region is significantly larger than in the southern Pastaza basin (6 degrees vs. 2 degrees) and soils are less acidic and more fertile in the riverine area than in the inter-fluvial area (see Figure 4.9 in Chapter Four). These differences indicate that terrain conditions for cultivation purposes are probably better in the riverine area than in the inver-fluvial habitat, which, in turn explain differences in cropping and fallow periods. Cropping periods are longer in the riverine area and shorter in the inter-fluvial habitat however this difference is not statistically significant. On the other hand, fallow periods are significantly longer in the inter-fluve than in the riverine system. Interestingly, there are apparently no significant differences in relation to family size between both regions, which suggests productivity variation at the ecological level. Table 7.3 summarizes these results.

4.2 Changes in pasturlands and cattle ranching

Indigenous households in the region are apparently abandoning cattle ranching and many pasture areas are becoming fallows or turning into agricultural areas. Results obtained from change detection analysis in the community of Sawastian for the period 2003-2006 (Figures 7.18 and 7.19), showed that the agricultural area in this community increased 7.68 ha (0.18 percent), of which 1.17 ha (17.5 percent) were formerly pasture lands (Table 7.4). Seventy five percent (10.53 ha) of pastures in 2003 was left as fallow and returned to secondary vegetation in 2006. The extent of pastures decreased from 14.17 ha in 2003 to 4.12 ha in 2006, which represents a reduction of approximately 70 percent.

Table 7.3: Descriptive statistics of cropping, fallow, slope, population pressure, and family size conditions in the in the northern (inter-fluvial) and southern (riverine) PRBEA, and results of the statistical t-tests.

	Descriptive Statistics	*Northern PRBEA*	*Southern PRBEA*	*Levene's Test for Equality of Variances*		*t-test for Equality of Means*		
				F	***Sig.***	***t***	***df***	***P value***
Average activity time of cultivation fields (in years)	N	34	20					
	Mean	2.7	3.7	14.20	0.00	-1.61	52.00	0.11
	Std. Dev	1.3	2.8					
Average fallow period of old cultivation areas (in years)	N	34	20					
	Mean	20.29	6.90	14.19	0.00	7.66	52.00	0.00
	Std. Dev	7.58	2.29					
Slope of cultivation plots (in degrees)	N	34	20					
	Mean	5.84	2.16	28.04	0.00	6.69	52.00	0.00
	Std. Dev	2.36	0.82					
Population pressure (people/ha of cultivated land)	N	34	20					
	Mean	5.60	9.90	2.21	0.14	-1.97	52.00	0.05
	Std. Dev	5.28	10.75					
Family Size (number of people)	N	34	20					
	Mean	7.18	7.70	1.50	0.23	-0.51	52.00	0.61
	Std. Dev	3.18	4.31					

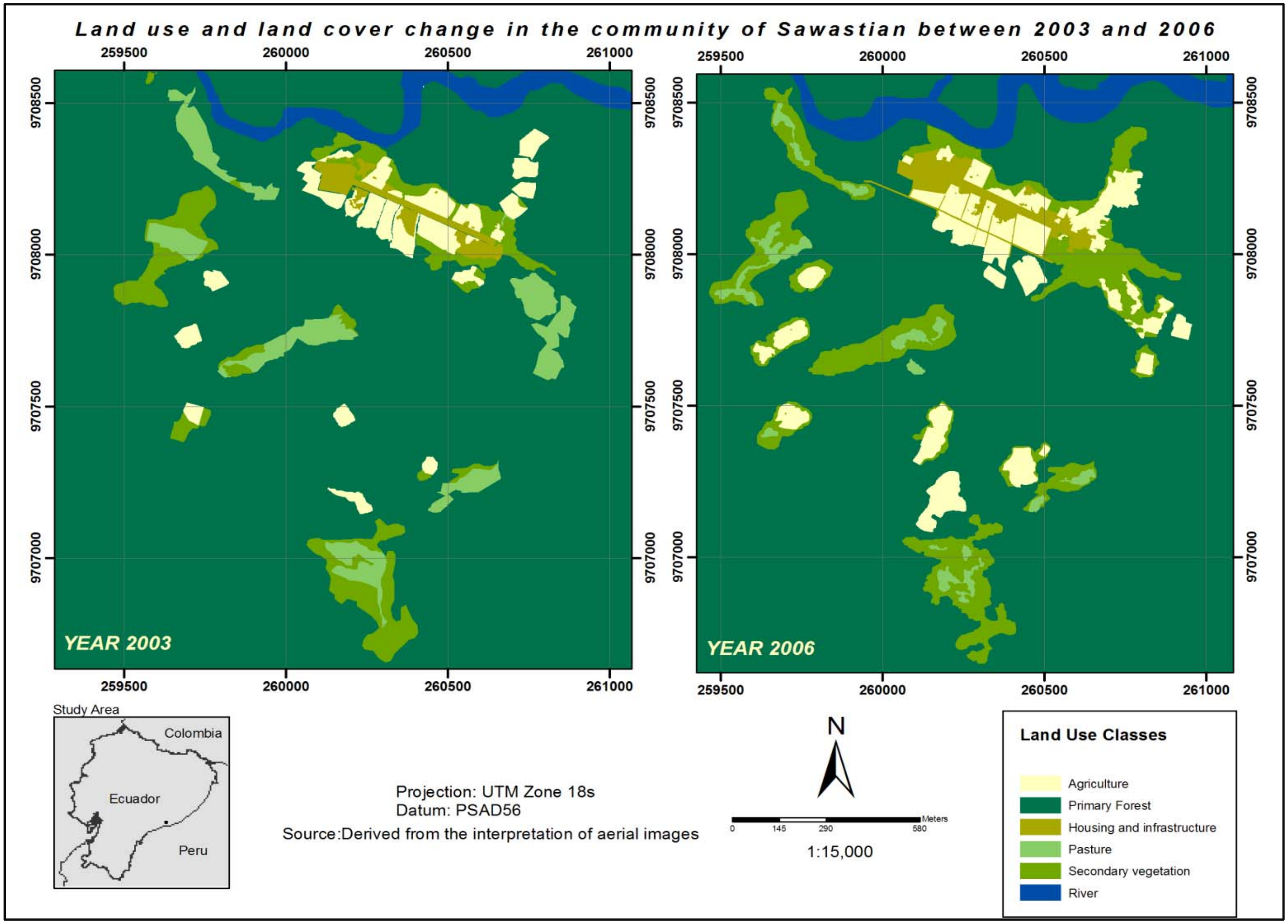


Figure 7.18: Land use and land cover change in *centro* Sawastian between 2003 and 2006.

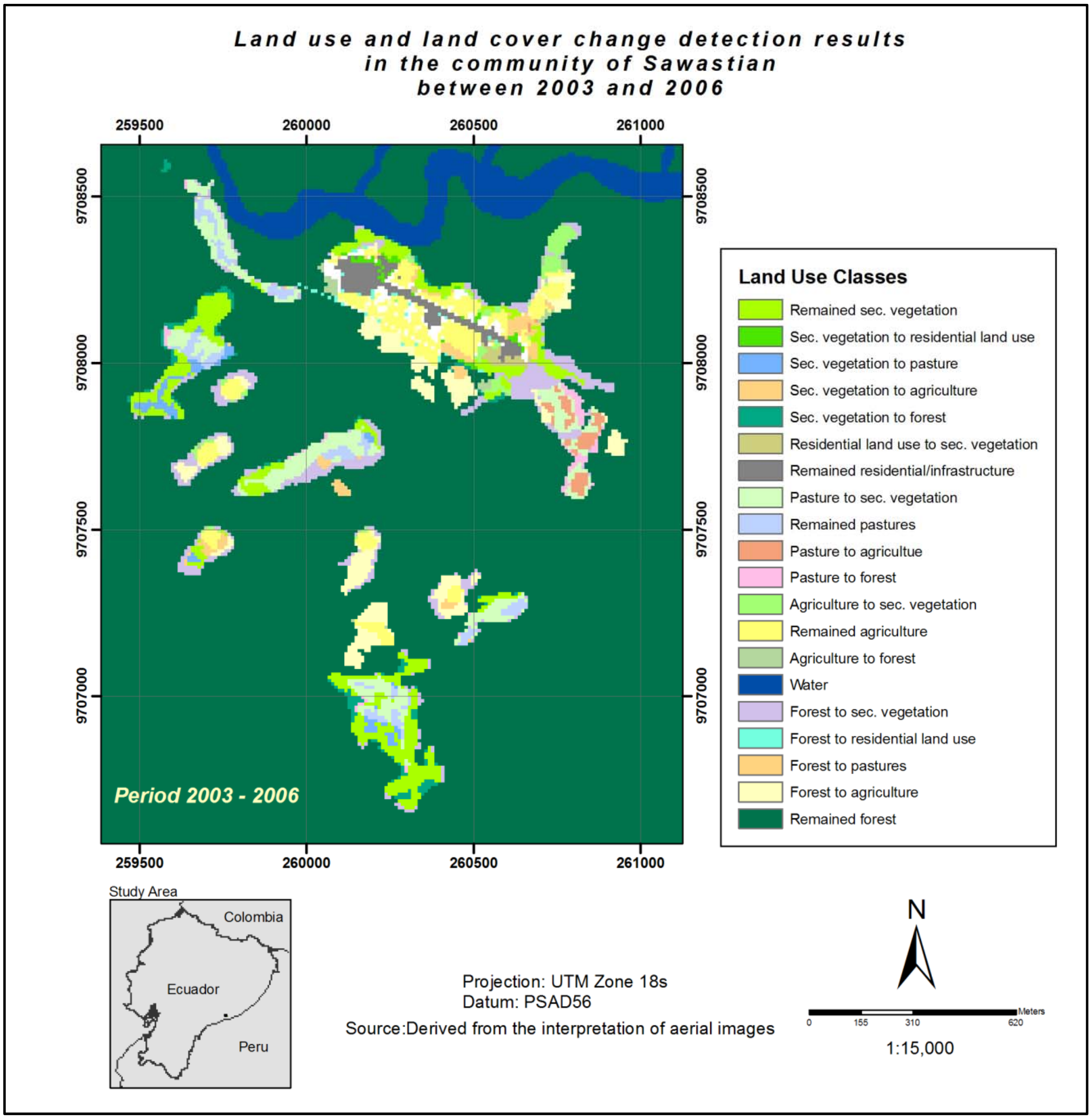


Figure 7.19: Land use and land cover change detection in c*entro* Sawastian between 2003 and 2006.

Table 7.4: Contingency table of land use and land cover areasin *centro* Sawastian between 2003 and 2006

*Areas in ha.

	Land Use in 2003						
LAND USE CLASSES*	**Agriculture**	**Pasture**	**Housing**	**Secondary Vegetation**	**Primary Forest**	**TOTAL**	**%**
Agriculture	6.79	1.17	0.48	1.53	7.00	**16.97**	**0.463**
Pasture	0.00	2.47	0.00	1.27	0.38	**4.12**	**0.112**
Housing	1.37	0.00	2.69	0.59	0.34	**4.99**	**0.136**
Secondary Vegetation	1.57	10.53	0.48	10.02	12.38	**34.98**	**0.955**
Primary Forest	0.56	0.00	0.00	1.85	3600.69	**3603.10**	**98.334**
TOTAL	**10.29**	**14.17**	**3.65**	**8.16**	**3627.89**	**3664.16**	
%	**0.281**	**0.387**	**0.100**	**0.223**	**99.010**		100

Land Use in 2006

From this amount, 2.47 ha (60 percent) remained as pasture land in both years. Thirty one percent (1.27 ha) of the extent pastures in 2006 was obtained from clearing secondary vegetation and 10 percent was from clearing forest cover. Forest cover experienced a decrease of ~24 ha in three years at an annual loss rate of 0.23 percent. Presently, the average household in the northern region allocates 0.17 ha less to pastures than in the south, but this difference is not statistically significant. A typical household allocates, on average, approximately 1 ha to pastures.

4.3. The structural characteristics of cultivation systems

Results from the two sample t-tests show that the extent and intensity of agriculture is significantly different in the inter-fluvial habitat (northern PRBEA) and riverine habitat (southern PRBEA) (Table 7.5). It is important to note that the use of the terms “extensive” or “intensive” is relative to the system under study, in this case, traditional and subsistence based cultivation systems. This study used a simple comparison of the average cultivated area per person to characterize the level of efficiency of cultivation systems in the northern and southern PRBEA. Results indicate that groups in the inter-fluvial biotope tend to cultivate, on average, 49 percent more area than people in the riverine biotope, which indicates that cultivation in the north of the Pastaza River is more extensive or labor efficient than in the south (Figure 7.20).

It should be acknowledged that average area cultivated per capita is only a very general descriptor of the efficiency of one particular system. In order to place the Jivaroan situation within a broader context and conclusively evaluate this parameter, the study compared the average size of cultivated areas in this sample with those reported for

Table 7.5: Descriptive statistics and t-tests of the extent and intensity of agriculture in the northern and southern PRBEA.

	Descriptive Statistics	Northern PRBEA	Southern PRBEA	Levene's Test for Equality of		t-test for Equality of Means		
				F	Sig.	t	df	P value
Cultivation extent (m2/person)	N	34	20	6.69	0.01	2.98	52.00	0.004
	Mean	2084.34	1012.87					
	Std. Dev	1490.62	767.13					
Agricultural Output (Kg/ha/year)	N	34	20	15.10	0.00	-3.19	52.00	0.002
	Mean	3083.67	8551.63					
	Std. Dev	4039.82	8541.56					
Agricultural Intensity (Percentage)	N	34	20	20.45	0.00	-5.47	52.00	0.000
	Mean	12.66	31.52					
	Std. Dev	7.00	18.00					

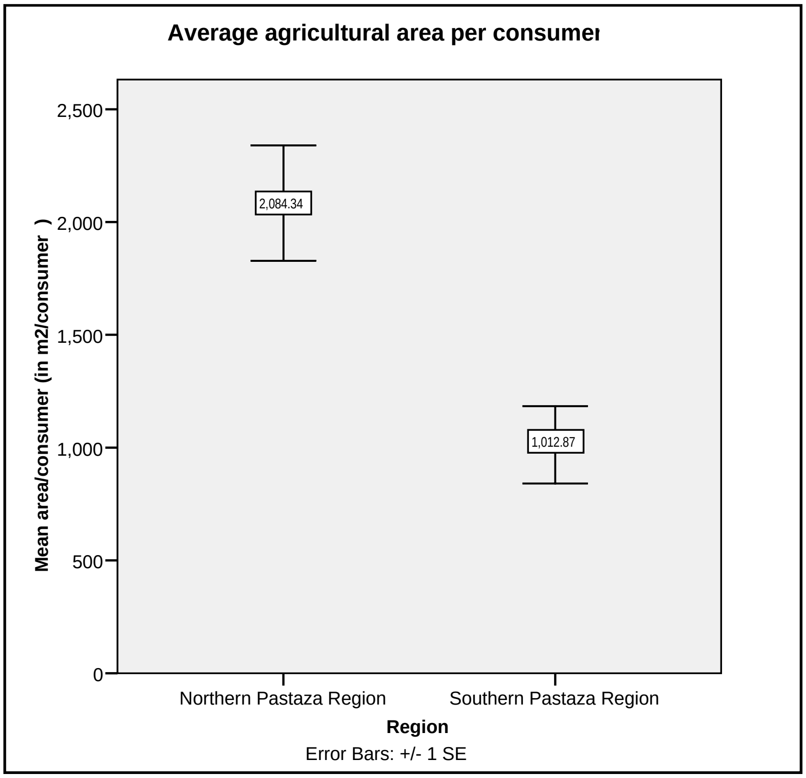


Figure 7.20: Average cultivation area per person in the northern and southern Pastaza River Basin in the Ecuadorian Amazon.

other Amazonian swidden cultivators (Table 7.6). It is clear from this table that the Jívaro of the southern PRBEA produce at least average and the Jívaro of the northern PRBEA produce almost 1 std. deviation above the average Amazonian swidden cultivators. If we compare the lowlands Jívaro with New Guinea slash-and-burn gardeners in the early 1970s, renowned for their productivity (Brookfield & Brown, 1963), we find that the riverine Jívaro cultivate slightly less area per person than the Kapauku (1,142m^2/person) (Pospisil, 1972) and almost the same average area for the Chimbu: 1,012 m^2/person (Brookfield & Brown, 1963). However, the Jívaro of the inter-fluvial region cultivate significantly above these amounts. This finding suggests that indigenous societies in the lower Pastaza River Basin that have similar social and cultural characteristics, have developed two cultivation systems that show significant structural differences.

This study used two measurements to evaluate the degree of agricultural intensity. The first measurement is a simple relationship between the yields of subsistence production and the area where these are obtained in a certain time period. Data derived from interviews and land use maps show that the average yearly subsistence production per household in the south (riverne habitat) significantly exceeds the production of the northern communities (inter-fluvial setting) by 5,469 kg/ha. The average household in the south produces roughly 8,552 kg/ha of food per annum for subsistence. The average household in the north produces 3,084 kg/ha. The second measurement is the proportion of time that each crop-fallow cycle is in the cropping phase. For instance, a crop-fallow cycle of 1:1 (one year of cropping to one year of fallow) is considered to have 50 percent intensity since each cropping unit is cultivated once every other year. A cycle of 1:0 is

Table 7.6: Average cultivated area per person in seven Amazonian populations (source Descola, 1994).

Population	Location	m2 / consumer	Z-score
Yanoama (Jorocoba -Teri)	Northern Brazil	405.00	-1.11
Yanoama (Niyayoba -Teri)	Northern Brazil	607.00	-0.86
Cubeo	Southeastern Colombia	810.00	-0.61
Central Yanomami	Brazil and Venezuela	900.00	-0.50
Jivaro (Southern Pastaza Region)	Southeastern Ecuador	1013.00	-0.36
Siona-Secoya	Norheastern Ecuador	1970.00	0.82
Jivaro (Northern Pastaza Region)	Southeastern Ecuador	2084.00	0.96
Kuikuru	Central Brazil	2632.00	1.64

taken to have one hundred percent intensity since each cropping unit is cultivated once every year with no fallow.

Results from the analysis of the crop/fallow ratio are consistent with the previous outcome. Agricultural intensity in the south (31.52 percent) is significantly higher than in the north (12.66 percent) (Figure 7.21). A descriptive comparison between different subsistence groups of the Amazon region and other tropical lowlands allows assessing whether the situation of indigenous groups in the Pastaza region is exceptional in this respect. Table 7.7 and Figure 7.22 show the agricultural intensities of twenty groups of tropical subsistence cultivators. These groups maintain different subsistence bases and occupy different tropical lowlands environments. It should be acknowledged though that the comparative data available in the literature on subsistence groups is both incomplete and inaccurate because it is based on estimates and no on direct field measurements as in this study. Moreover, data are presented as global averages, with no mention of the size of the sample. However, from these data it is clear that agricultural systems in the lower basin of the Pastaza River occupy different positions in the agricultural change continuum. In fact, the Jívaro from the interfluvial area are about 1 standard deviation below the sample's average agricultural intensity (the fifth lowest productivity of the sample), whereas the Jivaro from the riverine habitat produce about average.

These findings and comparisons between subsistence tropical groups suggest that forest-dwellers living in riverine and inter-fluvial habitats of Western Amazonia have developed cultivation systems that have significant differences in intensity and efficiency. These differences justify placing them at different stages of the agricultural

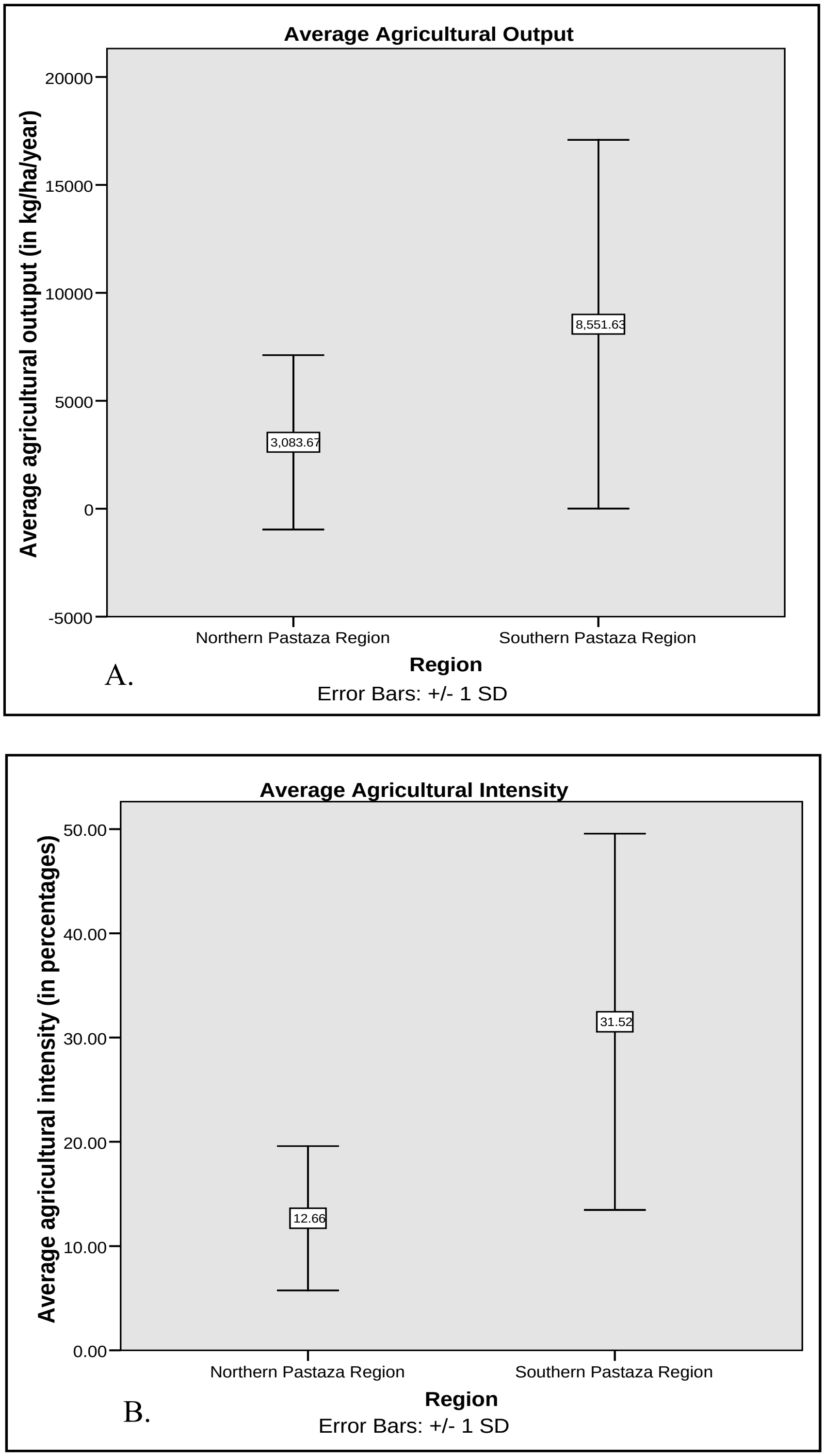


Figure 7.21: Level of agricultural intensity. A) Agricultural intensity measured as annual yield per area. B) Agricultural intensity measured as a percentage based on the crop-fallow cycle.

Table 7.7: Agricultural intensity and population pressure for twenty one tropical lowlands subsistence groups (source: modified from Turner, Hanham, & Portararo, 1977)

Group Id	Population	Location	Agricultural Intensity (percentage)	Z-Score Agr. Intensity
1	Kuikuru	Central Brazil	6	-0.8
2	Tsembaga	Madang Dist., New Guinea	7	-0.8
3	Iban	Baleh, Sarawak	7	-0.8
4	Campa	Gran Pajonal, eastern Peru	9	-0.8
5	Jivaro Achuar-Shiwiar (interfluvial habitat)	Western Amazonia, southeastern Ecuador	13	-0.7
6	Ngawbe	Western Panama	14	-0.6
7	Baegu	Malaita	16	-0.6
8	Yakö	Umor, Nigeria	16	-0.6
9	Miskito-Tasbapauni	Nicaragua	18	-0.5
10	Yaruro-Caño	Southeastern Venezuela	20	-0.5
11	Rarak village	Western Sumbawa	22	-0.4
12	Dani-Dugum	Balim Valley, West Irian	29	-0.3
13	Jivaro Achuar (riverine habitat)	Western Amazonia, southeastern Ecuador	32	-0.2
14	Ba Dugu Djoliba	Niger Valley, Southwestern Mali	35	-0.1
15	Chimbu	Naregu, New Guinea	50	0.3
16	Há apaí	Tonga Is., Polynesia	59	0.5
17	Amba	Toro Dist., Uganda	67	0.7
18	Karinya-Bajo Hondo	Venezuela	70	0.8
19	Kofyar	Jos Plateau, Nigeria	100	1.5
20	Kara	Ukara Is., Lake Victoria	100	1.5
21	Gwemba Tonga	Mid Zambesi, Zambia	150	2.8

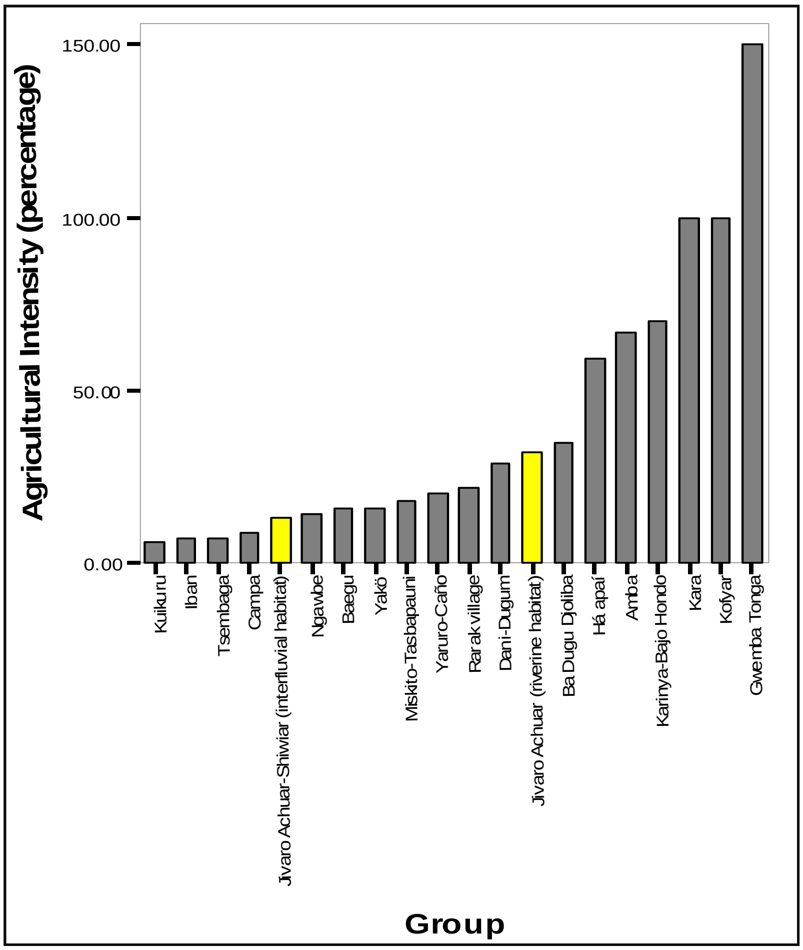


Figure 7.22: Agricultural intensity for twenty tropical lowlands subsistence groups (source: modified from Turner, Hanham, & Portararo, 1977). The yellow color depicts the populations studied in this document.

change continuum. Following Turner & Brush (1987) classification typology, indigenous agricultural systems in the riverine and inter-fluvial areas of the lower Pastaza River basin can be classified as paleotechnic (i.e. based on the usage of non-fossil fuels) and subsistence oriented (i.e. produce mainly for consumption). While the direction of both systems is towards the intersection of the three axes in Figure 2.1 in Chapter Two, the riverine system lies significantly above the inter-fluvial system along the vertical axis of production intensity.

5. The foraging element of indigenous production

Foraging areas are well known spaces and constitute an extension of the domestic unit. Hunting and gathering are two forms of occasional collection that differ from horticultural production, which occurs almost permanently. GPS data show that, generally, the area of intensive gathering extends one or two kilometers around pastures and cultivation areas. Hunting territories lie beyond the extent of the intensive gathering zone and stretch for a radius of approximately four kilometers. However, hunting may occur at any given distance from the household, which means that hunting territories may overlap with the other production zones. Further, agricultural areas and pastures are also used for hunting small rodents such as *guatusas* or *guatines* and could also be incorporated into the hunter's domain.

Figure 7.23 shows the main hunting trails of the seven subject communities mapped with GPS. Data on 77 hunting trails indicate that the length of a hunting trail ranges between 2.5 km and 21 km, averaging 10.5 km (Table 7.8). These distances may require walking times between 1.5 to 10.5 hours, depending on terrain conditions and

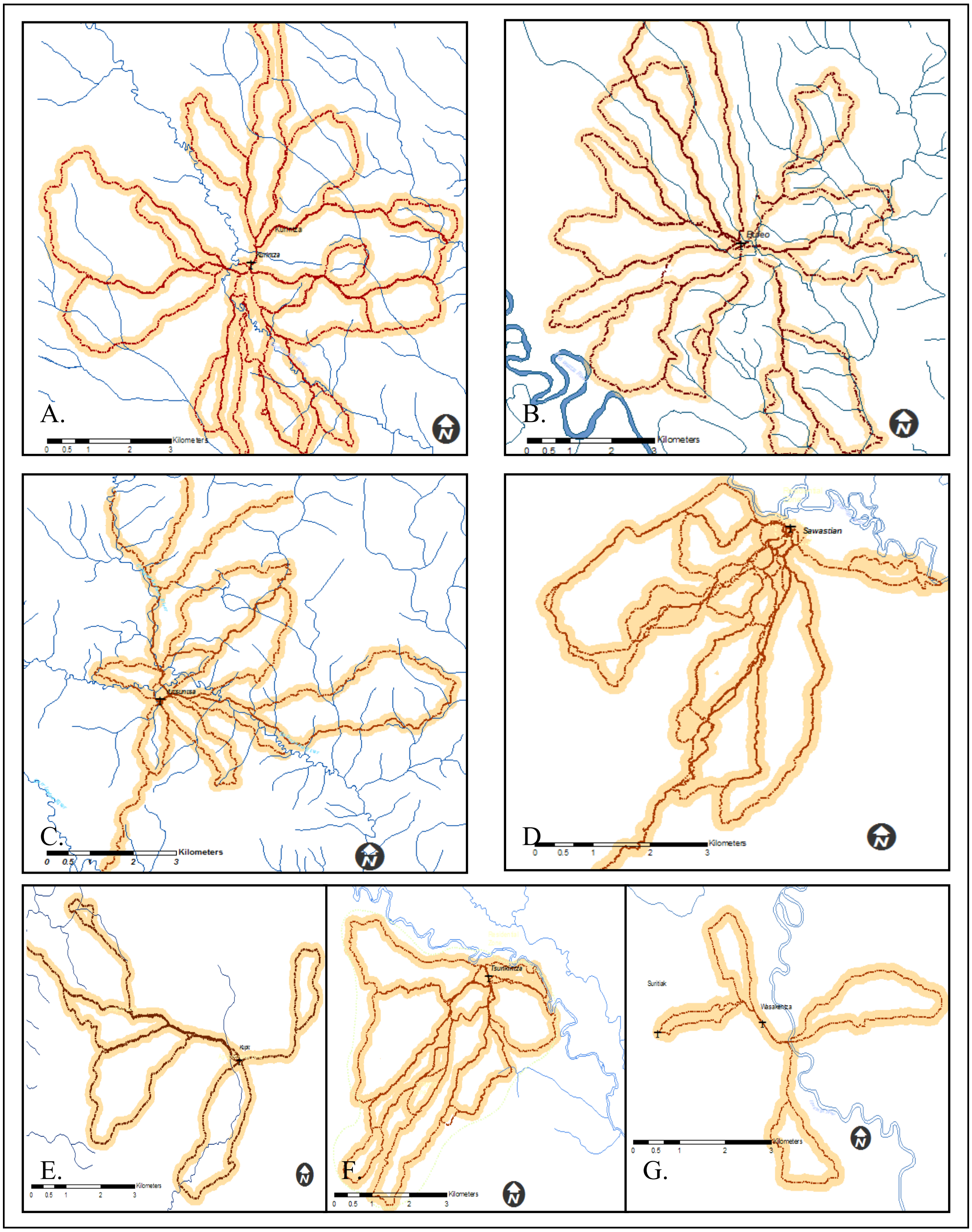


Figure 7.23: Main hunting trails and areas of the subject communities. A) Kurintza, B) Bufeo, C) Yuntsuntza, D) Sawastian, E) Kupit, F) Tsunkintza, G) Wasakentza.

Table 7.8: Descriptive statistics of variables used to characterize hunting areas and trails

Variable	N	Mean	Min	Max	Std. Dev
Length of hunting trails (in Km)	77.00	10.50	2.50	20.70	3.10
Euclidean distance from the center of the village to the trail's outmost coordinate (in Km)	77.00	4.10	1.50	8.10	1.30
Hunting areas (in ha)	77.00	247.00	43.00	429.00	84.90

vegetation cover. Straight distances between the outmost point of a hunting trail and the center of the village ranged between 1.5 km and 8.1 km, averaging 4.1km. Hunting areas, which were delimited using 150 m buffers along hunting trails, are on average 12 ha larger in the riverine habitat than in the inter-fluvial area, but this difference is not statistically significant.

The density of trails at five different distances from villages was also calculated as a proxy of hunting pressure. Results show that the density of trails declines with an increase in distance, which may be an indication that most hunting occurs close to villages (Figure 7.24). However, trails close to the landing strip can be considered as general purpose pathways since they are also used for connecting households with cultivation, residential, and service areas. These trails usually spread up to two km around the landing strip. Trails that are used almost exclusively for hunting exist beyond the extent of general purpose trails and it could take up to one hour of walking from the landing strip to find them. Whether or not general purpose trail segments are taken into account for the estimation of hunting pressure, it can be suggested that hunting pressure declines with an increase in distance from the center of the community. Further, it be suggested that hunting is usually preferred within a radius of 5-10 km from the village's center. In general, spatial patterns of hunting trails, areas, and densities are not significantly different in the southern or northern regions of the PRBEA.

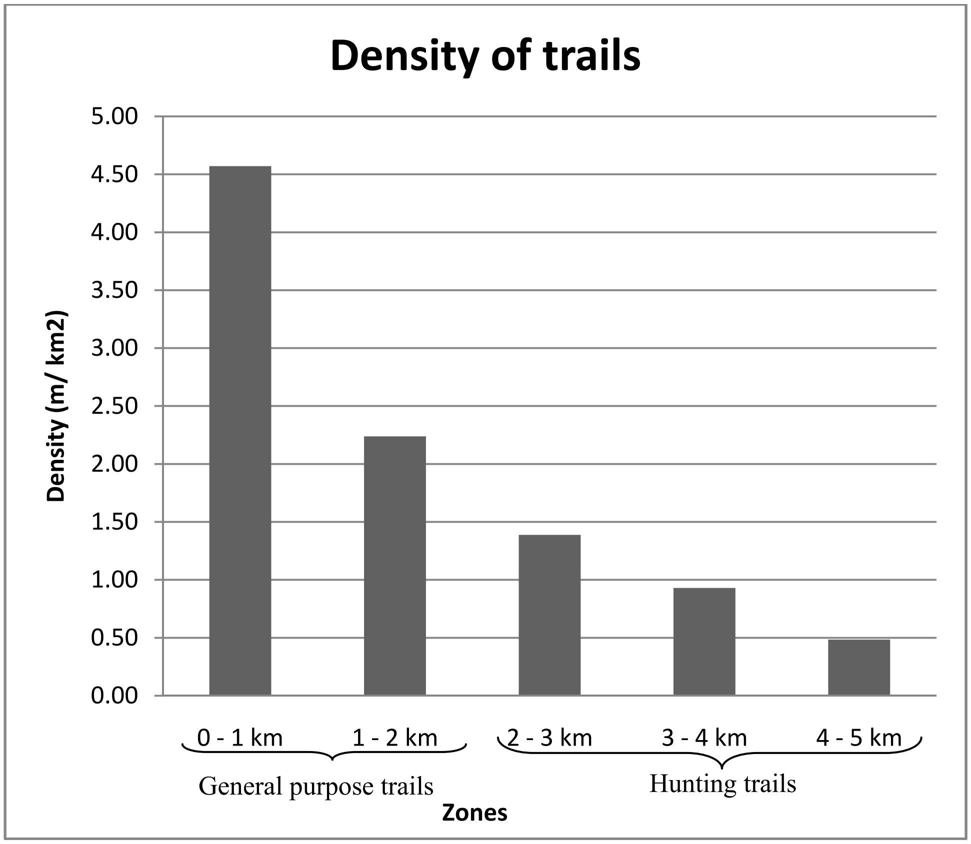


Figure 7.24: Density of trails at different distances from a village. Trails close to the landing strip are also used for connecting households with cultivation, residential, and service areas. These trails usually spread up to two km from the landing strip. Trails used almost exclusively for hunting exist beyond the extent of general purpose trails. In general, spatial patterns of hunting trails, areas, and densities are not significantly different in the southern or northern regions of the PRBEA.

Chapter Eight

The Demand for Land Resources in Traditional Agricultural Systems

1. Introduction

The analysis of the relationships between agricultural land use and the socio-ecological context of indigenous peoples allows determining the factors that cause environmental change. The first step in this process is to explore the relationships between a series of factors that may affect household's decisions on whether to clear forest area for agricultural production or leave it unchanged. This can be done using descriptive analyses that can show not only possible relationships, but also nonlinearities and threshold effects that can be important to consider in formulating variables for the examination of the extent and occurrence of agricultural land use. The next step is to analyze the combinatory effect of the most important factors that explain the occurrence of cultivation. This can be done using a multivariate statistical approach that allows determining the contribution of each factor to the overall level of landscape variation. This step is fundamental for the construction of a spatially explicit land use model that could be used for the systematic evaluation of the combination of individual decision-making processes on the demand for land resources at a community level.

This chapter presents the results of the analysis of the statistical and spatial analyses of indigenous production with emphasis on agricultural land use. Section Two discusses the results of the descriptive analyses. Section Three shows the results of the multivariate statistical evaluation. The analyses concentrate on the identification of key factors associated with the presence of agricultural land use. Finally, Section Four integrates the multivariate analysis into a spatially explicit model that simulates the expansion of agriculture within the context of a shifting cultivation land use system. The results of the validation process are presented and discussed.

2. Descriptive analysis of the demand for land resources

Before undertaking a multivariate approach to analyze households' preferences on land allocation for agricultural purposes, it is important to explore the relationships between dependent and independent variables using descriptive analyses. Table 8.1 shows the descriptive statistics of the size of cultivation areas and possible independent variables used in the analysis of the extent of agriculture. Results of the correlation analysis between cultivated area per household and a series of possible independent variables show important, although bivariate, relationships. Table 8.2 shows the results of an exploratory cross-tabulation of these variables.

The bivariate analysis shows that conversion costs, proxied as slope, is positively associated with the size of agricultural areas. Despite the fact that the average slope of agricultural areas is relatively small (4 degrees or 7 percent), there is a trend that indicates that larger parcels are more likely to be placed on relatively steeper terrain than on flat areas. Although this correlation may contradict the initial hypothesis that agricultural expansion is more likely to occur in flat terrain areas, it provides some insight on the effects of land resource management in a limited cultivable-land environment. Since pioneering households established residence in the surveyed villages between the late 1970s and mid 1980s, it can be expected that optimal areas for food cultivation are currently scarce, recuperating as fallows, not available to younger households due to local

Table 8.1: Descriptive statistics of the dependent and independent variables used in the analysis of agricultural land use.

		Variable	Minimum	Maximum	Mean	Standard Deviation
Sparial variables	N=101	*Agricultural area (in ha)*	0.16	4.87	1.35	0.88
		Conversion costs (Average slope in degrees)	0.00	10.49	4.00	2.48
		Costs of moving (Travelling time in minutes)	0.00	49.98	11.03	10.60
		Distance to landing strip (in Km)	0.00	3.11	0.46	0.56
		Nearest neighbor (in Km)	0.00	1.34	0.20	0.21
		Soils (categorical)	0 ="bad"	1 = "good"	—	—
Demographic variables	N = 55	*Family size (# of people)*	2.00	18.00	7.37	3.60
		Number of Producers (# of people)	1.00	6.00	2.83	1.29
		Number of Consumers (# of people)	0.00	12.00	4.50	2.54
		Dependency ratio (no units)	0.00	3.00	1.65	0.78
		Age of household's head (years)	20.00	74.00	39.13	12.85

Table 8.2: An exploratory cross-tabulation of the dependent variable against a number of possible independent variables

		Conversion costs	*Soils*	*Costs of moving*	*Dist. to landing strip*	*Nrst. Nbor. Dist.*	*Family size*	*Producers*	*Consumers*	*Dependency ratio*	*Age of household head*
Agricultural Area	***Pearson (Point Biserial if variable is categorical) Correlation***	0.202**	-0.332***	0.348**	0.329***	0.256**	0.28**	0.25*	0.27**	0.08	0.06
	Sig. (two tailed)	0.041	0.002	0.012	0.000	0.010	0.043	0.070	0.050	0.567	0.668
	N	101.00	101.00	101.00	101.00	101.00	55.00	55.00	55.00	55.00	55.00

* 0.1 level
** 0.05 level
*** 0.01 level

institutions regulating the access to land, or used for other purposes such as for residential or infrastructure development (e.g. extension of the landing strip, construction of communal services, etc). Similarly, the negative correlation between soils and the extent of cultivation areas suggests that larger agricultural areas tend to be located in areas with poorer soil conditions. These results suggest that agriculture is expanding to areas with topographic and pedologic conditions that are less than optimal for cultivation, where conversion costs are high, but the need for food outweighs these costs. This explanation is consistent with the interpretation of the relationship between agricultural areas and the average travelling time from residential to cultivation areas.

Contrary to what was expected, travelling time from homes to cultivation plots is positively correlated to the size of cultivation areas. Results show that people currently travel longer distances from their houses in the search for suitable agricultural land than they used to in the past right after settling in the village. As agricultural area increases with walking time to agricultural plots, people are apparently walking longer distances to access available, although less suitable, land for cultivation. Hence, although available land is currently located farther away from homes than in the past, production obtained from these areas probably outweighs the costs of traveling longer distances. The positive correlation between size of cultivation areas and distance to landing strip may be explained by similar reasons influencing the positive correlation with travelling time. Since most households have settled around landing strips, both variables are probably explaining the same kind of variation in the dependent variable. Whether travelling time or distance to landing strip is more useful to explain variations in agricultural land use will be discussed more in detail through the analysis of their combinatory effect.

The correlation analysis shows that average distance from an agricultural area to its closest neighbor is positively linked to the size of cultivation areas. That is, the farther agricultural plots are from each other the larger they become. This correlation helps to explain current land use patterns related to the density of cultivation areas. As less space is available around landing strips due to demographic growth and agricultural extensification, cultivation plots tend to be located farther away from airfields where land is available. Cultivation plots tend to be smaller the closer they are from each other due to the concentration of sites and limited space. In contrast, agricultural areas tend to be larger the farther apart they are from each other, but are located where enough space exists. This finding reinforces the notion that, currently, there is more available land for cultivation on the periphery of current residential and cultivation zones than in areas immediately adjacent to them.

As it was hypothesized, there is a positive correlation between family size and amount of cultivated land, which indicates that household size is a key variable that is useful to predict agricultural expansion in indigenous production systems. When family size is disaggregated into consumers and producers, the number of producers shows a weaker correlation with the size of cultivation areas, whereas the number of consumers is significantly correlated. This means that the number of consumers plays a more significant role in determining the demand for land than producers. The explanation for the lack of effect of the number of producers on the size of agricultural area may be that the amount of food required to sustain producers can be obtained from a relatively small fraction of the total cultivated land required to feed children and elders.

Apparently, there is no relationship between agricultural area and the dependency ratio or household's age. However, the proportion between consumers and producers varies along the household's life cycle (e.g. from having no children to small children, adolescent children, young adults, children leaving the household, or marrying). Thus, the extent of agriculture may vary in a non-linear way along this cycle. Figure 8.1 depicts the household's life cycle using a sample of fifty five households. The blue line depicts the dependency ratio by age group. The gray bars represent the average farmed land. This figures shows that there is a clear correlation between farmed area and the dependency ratio along the different phases of household development. It can be observed that at the beginning of the cycle, young households with no children start with no or a minimum amount of farmed land. As the size of households increases, the amount of farmed land increases as well. An inflexion point on this trend occurs when the children are old enough to get married (i.e. between 16 and 25 years old as shown in the graph), and leave the household. The household's size decreases as well as the amount of cultivation land. As less people live in the household and less resources are demanded to feed the remaining members of the household, the amount of accumulated land decreases. In some cases, parents may redistribute land among their married children which will also contribute to a decrease in farmed land. A change in the slope's direction is noticed when households are between 31 and 35 years old. The increase of the dependency ratio can be explained by the presence of satellite relatives such as brothers or sisters in law, widows,

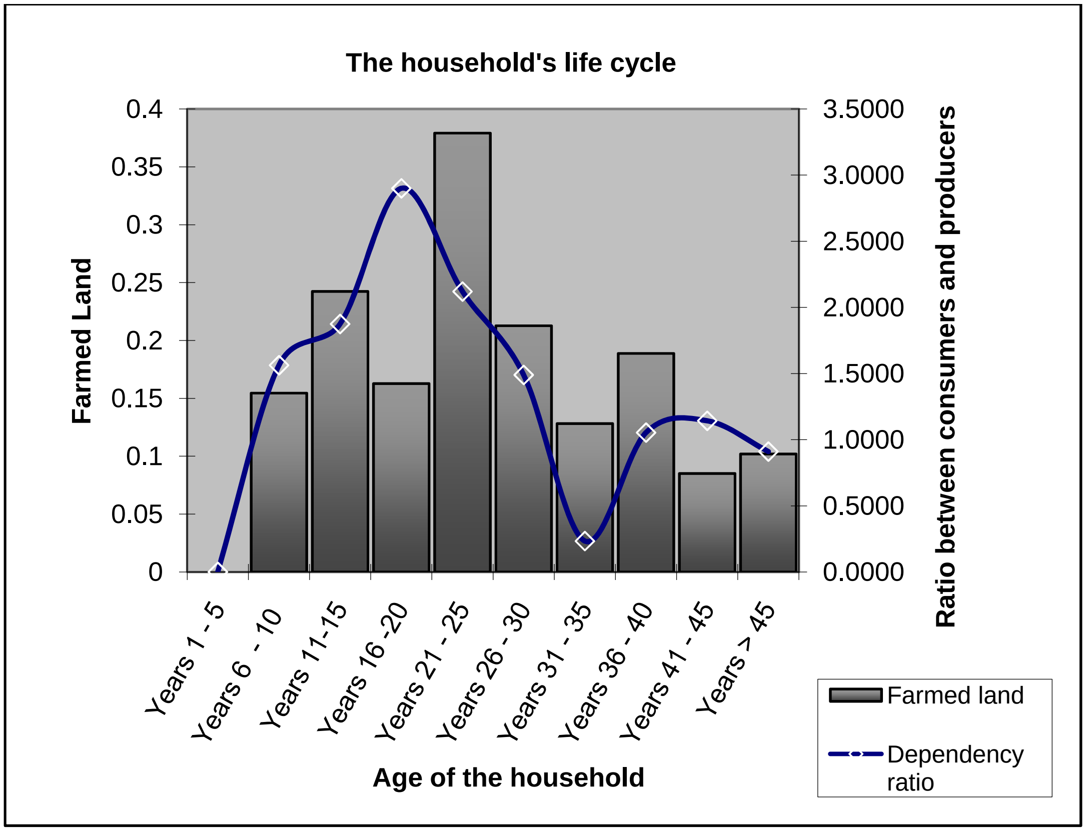


Figure 8.1: Empirical model of the household's life cycle. Chayanov stated that "the force of the influence of consumer demands is so great that the worker, under pressure from a growing consumer demand, develops his output in strict accordance with growing number of consumers". This graphic, which shows this relationship very clearly, depicts the household's developmental cycle based on a sample of fifty five households. The blue line depicts the dependency ratio (proportion between consumers and producers). The histogram represents the average cultivation land for each household age group.

or relatives that join the household on a temporal basis. This addition increases the demand for land resources for a few years. As these relatives abandon the house, the land demanded at the end of the cycle is only the area needed to sustain the oldest members. Figure 8.2 shows a direct and positive correlation between average farmed land by age group and the dependency ratio. Table 8.3 shows the result of the regression analysis of this relationship. The dependency ratio explains 60 percent of the variation of the area demanded by households for food production. A one-unit change in the dependency ratio will increase the average farmed land 0.11 times. Thus, the dependency ratio shows how household dynamics affect the demand for land resources along the different stages of household development.

3. A household-based multivariate analysis of indigenous cultivation systems

The previous analysis of bivariate relationships between the extent of agriculture and several independent variables suggests that agricultural production varies according to the environmental and demographic characteristics of the regions where production occurs. Based on these insights, a forward stepwise logistic multiple regression (LMR) procedure was used to test the combined explanatory effects of the independent variables regarding the probability of the presence or absence of agricultural land use. Since the probability of such an event must lie between 0 and 1, it is impractical to model probabilities with linear regression techniques, because the linear regression model allows the dependent variable to take values greater than 1 or less than 0. To generate a spatially explicit land use model, I selected those variables that could be spatially

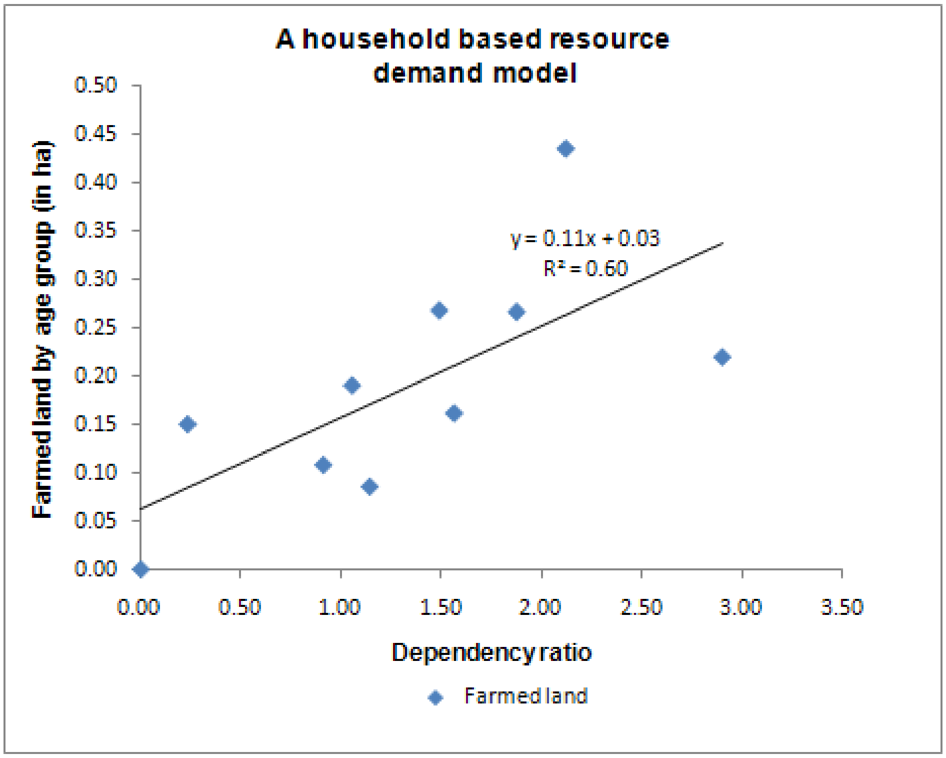


Figure 8.2: A household-based resource demand model. The dependency ratio is used to explain variations in farmed land.

Table 8.3: Results of the linear regression analysis describing the relationship between farmed land by age group and the dependency ratio.

	B	*Std. Error*	*Beta*	*t*	*Sig.*
Constant	0.03	0.04739		0.575511	0.580768
Dependecy Ratio	0.11	0.032022	0.758369	3.290741	0.01101
Dependent Variable:	Average farmed land				
R Square	0.60				

represented in a lattice of cells to model the probability of occurrence of agricultural land use. Table 8.4 shows the descriptive statistics of the variables used in the logistic model. The first step was to identify the levels of collinearity between independent variables in order to determine the data's adequacy for the application of the LMR procedure. Low levels of collinearity were found between the independent variables, with values of the coefficients of determination (R^2) of the relationships between one independent variable against all the others ranging between 0.01 and 0.18. It is only with R^2 larger than 0.80 for at least one of the independent variables that collinearity is considered as being problematic in LMR (Menrad, 1995). So, even though there is some dependence between the explanatory variables, it is not to a level that should pose a problem for logistic regression. The R^2 of the bivariate relationships between variables that were expected to be related such as travelling costs and distance to landing strip was in fact low (0.18 in that case), although the highest one from the analysis.

In general, the regression has a high power of explanation (Nagelkerke $R^2 = 0.88$) probably due to the spatial character of most independent variables. The results of the LMR model are given in Table 8.5. FamDen and NrsNbr are significant at a 0.001 level, Slope is significant at a 0.05 level, and DstLnd is significant at a 0.1 level. The CstDstHo and Soil variables are not useful to the model. This table presents the values of the parameter estimates with their corresponding standard error, Wald statistic, and significance probabilities. The resulting equation allows us to calculate the probability of agricultural expansion for any given area. Table 8.6 shows the results of the change in -2log- likelihood test. The -2log-likelihood ratio test tests the significance of the model as

Table 8.4: Descriptive statistics of the variables used in the logistic model.

Variable	N	Minimum	Maximum	Mean	Std. Deviation
CstDistHo: *Travel time between residential and agricultural areas (in minutes)*	2948	0	275.38	11.56	15.54
DstLdn*: Euclidean distance from agricultrual areas to landing strips (in m)*	2948	0	3262.14	1246.26	691.06
Slope*: Terrain slope (in degrees)*	2948	0	15.78	5.53	2.99
FamDen*: Population density (Number of people per cell of agriculture)*	2922	0	4.25	0.09	0.48
NstNbr: Proximity to an agricultural area (in m)	2948	0	1210.89	270.14	234.42
Soil*: Soil quality (Good = 1; Bad = 0)*	2948	0	1.00		

Table 8.5: Results of the logistic regression and the Hosmer and Lemeshow goodness of fit test.

Variable	B	S.E.	Wald	df	P value		Exp(B)
Constant	-0.6496	0.38	2.95	1.00	0.09		0.52
FamDen	8.1526	1.02	63.37	1.00	0.00	***	3472.48
Slope	0.1154	0.05	4.76	1.00	0.03	**	1.12
NstNbr	-0.0665	0.01	63.42	1.00	0.00	***	0.94
DstLnd	0.0005	0.00	3.24	1.00	0.07	*	1.00
CstDstHo	-0.0051	0.02	0.06	1.00	0.81		1.00
Soil [c]	-0.1492	0.49	0.09	1.00	0.76		0.86

*** Correlation is significant at a 0.001 level
** Correlation is significant at a 0.05 level
* Correlation is significant at a 0.1 level
[c] Categorical variable: differential effect of n-1 levels of the variable

Cox & Snell R Square 0.40
Nagelkerke R Square 0.88

Hosmer and Lemeshow Test

Chi-square	df	Sig.
1.04	8.0000	0.98

Table 8.6: Results of the Change in -2 Log likelihood test to determine the significance of independent variables.

Variable	Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change	
FamDen	-239.52	242.64	1	0.0000	***
Slope	-120.55	4.71	1	0.0299	**
NstNbr	-225.55	214.70	1	0.0000	***
DstLnd	-119.78	3.16	1	0.0752	*

*** Correlation is significant at a 0.001 level
** Correlation is significant at a 0.05 level
* Correlation is significant at a 0.1 level

a whole. A well-fitting model is significant at the 0.05 level or better, meaning that the model is significantly different from the one with the constant only. The change in -2log-likelihood is generally more reliable than the Wald statistic. If the two disagree as to whether a predictor is useful to the model, the change-in-2log-likelihood statistic should be trusted. In this case, both the Wald and the change-in-2log-likelihood statistics are consistent with each other. The Hosmer-Lemeshow test was used to evaluate how well the model described the data. The Hosmer-Lemeshow statistic indicates a poor fit if the significance value is less than 0.05. In this case, the model adequately fits the data since the significance value is 0.90. The resulting equation allows us to calculate the probability of agricultural expansion for any given area.

As was initially expected, the model suggests that population pressure is significantly correlated with the probability of encountering agricultural land use. As the number of people per available cultivation unit increases, the probability of an area being used for agricultural purposes also increases. The model determines that most of the variation in the odds of finding an agricultural area is explained by changes in this predictor. Each extra person per available cultivated unit increases the odds of finding an agricultural cell by 3,472 times. Thus, population pressure has a very strong influence on the probability of the presence of agricultural land use. This finding supports the conclusions of previous studies that also found strong positive linkages between population pressure and land cover change (Barbier & Burges, 1996; Andersen, 1997; McCracken *et al*., 2002).

Contrary to initial expectations, on-site conversion costs, proxied as slope values, are positively linked to the probability of the presence of agriculture. Each extra unit of change in conversion costs increases the odds of finding an agricultural area by 1.12 times, which is an indication that even though conversion costs may be high, nourishment needs outweigh them. Also, though terrain slopes in cultivation areas could generally be considered gentle -- the maximum average slope calculated for agricultural plots was 12 degrees or 21 percent with a mean of 4 degrees or 7 percent -- there is a tendency of people clearing steeper areas rather than flat ones. This could be interpreted as a signal of agricultural sprawl into areas that are less suited for this type of land use, and that people in the communities may be facing land shortages.

Travelling costs from a house to the closest agricultural plot is not significantly related to the probability of the presence of agricultural land use. However, the lack of predictive power of this variable could be a sign of the existence of multi-collinearity with other variables. Since travelling costs and distance to landing strips measure the spatial interaction between agricultural areas and nearby features (i.e. homes and landing strips), the model eliminates the variable that contributes less to the model. In fact, distance to landing strip is identified as a significant predictor of the presence of agriculture, which may be more useful to the model than walking time to houses. The probability of finding a cultivation plot increases one unit with one unit variation in the distance from a landing strip.

The examination of distances from landing strips to cultivation areas provides important insights on current land use patterns in nucleated settlements. In older settlements, agricultural areas expand outwards from landing strips, whereas areas immediately adjacent to them are most likely fallows or old agricultural plots. The land use maps derived from the interpretation of aerial photomosaics show this pattern very clearly. Areas of secondary vegetation are generally adjacent to landing strips. This pattern could also be an indication of scarcity of land resources for cultivation, thus another effect of the process of sedentarization and nucleation. As discussed in the conceptual model, people prefer flat terrain areas close to residential units for cultivation purposes. However, this research found that people are cultivating in areas that tend to be steeper than in optimal conditions, and that are farther away from the overall residential zone than ideal locations. Hence, this is another indication that people may be at the outset of facing land shortages. If this is the case, changes in local institutions regarding control and access to resources could be expected in the short term. Absence of or ineffectiveness of institutions that regulate the use of communally owned land may result in an increased rate of agricultural expansion in some areas (Baland & Platteau, 1996), or a shortening of fallow periods beyond the social optimum in other areas (Boserup, 1965). These circumstances could also lead to a race to clear an area of forest or fallow before someone else does, which could ultimately cause social conflict.

Distance from a forest area to the closest cultivation area is correlated with agricultural expansion. The regression analysis shows that the conversion probability of forest areas to agricultural land use increases one unit with an increase of one unit in distance to existing cultivation areas. This measurement specifically accounts for the inertia inherited in any spatial phenomenon (Walsh & Crews-Meyer, 2002; Fox *et al.*, 2003; Parker *et al.,* 2003); agricultural expansion is more likely to occur on lands adjacent to existing cultivation fields than in areas farther away from them. Finally, soil quality is not a determinant of the presence of agriculture. This finding suggests that agricultural land use occurs in the region despite the constraints imposed by the physical environment. Once a household has settled, the likelihood that its members will clear a forest area for agricultural purposes is the same in the riverine and interfluvial habitats. In subsistence societies, people need to produce food no matter the environment they choose to live in. Yet, physical constraints may influence the extent and intensity of production. In this sense, the bivariate analysis found that larger cultivation fields are associated with poorer soil conditions, which suggests that reddish-low-quality soils in the inter-fluvial area produce less than black-high-quality soils in the riverine area and, therefore, cultivation fields need to be larger to produce equivalent yields. Further, the analysis of agricultural intensity suggests that black soils in the riverine area may produce for longer periods and may recuperate quicker through slash-and-burn or mulch techniques than red soils in the inter-fluvial region. Thus, riverine habitats may support more intensive management than inter-fluvial areas.

4. Validation of the statistical land use model

A subset sample containing 20 percent of observations was used to validate the model. Table 8.7 shows the results of the validation of the statistical model. For each case, the predicted response is one if that case's model-predicted probability is greater than the cutoff value of 0.5. In the table, cells on the top left – lower right diagonal are

Table 8.7: Results of the subset validation of the logistic regression model.

Observed		Predicted					
		Selected cases for model generation			*Selected cases for validation*		
		Dependent		Percentage Correct	Dependent		Percentage Correct
		Non agriculture 0	Agriculture 1		Non Agriculture 0	Agriculture 1	
Dependent	Non agriculture 0	2131	12	99.40	506	3	99.40
	Agriculture 1	35	182	83.90	8	45	84.90
	Overall Percentage			98.00			98.00

The cut value is .500

correct predictions. Cells off this diagonal are incorrect predictions. 83.9 percent of cells used for model generation were correctly classified as agricultural areas, whereas 99.4 percent of cells were correctly classified as non agriculture. Overall, 98.0 percent of the cases were correctly classified. However, classifications based upon the cases used to create the model tend to be too “optimistic” in the sense that their classification rate is inflated. A better model should correctly identify a higher percentage of the cases. Subset validation was obtained by classifying those cells that were not used to create the model. These results are shown in the Unselected Cases section of the table.

Overall, 98 percent of the cases were correctly classified by the model. However, even the subset validation is limited because it is based on only one cutoff value. It is more useful to use the predicted probabilities to construct a Receiver Operating Characteristic (ROC) curve and evaluate the performance of the model more rigorously analyzing different cutoff values. Figure 8.3 shows the ROC curve resulting from the evaluation of the LMR model. The ROC curve is a visual index of the accuracy of the model. The area under the curve (0.9950) represents the likelihood that the predicted probability for a randomly chosen positive case will exceed the probability for a randomly chosen negative case (Table 8.8). The asymptotic significance is less than 0.05, which means that using the LMR model for the prediction of the presence or absence of agricultural land use is better than speculating with random probabilities. According to the ROC-curve test (Table 8.9), if 0.5 is used as the cutoff value for classifying cells as agricultural or non-agricultural areas, 84 percent of all agricultural cells would be correctly identified as such, and 1 percent of all non-agricultural cells would be

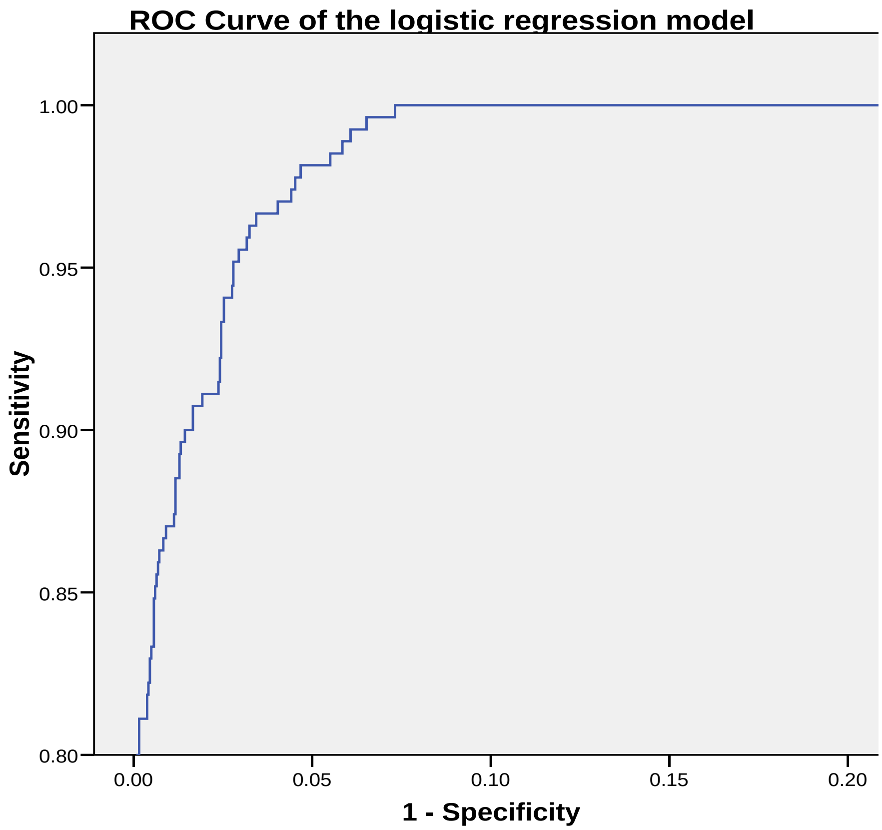


Figure 8.3: Receiver Operating Characteristic (ROC) curve for the evaluation of the usefulness of the LMR for predicting the presence or absence of agricultural land use. The closer the curve is to the Sensitivity axis the more useful the model.

Table 8.8: Parameters of the area under the ROC curve used for the evaluation of the LMR model.

Area	*Std. Error(a)*	*Asymptotic Sig.(b)*	*Asymptotic 95% Confidence Interval*	
			Upper Bound	*Lower Bound*
0.9950	0.0010	0.0000	0.9940	0.9970

a Under the nonparametric assumption

b Null hypothesis: true area = 0.5

Table 8.9: Proportion of correctly (Sensitivity) and incorrectly (1-Specificity) classified cells based on the ROC curve test of the predicted probability variable. With a threshold probability value of 0.5, 84 percent of cells will be correctly classified.

Positive if Greater Than or Equal To	***Sensitivity***	***1 - Specificity***
0.0	1.00	1.000
0.1	0.97	0.040
0.2	0.94	0.026
0.3	0.91	0.017
0.4	0.87	0.011
0.5	0.84	0.010
0.6	0.81	0.002
0.7	0.79	0.001
0.8	0.77	0.001
0.9	0.74	0.001
1.0	0.08	0.000

incorrectly identified as agricultural areas. The choice of the cutoff will be mandated by the need to closely match the sensitivity and specificity of traditional tests according to the objective of the model. In this study, the 0.5-cutoff threshold was used to compare the results with those obtained from the subset validation of Table 8.6.

5. A community-based spatially explicit agricultural land use model

A spatially explicit land use model was developed within a GIS framework to analyze agricultural expansion at a community level. The system was implemented using common map algebra operations and spatial modeling tools. The LMR coefficients obtained from Table 8.4 were used as parameter estimates for the prediction of agricultural land use. Table 8.10 shows a list of input parameters required by the system at the beginning of the simulation process. Detailed rate information about household demographics (e.g. growth rates of consumers and producers) would have been necessary to incorporate the dependency ratio into the spatially explicit model and avoid relying on a constant population growth rate to determine the demand for land.

In this example, the simulation starts with a population of 10 people, distributed in two households. Population grows at an annual rate of 5.6 percent, which is the average growth rate for the Achuar and Shiwiar populations. The period of cultivation activity is 7 years, which is the average production time of cultivation fields in the community of Yuntsuntza. Fallow periods in the area average roughly 20 years. The simulation was run for 30 years but was validated after 18 years since this is when Yuntsuntza was established. Click on Figure 8.4 to run simulation.

Figures 8.5, 8.6, and 8.7 show the results of a single simulation. After each

Table 8.10: List of input parameters required by the system at the beginning of the simulation process.

Input parameters	***Value***
Initial population (number of people)	10.00
Population annual growth (percentage)	5.60
Period of cultivation activity (years)	7 years
Fallow period (years)	20 years
Simulation period (years)	30 years

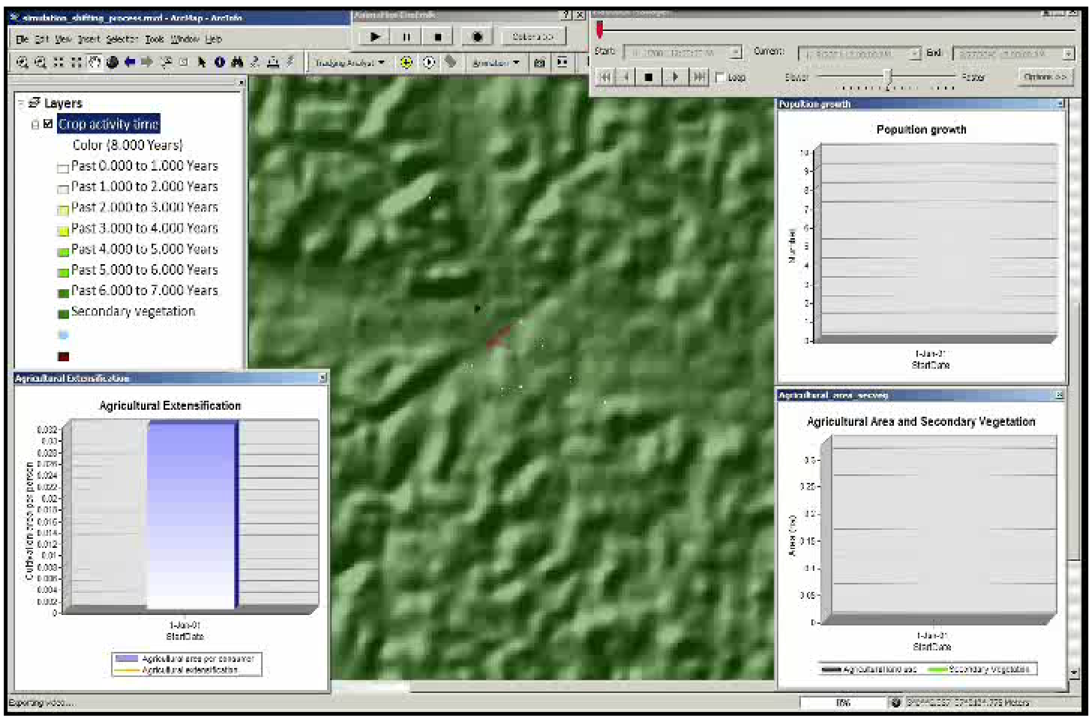
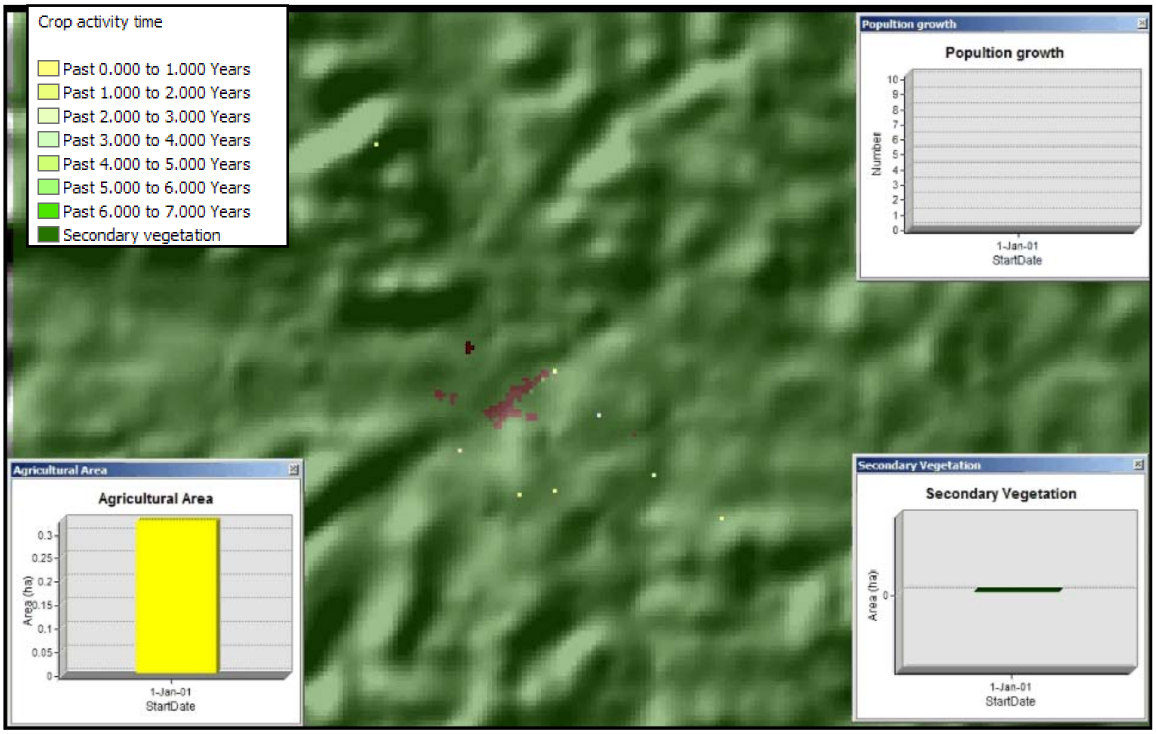
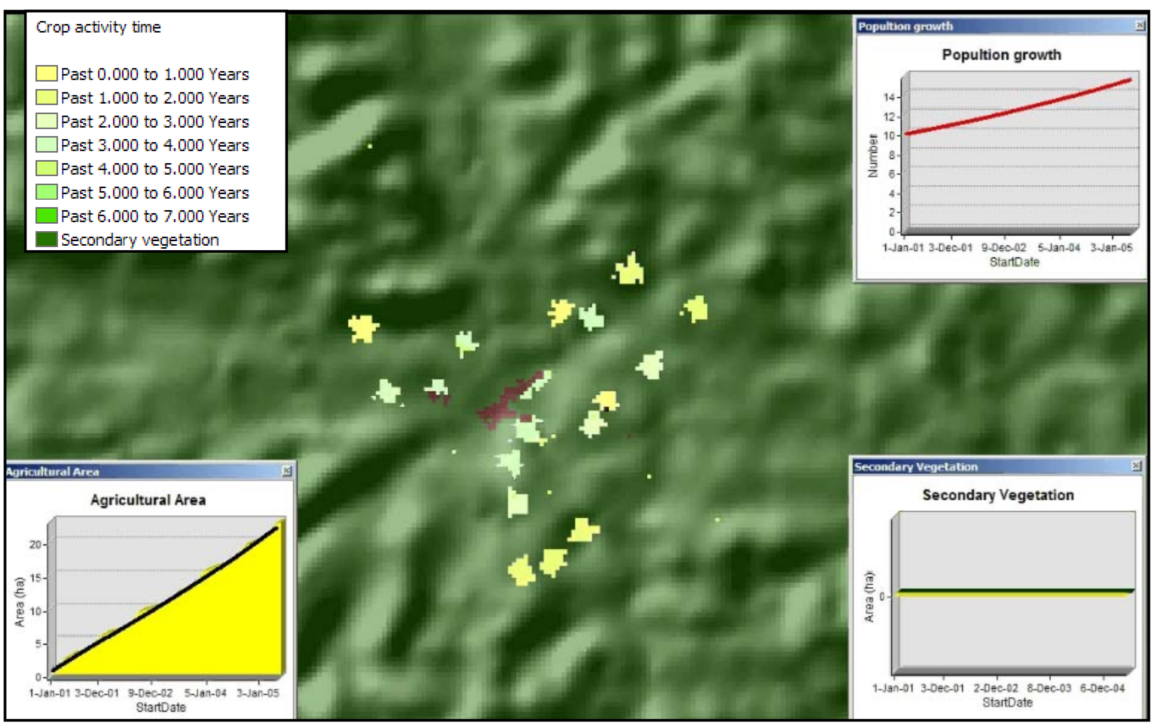


Figure 8.4: Simulation of an ideal shifting cultivation system. The simulation shows and expansive behavior at initial phases of village formation. As populations grow there is a transition from extensive to intensive practices. Intensification may occur by producing higher yields per unit of area or by shortening fallow periods.

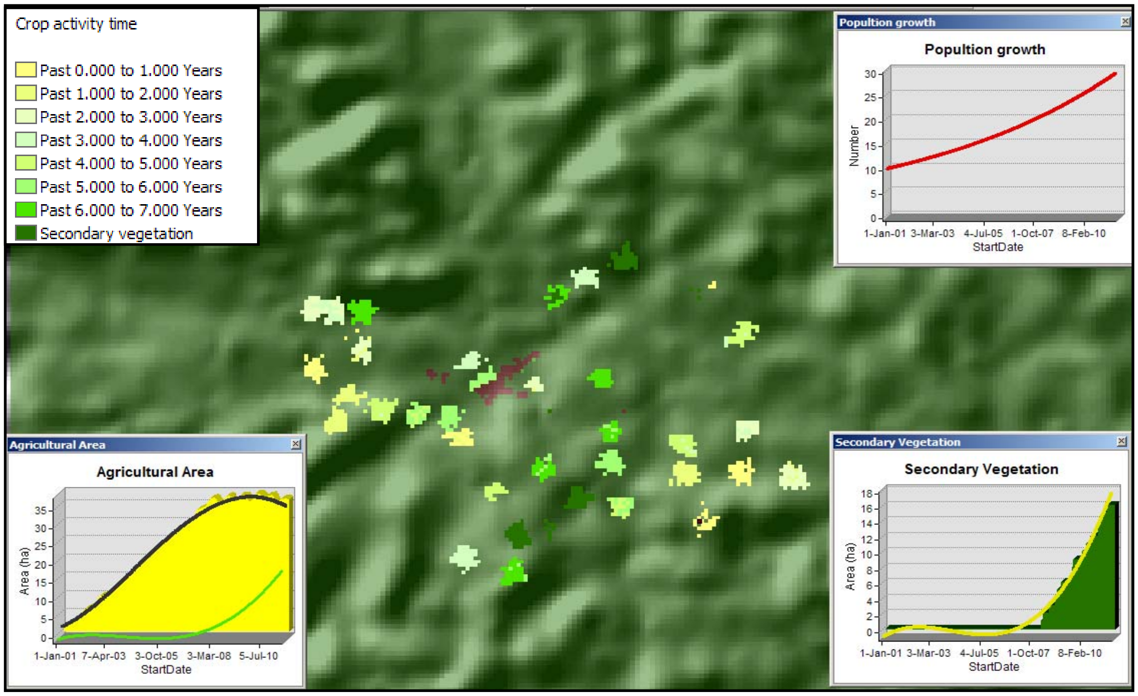


A.

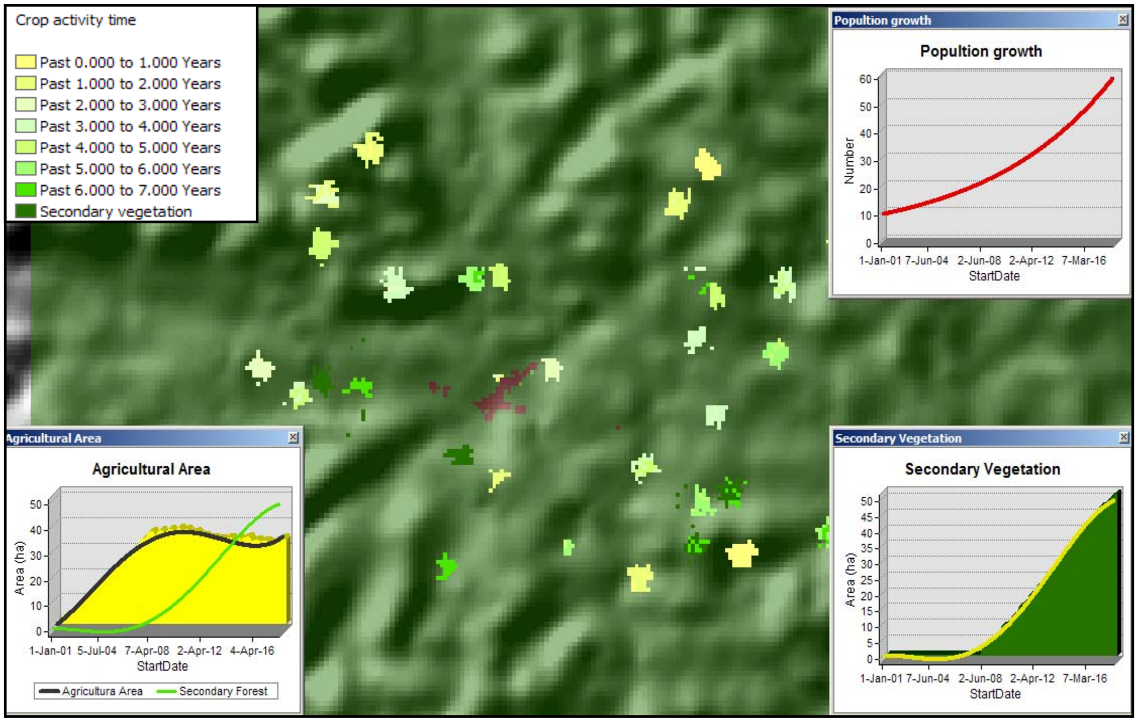


B.

Figure 8.5: Results of a single simulation in a time period of five years. A.) Simulated landscape after the first year. B) Simulated landscape after five years.

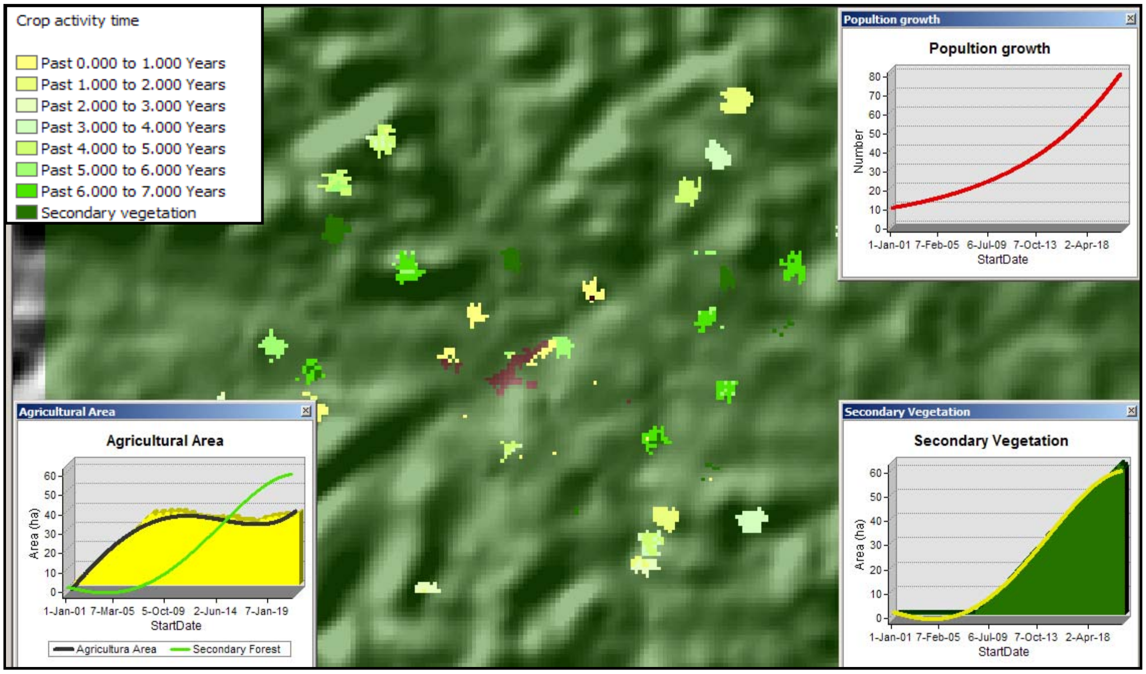


A.

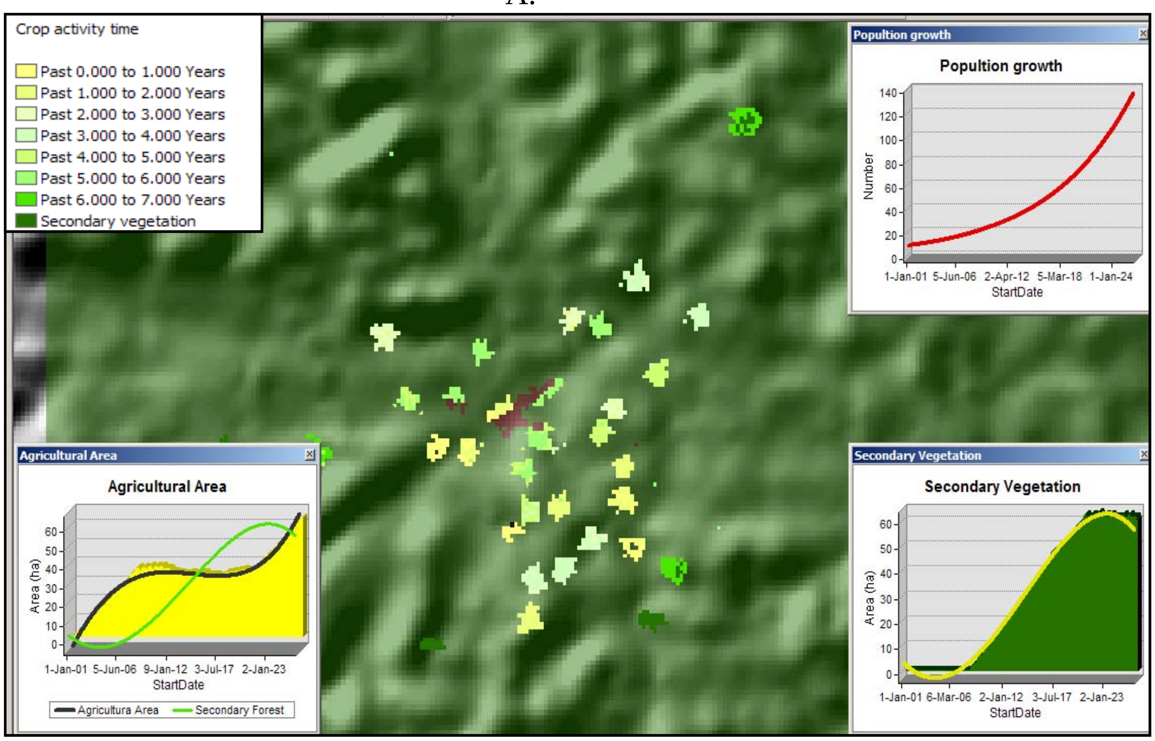


B.

Figure 8.6: Results of a single simulation in a time period of 18 years. A.) Simulated landscape after 10 years. B) Simulated landscape after 18 years. The bottom left graphic shows the fitting curves of both "Agricultural" (in black) and "Secondary Vegetation" (in green) areas.



A.



B.

Figure 8.7: Results of a single simulation in a time period of 25 years. A.) Simulated landscape after 20 years. Note how former secondary forest around the landing strip turns back into agricultural land use B) Simulated landscape after 25 years. At this stage agricultural area increases while secondary vegetation decreases (bottom left graphic).

iteration the system updates three graphics that summarize information about total agricultural area, amount of secondary vegetation, and number of people at a particular time step. The land use maps show where the transitions from forest to agriculture and from agriculture to secondary vegetation take place at a specific time step.

At the beginning of the iterative process, forest dominates the landscape, agricultural land use is minimal, and there is no secondary vegetation. Figure 8.5a shows the results of a single simulation after the first iteration. Conceptually, the figure shows that agricultural area expands since farmers practice extensive or labor-efficient agriculture to sustain the initial requirements the household. As production pressure increases to cover the demand for food of growing families, agriculture is expanded throughout the land. At this point in time secondary vegetation is minimal since all agricultural areas are active and under production (Figure 8.5b). Agricultural area increases until food demand can no longer be met with this option, then agriculture is intensified on land already under cultivation. As expansion rates decrease, the extent of land under cultivation in lands of varying quality follows a sequence opposite to expansion (Figure 8.6a). Lands of low quality are taken out of production and left as fallows prior to lands of optimal quality because they require greater inputs to produce comparable yields. Hence, the extent of secondary vegetation increases (Figure 8.6b). As demand increases because of population growth additional land is put into production (Figure 8.7a). Lands that have been recuperated by means of fallow will be preferred to old-growth forest areas if they produce comparable yields. Areas closer to residential units and landing strip will be preferred than areas farther away since clearing this areas may be easier than old-growth forest due to lower conversion costs (e.g. lack of large trees and topographic conditions) and travel costs from homes. Thus, the extent of secondary forest may decrease and cultivation areas will be clustered around the landing strip (Figure 8.7b). In the model, the extent of agricultural and secondary vegetation areas depend on the cropping and fallow periods, which are empirically calculated and introduced in the model as input parameters. The model depicts an ideal shifting cultivation system, with a complete cropping/fallow/cropping cycle and shows how agricultural areas expand and contract across space and over time.

6. Validation of the spatially explicit land use model

Fifty simulations were executed to validate the system's performance. The output of each simulation is a layer that represents an anthropogenic landscape showing cultivation and secondary forest areas for an 18-year period. The validation procedure involved comparisons between the system's outputs and current observations of the community that was not included in the calibration of the model.

Figure 8.8 shows the aggregated map of the 50 simulations for the 18-year period and the actual agricultural areas and secondary forest derived from the interpretation of the 2006 aerial images of *centro* Yuntsuntza. The map depicts the likelihood of an area of being selected for cultivation purposes based on the outputs of the 50 simulations and also contains the actual agricultural areas. The aggregated map was converted into a binary map in order to show those areas with high ($p >= 0.5$) and low ($p < 0.5$) probabilities. Those areas with high probabilities were considered as potential cultivation

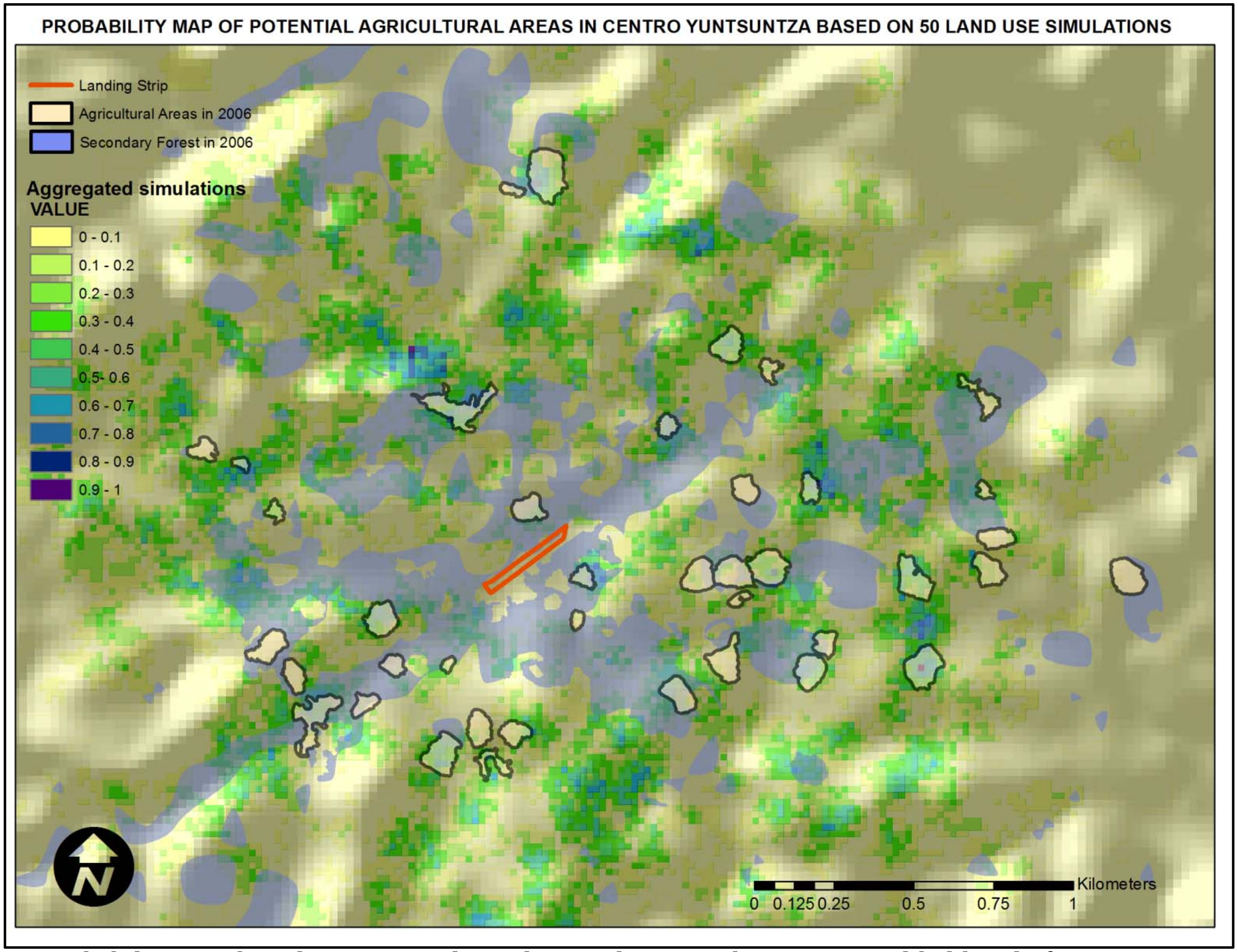


Figure 8.8: Probability map based on 50 spatial simulations depicting the conversion likelihood of an area to agricultural land use. Note that current agricultural plots are not adjacent to the landing strip. Areas around landing strip are covered by secondary forest.

zones. A cross tabulation procedure was applied in the GIS to create a contingency table to evaluate the statistical relationship between potential and observed agricultural land use areas by means of a chi-square test. Table 8.11 contains the contingency table of potential and observed areas and results of the statistical test. The results show that there is a statistical significant relationship between the both distributions at significance level of 0.05. However, according to the Cramer's Phi Statistic, this relationship is weak (correlation = 0.03). That is, the model predicted the location of cultivation areas reasonably well. However, since the surface depicting the accumulated simulations shows all possible locations and only a fraction of these actually match the observed cultivation areas, the strength of the correlation is low.

A simple visual analysis of the probability map shows that areas around the landing strip are less likely to be actively used for agriculture. The model predicted that cultivation field in a time period of 18 years are more likely to be located, on average, at a distance of 830 meters from the landing strip. According to observed measurements, agricultural areas in the community of Yuntsuntza are currently located, on average, 700 meters away from the airfield. This finding is consistent with the evaluation of distance from agricultural areas to the landing strip. As the statistical model suggested, cultivation plots are located in non-adjacent areas to the landing strip since these are most likely recuperating as fallows or used for residential purposes. In fact, results from the interpretation of aerial images indicate that areas adjacent to the landing strip are currently occupied by secondary forests and residential units are clustered around the airfield. In terms of population, the model predicted, on average, 65.62 people at the end

Table 8.11: Contingency table and Chi-square results showing the relationship between predicted agricultural areas based using 50 land use models and observed agricultural areas in *centro* Yuntsuntza.

		PREDICTED		
		Non Agriculture	***Agriculture***	***TOTAL***
OBSERVED	***Non Agriculture***	26082	1152	27234
	Agriculture	819	67	886
	TOTAL	26901	1219	28120

Chi Square= 22.973
Critical Chi Square= 3.8414
p= 0.0001
Df= 1
Cramer's Phi Statistic= 0.03

of the 18-year simulation period, which is less than the actual number of residents (76 people).

In general, the analysis of the structural characteristics of the simulated landscapes allowed a formal evaluation of the performance of the spatially explicit land use model. Table 8.12 summarizes the descriptive statistics of the proportions between the predicted and observed landscape metrics used for validation purposes. This table indicates that the simulations predicted, on average, slightly less cultivation area (0.94< 1) than the amount calculated from the interpretation of aerial images (Figure 8.9a). The land use model predicted in average 6.38 percent less agricultural area than the information obtained from observed measurements (Figure 8.9b). This result is consistent with the estimation of total population. Since the model underestimated the amount of people, and this value, in turn, is used to calculate the number of agricultural cells, it should be expected that the size of agricultural area at the end of the simulation will be less than the observed pattern as well. This estimation could be improved with the inclusion of population estimates that more accurately represent local demographics than the general rate averages.

The analysis of mean patch area allows an evaluation of how well the system performed to predict the size of a cultivation plot. In terms of landscape configuration, the proportion between predicted and observed mean patch area indicates that the model predicted smaller patches of agricultural land use (0.74 < 1) (Figure 8.10a). Patches of agricultural land use were, on average, 26.24 percent smaller than the actual cultivation plots (Figure 8.10b). This error can be explained by the fact that the size of cultivation

Table 8.12: Descriptive statistics of proportions between the predicted and observed landscape metrics obtained from 50 land use models.

Landscape metric	*Mean*	*Std Dev*	*Max*	*Min*
Proportion between observed and predicted agricultural land use area	0.94	0.11	1.13	0.68
Agricultural Area Error (%)	-6.37	10.89	12.75	-31.60
Proportion between observed and predicted mean patch area	0.74	0.07	0.90	0.61
Mean Patch Area Error (%)	-26.24	6.57	38.65	10.39
Proportion between observed and predicted patch density	1.79	0.26	2.57	1.26
Patch Density Error (%)	79.13	25.52	156.52	26.09
Proportion between observed and predicted nearest neighbor distance	0.82	0.12	1.05	0.65
Nearest Neighbor Distance Error (%)	-17.94	11.80	35.13	-5.40
Proportion between observed and predicted perimeter-area fractal dimension	0.89	0.02	0.95	0.85
Fractal dimension error (%)	-11.33	2.22	-4.73	-14.95

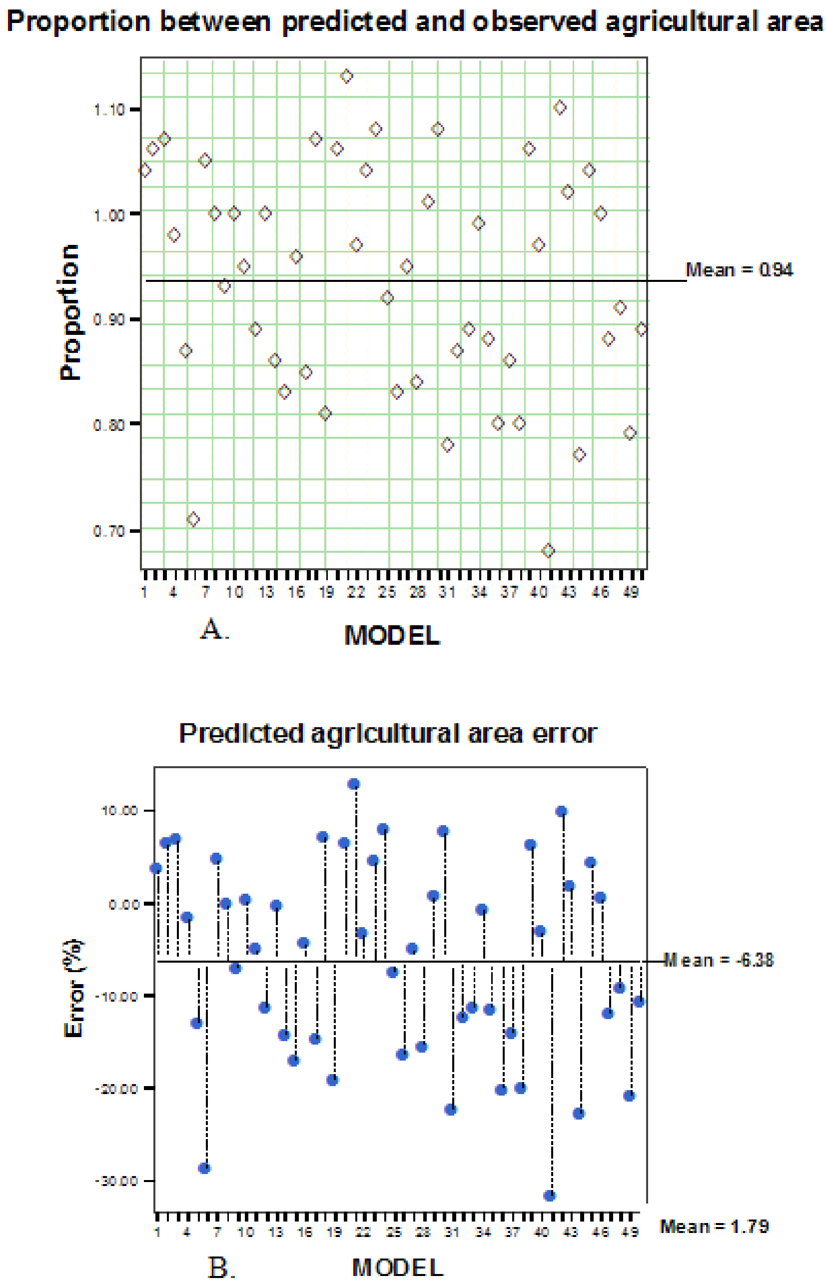


Figure 8.9: Results of the evaluation of 50 land use change simulations. A) Proportion between predicted and observed agricultural area. The mean proportion is 0.94 which indicates that the model predicted less area than the observed pattern. B) The model generated a mean area error of 6.4 percent. Spikes represent the error distance from each simulation to the fitting average error.

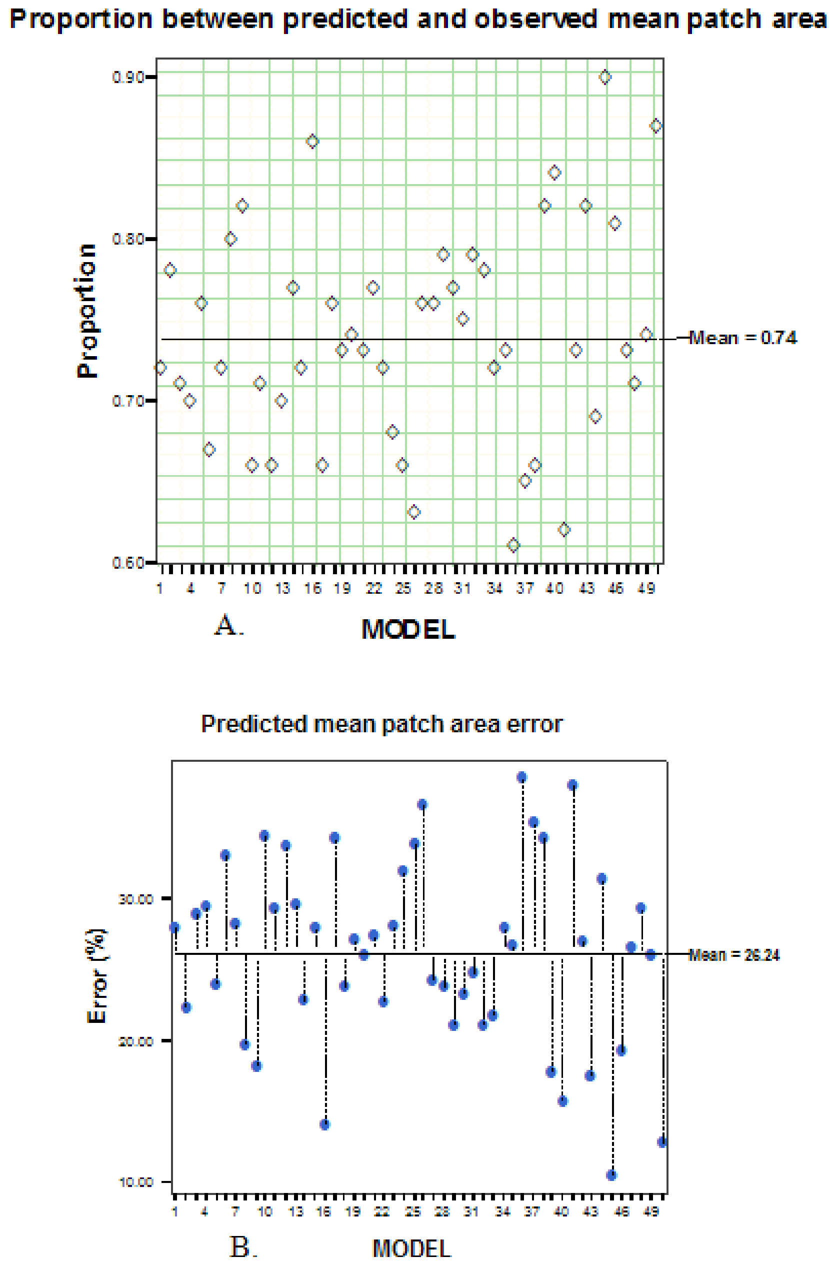


Figure 8.10: Results of the evaluation of 50 land use change simulations. A) Proportion between predicted and observed mean patch area. The mean proportion is 0.74 which indicates that the model predicted smaller of agriculture than the observed pattern. B) The model generated an average mean patch area error of 26.24 percent. Spikes represent the error distance from each simulation to the fitting average error.

fields was determined by fixed transition rules employed by the cellular automata procedure. This parameter can be improved by relaxing the set of rules that allows the expansion of cultivation areas, or by decreasing the cut-off probability value for the transition from one state to the other. These results are consistent with the analysis of patch density that indicate that the model predicted a relatively higher density of agricultural plots (1.79 > 1) in comparison with the observed landscape (Figure 8.11a). In this case, the model predicted a density 79.13 percent larger than the observed patch density (Figure 8.11b). However, these errors can be explained by the existence of areas that may not necessarily be considered as agricultural patches, but as effects of the cellular automata procedure, which could have isolated areas that were be too small to be considered cultivation plots and should have not be considered in the final evaluation. The application of a filtering technique, such as a modal algorithm at the end of the iterative process, could help minimize the effect of sliver areas.

The analysis of nearest neighbor distances allows a characterization of dispersion or clustering of cultivation plots. Results show that the model predicted a more clustered mosaic of patches than the observed distribution (0.82 < 1) (Figure 8.12a). The simulated landscapes contained on average 18.94 percent more clustered patches of agricultural land use than the observed distribution of cultivation areas (Figure 8.12b). This error can be explained by how cells are selected in the iteration process. Usually, cells that are closer to existing cultivation areas will more likely be chosen than cells that lie farther away. The result is a more clustered pattern of agricultural areas. The model could be improved by decreasing the cut-off probability value so that areas located farther away

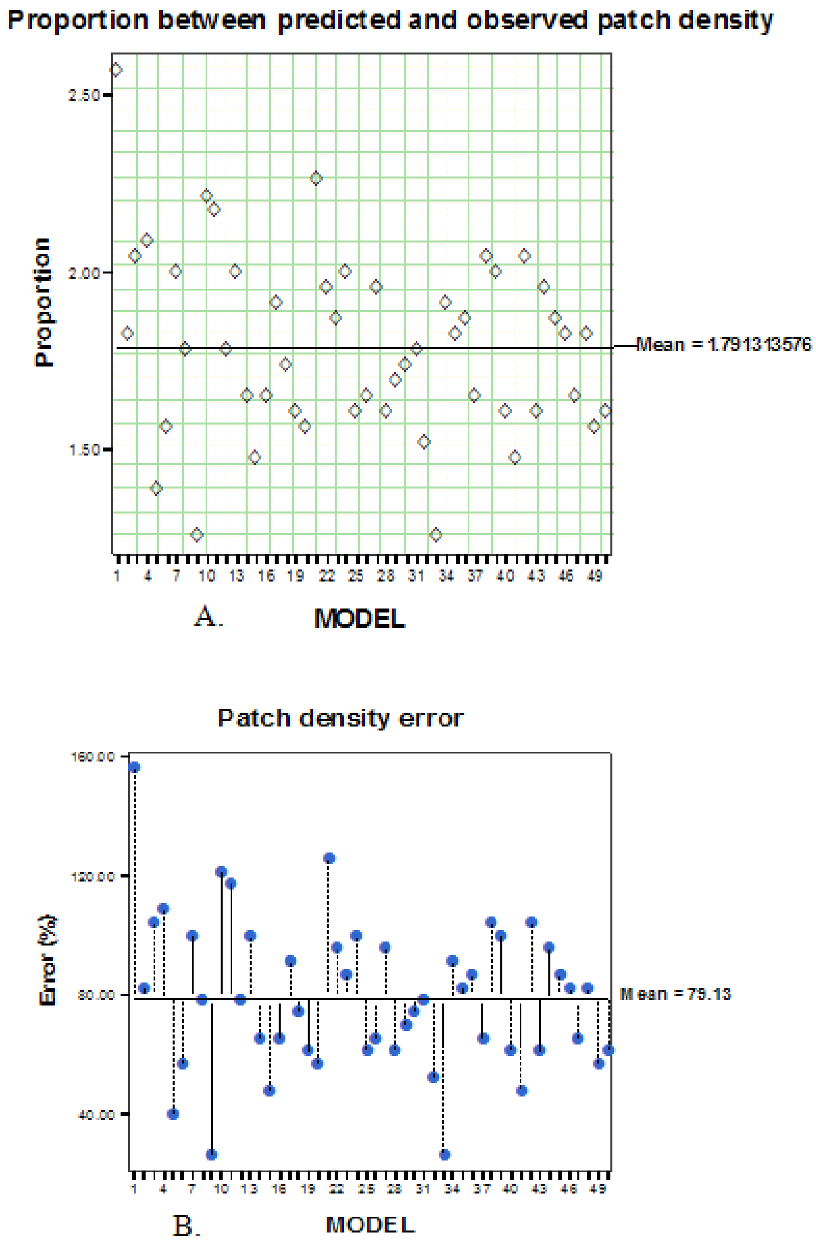
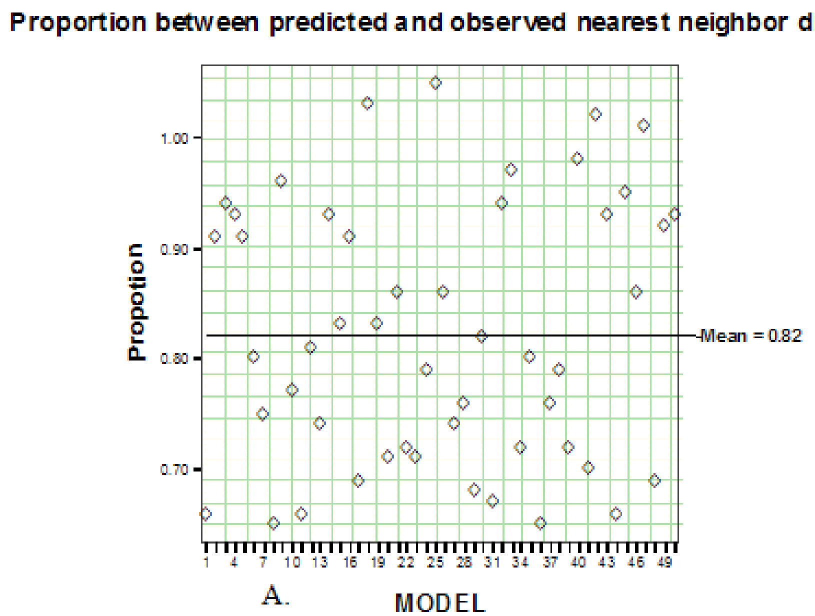


Figure 8.11: Results of the evaluation of 50 land use change simulations. A) Proportion between predicted and observed patch density. The mean proportion is 1.79 which indicates that the model over predicted the number of patches per unit of area. B) The model generated a mean patch density error of 79 percent. Spikes represent the error distance from each simulation to the fitting average error.



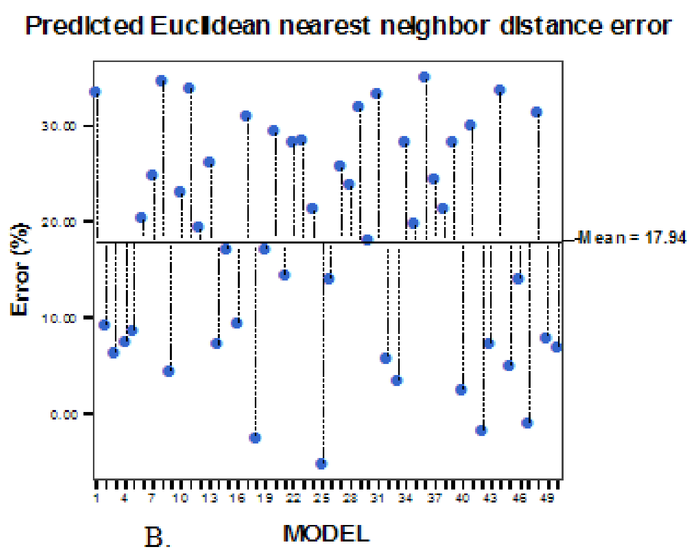


Figure 8.12: Results of the evaluation of 50 land use change simulations. A) Proportion between predicted and observed Euclidean nearest neighbor distance. The mean proportion is 0.82 which indicates that the model predicted a more clustered distribution of patches than the observed pattern. B) The model generated a mean nearest neighbor distance error of 18.94 percent. Spikes represent the error distance from each simulation to the fitting average error.

could be selected. However, this should be carefully justified by either empirical (based on actual multi-temporal land cover changes) or theoretical means.

Finally, the analysis of the fractal dimension allows an evaluation of the shape of cultivation plots in the observed and simulated landscapes. The average perimeter-area fractal dimension value of the agricultural patches of the simulations is lower than the observed pattern (0.89 < 1) (Figure 8.13a). This means that the simulated patches are 11.33 percent more regular than the observed cultivation areas (Figure 8.13b). This error could be an effect of using fixed transitional rules. The model could be improved by creating different sets of rules and evaluating the interaction among cells with these sets.

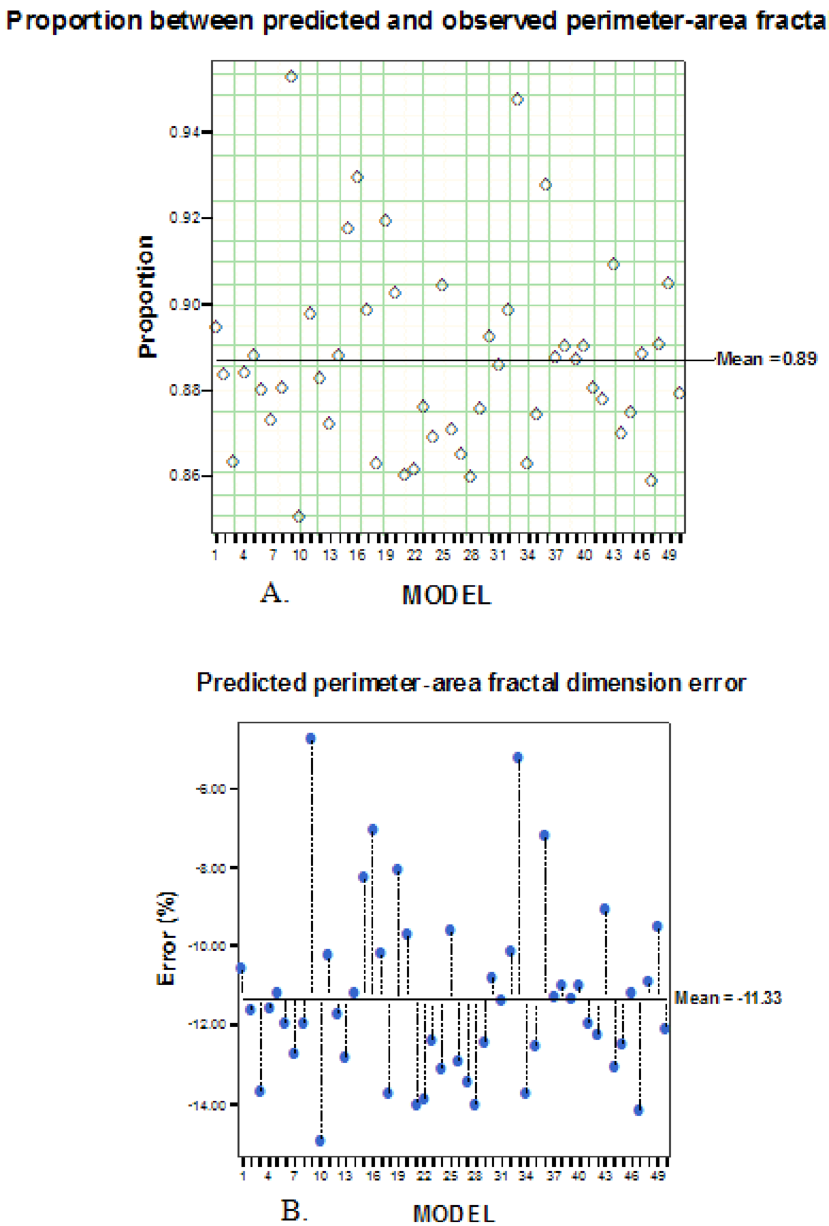


Figure 8.13: Results of 50 land use change simulations. A) Proportion between predicted and observed perimeter-area fractal dimension. The mean proportion is 0.89 which indicates that the model predicted more regular cultivation patches than the observed pattern. B) The model generated a mean perimeter-area fractal dimension error of 11.33 percent. Spikes represent the error distance from each simulation to the fitting average error.

7. Final remarks

As indigenous peoples are granted permanent and legal ownership of their ancestral territories and traditional nomadic-dispersed settlements are not viable under conditions of limited space, it would be necessary to improve agricultural productivity to sustain growing populations. Results of the analysis of the structural characteristics of cultivation systems in the PRBEA suggest that permanent and more intensive agriculture may be technically more feasible in riverine areas rather than in inter-fluvial areas. Perhaps improved technology for weed control or improved transportation systems and networks (i.e. fluvial, terrestrial, and aerial) could make an intensive system more feasible and attractive to populations that live in the inter-fluvial habitat. Additionally, the introduction of new technologies to diversify food production and improvements in commercial networks may help to reduce the pressure on forest resources and guarantee the well-being of indigenous peoples in the future. However, technological improvement and transportation infrastructure development may also increase environmental degradation in the form of deforestation or resource depletion. This effect will depend in the end, as shown in other parts of the tropics, on the type of technology, particular socioeconomic and historical circumstances, and on the goals of the people (Angelsen & Kaimowitz, 2001).

Results of the multivariate statistical analysis suggest that human populations in the Pastaza River Basin may be at the outset of land shortages. Resource depletion and land scarcity in the Amazon region is a serious concern that could potentially affect various indigenous groups in the near future. The problem of land scarcity is, in the end, most likely an effect of sedentarization and nucleation of growing populations around access infrastructure and service areas. Since such areas represent a high investment of resources (i.e. labor and time), people are most likely to avoid returning to a dispersed settlement pattern. Given the current demand for services such as hospitals, shops, schools, or medical centers a return to dispersed settlement pattern of the past is not the best option. Another issue that may arise from land scarcity in permanent settlements involves a future demographic explosion leading to a progressive decline of forest resources clearly affecting other groups in the tropics (e.g. the Shuar in Ecuador (Harner, 1972; Rudel *et al.*, 2002), the Machiguenga in Peru (Henrich, 1997), the Yanomami in Venezuela (Wilbert, 1972), and the Sirionó in Eastern Bolivia (Holmberg, 1969). These issues should be carefully considered and more research is suggested to address the consequences of changes in production systems in limited-resource environments such as the Amazon region.

As indigenous peoples become important actors in the regional, national, and international economies, further research and interest on both local indigenous and peasant organizations in tropical Latin America is urged. As external agents such as oil and mining companies threaten current native populations with the introduction of activities in their territories that can cause drastic socioeconomic and environmental change, indigenous peoples will continue to struggle to defend their lands. Nevertheless, indigenous people in the tropics have developed political strategies to help them overcome these threats. The formation of indigenous organizations has been an efficient strategy to obtain and maintain control over their territories. The future of indigenous peoples and their territory will probably depend on the role their leaders assume at the national and international levels, and not only on practices that involve the use of axes, machetes, or shotguns. Any effort made to improve the livelihoods of indigenous peoples should not underestimate their resilience and adaptive capabilities in new or unknown situations.

Chapter Nine

Discussion and Conclusions

1. Introduction

There is no unified theory to explain why and how indigenous people produce food or what triggers changes in production systems. Rather than develop such a theory, this study concentrated on the spatial aspects of indigenous production systems in lowland tropics. The goal was to contribute to the understanding of how production strategies vary according to changes in demographic and environmental conditions.

In the specific context of the Amazon region, commercial goods and relations have seeped into lowland indigenous societies since the arrival of the Europeans in the fifteen century. However, the rate of acculturation and socio-economic change has notably increased in recent decades (Lu; 1999; Godoy, 2001; Lu, 2001). The formation of new trade networks and broader social relationships influence how people produce, but differences in production strategies also depend on cultural legacies and on local adaptations to changes in demographics and environmental conditions. This study relied on theories of land use and agricultural change, and on empirical data to show that even in the relative absence of formal markets and significant commercial options, changes in the spatial and structural characteristics of production can still occur.

From the results obtained in this study, several generalizations can be made on the spatial and structural characteristics of indigenous production. First, Chapter Six showed that a shift from nomadic-dispersed settlements to sedentary-nucleated living arrangements have led to changes in the spatial configuration of production systems.

These changes can be seen as an adaptive response to situations of increased pressure on resource availability, specifically on limited land resources around population centers. Second, the analysis of the structural characteristics of production discussed in Chapter Seven suggests that cultivation strategies in areas in relative isolation from markets can be understood as a mixture of cultural legacies and technological adaptations to ecological conditions that have led to the emergence of two distinctive cultivation systems: 1) a relatively more extensive system (i.e. smaller yields but larger cultivated area per capita) in the inter-fluvial area, and 2) a relatively more intensive (i.e. larger yields but smaller cultivated area per capita) in the riverine habitat. Third, the bivariate and multivariate analyses of land use and land cover change suggest that the main underlying force that underpins agricultural expansion in indigenous areas in the PRBEA is demographic growth. While demographics explain most of the variation in the probability of turning forest cover into agricultural land use, the spatial interaction between anthropogenic and natural features provides further insights on current landscape patterns. The model described and discussed in Chapter Seven contributes to the understanding of the cyclic behavior of landscape change. That is, it provides further insights to improve the understanding of landscape responses to cycles in the demand for food resources.

This chapter concentrates on the discussion of these findings and addresses the main research questions of the dissertation. Further, this chapter shows how this study has contributed to each of the major literatures described in Chapters Two and Three. Specifically, Section Two discusses the spatial dimensions of indigenous production systems and provides further insights on the evolution of food production systems. Section Three focuses on the results of the analysis of the structural characteristics of traditional agricultural systems in the Pastaza River basin and highlights the existence of the riverine-interfluvial dichotomy in the upper Amazon basin. Section Four concentrates on the drivers of agricultural land use in indigenous territories. This section contributes to the literature on the underlying factors of land use/land cover change in traditional cultivation systems.

2. The spatial dimensions of indigenous production

The analysis of traditional land uses and zoning systems is utilized to answer the first general question of this study: What is the effect of the transition from dispersed to nucleic settlements on the spatial patterns of production systems in contemporary tropical lowland indigenous areas? To answer this question, this study presented a descriptive evaluation of traditional production systems linked to the process of settlement nucleation and sedentarization. The Introduction and Study Area chapters described a variety of social processes that have led to a shift from dispersed to nucleic permanent settlements in areas that lack road or river accessibility. The transition to nucleic permanent settlements in the Amazon region has radically transformed forested landscapes, and current land use patterns are a consequence of this shift. Based on data obtained from past studies and on direct field measurements of the spatial extent of production zones, this study allows some generalizations about how changes in settlement types have led to changes in production patterns in Western Amazonia.

In several regions of the Amazon, landing strips constitute a main landscape feature. The landing strip is the link between traditional and modern life styles and it represents one of the most obvious evidence of external influence. The landing strip also serves as a nucleus that amalgamates families, demarcates the existence of geographic administrative areas, and establishes a physical landmark that serves as the baseline of modern indigenous social and spatial organization. The opening of a landing strip is generally followed by the construction of a chapel, school buildings, a teacher's house, and, in some villages, service structures such as health centers or communal buildings. Since this kind of infrastructure represents a high investment of labor and time and cannot be repeated on a regular basis, it becomes permanent. The landing becomes the center of social organization and distribution of services such as health and education.

In several indigenous territories of the Amazon, the nucleated settlement has been generally adopted as a mechanism of political and administrative control of a territory. The controlled territory of nucleic villages includes the sum of the individual residential areas, cultivation plots, pastures, and hunting territories of each of its members, who maintain entirely their privileges of utilization of the total area. The sum of the domestic management units individually exploited by each member of the new nucleated center forms a territory of exclusive rights of use. A series of highly respected rules protects the domestic unit's control over its territory. Some of these rules include the prohibition of killing large game, fishing with piscicides, foraging seasonal seeds, or felling palms in each acknowledged territory. The nucleation of a settlement within the habitat does not fundamentally affect the control which a group exerts over its territory. Nucleation even tends to reinforce control, since under the circumstances of a nucleated residential pattern, the rapid exhaustion of natural resources in the immediate vicinity of the *centro* reinforces the necessity of the community's control over large territories. If populations in nucleated settlements continue to grow, enough land has to be incorporated into the system to provide food for the growing populations through traditional production strategies. On the other hand, if the carrying capacity of the environment is reached through extensification and no technological change is introduced, population growth could lead to the formation of new settlements as community fission occurs more frequently.

As shown in Chapter Six, in current nucleated villages land use zones can be depicted by a model of concentric rings spreading outwards from the center of a permanent village. Such a zoning system can be seen as an adaptive response to changes in the institutions that regulate the access to land and forest resources. In this model, the closest ring to the landing strip depicts the residential or housing zone. Households are most likely to establish residence around the airfield to minimize travelling time from homes to service areas. In fact, in personal conversations with household heads, the Achuar and Shiwiar people have repeatedly mentioned their desire of acquiring land next to the landing strip because of benefits such as: 1) easier access to school for children, 2) better control of who enters their territory, 3) better response in case of an emergency, 4) better communication when communal work is required, and 5) easier access to special infrastructure like water tanks, schools, or health centers. This study showed that houses are generally built in areas that are less than 1 km away from an airfield, which indicates a clustered arrangement of residences around this kind of infrastructure. As shown in Chapter Six, the level of clustering is closely related to the type of existing ecological conditions. Settlements in the inter-fluvial area are more dispersed than in the riverine habitat due to the presence of hills and mesas. People tend to disperse in the search for adequate land for residential and cultivation purposes since these areas are not plentiful. Notwithstanding some settlements are more dispersed in certain areas that in others, this study suggests that, in general, residences are more clustered today than they were before modern nucleation began in the 1950s. Results presented in Chapter Six showed that the average distance between houses in present settlements is roughly 100 m. In traditional dispersed settlements in the Pastaza River of Basin of Western Amazonia, houses were built approximately three to ten kilometers away from each other (Seymour-Smith, 1988; Descola, 1994; Taylor, 1999).

The next element of the production system includes agricultural areas and pastures, and is represented by the second ring in the descriptive land use model of indigenous production shown in Chapter Six. It should be acknowledged that indigenous horticulture is predominantly a female domain and more research is encouraged on the implications of the division of labor by sex since this is a very important determinant of overall production. This study is limited to general aspects of agricultural production to trace a baseline for further inquiry. Agricultural and cattle-raising areas are found close to residential areas and spread outwards from the center of the village, but differences exist between the inter-fluvial habitat (northern PRBEA) and riverine environment (southern PRBEA). Agricultural land use and pasture areas are placed on average 1 km closer to the landing strip in the riverine habitat than in the inter-fluvial habitat. Forest dwellers in the riverine environment allocate land for residential and agricultural land uses closer to landing strips because terrain conditions (i.e. slope and soil quality) are better than in the inter-fluvial region. Since cultivation areas are placed near residences, and residences are built around the landing strip, the resulting pattern is a clustered arrangement of residential units, cultivation plots, and pastures around airfields. In contrast, the inter-fluvial area in the northern region is characterized by poorer soils and hilly topography. These factors complicate the access to and conversion of forests to agricultural land use. Thus, people could face difficulties in finding available and suitable land around the landing strip for residential and cultivation purposes and require walking longer distances to overcome land shortage problems around service areas. Since soil conditions are poor, once a household finds a suitable site, it is preferable to clear large areas to guarantee food supply for longer periods if new technologies to intensify production in areas already under cultivation are not adopted. The consequence of this process is a dispersed pattern of residences and large cultivation areas. This finding suggests that, although decisions on whether or not to clear a forest area for agriculture in the riverine and inter-fluvial areas are based on the same criteria (i.e. terrain conditions, distance to homes, distance to landing strips), local alterations and adaptations exist that regulate the intensity and expansion of production. These responses will be discussed further in Section Three of this chapter.

Pasture lands for cattle-raising are a relatively new form of land use in the Jívaro territories. It was merely in the mid 1960s when cattle were introduced by the missionaries as a means of helping indigenous people acquire legal rights to the land and also to provide them with an income for purchasing certain goods such as clothing, radios, or medicine. This activity contributed to the sedentary character of nucleated settlements since, unlike the swidden *chacras*, pastures became permanent features once they were established and cattle were introduced. The introduction of cattle stimulated households to clear new land or convert old *chacras* into pastures. Pastures were generally located on the periphery of the residential zone, sometimes close to cultivation plots.

Presently, however, old pasture lands are being left as fallows and converted into horticultural areas since cattle-raising activities are being abandoned. This statement is supported with the results of the land use and land cover change detection analysis in the community of Sawastian in Chapter Six. Further research is needed to explain the decrease in the extent of pastures but field observations and personal communication with community leaders in 2006 suggest that this situation could be the result of three factors: 1) the presence of cattle and pastures is no longer a strategy to acquire land rights granted by the government. Other means to secure land rights are being utilized; for example, both Achuar and Shiwiar federations (NAE and NASHIE, respectively) are working with several non-governmental organizations to complete the legalization of the remainder of their territories; 2) the low prices of beef and the high costs of transportation have turned indigenous groups away from cattle ranching ; and 3) raising cattle in the tropics, particularly with limited technology and experience, creates significant challenges. Cattle are highly susceptible to bacterial infections. Communities require knowledge of and access to antibiotics, though these are generally lacking. Cattle can also die from eating poisonous plants, from snake bites, and from parasites. Some pastures, even newly cut ones, generally lack nutrients to maintain cattle. Therefore, when cows die from one of any multiple potential causes, the significant investment involved in the clearing of land turns into an important loss. Thus, people prefer to avoid the risk by allocating their time to other activities aimed at capital accumulation such as cash cropping.

Foraging areas (i.e. hunting and gathering zones) are represented by the next two rings of the land use model, and lie beyond agricultural and pasture areas. Gathering zones are extensions of the cultivation and residential areas and generally belong to the female domain. Further research should concentrate on the structural characteristics of this component to provide further insights on the contribution of extractive activities in the provision of food resources. In this study, even though the measurements of hunting areas and trails should only be considered as fairly rough approximations of the extent of hunting, some generalizations can be made from the analysis of these estimations. First, hunting area is positively correlated to the level of dispersion of settlements. According to Descola (1987), in traditional dispersed settlements where houses were three to ten kilometers away from each other, the hunting territory required to sustain a household varied between 1,000 and 2,500 ha. These areas are rough estimations of hunting territories based on analyses of hunting productivity, and the average per capita consumption of local populations. According to the present study, however, the average size of a hunting territory of an average household is ~ 250 ha, which means that hunting areas in new nucleic arrangements are only a fraction (between 10 percent and 25 percent) of what they previously were in traditional dispersed settlements. In general, the amount of land available for hunting and gathering has probably decreased in order to accommodate increasing populations that concentrate in permanent settlements. However, in order to sustain the demand for food of current populations, enough production and extraction has to take place in these reduced territories as in the past. Some of the strategies used by local people for this purpose have been oriented towards raising domestic animal species such as chicken, pork, and certain types of fish. Such strategies could have probably reduced the need of hunting and fishing in extensive territories. However, this study cannot provide any conclusive statement on this issue without further research on the implications of nucleation in foraging patterns.

Second, although a quantitative assessment of wildlife harvestings (i.e. hunting volumes or frequencies) is beyond the scope of this analysis, it can be suggested that hunting is preferred in areas relatively close to the focal hunting community. In fact, as shown in Chapter Six, a simple analysis of the density of trails at specific distances from the center of the villages shows that hunting trails concentrate around landing strips, which could be an indication that most hunting occurs near, or within five kilometers of villages. These results support the findings of other studies which show that in indigenous territories of forest regions in Paraguay (Hill, 1997), Brazil (De Souza Mazurek, 1997), Peru (Alvard, 1994), Belize (Fragoso, 1991), or Venezuela (Hames, 1980), most hunting occurs in the proximity of villages, or within a radius of 10 kilometers. However, apart from providing a general explanation on location preferences for hunting, this study cannot provide any direct, structural, and detailed analysis of hunting patterns without further study. This study advocates further empirical research on wildlife harvestings, as well as field studies that more directly focus on harvest technologies, frequencies, and volumes, in order to provide a more conclusive statement on the structural characteristics of hunting.

3. The structural characteristics of traditional agricultural systems

The analysis of agricultural expansion and intensity is applied when drawing a baseline for the characterization of indigenous cultivation systems and addressing the second research question: What are the structural characteristics of cultivation systems of contemporary subsistence groups in tropical lowlands that are at early stages of market integration? To answer this question, this study focused on two specific aspects of agricultural change: 1) the analysis of the average cultivated area per capita, and 2) the evaluation of agricultural intensity.

It was shown in Chapter Six that households in the north and south of the Pastaza River Basin show significantly different average cultivation areas per person. Results show that families in the inter-fluvial habitat manage larger cultivation areas than in the south despite the fact that there is no significant difference between household sizes or population pressure in the sample communities. Because extensive cultivation systems generally produce lower yields (i.e. kg per unit of area) than intensive ones, it is expected that production intensity in areas with poor soil and terrain conditions (inter-fluvial system) is lower than in areas with the opposite characteristics (riverine system). To evaluate this assumption, this study focused on two measures of agricultural intensity: 1) agricultural output measured as the amount of food produced in one year per hectare, and

2) the relationship between crop and fallow cycles measured as percentages. Results of the analysis of these two measurements are, in fact, consistent with the analysis of average cultivated area per person and suggest that agricultural systems in the southern region (riverine habitat) are structurally different than in the north of the Pastaza River (inter-fluvial biotope). The increased productivity of more intensive agriculture enables landholders in the southern system to use a relatively smaller land area than in northern system under similar demographic conditions.

This finding is in accordance with Descola's (1987) characterization, which suggests that production is significantly more intensive in the riverine system than in the inter-fluvial environment. However, this study found that the average cultivated area per person in the riverine habitat is significantly smaller than in the inter-fluvial biotope, which contradicts Descola's assumption that there are no important differences in the demand for land resources at a local level between riverine and inter-fluvial populations. Descola points out that the large disproportion between cultivation areas in both biotopes does not respond to local ecological conditions, but to differences in the social status of families. Yet, this study shows exactly the opposite: the demand for land resources is in concordance with the type of habitat, and specifically with the types of soils. High fertility soils of the riverine habitat produce higher yields in smaller cultivation fields than the inter-fluvial biotope. The importance of local ecological variation in cultivation is highlighted by the fact that there are no statistically significant differences in the composition and size of consumption units in both environments.

The spatial configuration of cultivation areas in these two cultivation systems clearly delineates distinctive land use footprints for each biotope. Cultivation areas in the inter-fluvial habitat appear to be significantly larger than in the riverine system. Thus, this study supports the recurrent distinction between riverine and inter-fluvial groups. It confirms the isolated observations made in previous studies on the existence of the riverine/inter-fluvial dichotomy in the whole Amazon region (Hegen, 1966; Lathrap, 1968, 1970; Carneiro, 1988; Denevan, 1996, 2001) and not only in the alluvial plains of the middle and lower watersheds (Meggers, 1971).

Nevertheless, measures of labor efficiency and agricultural intensity are only a general indication of the structural characteristics of one particular system; these values can be conclusively evaluated only in combination with other data on garden productivity, within a regional context. The results in Chapter Six on the extent, intensity of agriculture, and comparisons between subsistence tropical groups suggest that traditional indigenous groups in Western Amazonia have developed two distinctive cultivation systems that have been adapted not only to the technology available to them but also to local ecological conditions. Hence, in light of an apparent dichotomy between the riverine and inter-fluvial production systems in terms of their intensities, an obvious question arises: What are other factors besides ecological conditions determine differences in intensity between riverine and inter-fluvial production systems? Some authors have suggested that riverine and inter-fluvial societies with similar cultural backgrounds employ production strategies that are almost identical (Harner, 1984; Descola, 1994). However, the fact that the riverine and inter-fluvial cultivation systems show significant structural differences challenges this assumption. It could be suggested that important differences exist in resource management that could also be related to cultural legacies. Although a more exhaustive discussion of how the cultural and social makeup affects production levels is beyond the objectives of this study, attention should be placed on cultural aspects that could influence resource management within a particular biotope.

4. The demand for land resources in subsistence-based societies

The analysis of the relationship between agricultural land use and the socio-ecological context of forest-based inhabitants is used to answer the third general question of this study: What are the factors that affect the demand for land resources in indigenous and subsistence-based societies in tropical lowlands? Three approaches were followed in this study to help answering this question. First, this study focused on the household's life cycle to provide further insights on the aspects of agricultural productivity that change with household development (from having no children to small children, adolescent children, young adults, and finally to children leaving the household or marrying). Second, this study used bivariate and multivariate statistical analyses to identify the relationships between the extent of cultivation and a series of possible independent variables such as terrain conditions, distance from infrastructure, travelling costs from homes, and household demographics. Finally, since landscape change is a dynamic phenomenon, this study followed a spatially explicit approach that integrates the results of the multivariate statistical analysis into a GIS framework. This approach was used to provide further clues on the underlying processes that lead to landscape transformation due to the utilization of traditional systems.

4.1 The effect of household dynamics in landscape transformation

This study has relied on Chayanovian theory to analyze how household composition affects the demand for land for cultivation purposes. This framework has generally been used in the context of peasant farming and colonization for deforestation studies (Walker & Homma, 1996; Perz, 2002; McCracken *et al.*, 2002), but it has also contributed, in this case, to the understanding of resource demand in areas managed and controlled by native populations. The approach consisted of analyzing the relationship between the dependency ratio and the amount of cultivated land at different stages of household development.

Although the grouping of households by age group and the use of averages may reduce data variability, a few generalizations can be made from this analysis. First, Chayanovian theory helps to understand how demographic conditions of households influence the demand for land resources for agricultural land use. This study agrees with Chayanov's findings and supports the thesis that in societies that produce mainly for subsistence the force of the influence of consumer demands determines the overall production output, which varies in accordance with growing numbers of consumers. The analysis of the household's life cycle suggests that native cultivation systems incorporate more land at early stages of household development than at later phases. This behavior continues until the proportion between consumers and producers lessens for any reason (e.g. adolescent children leave for boarding school or young adults get married and leave the house). As households mature, the extent of farmed land decreases since there are fewer “mouths to feed”. This finding coincides with the results of some deforestation studies which suggest that higher rates of deforestation generally occur at early stages of farm settlement in colonization fronts and may decrease as households age (Perz, 2001). Generally, these effects are most evident in sites that are physically isolated and therefore less affected by exogenous factors, such as market influences or technological change (McCracken *et al*., 1999; Perz &Walker, 2002).

Second, this study has shown that demographic composition and development at the household level are increasingly important to explain environmental transformations at coarser levels of aggregation, especially in areas that are relatively isolated from external influence. Agricultural intensification or extensification (Brown & Podolefsky, 1976; Netting *et al*., 1993; Brondizio, 1999), deforestation (Godoy, *et al.* 1997; Walker *et al.,* 2000; Godoy, 2001Perz, 2001), forest succession (Coomes, Grimard, & Burt, 2000; Perz & Walker, 2002), or landscape fragmentation (Pan *et al*., 2004) in some way are driven by household dynamics. This means that understanding how demographics at local levels affect the landscape over broader extensions may help improve knowledge of global environmental change. Changes in the landscape are in the end the combined effect of multiple domestic units producing and consuming independently, whatever may be the nature and goal of production. With this premise in mind, projects that are intended to improve the livelihoods of indigenous people should incorporate these factors into their agendas to reduce the level of uncertainty in their results. Further, the recognition of the intrinsic diversity of social behaviors at lower levels of social organization (i.e. household level) allows an adequate prediction of future natural resource consumption at coarser scales (i.e. community or regional level).

4.2 The social and spatial context of indigenous cultivation systems

While Chayanovian theory allowed the analysis of the effects of household dynamics on landscape change, it adds little explanation about the factors that affect the demand for land resources but are external to the household. This study relied on theories on land use and land cover change to determine the linkages between environmental change and human land use in tropical lowlands. Based on the results of the bivariate analyses, this study evaluated the combinatory effects of population and its spatial context on the amount of cultivated area by means of a logistic multiple regression (LMR).

The LMR analysis indicated that population pressure in subsistence production systems is an important factor that allows the prediction of the location of agricultural land use; larger families demand more land resources for food production. This is not surprising since other empirical studies also suggest that population pressure is tied to environmental change in analyses of deforestation (Bilsborrow & Geores, 1994; Palo, 1994; Cropper *et al.*, 1997; Barbier & Burgess 1996; Andersen, 1997; McCracken *et al.* 2002), agricultural intensity (Turner II *et al.*, 1977; Boserup, 1981; Guillet, 1987; Humphries, 1993), habitat fragmentation (Hogan, 2001), or urban sprawl (Vosti, Witcover, & Carpentier, 1998; Browder, 2002). However, it indicates that even when producing a surplus could be important to some high status households, this is in general less important for the majority of households than it was previously believed (cf.

Descola, 1987; Taylor, 1999). In Western Amazonia, people produce to satisfy the demand for food, which can be seen as an indication that indigenous peoples optimize labor and time to pursue specific goals.

At local and regional levels, the effect of population on land cover is interconnected with other factors. This study shows that spatial inertia plays an important role in land use change; changes from one state to another are more likely to occur close to areas where those changes have already occurred. Openings in the forest cover increase accessibility into the forest and, consequently, the probability of the presence of agricultural land use. Therefore, there is also a strong “spatial spread” effect (Mertens & Lambin, 2000) on the expansion of agriculture where traditional cultivation occurs, which could be incorporated as a general principle in land use and land cover change literature. Future research should take into account land cover trajectories (i.e. succession of land cover types over more than a single date), which will allow for more reliable spatial projections of the expansion of agriculture in indigenous lands than taking into consideration only one-point-in-time data.

The environment provides a series of constraints and opportunities that have the effect of allowing or limiting the expansion and intensification of agriculture. The analysis of conversion costs and distance to landing strip showed that people are cultivating in areas that are less than optimal for cultivation, which can be an indication of land scarcity or of inefficient technology to increase output production in already cultivated areas. Yet, people adapt to hardship conditions in different ways, and may respond consequently with technological innovation and intensification (Boserup, 1965). Brookfield suggested in an earlier writing that:

> In an environment offering minimal constraints, it is possible to sustain cultivation by very simple means over long periods of time, under moderate population densities, and even quite high densities where conditions are unusually good… Where constraints are more severe, it remains possible to support low densities of populations by simple means, but rising densities demand [different] measures to continue in production (Brookfield, 1972: pp. 41-43).

Some of these measures may include changes in cultivation practices from extensive to intensive methods by reducing fallow periods or enhancing weeding and intercropping techniques. Other measures of adaptation to adverse conditions may include the integration to a market economy in order to access other sources of food. Indigenous people have often used strategies such as taking advantage of the availability of natural resources for profit (Sirén, 2007), particularly timber and minerals (e.g. Turner, 1999), and to a lesser extent flora and fauna (Seerger, 1982; Le Duc, 1996) to obtain non-traditional goods and food products. Indigenous peoples have also increased the production of domestic animals such as chicken, pork, and more recently of certain types of fish, in order to substitute for the lack of wild game and fish (Sirén, 2007). Other strategies appear to be changes in local common property institutions that regulate the access to land. The implementation of the concentric zone model discussed in this study is probably the result of the application of implicit or explicit institutions that allows a more equitable distribution of resources. When people cannot obtain enough resources to sustain their needs through this system, they may also choose to relocate in other forest areas. In the context of land or resource scarcity, community fission may be seen as an adaptive strategy that reduces competition for sources of food.

Production intensification and changes in technology may reduce the demand and dependability of subsistence societies on forest resources in the long term (Raintree & Warner, 1986; Unruh, 1990; Godoy, 2001). However, technological improvement may also lead to environmental degradation. The effect of intensification and technological development will ultimately depend on how technology is applied within particular political and historical conditions. Some authors (e.g. Denevan *et al*., 1984; Irvine, 1989; Poole, 1989; Laird, 2002) have recommended more research into the economics and the implications of indigenous activities to manage wild resources, especially in areas such as tropical rainforests, to create a basis for a sustainable integration of indigenous peoples into national development plans.

4.3 The prediction of landscape change in a shifting cultivation system

Since landscape change is an inherently spatial and dynamic phenomenon, a one-point-in-time analysis or static approach is only the first step in the attempt to understand the processes associated with land cover change. Based on the identification of key variables that explain agricultural expansion, the next step in this research consisted of developing a spatially explicit model, in which time and space are explicitly incorporated into one system that will allow the simulation of agricultural expansion over time. However, this was not a simple task; the lack of multi-temporal spatial data with the appropriate level of detail hindered the development of a land use model using techniques such as Markov chains, stochastic cellular automata, Monte Carlo approaches, or combinations of these, because these approaches rely on spatial information of past periods to predict future changes. As an alternative, this study used a combination of a deterministic cellular automata approach and logistic regression to simulate agricultural expansion. The approach was based on the use of global transitional rules, estimated demographic projections, and statistical relationships between land use and a series of spatial and demographic factors, which has not been done before. However, this approach posed significant problems because: 1) transition rules were global (applied to all cells) and deterministic (known and certain), which resulted in the "homogenization" of human behavior; people made the same decisions about landscape utilization based on similar known pre-conditions, which hindered the representation of individual preferences, 2) demographic growth rates were constant and global averages may not have reflected the conditions of individual households at a particular time step, and 3) some of the relationships are not necessarily linear in the long term.

The ability to add randomness and uncertainty helped to overcome the first restriction. In this particular study, the introduction of randomness in the process of selection of areas for cultivation accounts for the lack of complete data on human behavior (e.g. values, experience, ability) affecting decisions on land allocation, accounts for modeling the average case and not the individuals, and gives some kind of assignation to human preferences. The second and third restrictions limited the application of the model to conditions of steadily population growth and projected interactions between human population and the environment based on statistical analyses. Despite these limitations, the model simulated the expansion of agriculture with relatively good results for a time frame of eighteen years, as shown with the validation procedure of the spatial simulations.

Currently, the formation of *centros* in the Pastaza region is a common strategy to gain control over resources that appear to be diminishing. Thus, this practice will most likely continue until it becomes too costly to build new airfields or other type of accessibility infrastructure is created. Even though the impact of these landing strips, as far as the author knows, has not been evaluated previously, it can lead to debates in the conservation and development arenas on whether their impact is beneficial or detrimental. The simulation system implemented in this study is flexible for experimentation and further insights can be obtained on how changes in the social and spatial configuration of anthropogenic land uses affect the natural setting. This can be done by systematically making small changes in a parameter and exploring the influence that parameter has on the final landscape. Ultimately, it generates spatially explicit projections that may allow improving our understanding of the interaction between the demand for land resources and the intrinsic dynamics of any social phenomenon

This study presented an integrated evaluation of coupled human-natural systems to address the effects of agriculture in tropical lowlands. It provided a baseline for further research about the linkages between resource demand and the intensification of agriculture. The methodology presented in this study can lead to a decision support system that can be used by local organizations as a policy tool to conduct the assessment of the effects of new settlement formation and infrastructure development in indigenous territories.

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