

**NATURE-CULTURE INTERACTIONS: UNDERSTANDING THE PREVALENCE  
OF MALARIA IN THE NORTHERN ECUADORIAN AMAZON**

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## ABSTRACT

**PATRICIA E. POLO: Nature-Culture interactions: Understanding the Prevalence of Malaria in the Northern Ecuadorian Amazon  
(Under the direction of Stephen J. Walsh)**

Malaria is an endemic disease in Ecuador with epidemic episodes. About 60% of Ecuadorians are at risk of becoming infected with the malaria parasite (*falciparum* and *vivax*). The country faces all the malaria impacts present elsewhere, including physical and mental incapacities of infected people, economic loss at the individual and country level, mortality, and resistance of vectors and parasites to insecticides and drugs. This study analyzes how the prevalence of malaria is related to colonos' (peasants) cultural practices and to land use/land cover change in the agricultural frontier of the Northern Ecuadorian Amazon, where malaria is endemic. The effects of socio-economic, demographic, and land use/land cover factors on the presence of malaria in households were studied at the farm and household level, through a binomial logistic regression model. Landscape dynamics and their impact on malaria were studied at the provincial level using Remote Sensing imagery, GIS coverages, and pattern metrics analysis. Results indicate the Ecuadorian Amazon is subject to "frontier malaria", with a high incidence of malaria in the first 6-8 years of settlement, when the rate of forest clearing is greatest, and declining incidence after this period. The decline is believed to be due to geographic factors, such as the retreat of forest edges from colonos' dwelling units and the consequent decline in contact with the forest. Nevertheless, malaria remains prevalent. In sum, the fragmentation of the landscape has influenced the spatial trajectory of this disease, while colonos behavior has emerged as a primary factor in determining their likelihood of receiving anopheles mosquito bites.

## **DEDICATION**

This document, the effort, and joy that I had while doing my master's program is dedicated to my Mother, Cecilia, and my father, Marco.

To my sisters Myriam, y Bernarda.

To my brother Daniel

To my nieces and nephews

To my friends.

To those people that work for better days in the Amazonia

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## LIST OF ABBREVIATIONS

CDC, Center for Disease and Control Prevention, USA

CPC, Carolina Population Center, at University of North Carolina at Chapel Hill.

ENSO, El Nino-Southern Oscillation

FAO, Food and Agriculture Organization.

GIS, Geographic Information Systems

IERAC, Land Reform and Colonization Agency. This institution was named as INDA

IGM, Instituto Geográfico Militar/ Geographic Militar Institute.

INDA, Instituto Nacional de Desarrollo Agrario (National Institute of Agrarian Development).

INEC Instituto Nacional de Estadística y Censos, in Spanish. The National Institute for Statistics and Census of Ecuador.

MPH, Ministry of Public Health of Ecuador

PAHO, Pan American Organization

SNEM, National Malaria Eradication Service and Other diseases transmitted by vectors, of Ecuador.

UNC, University of North Carolina

WHO, World Health Organization

## CHAPTER 1

### Malaria Infecting and Affecting Humans' Health

#### 1.1 Introduction

To account for why and how malaria is a prevalent disease in the Northern Ecuadorian Amazon, this research is organized into five sections that describe the behavior of the *colonos* and the tropical landscape modifications. In Chapter 1, the context of the study is briefly described as well as the history of malaria around the world, the burden of the disease in the present as reported by WHO (World Health Organization) and PAHO (Pan-American Health Organization), the disease cycle, and the current world-wide problem of malaria as a disease affecting humans. This chapter also describes the problem and the research questions, hypotheses, methodological approaches, and the objectives of this research. Chapter 2 reviews and integrates land change related to human health, and cultural ecology of disease as the theoretical frameworks to examine the prevalence of malaria among the *colonos* in the agricultural frontier of the Northern Ecuadorian Amazon. In greater detail, Chapter 2 describes the processes that have modified the landscape in the area during the 1990s, such as colonization, deforestation, and agricultural extensification and intensification. It also describes the presence, incidence, and transmission of malaria in Latin America, particularly in the Amazon Basin. In close, it depicts the cultural and socioeconomic characteristics of the settlers of the Northern Ecuadorian rainforest and their links to endemic malaria. Chapter 3 explains the data used and the research methodology

followed to describe how the self-reported cases of malaria defined in the longitudinal 1990 and 1999 socio-economic and demographic surveys are spatially distributed in relation to land use/land cover changes and roads. This chapter also reports the results of the regression model and cross-tabulations that are used to determine the relationship between malaria and the cultural practices of the *colonos*. Chapter 4 integrates the results into a discussion of how and why malaria prevalence in the Northern Ecuadorian Amazon can be understood through an integrated analysis and interpretation of land use/land cover change, the cultural ecology of the disease, and human health. Finally, Chapter 5 presents conclusions of the study, policy implications, and directions for future research

## 1.2 What we know about Malaria

Attributed over centuries to everything from bad air, swamps, protozoa, and mosquitoes, malaria is currently recognized as a disease sustained by the interaction of landscape and human activity, and exacerbated in areas characterized by impoverished populations. Defined by the World Health Organization (WHO)<sup>1</sup>, malaria is a disease caused by *Plasmodium* parasites that are spread among humans through infected female anopheles mosquitoes. The original infections of wild primates and birds with plasmodia crossed to humans when agriculture and animal domestication began in Africa, about 8,000 years ago (Harrison, 1978; Howe, 1977; Alvarez, 1987). Human malaria is an infection only of humans which, unlike most arthropod-borne diseases, does not have an animal reservoir (Meade et

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<sup>1</sup> This information about the state of malaria in the world is derived from the web page of World Health Organization (WHO), <http://www.who.int/topics/malaria/en/>

al., 2000; Bruce-Chwatt, 1985). Over the course of time, this malady has affected humans in temperate climates as well as in the tropics, in England as well as in Sub-Saharan Africa (Howe, 1977; Meade, 1980; Alvarez, 1987). Throughout human history, malaria has caused the demise of entire societies and has taken more lives than warfare (Dubos, 1987).

The discoveries of Laveran (1880) and Ross (1897) became the scientific basis on which the world currently deals with the control of malaria and its effects on human health (Harrison, 1978). Laveran proposed that malaria was caused by flagellate bodies, now known as plasmodia. Ross explained the sexual cycle of the plasmodium within the female anopheles mosquito and its transmission from a diseased person to a healthy person by mosquito bites.

In the mid 20<sup>th</sup> century, malaria was eliminated in Europe and the United States, mainly due to intensive public health work and extensive use of quinine and its derivatives, although DDT<sup>2</sup> was used to eliminate the last malaria pockets. However, the lingering disease remained latent in the tropics (Stepan, 2002; Meade, 1980; Arnold, 1997; Harrison, 1978). Thus, currently, malaria is seen as a disease that is present only in warm, tropical climates, where dense vegetation and frequent precipitation are key factors for the reproduction of the anopheles. In addition, these characteristics partially explain the endemic and epidemic character of the disease (WHO, 2007).

The literature defines the infecting plasmodium, the anopheles vector, and the human host as the determinants of the malaria cycle (Breman et al., 2006; WHO, 2007; CDC, 2008).

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<sup>2</sup> DDT, Dichloro-Diphenyl-Trichloroethane.



Anopheles mosquitoes by themselves do not cause malaria; they require humans to be infected with the malaria plasmodium to start the “vector-human” malaria disease cycle (Alvarez, 1987; Harrison, 1978; Meade et al., 2000). Four *Plasmodia* affect humans’ health, *Plasmodium vivax*, *P. ovale*, *P. malariae*, and *P. falciparum*; the last more often causes death (Breman et al., 2006; Meade et al., 2000; Howe, 1977; Harrison, 1978). The complicated life cycle of the malaria *plasmodium* –sexual phase inside the anopheles mosquitoes’ gut, the infectious phase in mosquitoes’ proboscis, the dormant phase in the human liver, and the multiplying forms in the human red blood cells-- has hampered vaccine development. Regarding the anopheles mosquitoes, there are over 40 anopheles types in the world that transmit malaria to humans (Breman et al., 2006), but few types prefer biting humans over animals (Yasuoka et al., 2007). The female anopheles mosquitoes’ ecology, biting behavior, and survival mechanism shape the endemism as well as the degree of transmission of the disease (Zimmerman, 1992). Physiology and genetics determine the severity or absence of malaria infections (Puente et al., 2005), while human proximity to breeding sites defines endemic and epidemic episodes (Yasuoka et al., 2007). In addition, socio-economic, demographics, and mobility shape the endemic character of the ailment (Yasuoka et al., 2007; Castro et al., 2006; Barbieri, et al., 2005b).

The effects of contracting malaria vary from mild to severe, and range from the physical inability to work and perform other tasks, brain damage, and loss of life (Breman et al., 2006). The type of plasmodium defines the intensity of symptoms that an infected person with malaria faces, such as fevers, chills, and weakness (Meade, 2000; Harrison, 1978; Howe, 1977). Anemia, encephalitis, dysfunction in vital organs, kidney failure, clotting,

seizures, and pulmonary edema are some of the clinical manifestations of the disease that depend on the infected person's physiology and the plasmodium type (Breman et al., 2006; Puente et al., 2005). Cerebral malaria caused by falciparum is the worst case scenario, because it leads to the death of the patient (Puente et al., 2005). Further, anemia caused by falciparum, when present in pregnant women and other adults, raises the risk of killing the fetus and to acquire HIV infection by means of blood transfusions.

Currently, WHO reports that about one-half of the world's population is at risk of acquiring malaria. Yearly, over 500 million people become ill from malaria and an average of 1.5 million people die from this disease (Breman et al., 2004). The highest incidence of malaria is reported in Africa, about 2000 children die daily in this continent (Gates Foundation, 2008), though Asia, Latin America, the Middle East, and certain areas of Europe also have high incidences (WHO, 2008). According to the WHO, most malaria cases are localized in poor countries that experience low economic growth. WHO's goals against malaria have changed through time, from eradicating the disease to controlling and preventing its occurrence. DDT and chloroquine have been the weapons that WHO has suggested to fight malaria, as well as re-engineering landscapes to eliminate breeding sites. At present, *Artemisia annua*, a Chinese plant, is being used as part of a cocktail drug to treat those infected by resistant organisms (WHO, 2008; Breman et al., 2004; Meade et al., 2000). It also constitutes the drug of last resort (Shiff, 2002; Meade et al., 2000; Turnbull, 2000).

Today, there are several initiatives to combat malaria mainly focused in the tropics, most of them being implemented in Africa, where the highest morbidity and mortality is

reported. The United Nations Global AIDS and Health Fund was created in 2000 to combat AIDS, tuberculosis, and malaria in the world (WHO, 2008). This initiative is part of the Millennium Development Goals and supports countries economically and through technical advice (United Nations, 2001). Another global initiative is the Bill and Melinda Gates Foundation, that supports research and projects that fight malaria among other diseases around the world, mostly concentrated in Africa. The Gates Foundation started in 2000 and also supports other global health related projects such as, the Global AIDS and Health fund of the United Nations and the Roll Back Malaria program of WHO (Bill and Melinda Gates Foundation, 2008).

Until the first-half of the 20<sup>th</sup> century, the American continent was affected by malaria (OPS/OMS, 2003; Rodriguez, 2006). Even though DDT has been widely used since 1941, malaria continues to be prevalent in Central and most of the South America, as well as in certain Caribbean islands (Rodriguez, 2006; Franco, 1990). About 35-percent of the population of the continent is at risk of getting infected with the parasite, including people living in areas that do not report transmission (PAHO, 2007). In 2001, the Amazon countries accounted for 90-percent of the cases; where Brazil (~ 40%), Colombia (~21%) and Ecuador (~ 11%) had the greatest number of cases. In 2007, a report of PAHO, however, stated that malaria cases have decreased by 30-percent in the Amazon Basin. The important *plasmodia* species present in the region are *vivax* and *falciparum*; the former accounts for approximately 75-percent of the reported cases.

Even though there have been different strategic and systematic efforts to combat malaria through history, the malady is still present among us. Recent reports from health agencies such as WHO, PAHO, and Ministries of Public Health of different countries indicate that the anopheles vector and the malaria parasites have become resistant to insecticides and medicines, respectively. At present, there is no vaccine to prevent malaria, and any attempt to develop one has failed due to the complexity of the plasmodium life cycle (Shiff, 2002; Meade et al., 2000). In addition, malaria affects the economic livelihoods of families and the wealth and economic status of countries. Further, academic work posits that landscape modification is affecting habitat and behavior of the anopheles mosquitoes; therefore, there has been a frightening increase of malaria cases in certain regions of the world, while in others there are reports about its emergence (Eisenberg et al., 2007; Yasuoka et al., 2007; Vittor et al., 2006; Arambarú et al., 1999; Singhanetra-Renard, 1999, cited in Bilsborrow et al., 1999; Weil, 1981; Meade, 1980). As a consequence, the world continues to face the dire effects of malaria on human health and livelihood, as well as on the general well-being of people and society.

In the Coastal provinces of Ecuador as well as in the Amazon region during the first half of the 20<sup>th</sup> century, malaria cases increased, mainly related to agricultural activities and the lack of public health services (Aguilar, 2007, cited in OPS/OMS, 2007; Alvarez, 1987). In 1994, the National Malaria Eradication Service (SNEM, its Spanish acronym) reported that malaria cases began to decrease following the initial 1948 eradication campaign extended through the early 1970s. At the end of the 1950s, however, anopheles resistance to dieldrin spray was reported, and in 1969, Ecuador faced a serious epidemic (Narvaez et al.,

1994; Aguilar et al., 1994). During the mid-1980s, and extending through the 1990s and into the new millennia, waves of malaria epidemics ravaged Ecuadorians (SNEM, 2007; Aguilar, 2007, cited in OPS/OMS, 2007), mostly populations living in rural areas of the Coastal and Amazon regions. Resistance to quinine by *falciparum* was reported during the 1980s (Aguilar, 2007, cited in OPS/OMS, 2007; Narvaez et al., 1994). Although reported cases have plummeted since 2002, 60-percent of the population is at risk of being infected (SNEM, 2007). The purpose of this research is to increase understanding of “why and how” malaria continues to be endemic in the Northern Ecuadorian Amazon after 60-years of anti-malaria campaigns, severe landscape modifications, and changing socio-economic and demographics conditions.

### **1.3 The Problem**

Malaria episodes in the Amazon region have tended to increase since the beginning of the 20<sup>th</sup> century (Aguilar, 2007, cited in OPS/OMS, 2007), yet outbreaks have been controlled and the number of cases lessened by aggressive DDT campaigns (SNEM, 2007). These efforts, however, have not been consistently applied nor has interest about understanding the vector been a high priority. Additionally, resistance to drugs and to insecticides has been reported in the region (SNEM, 2007; Aguilar et al, 1994). On the other hand, the Northern Ecuadorian Amazon faced two severe epidemics during the early and late parts of the 1990s (SNEM, 2007). During the same decade, the area continued receiving in-migrants, mostly from the Andes (Bilsborrow et al., 2004; Marquette, 1998; Pichon, 1997). This process of spontaneous resettlement, known as colonization, started at the end of the 1960s due to oil exploitation and agrarian reform (Bilsborrow et al., 2004; Pichon, 1997;

Tamariz et al., 1997). Thus, the rainforest of the Northern Ecuadorian Amazon has been under constant anthropogenic pressures, evidenced through deforestation to build roads, develop urban and rural settlements, and support agricultural, logging, and cattle activities. The literature confirms that landscape modification leads to modifications of the anopheles' habitat and behavior (Vittor et al., 2006; Guimaraes et al., 2000; Walsh et al., 1993; Zimmerman, 1992), which in turn determines the prevalence, emergence and reemergence of malaria (Yasuoka et al., 2007; Eisenberg et al., 2007; Castro et al., 2006; Barbieri et al., 2005b; Patz et al., 2004; Beck et al., 1994; Weil, 1981). In addition, Meade (1976) argues that cultural practices, beliefs, and population characteristics determine the health and risk status of human populations. The *colonos*<sup>3</sup> in the rainforest of the Ecuadorian Amazon have imported their cultural practices from other regions of the country, mostly from the Sierra, that are generally not suitable for living in a tropical environment. Thus, this research indicates that the prevalence<sup>4</sup> of malaria in the rainforest of the Ecuadorian Amazon is a complex problem that integrates land use/land cover patterns and dynamics, socio-economic and demographic characteristics of the population living in the NEA, the ecology of mosquitoes, and the nature of the parasites.

#### **1.4 Research Questions**

The assessment of how human health is affected by population- environment feedbacks is a complex endeavor, because it implies contextual analysis of human behavior, the functioning of the disease, and changes in the environment -all are embedded in local,

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<sup>3</sup> *Colonos* are immigrants from the Andes and from the Coast that settled in the Amazon region looking for lands to own and produce them.

<sup>4</sup> Prevalence is an epidemiologic measure that accounts for the total number of cases of a disease in a population at a given time.

regional, national and international discourses, socio-economic patterns, and political dynamics. Nature is constantly being modified, not just by anthropogenic forces, but also by ecological processes that occur within a space-time context (Blaikie et al., 1987) that, in turn, shape a new ecology that influences the emergence of infectious diseases (Patz et al., 2004), such as malaria (Yasuoka et al., 2007). In addition, cultural practices, physiologic characteristics, and socioeconomic activities expose populations to becoming infected with malaria and suffer its consequences (Yasuoka et al., 2007; Norris, 2004; Meade et al., 2000; Aguilar et al., 1994; Alvarez, 1987). Further, national and international policies and campaigns to fight malaria are still ongoing after 150<sup>5</sup> years of knowledge about germ theory<sup>6</sup> and 127 years after Laveran discovered the agent of malaria, the *plasmodium* species (Dubos, 1987; Harrison, 1978). The main aim of this research is to assess how environmental and cultural factors are related, and how they combine to shape the prevalence of malaria for *colonos* of the agricultural frontier of the Northern Ecuadorian Amazon.

This study addresses two central research questions that are posed at local and regional (space-time) scales. At the local scale, the Cultural Ecology of Disease explains how the malaria disease system is maintained and perpetuated by the daily practices of rural farmers living in the North Ecuadorian Amazon during the 1990's. At the regional scale, Land Change Science (LCS) is used to study how the natural and built environments in the agricultural frontier have shaped the spatial distribution of the prevalence of malaria among the rural settlers of the Northern Ecuadorian Amazon (Figure 1.1) in 1990 and 1999.

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<sup>5</sup> It was 1857 when Louis Pasteur published his first paper about germ theory.

<sup>6</sup> Germ theory was first proposed by Louis Pasteur, who suggested that any disease is caused by only one germ.

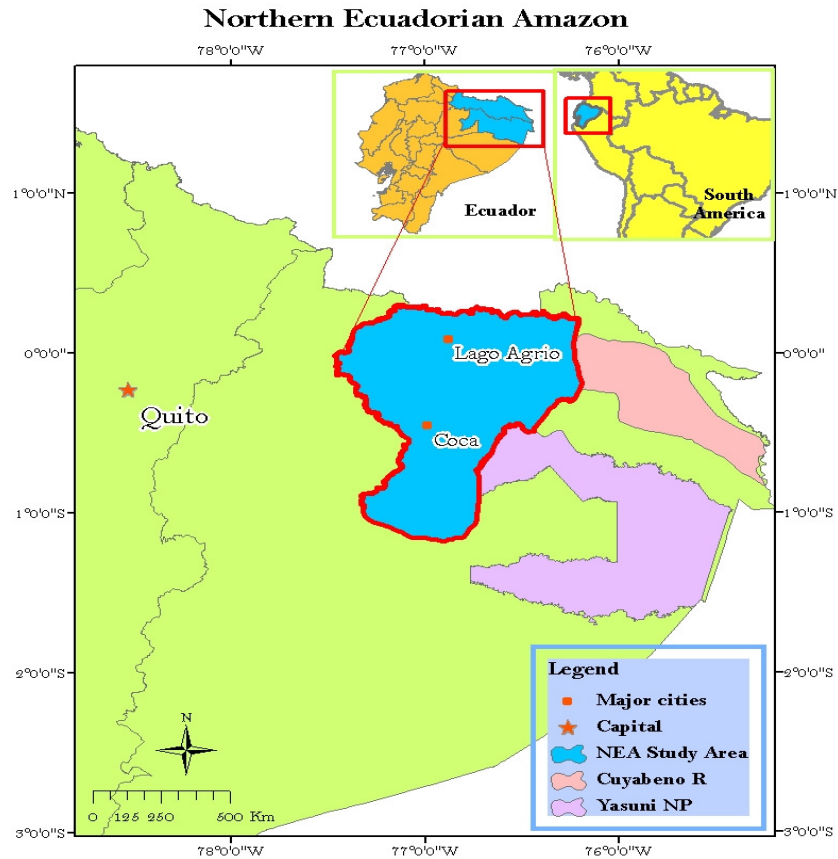


Figure 1.1. Study Area: The Northern Ecuadorian Amazon (NEA).

## 1.5 Hypotheses

An understanding of how malaria maintains a continuous presence within the *colonos* living in the fringes of the Ecuadorian rainforest calls for an integrative approach for analyzing population-landscape dynamics and feedbacks between the behavior of settlers and the past and present efforts of the Ecuadorian government to combat the “tropical scourge,” malaria.

The imprints of population-environment interactions merit attention as factors influencing the prevalence of malaria in the Northern Ecuadorian Amazon. This area has



been facing dramatic landscape modifications over the last 4-5 decades, mainly through deforestation and road-building resulting from colonization, oil exploitation, agricultural extensification, and community growth (Bilsborrow et al., 2004; Walsh et al., 2002). *It is hypothesized that in the rainforest of the Northern Ecuadorian Amazon, deforestation and agricultural extensification and intensification processes have modified the habitat and behavior of the malaria vector in substantial and compelling ways that increase the prevalence of malaria.* After the forest has been cleared from a continuous forest canopy to a more fragmented and open canopy, Anopheles females mosquitoes have a larger breeding area, thus increasing the population density of the mosquitoes and maintaining a constant presence of plasmodium among the *colonos* in the agricultural frontier. Further, the absence of forest (and forest animal species) means a reduction in natural prey for the anopheles, so their behavior becomes more aggressive toward human blood sources. In addition, the Ecuadorian Amazon basin is acknowledged as a high-risk area for malaria transmission and malaria epidemiology are under-reported (San Sebastian et al., 2000; Aguilar et al., 1994). In addition, there are few studies about the habitat and behavior of the anopheles mosquitoes in the Ecuadorian Amazon, and none describes the ecology of the vectors that result from land use/land cover change and population characteristics dynamics.

Second, in-migration flows and natural population growth were high in the rainforest of the NEA during the 1990s (Carr et al., 2006; Bilsborrow et al., 2004; Pichon, 1997; Murphy et al., 1997). These incoming populations were from other rural areas of the country, mainly the Andes (Bilsborrow et al., 2004; Marquette 1998; Tamariz et al., 1997). *It is further hypothesized that the colonos who settled in the agricultural frontier of the rainforest*

*have perpetuated the prevalence of malaria, because of their cultural and labor background, as well as their socio-economic conditions.* Rural settlers in the NEA typically have large household sizes and high density per room. This concentration of people increases the infection rates of malaria. Also, the dwelling units of the *colonos* are mostly constructed of wood that does not protect the inhabitants from anopheles mosquitoes and their bites. Finally, agricultural activities are the main household livelihood of the *colonos* in the NEA, which further increases the risk of exposure of settlers to anopheles.

## **1.6 Methods**

To understand the prevalence of malaria among the *colonos* of the agricultural frontier of the Northern Ecuadorian Amazon, this study includes two aspects that are relevant to the disease cycle, i.e., landscape modifications and human behavior. Each aspect is assessed independently through different methodologies that integrate remote sensing, Geographic Information Systems (GIS), and statistical tools as well as descriptive analysis. The resulting schemes are then analyzed in an integrative approach that informs the pattern-processes relations and the mechanisms that shape endemic malaria in the Northern Ecuadorian Amazon. This research uses the NASA data<sup>7</sup> about demographic, socioeconomic, and land use/land cover change characteristics of the rural settlers of the Northern Ecuadorian Amazon collected through interviews in 1990 and 1999. Field data collected in the rainforest of the Northern Ecuadorian Amazon during the summer of 2007 complements the population and environment NASA data. This study evaluates the prevalence of malaria

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<sup>7</sup> The NASA data results from the UNC-NASA project managed by a research team of the Carolina Population Center (CPC), which is part of the University of North Carolina (UNC) at Chapel Hill, USA. The research includes the two northern Amazonian provinces of Sucumbios and Francisco de Orellana, and a small region of the Napo province, its northern area.

based on self-reports by *colonos* in the 3-months preceding the interviews in 1990 and 1999. Prevalence is the presence or absence of malaria within a population in a given time.

The spatial distribution of the prevalence of malaria among the Northern Ecuadorian Amazon settlers uses self-reported cases of malaria in the 3-months preceding 1990 and 1999, and is assessed by using remote sensing images and various GIS layers. Two classified Landsat images from 1986 and 1999 are used to represent land cover/land use --primary forest, fallow, agriculture, urban and barren areas, and water bodies. A reclassification process was applied to both satellite images to derive forest, agriculture, urban/barren, water, and unclassified classes. This new classification scheme is used to measure the composition and spatial organization of the tropical landscape and determine whether it is related to the prevalence of malaria in the area. These pattern metrics inform about the fragmentation of the landscape, the diversity of land use/land cover types, and how patch types are spatially distributed. GIS layers of roads (1990 and 1999), finca madre<sup>8</sup> (farm) boundaries, rivers, communities, and major cities digitized by the Ecuador project team from 1:50,000 topographic maps are overlaid with the two Landsat images. Households reporting malaria in the 1990 and 1999 surveys are represented by spatially-referenced using UTM-coordinates and registered to the satellite images. Spatial links between deforestation, land use/land cover, and the socio-economic and demographic characteristics of households reporting (and not reporting) malaria cases are mapped and their spatial patterns are interpreted for both study periods. An analysis is conducted to assess geographic areas of high, medium, and low rates of deforestation at the farm-level that is integrated with roads, rivers, and malarial households, as an indicator of the disruption of the ecology of anopheles mosquitoes,

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<sup>8</sup> *Finca madre* are farms without any subdivision. I will use farm and *finca madre* as synonyms.

thereby, encompassing the factors shaping the prevalence of the disease in the Northern Ecuadorian Amazon.

The link between malaria and behavioral characteristics of the rural settlers in the Northern Ecuadorian Amazon is statistically assessed. The data used in this research are taken from a socio-economic and demographic longitudinal survey (1990 and 1999) conducted at the household and community levels by the UNC Ecuador Project team. The dependent variable, malaria occurrence at the household-level of surveyed farms during the 3-months preceding the surveys, and the independent variables, such as land cover/land use, demographic characteristics, and economic and social behaviors, are derived from this rich dataset. It is important to note that other studies, conducted in Latin America by Castro et al. (2006) and Kroeger et al. (1995), have shown that self-reported cases have a reliability of 67-percent and 81-percent, respectively. Descriptive statistics summarize the demographic characteristics of household members reporting on malaria, such as gender, age, and education level of the parents. A cluster analysis is performed on the behavioral variables and malaria prevalence to assess spatial autocorrelation. Then, a binomial logistic statistical regression model is developed to determine the strength and direction of the relationship between the prevalence of malaria and dwelling unit types, household composition, community integration, and economic behavior.

Finally, *colonos*, rainforest, mosquitoes, and plasmodium are integrated to assess how and why malaria continues to be prevalent among the *colonos* of the Northern Ecuadorian Amazon. Self-reported malarial households are compared with non-malarial households with

regard to land use/land cover change, behavioral practices of the *colonos*, and the results of anti-malaria campaign. This analysis is used to describe the mechanisms and processes through which malaria has become endemic within the tropical Ecuadorian rainforest.

## **1.7 Objectives**

This research describes the historical and current background of malaria as a disease affecting human health in the Northern Ecuadorian Amazon during the 1990s compared to the state of the disease state around the world. Contextual factors are described to embrace a comprehensive understanding of how malaria is crafted with its prevalent character. Cultural, socio-economic, demographic and land cover/land use change local factors are described to study malaria in the agricultural frontier affecting the *colonos*.

Human behavior is analyzed by a logistic multivariate model, that allows for an enhanced understating of the relationship between the prevalence of malaria as the dependent variable and a set of independent variables. These independent factors are education level of household parents, household income, house type –specifically wall types, water sources for drinking water, age of the head of the household, topography of the farm, year of acquisition of the farm, and land use –e.g. perennials, forest, pasture, and swamp.

Spatial analysis is performed to determine how the composition and structure of the landscape over time have influenced the constant presence of malaria within the Ecuadorian rainforest affecting the *colonos*' health. A reclassification process is applied to the satellite images of 1986 and 1999 to characterize land use/land cover: forest, agriculture,

urban/barren, water, and unclassified. Then, landscape metrics are calculated using the reclassified satellite imagery. Metrics such as fragmentation, types of forest patches, and spatial aggregation of patches are calculated.

Last, an integrated analysis of land use/land cover change and cultural practices is performed to describe whether there exist links with the prevalence of malaria in the study area, and describe how the disease survives over time.

## CHAPTER 2

### Prevalence of Malaria Through the Lenses of Land Use Change and the Cultural Ecology of Disease

Ecuador has a history of endemic malaria (Ministerio de Salud Pública del Ecuador, 2006). Resistance to quinine and dieldrin, the El Niño-Southern Oscillation (ENSO), as well as political and social factors are reported as problems that exacerbate [or define] the endemicity of malaria in Ecuador (Ministry of Public Health of Ecuador –MPH-, 2006). In addition, Alvarez (1987) and Aguilar et al. (1994) point out that malaria in Ecuador is present where land change has been most pronounced.

This chapter describes the theoretical framework used to analyze the prevalence of malaria among the *colonos* who established in the agricultural frontier of the Northern Ecuadorian Amazon. Literature about land use/land cover change and infectious diseases, as well as cultural ecology of disease are examined. While the former helps to determine the links between land use/land cover and the prevalent spatial distribution of malaria, the latter sheds light on how cultural practices of the *colonos* are intertwined with endemic malaria. Examining malaria as a result of dynamic and intimate forces, created by nature and culture, is a comprehensive and integrated approach to address the prevalence of malaria in a frontier setting.

## **2.1 Unhealthy Landscapes**

### **2.1.1 Land Use/Land Cover Change and Re-Emergence of Infectious Diseases**

Anthropogenic forces modify the dynamics of land use/land cover change, and, in turn, human health is affected (Patz et al., 2005; Eisenberg et al., 2007; McMichael, 2004). These human-induced disturbances convert biomes into simple and young ecosystems so that feedbacks lose their resilience and complexity; therefore, some ecological elements disappear, while others hazardously thrive (Meade et al., 2000; Odum, 1975). First, regarding human health effects, one threatening outcome of ecologic simplification is that the vectors' ecology, behavior, and density tend to increase, while at the same time natural predators may disappear (Eisenberg et al., 2007; Patz et al., 2005). Second, ecological services become diminished, if not lost entirely; thus, food, water, forests, and climate regulation are at risk of losing their quality for human consumption (Foley et al., 2005; Eisenberg et al., 2007; Guest et al., 2005). A special and direct service for human health is that some biomes, such as the tropical rainforest, act as a foci of diseases. When humans encroach into such ecosystems, the vectors, the reservoirs, as well as the pathogens impact humans, thus affecting their health status (McMichael 2004; Patz et al., 2004). However, a reverse situation can also happen, whereby people transmit pathogens to wildlife, which, in turn, will have unfavorable effects on human health (McMichael 2004; Patz et al., 2004; Meade et al., 2000). Finally, if human populations lack resources to sustain their lives, they increase their susceptibility to contracting infectious diseases (Eisenberg et al., 2007; Guest 2005). Thus, neither landscapes nor humans are unhealthy; human health is a constant adaptation of population-environmental interactions.



The literature points out various causes that affect the emergence of infectious diseases, such as malaria. Eisenberg et al. (2007) classify the causes of infectious diseases as proximal and distal, adding that they are a result of the complex interplay of social and ecological factors. In the case of malaria, the distal causes are infrastructure projects (e.g., water projects, building and expansion of transportation roads), deforestation, infrastructure, and climate change, while the proximal are vector's biting, survival, and human proximity. Patz et al. (2005) also define malaria as an infectious disease whose incidence and emergence are highly related to ecological changes. Other land use changes that account for the re-emergence of malaria are agriculture, settlements, urbanization, mining, and road building (Yasuoka et al., 2007; Barbieri et al., 2005b; Norris, 2004). In addition, human populations that are established in forest fringes exist in close proximity to vectors and pathogens, increasing the likelihood of becoming easily infected and even facing outbreaks (Patz et al., 2004). Climate factors such as temperature, rainfall, floods, and ENSO define the presence, seasonality, and severity of malaria (Patz et al., 2002). Further, the effects of global warming are exacerbating the presence of malaria in the world through wider spatial distribution, increased incidence, and the adaptability of anopheles (Eisenberg et al., 2007; Patz et al., 2005; McMichael, 2004), and likely of the plasmodium (McMichael, 2004). However, the literature also points out that landscape modifications have led to the decrease of malaria, and in certain areas even to the total suppression of malaria (Yasuoka et al., 2007; Molyneux, 2002). Of interest to this research is how land use, specifically clearing of forest, agriculture, rural settlements, and roads, are related to the prevalence of malaria in the Ecuadorian rainforest.

Landscape modifications, such as land use/land change, promote changes in the behavior, habitat, or density of disease vectors, such as anopheles (Walsh et al., 1993; Patz et al., 2004). Vittor et al. (2006) report that anopheles have become more aggressive and their human-biting rate has increased in deforested areas in the Peruvian Amazon, which indicates the likelihood of higher malaria transmission. They argue that the breeding sites that deforestation has created for anopheles shape their aggressive behavior as well as their density. These areas are large deep ponds and fish farms of clean water, partially shaded and surrounded by grass and crops with fallow and shrubs. Moreover, studies report that certain anopheles' blood meal sources as well as biting and resting places have been modified over time (Yasuoka et al., 2007; Guimaraes et al., 2000; Zimmerman, 1992). For instance, *Anopheles darlingi*, the main vector of the Brazilian Amazon, has been reported to have changed its blood meal preferences during the 20<sup>th</sup> century, from biting and resting inside homes to biting and resting outdoors, and even from humans to animals (Zimmerman, 1992). Zimmerman (1992) indicates that the causes that shape these changes in anopheles behavior may be affected by insecticides, human proximity, ecologic variations, and even evolution. A study of *Anopheles oswaldoi* in Brazil suggests that after deforestation, this vector, though it prefers the forest edge as its residence, is found near houses for its hematophagic activities upon humans (Guimaraes et al., 2000).

Regarding anopheles habitat and density, Yasuoka et al. (2007) posits that the malaria vector's survival and behavior are determined by climate conditions as well as sunlight, vegetation, soil, and water type. The dynamics of temperature, rain, and humidity determine the presence or absence of anopheles as well as their number; these environmental factors, in

turn, are altered by human agency (Walsh et al., 1993; Yasuoka et al., 2007; Zimmerman, 1992). In the Peruvian Amazon, Aramburú et al. (1999) report that malaria's prevalence in Iquitos is seasonal and highly related to rains, but temperature and humidity are not significant factors. Vegetation, sunlight, and water type are inherently related to anopheles habitat preference. For instance, some anopheles in Trinidad prefer bromeliads, strong sun light, and water with an acidity level of 5 as the place to breed (Zimmerman, 1992; Faranoff, 1968). An interesting environmental adaptation is reported for *Anopheles nuñeztovari*, whose favorite breeding sites are flooded areas, but their density increases, during the dry season in Surinam and during the rainy season in Venezuela (Rodriguez, 2006). While Vittor et al. (2007) report an increase of anopheles density due to deforestation in the Peruvian Amazon, Guimaraes et al. (2004) describe that the number of anopheles is modulated by the water level of a hydroelectric dam in Brazil. However, the literature points out that the anopheles mosquito' species is a key factor intrinsically related to the interplay of climatic and environmental factors that shape the presence or absence of malaria (Walsh et al., 1993; Zimmerman, 1992; Yasuoka et al., 2007). In sum, the nature and the stage of land cover/land use change affect the ecology of the anopheles mosquitoes, and along with human proximity to breeding sites, modulate the epidemiology of malaria (Yasuoka et al., 2007; Eisenberg et al., 2007; Patz et al., 2000).

The Ecuadorian rainforest represents an important biome element of the world's ecology. Internationally, it is acknowledged as a "hotspot" of biodiversity and species endemism (Myers et al., 2000). On the other hand, Guzman (1995) warns about the high rates of infectious diseases, such as malaria in the region. Since the mid-1960s the region has

become the main provider of Ecuador's revenues from the exploitation of oil. Also, the region is a very important source of wood to supply the country and international markets, as well as a provider of agricultural products for the national market. This same rainforest is a place where people, both indigenous and *colonos*, make their living. The former are long time occupants of these lands (Rival, 2002). The latter mostly in-migrated to the region since 1990, looking for land and work, following the oil roads and other economic developments (Pichon, 1997). The in-migrants outnumber the indigenous people, which has put commensurable pressure on natural resources. However, both indigenous and *colonos* face the consequences of these ecological disruptions, including diseases such as malaria, as the results of population-environment interactions. Yet despite 60 years of anti-malaria campaigns of the Ecuadorian government, the rural settlers' health is still affected by malaria. My research proposes that landscape changes over time, such as forest clearing, intensive and extensive agriculture, roads, water bodies, and settlements have promoted ecological changes in anopheles breeding sites and increased their proximity to the *colonos*, thus allowing infections to continue, despite the eradication campaigns.

### **2.1.2 The Ecuadorian Amazon: Historic Land Occupation**

The Northern Ecuadorian Amazon has become increasingly populated since the mid-1960s, associated with oil exploitation and colonization, and in turn human health has become threatened. According to Tamariz et al. (1997), an incipient colonization of the Amazon region started with the Unoccupied Lands and Colonization Law of 1930. However, since the mid-1960s with the First Agrarian Reform, migratory fluxes to the Amazon have

persistently increased, facilitated by the roads opened by oil companies (Tamariz et al., 1997; Pichon 1997). These in-migrants settled on plots of 50 hectares (250 meters wide by 2,000 meters long) along the oil roads, or on secondary roads opened by themselves that parallel to the existing ones (Walsh et al., 2002; Bilsborrow, 1998). Tamariz et al. (1997) describe a more organized but very small process of directed colonization in the same area, carried out by the military regime under the Colonization of the Amazonian Region Law of 1977. In sum, the colonization process in the Amazon region is a result of national security to have a human presence in the area, politics to relieve tension of the land concentration and oppressive<sup>9</sup> agricultural system of the Andes and Coast, and economic development including incentives for cattle ranching and agricultural productivity. (Tamariz et al., 1997; Murphy et al., 1997).

Settlers have transformed natural forest to different land uses through deforestation and agricultural extensification and intensification practices (Pichon, 1997; Bilsborrow et al., 2004). Settlers cleared the forest within their farms to boost development through logging, cattle ranching, and agricultural activities (Tamariz et al., 1997). Bilsborrow et al. (2004) and Walsh et al. (2002) found that the influx of migrants and increased population growth in the Northern Ecuadorian rainforest have changed the spatial structure and composition of the landscape. These drastic and even irreversible changes to the Ecuadorian rainforest have triggered feedbacks affecting the *colonos*' health and disease status (Tamariz et al., 1997; Aguilar et al., 1994). The five most common causes of morbidity and mortality among the

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<sup>9</sup> As oppressive has been labeled the agricultural system that Ecuador has had until de Second Agrarian Reform. The administrative structure was an inheritance of colonial times, when the Spanish conquered and dominated indigenous people living in the American continent. Indigenous people were forced to work without payment in their lands taken away by the conquerors.

inhabitants of the Amazon are respiratory infections, gastro-intestinal, vector-borne, dermatologic, and vaccine preventable diseases (Tamariz et al., 1997; Pan et al., 2004).

### **2.1.3 Land Use Intensification in the Northern Ecuadorian Amazon During the 1990s**

Sucumbios and Orellana are the provinces of study in the Northern Ecuadorian Amazon (Figure 2.1). Ecuador, between 1990 and 2000, had a deforestation rate of 2.1-percent, the highest rate in the South Latin American region (Food and Agriculture Organization, 2001), whereas the Northeast Amazon had an average annual deforestation rates of 2.5-percent and 1.8-percent during 1986-1996 and 1996-2002, respectively (Mena et al., 2006). Among the farms of the UNC-NASA project, the annual rate of deforestation was 3-percent, and the average household plot size was also reduced from 44 ha in 1990 to 24 ha in 1999, because of land subdivision (Bilborrow, 2002; Bilborrow et al., 2004).

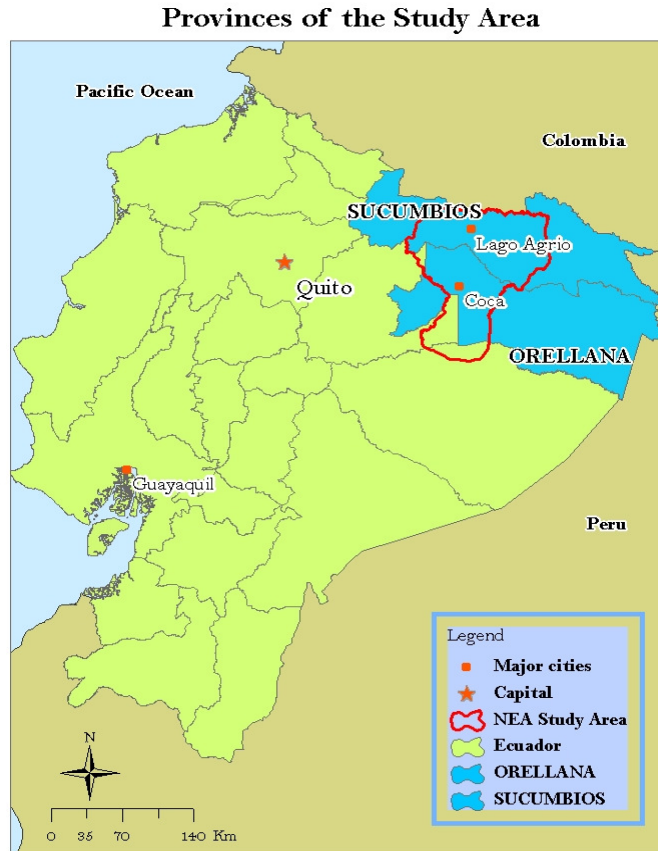


Figure 2.1. Sucumbíos and Orellana, provinces of the Study Area.

Land use in the Northern Ecuadorian Amazon has shifted from clearing before 1990 to extensification in 1999. The agricultural development of the *colonos* in the area includes subsistence, annual crops (e.g., rice, corn, plantains, sugar cane, yucca), commercial perennial crops (e.g., coffee, cacao, African palm, naranjilla), and cattle, though it is not a wide spread activity (Barbieri et al., 2005c). Pan et al. (2004) report that the Northern Ecuadorian Amazon landscape has become heavily fragmented during the 1990s due to farm subdivisions, household demographics, road building, and electricity extensification. Thus, during the 1990s, forested areas on farms have decreased from 59 percent to 45 percent, while perennials, pasture, and annuals have increased from 21 percent to 54 percent, and

swamps and fallow have remained relatively unchanged at about 3 percent both (Bilborrow, 2002). Land cover/land use processes have created a homogenous, cleared pattern in the landscape (Bilborrow, 2002; Pan et al., 2004), which resembles a fish bone pattern (Walsh et al., 2002; Bilborrow et al., 2001). See Figure 2.2: deforested area in the Northern Ecuadorian Amazon.



Figure 2.2. Deforestation in the study area. Fieldwork, summer 2007, P. Polo.

Studies about malaria in the Ecuadorian Amazon acknowledge that land use/ land cover changes have increased malaria rates (San Sebastian, 2000; Aguilar et al., 1994; Amunarriz, 1991). In this study, the prevalence of malaria is attributed to the expansion of areas where the anopheles can breed, and the increased proximity of the mosquitoes to rural farmers' houses. Roads constitute the perfect means of conveyance for the malaria plasmodium in the area. Once an infected person has traveled along a road to a frontier area or within it, a female mosquito may acquire the parasite through biting, and the process of



malaria transmission will start over again in the agricultural frontier. Thus, in the case of the Ecuadorian rainforest, these landscape changes can also work as a constant crafter of the prevalence of malaria among *colonos* living in the agricultural frontier.

#### **2.1.4 The Anopheles, the Plasmodium, and Public Health in the NEA**

Ecuador, among the Amazon basin countries, accounts for a malaria burden of approximately 11-percent, while the Amazon basin recently accounted for 90-percent of the regional cases (OPS/OMS, 2003). However, the region has decreased its malaria burden by 30-percent since 2000 (PAHO, 2007) and, Ecuador has reported a decrease of 92-percent of malaria incidence since 2000 (PAHO, 2007). The incidence of malaria in the Amazon region during the two outbreaks of the 1990s had about 75,000 reported cases in 1990, while in 1998-1999, there were approximately 85,000 reported cases (Ministerio de Salud Pública / SNEM, 2008). During the same decade, the mortality rate was low relatively, 16 deaths reported in 1999 (PAHO, 2007), but there are no mortality reports for 1990.

Malaria in Ecuador is reported to have been introduced by African slaves during the Spanish conquest of the American continent (Alvarez, 1987). Most inhabitants of rural areas in the country face malaria (SNEM, 2007; Aguilar et al., 1994; Alvarez, 1987). According to the SNEM report of 2007, the most affected population was the economically active, between 15 and 44 years old, that accounted for 65-percent of total cases (SNEM, 2007). Anopheles mosquitoes have become resistant to sprays and the plasmodium to drugs (SNEM, 2007; Aguilar et al., 1994; Alvarez, 1987). Currently, approximately 60-percent of the

Ecuadorian territory is at risk for getting becoming infected with the plasmodium (SNEM, 2007; PAHO 2007; OPS/OMS, 2006). According to SNEM' statistics, generally *Plasmodium vivax* cases account for 80-percent, while 20-percent are *falciparum* or mixed cases (SNEM, 2007; Aguilar et al., 1994). The country has faced serious epidemics during each decade since the beginning of the 20<sup>th</sup> century (Alvarez, 1987). Indeed, serious malaria outbreaks occurred twice within the 1980s and within the 1990s (Aguilar et al., 1994).

During the 1990s, the coastal provinces of Ecuador accounted for 77-percent of the total malaria cases of the country (Ministerio de Salud Pública del Ecuador, 2006). The Amazon region represented about 12-percent of cases, and the lower Andes had 11-percent of the reported malaria. The provinces that report the highest incidence rates of malaria are on the coast of Ecuador, Esmeraldas and Manabí, that account for 44-percent; however, the northern provinces of the Amazon have reported an increasing number of cases, mainly *falciparum*, since the 1980s (SNEM, 2007; Aguilar, 2007, cited in OPS/OMS, 2007; Narvaez et al., 1994). The real number of malaria cases in the country, however, is believed to be 4 to 8 times greater than the formal reports (SNEM, 2007; Aguilar et al., 1994). Malaria is constant through the years in the Ecuadorian Amazon and in the sup-tropic areas, whereas on the Coast malaria cases increase after the rainy season, i.e., December to May (Aguilar, 2007, cited in OPS/OMS, 2007). Reports indicate that malaria in Ecuador is exacerbated by the ENSO phenomenon and by the failure to use DDT since the 1980s, among other economic, administrative and ecologic factors (Aguilar, 2007, cited in OPS/OMS, 2007; SNEM, 2007; Narvaez et al., 1994).

The Amazon region is categorized between high and medium malaria risk (SNEM, 2007). Within the Northern Ecuadorian Amazon, malaria incidence rates are high, compared to other areas within the Amazon region (OPS/OMS, 2006; Aguilar et al., 1994). Rainfall seems not to be related with malaria incidence in the Amazon (San Sebastian et al., 2000; Aguilar et al., 1994), since it almost rains all the time. But in the lower Napo Basin, malaria epidemics occur in May and December (Amunarriz, 1994). Similarly, as in the rest of the country, the populations at greatest risk of getting infected with the plasmodium are those engaged in activities in forested areas, about 68-percent (San Sebastian et al., 2000; Aguilar et al., 1994; Amunarriz, 1994). However, children represent an important percentage among the infected, near 20-percent (San Sebastian, et al., 2000). There is no gender difference in people infected with malaria (SNEM, 2007; San Sebastian et al., 2000). The same authors point out that in the Northern Ecuadorian Amazon, malaria cases are under-reported by a factor of 7 by the SNEM.

There is no agreement on the types of anopheles that exist in the Ecuadorian rainforest. The most commonly anopheles species described are *rangeli*, *nuñeztovari*, *noroestensis*, *oswaldoi*, and *trinkae* (Narvaez et al. 1994, Aguilar et al. 1994). *Plasmodium vivax* is the most prevalent malaria parasite in this area, it accounts for 90-percent of the cases; and the remaining cases are caused by *P. falciparum* or mixed (San Sebastian et al., 2000; Guzman et al., 1995; Aguilar et al. 1994; Armunarriz, 1991). During the 1990s, malaria had two main outbreaks in the Northern Ecuadorian Amazon: see Figure 2.3 (SNEM, 2007; Narvaez et al., 1994). Further, there are no published studies about the ecology of the vector in the Northern Ecuadorian Amazon, nor are there reports of whether and how the

vector's behavior, habitat, and population have been affected by land use/land cover change processes.

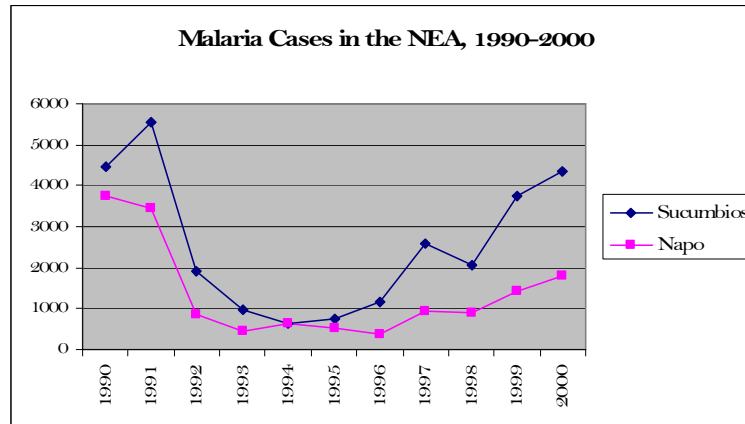


Figure 2.3. Malaria incidence in Sucumbios and Napo<sup>10</sup> provinces, Northern Ecuadorian Amazon. (Ministerio de Salud Publica del Ecuador / SNEM, 2008).

Malaria started being controlled, but not eradicated, in Ecuador after the first anti-malarial campaign in 1948. Different prevention and control programs to combat malaria have been developed in Ecuador. Two phases can be summarized as anti-malarial policies that followed WHO and PAHO policies: 1) Since its creation in 1956 until the mid-1990s, the National Center for Malaria Eradication (SNEM) enforced control by spraying malarial houses and impregnating bed nets with DDT, and prevention consisted of delivering quinine-based drugs to those people already infected; 2) since the end of the 1990s, drug treatments for the infected people have been relocated to urban health centers, while DDT campaigns have been eliminated. Although governmental reports of malaria incidence in the Ecuadorian Amazon region show a drastic decrease since 2003 (Ministerio de Salud Pública del Ecuador

<sup>10</sup> Figure 2.3 represents Napo province instead of Orellana because in 1990 Orellana was part of it. It is in 1998 when Orellana became a province.

/ SNEM, 2008; OPS/OMS, 2006), currently, malaria continues to affect adversely the colonists' health status as well as their social and economic conditions.

## **2.2 Population and Malaria in the Tropics**

### **2.2.1 Cultural Ecology of Malaria**

Cultural ecology, a sub-area of study within geography, aims to understand how human-environment relationships can influence humans' lives through processes of change and adaptation (Gesler et al., 2002). Of interest to the present research is the cultural ecology of disease, that focuses on humans' behavior, beliefs, social organization, and technology, within their surrounding landscape to learn how diseases are produced, reproduced, and sustained in a bidirectional interaction, and possibly to eradicate the ailments (Meade et al., 2000). Wearing shoes, even simple flip flops, is a simple example of how human behavior buffers diseases, such as hookworm infection (Meade et al., 2000). A report about how market integration has affected health among indigenous people and colonists in the Ecuadorian Amazon states that the former self-reported better health status and that their use of traditional medicines is twice as high as in their *colonos* counterparts (Waters et al., 1999). The indigenous people also reported visiting *curanderos* (traditional healers) to treat their diseases. Waters et al. (1999) suggest that the sense of well-being that the indigenous report is a result of using their traditional approaches in their daily lives, which gives them confidence and a feeling of control over their lives. Meade (1978) noted that the re-settlement project carried out by Malaysian authorities during the 1970s promoted higher rubber production and income, as well as better health outcomes. However, the community as a whole, because of its spatial configuration, may be at risk of massive infectious disease

outbreaks such as cholera. Regarding technology as a cultural factor affecting human health, the building of irrigation canals has brought schistosomiasis to rural populations in Kenya living along the Tana River (Patz et al., 2005). Further, the lack of maintenance of the channels led to an epidemic affecting mostly children.

Cultural ecology is important as a framework to understand how health and diseases are produced and treated. It has been largely used by medical and/or health geographers, because it goes beyond the germ disease paradigm that predominates in contemporary medical and public health practices (Meade et al., 2000; Gesler et al., 2002; Mayer, 2000). Cultural ecology looks to understand the disease cycle within a broader umbrella. It is interested in how and why the conjunction of economic, social, cultural, ecological, and biophysical realms produces human diseases and aggravates their severity. In addition to understanding the disease cycle, cultural ecology emphasizes the how and why of economic, social, cultural, ecological, and biophysical realms work in conjunction to determine the existence and severity of human diseases (Gesler et al., 2002; Meade, 1977). These authors suggest that culture does not explain health status; culture is constantly changing and by evaluating the effects of these changes health can be understood. Another interesting framework to study human health is proposed by Audy (1971) “health is a continuing property, potentially measurable by individuals’ ability to rally from insults, whether chemical, physical, infectious, psychological, or social” (Audy, 1971. In Shepard et al., 1971, p. 142). This study uses Audy’s and Gesler’s approach to understanding human health and disease, because the prevalence of malaria in the northern Ecuadorian Amazon is dynamic, spatial, and temporal. This framework of analysis extends beyond deploying a battle for

every pathogen, and its reservoirs, it cares for the well-being of individuals and communities embedded in their cultural realms.

Then, why is cultural ecology important to understand the prevalence of malaria the Ecuadorian rainforest. The Ministry of Public Health of Ecuador (2006) acknowledges malaria as an endemic infectious disease and a problem that threatens public health. There is no vaccine to prevent malaria and most likely there will not be one anytime soon (Meade et al., 2000; Turnbull, 2000; Shiff, 2002). Lessening human contact with anopheles mosquitoes, which are infected with the malaria plasmodium, has proven to be a tough task, specifically in tropical areas where conditions are ideal for breeding, survival, and increased density treatment (Shiff, 2002; Sachs, 2002; Gallup et al., 2001). In addition, lack of economic resources to deploy anti-malaria campaigns or to buy drugs for individual treatment are seen as main problems that keep malaria endemic in the world (Shiff, 2002; Breman et al., 2006; Sachs et al., 2002; Gallup et al., 2001). Further, the rainforest landscape will continue changing, as it has been changing for centuries, by natural forces as well as by human agency (Rival, 2002; Blaikie et al., 1987). Little or nothing is known about people's characteristics that are being infected by the plasmodium; therefore, no much can be achieved by customary anti-malaria campaigns.

Further, *colonos* in the agricultural frontier of the Ecuadorian rainforest have no knowledge and low immunity or non-immunity to malaria when first settling. However, they can gain knowledge of how to prevent the disease after years of settlement and contact with indigenous people. This information about the socio-economic, demographic, and cultural

characteristics of who is getting infected is necessary to learn. Indeed, the indigenous people of Malacatos (now Loja province, south of Ecuador) knew about the properties of cinchona bark to treat malaria fevers (Harrison, 1978; Rocco, 2003). This tree powder, known in colonial times as the Countess's powder, because the chronicles said that it saved the life of the wife of the Count of Chinchon in the 15<sup>th</sup> century, now is known as quinine (Harrison, 1978; Rocco, 2003), and has saved the lives of many people in the world infected with malaria (Franco, 1990; Alvarez, 1987).

Hence, the cultural ecology of disease allows a focus on *colonos'* behavior to understand how housing, jobs, cooking, farm animals, land ownership, household income and demographics interplay in shaping endemic malaria in the Ecuadorian Amazon.

### **2.2.2 The Cultural Ecology of Malaria in Asia, Africa, Latin America**

Shifting and fallow agricultural practices of people living in Vietnam, Laos, and Cambodia were transformed to intensive mono-crop practices at the end of the 19<sup>th</sup> century by the French and British colonizers to bring efficiency for their commercial purposes (Singhanetra-Renard, 1999). In addition, indigenous people were resettled to the mountains, where they had avoided living due to the fevers that "evil spirits" caused. These technological, socio-organizational, and belief alterations brought diseases to local inhabitants. Thus, malaria cases increased alarmingly due to the fast pace of environmental degradation played out by the European scientific forestry practices that did not allow settlers to adapt physiologically and culturally.



In Oceania, due to the lack of attention to the cultural realm of infected people, malaria eradication campaigns have failed (Turnbull, 2000). Turnbull states that anti-malaria campaigns did not take into account mobility and beliefs of the people living in Papua New Guinea. People migrate looking for jobs, while at the same time spreading the malaria plasmodium into new areas with low immunity to it. Further, DDT spraying failed, because people were living under constant wars, and public health workers were not welcome or not allowed to spray inside houses because of lack of confidence in someone unknown. Lack of economic resources to deploy anti-malaria campaigns and lack of knowledge about the dynamic ecology of mosquitoes (blood meal pattern changed from endophagic to exophagic)<sup>11</sup> also have contributed to the failure to eradicate malaria.

Prothero (1961), in his studies about African migrants and malaria eradication in the 1960s, specifically in Somalia and neighboring areas of Ethiopia, suggested that the human hosts need the same attention, if not more, than the anopheles and the pathogens have received. The study found that pastoralist groups moved where water and pasture resources were available to sustain humans and their livestock. However, this mobility exposed them to malaria infections. Unfortunately, DDT spraying campaigns in this country were disarticulated to these environmental constraints and its resulting social organization. Prothero (1995, 1961) recommends that cultural, socio-economic and demographic factors, such as population density and distribution, settlement patterns, house type, social and administrative organization, and economic activities be considered as elemental characteristics for attention

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<sup>11</sup> Endophagic activity refers to anopheles mosquitoes obtaining their blood meal inside human homes, while exophagic activities refer when mosquitoes feed outside homes.

when undertaken epidemiologic studies and anti-eradication campaigns that threaten public health.

An interesting example of how the understanding of human behavior influences the control and eradication of malaria on the American continent is the United States. Meade (1980) suggests that the knowledge of human behavior, such as jobs that expose people to anopheles mosquitoes bites, was important in the control of malaria in this country. The ordinance passed by Savannah, in 1817, to drain ponds around the city, as well as the motivation to shift from rice production to any other dry product are good examples. However, malaria in the United States was not eradicated until the Second World War when the knowledge about anopheles ecology was integrated with the knowledge of human activities to avoid contact with the mosquitoes; therefore an intense DDT campaign was deployed.

Fonaroff (1968) presented a historical study of how important cultural practices, as well as ecologic factors related to anopheles and the plasmodium, were understanding the occurrence of malaria and its spatial distribution in Trinidad. He mentioned that population mobility through the island was the perfect means that allowed the malarial plasmodium to be distributed widely among the inhabitants. Agricultural use of the land in crops such as sugar, rice, and cacao also offered suitable environments for anopheles breeding, but also it implied that anopheles became in closer contact with humans. This factor is exemplified by farmers who worked elsewhere but dedicate a few hours at the end of the afternoon to work on their cacao plantations. The diversification mechanism to survival chosen by the farmer

matched with the “working” hours of anopheles; therefore, high rates of malaria were seen among those farmers in Trinidad. Malaria now does not exist in Trinidad except for a few sporadic cases attributed to tourists. Malaria was eliminated by the use of DDT, prophylactic drugs, and a matter of geographic luck, even though the dynamic ecology of the vector was still incomplete understood.

Two studies about the re-emergence of malaria in the Peruvian Amazon, though they are not precisely about how human behavior is related to malaria, conclude that the type of occupation may represent a risk for being infected with the plasmodium (Vittor et al., 2006; Aramburú et al. 1999). A study in Uraba, a coastal town in Colombia, also points out that malaria is a bio-social disease (Franco et al., 1987). The variables that explained the distribution of the disease and who were infected included walls, electricity, household density, concentration of dwellings, and the surrounding ecology. Barbieri et al. (2005b) concluded that high malaria rates in the Brazilian Amazon (Mato Grosso) are associated with demographics, mainly young men, poor housing conditions, types of occupation, and years of settlement. Thus, malaria is more endemic in gold mining settlements than in agriculture and cattle ranching. Sawyer (1993) argues that the colonization projects in the Brazilian Amazon have shaped the endemic character of malaria there. Further, Sawyer (1993) claims that these governmental projects, in addition to failing, have brought economic and social costs onto the already impoverished landless populations. Finally, Castro et al. (2006) proposed that during the first stage, when malaria is epidemic, anthropogenic land use changes are also intense. Therefore, malaria decreases but continues to exist due to migration, low levels of education, lack of protective clothes, and material possessions as adequate housing.

### **2.2.3 The *Colonos* in the Northern Ecuadorian Rainforest**

Currently, there are approximately 215,000 inhabitants in the provinces of Sucumbios and Orellana, the former having approximately 129,000 (Instituto Nacional de Estadística y Censos -INEC, 2001). With the second process of Agrarian Reform in the 1960s, the *colonos* have come to outnumber the indigenous people living in the rainforest, who currently are about 180,000 (INEC, 2001). The number of rural inhabitants has increased by about 64-percent during the 1990s (Bilsborrow et al, 2001). But, the total fertility rate has declined among the inhabitants of the NEA during the same decade, from 7 to 5 births per woman (Carr et al., 2006; Bilsborrow et al., 2004). As expected, the density per household also has decreased during the same period, from 7.4 to 5.3 persons (Barbieri et al., 2005c). Thus, primary, constant im-migration along with high fertility rates have contributed to the growing of *colonos* settlements within the rural area (Carr et al., 2006; Bilsborrow et al., 2004; Pan et al., 2005; Bilsborrow et al. 2001). The male population is slightly higher than the female population due to agricultural labor options (Carr et al., 2006). The settlements had a large, young population (less than 12 years old), at the beginning of the 1990s of about 42-percent which dropped to 14-percent by 1999 (Barbieri et al., 2005a). Meanwhile, the population over 50- years increased in 1999 as well as the population entering the labor force (12-49 years). The level of education of the heads of the families and wives of the *colonos* has slightly increased during the 1990 decade, from 14 to 32 percent (Bilsborrow et al., 2001).

On average, 72-percent of the settlers who have arrived at the Ecuadorian rainforest prior and during the 1990s are peasants from other rural areas of the country, mainly from the

Andes (Bilsborrow et al., 2004; Tamariz et al., 1997). These settlers were required to organize into cooperatives or other types of social organization by IERAC (Land Reform and Colonization Agency) to get their parcels surveyed and to obtain ownership documents (Carr et al., 2006; Bilsborrow et al., 2004). Unfortunately, families with no land title increased from 7 percent to 49 percent during the 1990s when at the same time IERAC disappeared and also a massive subdivision of farms occurred (Bilsborrow, 2002). The spatial configuration of the settlements is described as fishbone, while each farm resembles a piano key (Walsh et al., 2002; Bilsborrow et al., 2001); see Figures 2.4 a and b. Settlement patterns have been shaped by oil roads and later by roads build by the Ecuadorian government (Bilsborrow et al., 2004). The *colonos* had reported an increase of access to primary or secondary roads during the 1990 decade, from 45 to 63-percent (Bilsborrow, 2002). The predominant type of house walls during the 1990s was wood, representing about 80 percent; however, there was an increase of cement houses about 2 percent and a decrease of bamboo walls about 4 percent in the 1999s (NASA data 2008). Latrines were not widely used in 1990, because *colonos* prefer open fields for their waste disposal, but the use of latrines and the existence of sewer system doubled by 1999 (NASA data 2008).

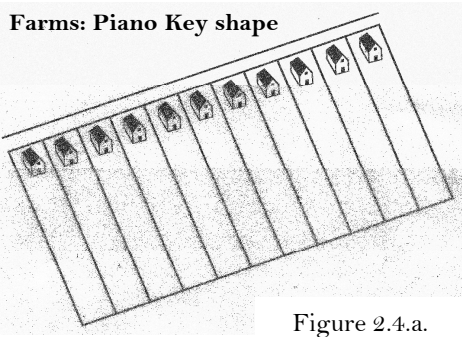


Figure 2.4.a.

**Settlements: Fish bone shape**

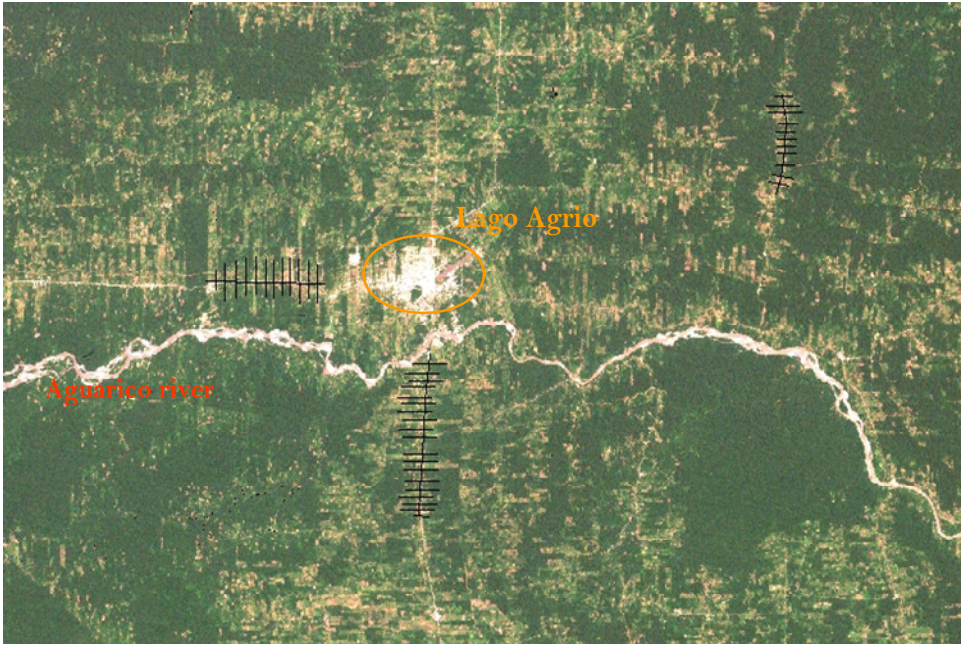


Figure 2.4.b.

Figure 2.4. a) above: farms shape as a piano key. b) below: spatial configuration of the settlements as fishbone.

Settlers’ socio-economic behavior in the Northern Ecuadorian Amazon during the 1990s relied heavily on agricultural activities and less on cattle ranching and other activities (Barbieri et al., 2005a). While agriculture extensification has increased during the decade, raising cattle decreased from 57 to 41 percent at the farm level (Bilsborrow et al., 2001).

However, off-farm employment among the settlers of the Ecuadorian Amazon has increased from 1990 to 1999 (Barbieri et al., 2005a), from 35 to 51 percent (Bilsborrow, 2002). Finally, mean household income and income per capita have decreased in about 30 and 21 percent in 1990 and 1999, respectively (Bilsborrow et al., 2004; Barbieri et al., 2005a).

The *colonos* living in the agricultural frontier of the North part of the Amazon in Ecuador during the 1990s have diversified their livelihood farming activities. The age structure has also changed; there are more adults in the work force, and there are more in-migrants, but there is an increased poverty. The tropical landscape has become highly deforested mainly due to expansion of agricultural land, but also more fragmented due to subdivision of the farms, and complexity due to the spatial structure and composition. The same area during the same period has faced two malaria outbreaks, however, malaria is constant all year round, mainly in the rural areas. But, there exist serious under-reports of malaria incidence. Moreover, there are no reports about the anopheles ecology nor reports about mosquitoes behavior in response to human encroachment into the rainforest.

In this chapter, the cultural ecology of disease as well as land use and infectious disease have been reviewed as part of the theoretical framework that help to understand how malaria was prevalent in the agricultural frontier of the Northern Ecuadorian Amazon during the 1990s. Chapter 3 describes the data type, socio-economic, demographic, and household characteristics as well as satellite imagery and GIS layers used to understand how the human and environmental interactions influence the prevalence of malaria in the Northern

Ecuadorian Amazon. A multivariate regression model is described as the core of the statistical analysis, and patch analysis is applied to the spatial data.



## **CHAPTER 3**

### **Analysis of Malaria**

Statistical tools as well as measurements of landscape change are used to examine the importance of human behavioral characteristics, i.e., socio-economics and demographic factors and land use/land cover changes in influencing the prevalence of malaria among the *colonos* settled in the agricultural frontier of the Northern Ecuadorian Amazon during the decade of the 1990s. The basic intent of the research is to examine household surveys collected in 1990 and 1999 and satellite images of land use/land cover change acquired for similar periods to examine the prevalence of malaria in the frontier environment of the Ecuadorian Amazon related to deforestation and agricultural extensification at the farm-level. The following describes the data types, analysis, and interpretation of results from the linking of people and the environment in the Northern Ecuadorian Amazon.

#### **3.1 The Cultural Determinants of Malaria: Human Behavior, Socio-Economics, Demographics, and Built Environment**

##### **3.1.1 NASA Project and Data**

The NASA project was developed to study and characterize the socio-economic and demographic determinants of land use/land cover change in the Northern Ecuadorian Amazon. Longitudinal household surveys were conducted in 1990 and 1999 at the farm level

for spontaneous *colonos* who had migrated into the study area on roads primarily developed by the petroleum industry. Both heads of the household, the male (jefe) and the spouse (esposa), were interviewed on topics that included land tenure, land use, farm production, market integration, work force, technical assistance, household composition, migration, living conditions, reproductive and general health, women's work, attitudes and satisfaction. In 1990, 418 household interviews were completed on 408 farms; in 1999, 767 households were interviewed on 392 farms (the larger number of households is due to the process of farm subdivision). In 1990, the survey farms were selected from farm sectors, i.e., groups of 5 to 10 contiguous farms were selected using IERAC's cadastral listing of the colonized farm plots in the study region frontier (Pichon, 1997; Bilsborrow et al., 2004). The farm sample accounts for ~6 percent of the rural population of the Northern Ecuadorian rainforest as of 1990; results using the NASA survey data are representative of the entire rural population of *colonos* in the study region as of that year (Bilsborrow et al., 2004). The data type used in this research –longitudinal- facilitated assessing the links between *colonos*' behavior and the prevalence of self-reported malaria in two specific years of the 1990 decade, 1990 and 1999.

The longitudinal dataset used in this study contains self-reported malaria information, i.e., the presence or absence of malaria for members of the household that were living in the agricultural frontier in the Northern Ecuadorian Amazon. The spouse of each survey household was asked if any member in the household had malaria during the prior three months. These data do not contain indices of malaria incidence or transmission; therefore, the prevalence of malaria was measured. Prevalence of malaria is defined as the presence or absence of malaria at every farm and household in 1990 and 1999. Research using self-

reported data indicates that its reliability lies between 76- and 81-percent (Caldas et al., 2006; Kroeger et al., 1995).

The research operates at two levels or scales of analysis, the farm and the household. In 1990, the farm and the household were useful units of analysis, as only one household was generally located on each survey farm (Bilsborrow et al., 2004). For the 1999 survey, the same group of farms was surveyed, but in the intervening period, nearly 70-percent of the farms were subdivisions created through different processes, such as inheritance or purchase by new settlers (Pan et al., 2005; Bilsborrow et al., 2004). The creation of multiple households on a single farm confounded the analysis and the linking of people to the land by creating a “finca madre” and “children” households for a single farm. In this research, the household became a more functional unit of analysis in terms of demographic, socio-economic, and land use factors. Working at the farm level for 1990 and the household level for 1999 facilitated the study of the cultural determinants as well as of land use/land cover change over space and time as key factors in shaping the prevalence of malaria in the agricultural frontier in the Northern Ecuadorian Amazon.

In addition, this study is supported by field data collected by the author in the summer of 2007, visiting 30 farms that are part of the NASA project. Farms in both provinces, Sucumbios and Orellana, were visited and an open-ended interview was developed to assess health and land use issues of the owners or renters of the farms. The interviews included questions regarding occupation, house infrastructure, deforestation land use, and health. Health questions focused on the presence or absence of malaria, its treatment, household

knowledge about the disease, methods to prevent it, and a general self-assessment of family health status compared to the past, 5 and 10 years. The open-ended interview is presented in Appendix A.

### 3.1.2 Multivariate Binomial Regression

The type of questions addressed in this research, as well as the type of data that described the presence or absence of malaria in the Northern Ecuadorian Amazon during the 1990s requires the use of a multivariate binomial regression approach to ascertain the connections between nature-cultures and the prevalence of malaria. This statistical model assesses the presence or absence of malaria (dependent variable) and the socio-economic, demographic, land use, and biophysical characteristics of the *colonos*' living conditions (independent variables), as well as the degree of significance and the direction of relationships. The form of the statistical model is presented below:

$$Y_i = \beta_0 + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \dots + \beta_k x_{i,k} + \varepsilon_i$$

where malaria ( $Y_i$ ) is the dependent variable – a binomial value coded as 1 (the existence of malaria in the interviewed household during the 3-months prior to the survey), and 0 (the absence of malaria in the interviewed household during the 3-months prior to the survey). The socio-economic factors taken into consideration to study the prevalence of malaria in the 1990s are education, household income, house type construction, year of acquisition of farm, use of latrine, female as member of community association, and water source (well and/or rivers). Age of the household head of the farm, number of people in the household, and

household head born in the Andes are the demographic factors analyzed at the household and farm levels. Land use types that were related to the prevalence of malaria are forest, perennial crops (coffee and cacao), pasture/secondary forest, and swamp. Finally, the topography of the farm was studied as a factor possibly contributing to the prevalence of malaria.

Due to the process of data collection, the NASA data may be affected by spatial autocorrelation. Neighboring farms were surveyed within each IERAC/INDA sector's<sup>12</sup> boundaries. According to Tobler's rule "Things that are closer together are more similar than those that are further apart" (Longley et al., 2005). Therefore, the information gathered may not be (spatially) independent observations due to the clustering of survey farms in the sampled development sectors and the *colonos*' close household proximity, suggesting that a neighbor's decision-making may be influenced by the spatial adjacency of other farms, which can violate the basic principle of statistical analysis that assumes independence among observations (Moore et al., 2006). The multivariate logistic regression of this research controlled for spatial autocorrelation.

### **3.1.3 Cultural Determinants of Malaria**

Education is considered to be an asset to any person, because it brings self-empowerment (Freire, 1970). Individuals having access to any type of education are expected to make decisions in a more informed, responsible, and ethical way. For example, in rural Kenya, pregnant women with higher levels of education are more likely to have used insecticide-treated nets and anti-malaria treatment (Gikandi et al., 2008). The NASA data

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<sup>12</sup> Sector refers to an administrative level boundary, a term coined and used by IERAC and later by INDA to organize and administer the process of colonization in the Ecuadorian rainforest. Each sector is composed of various farms or parcels of land claimed by *colonos* and indigenous people.

include information about the level of education that the head and spouse of the household had at the moment of interview. A new variable was created comparing levels of education of both head and wife, and choosing the higher level as the measure of household education: see Table 3.1. In this study, it is expected that with a higher level of education of parents it is less likely for members of the household to become infected with the malaria plasmodium, because they have learned how malaria is transmitted and have taken measures to avoid the anopheles mosquitoes.

Table 3.1. Codes of level of education of the household.

<b>Code</b>	<b>Level of education</b>
0	None
1	Primary (it includes complete and incomplete primary)
2	Secondary (complete and incomplete) and Technical
3	University
4	Other, e.g., farming techniques (which excludes the formal education system of the country)

Household income refers to the “earning capacity or quality” of household wealth or assets (Barbieri et al., 2005a). The literature states that there is no clear evidence of a relationship between malaria and socio-economic status of people being infected with the plasmodium, particularly with income level (Worrall et al., 2005). Other literature suggests that malaria and income levels are inversely related, adding that there is a positive

relationship between malaria and poverty (Gallup et al., 2001; Sachs et al., 2002). Sawyer (1993) states, however, that malaria has contributed to economic and social problems among the settlers in the Amazon through the ineffective colonization programs supported by the Brazilian government. In the case of the Northern Ecuadorian Amazon, income has been measured at the level of the household, which takes into account the selling of agricultural products from the sample farm as well as other farms owned by the household, plus any other income derived from off-farm employment by any member of the household. Farm and off-farm employment has been combined into a measure of household income that has been calculated as a net value. In addition, the *sucre*<sup>13</sup> was the Ecuadorian currency when both interviews were applied (1990 and 1999), therefore, an exchange rate was applied to convert to 1999 US dollars and applied to the income calculation, using 10,000 *sucre*s equal to 1 USD (one dollar) in 1999. The hypothesis is that with higher income fewer self-reported malaria cases are expected within the household members, because they have the economic means to protect themselves from anopheles mosquitoes, such as access to bednets, sprays, and even better housing conditions that prevent mosquitoes from entering the house.

The type of house in which household members live is considered in this study - specifically, the relationship between wall types and malaria. Housing material is a relevant factor when analyzing the ecology of the anopheles mosquitoes (Meade et al., 2000; Franco et al., 1987). Hematophagic anopheles activity depends upon the house type, some prefer biting indoors, while others wait for their blood source to move outside the house (Zimmerman, 1992). House type has been found relevant when analyzing the incidence and

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<sup>13</sup> El *sucre* was the currency of Ecuador until 1999. In the year 2000 the Ecuadorian government adopted the USD dollars as the currency of the country.

prevalence of malaria, indicating that poor housing materials, such as wood and canvas wall types, foster higher malaria rates (Barbieri et al., 2005b; Franco et al., 1987). The wall construction material of *colonos*' households in the Ecuadorian Amazon was recorded by the interviewer through direct observation at the time of the survey. A house-type variable using wall types was created that encompasses wood and bamboo, while cement is the control variable. Wood and bamboo house types are expected to have higher malaria presence than cement ones. The category other type of wall was not taken into account because its percentage was less than 1% of what wood, bamboo, and cement types represent. Based on personal fieldwork records, personnel working at SNEM in Coca declared that anopheles mosquitoes "are believed" to bite inside the house and rest in shaded places outside home. Therefore, if houses in the agricultural frontier of the Ecuadorian Amazon are wood or bamboo type, mosquitoes have a higher chance to enter the house looking for blood sources through wall interstices.

Year of acquisition of the farm refers to the year that a member, generally the head of the household, acquired the farm and started living on it. The acquisition may be through a title, a certificate of possession, or an official survey, or there may be no document at all. Literature about malaria in the Amazon region indicates the existence of a "frontier malaria cycle", stating that malaria during the first 6-8 years of establishment will have high incidence rates, but malaria rates will then decline due to lower population mobility and fewer ecologic pressures, i.e., deforestation and land use changes, and the mosquitoes' response to ecologic changes (Singer et al., 2001; Singer et al., 2006, Castro et al., 2006). However, dissimilar results about the malaria incidence cycle have been described by Vittor



et al. (2006) in the Peruvian Amazon, which had outbreaks after 10-15 years of land clearance. The year the farm was acquired indicate when it was established by the head of the household. It is hypothesized that malaria prevalence will decline through the 1990s, because proximity between breeding sites and *colonos* has decreased due to intensive forest clearing. This hypothesis is based on my fieldwork during the summer of 2007, that anopheles prefer shaded areas with clear water; they also prefer forest edges and these breeding sites are located farther from *colonos*' houses. In addition, prior to 1990 the majority of the *colonos* of the study area had settled, therefore, intensive deforestation and agricultural intensification had happened before the decade started, but also during the 1990s land use/cover dynamics continue occurring and forest edges were more distant from *colonos* dwelling units.

A latrine represents one way to deal with human waste. Anopheles presence has plummeted where there has been improvement of sewage systems; therefore, malaria rates also decreased (Dutta et al., 1978). In Uraba, Colombia, it has been reported that in rural areas populations have a higher risk to acquire malaria due to the poor housing conditions, highlighting that just one-third of the houses have a sewer system (Franco et al., 1987). In the Ecuadorian Amazon, latrines are separate from the house; they are small wood structures that contain a toilet or a septic pound. A new binary variable was therefore defined as the existence of a latrine on the farm, yes (1) and no (0). The existence of latrines can be a protective measure for the *colonos*, because latrines are usually close to the houses and relatively far from forest shade as well as clear water, the favorite places for anopheles to breed.

Social organizations are formed by groups of people with similar interests having common objectives. These associations vary widely from economic to religious, and to educational goals and social structures. A world-wide study about malaria and its links to poverty suggests that poor communities are more likely to have a higher malaria incidence when compared to the more wealthier communities (Worrall et al., 2005). Another study concludes that the lack of local social organization is a factor that increases the risk of the population of getting infected with malaria in both urban and rural areas (Franco et al., 1987). In this research, the answer of the spouse of the household (female) accounted for the link between the prevalence of malaria and group membership. The question asked if she or any family member was a member of any social, religious, or economic association at the time of the interview. A new binary variable was created to account for group membership of any member of the family, yes (1) and no (0). It is expected that the prevalence of malaria will decrease if any member of the household belongs to a social organization, because of the further impact that an organized civil group can have on individual efforts as a consequence of social networks and information transmission. In addition, during my fieldwork in the summer of 2007 I visited with SNEM personnel were conducted in rural communities whose community leader had previously contacted the SNEM and asked for help to control malaria.

The source for drinking water is another socio-economic variable studied as a factor affecting the prevalence of malaria. A study in the coastal province of Ecuador, i.e., Esmeraldas, describes that the incidence of malaria tends to be higher in rural areas where potable water is rarely provided (Kroeger et al., 1991). Aguilar et al. (1994) reported that in the Northern Ecuadorian Amazon, malaria cases are associated with collecting drinking

water from rivers. The NASA survey data contained questions about where *colonos* acquire their drinking water, i.e., well, spring, river/stream, cistern, rain, or other. Two binary variables were constructed for well and river. They were coded as yes (1), indicating that the household members used well or river as the main source for obtaining their drinking water; otherwise it was coded as no (0). The hypothesis is that obtaining drinking water from rivers is a factor that contributes to the prevalence of malaria in the area. On the other hand, water from wells is seen as a protective measure against anopheles bites because wells are usually close to houses, therefore they are not surrounded by trees, which can provide shelter to anopheles.

Age of the household is defined as the age of the farm's head. In the literature about malaria there is no direct measure of how the age of the household head affects malaria incidence, prevalence or transmission. From the NASA survey, data the age of the head of the farm was defined and used as a variable in the logistic regression model. It is expected that the older the head of the farm, the less the likelihood of having self-reported malaria among his/her family members because *colonos* have learned from their time living in the rainforest to avoid contact with anopheles breeding sites.

The number of people in the household is a key variable to study the prevalence of malaria. Reports about household density and increased malaria rates have been reported (Worrall et al., 2005; Aguilar, 2007, cited in OPS/OMS, 2007; Barbieri et al., 2005b). Even in refugee camps, the number of people may be a factor defining the emergence or re-

emergence of malaria within these unsettled places (Martens et al., 2000). Using the NASA survey data, the number of people was calculated for every farm in 1990 and household in 1999. This study did not take into account the density of the household, because some *colonos* declared no rooms in their house for sleeping purposes. Likely, with more people living in the household and being infected with the malaria parasite, the greater the chances that self-reported malaria will increase.

Place of birth of the household head also has been included as part of the effort to understand the prevalence of malaria in the Ecuadorian rainforest. Human mobility has been pointed out as a main factor for circulating the malaria plasmodium and, therefore, the spread of malaria to other non-infected or low immune people in other comparable malarious places (Prothero 1977; Meade, 1980; Martens et al., 2000; Barbieri et al., 2005b). The mobility seen in the Northern Ecuadorian Amazon can be spatial and temporal; the first implies rural-rural or rural-urban migration (Bilsborrow et al., 2004), and the later can be out-migration or circulation migration (Prothero, 1977; Meade, 1977). Using the NASA data, it is feasible to analyze the place of origin as an important factor to the prevalence of malaria in the agricultural frontier. A new binary variable was defined by recording yes (1) for those household heads who declared that they were born in the Andes; otherwise a no (0) was noted. The expected outcome is that being born in the Andes will show a positive correlation with malaria prevalence, because of the lack of immunity of *colonos* coming from the Andes. Further, the head of the household may not possess the knowledge for preventing malaria or treating members of the family.

Land use change refers to the various uses a particular area has over time. It has been widely supported that human encroachment into natural landscapes through deforestation has led to the emergence or re-emergence of malaria (Yasuoka et al., 2007; Vittor et al., 2006; Barbieri et al., 2005b; Meade et al., 2000; Zimmerman, 1992; Walsh et al., 1993). The literature describes land uses as irrigation systems, dam building, mining, settlements (urban or rural), and agricultural plantations growing rubber, cassava, coffee, cacao, sugar cane, tea, rice, and other subsistence and/or commercial agricultural crops. (Yasuoka et al., 2007; Norris, 2004). Some regional studies are specific in defining mining as a land use and its links to malaria epidemics within the Brazilian Amazon (Castro et al., 2006; Barbieri et al., 2005b). Other studies in the Peruvian, Brazilian, and Ecuadorian Amazon suggest that land clearing has led to resurgence of malaria (Vittor et al., 2006; Singer et al., 2006; Singer et al., 2001; Aramburu et al., 1999; Aguilar et al., 1994). From the NASA data, the land uses/land covers of interest are forest, perennial crops, secondary forest, pasture, and swamps. Each use or cover-type is indicated as the percentage of the farm area. Perennial crops is a variable that accounts for the combined areal extent of coffee and cacao. The hypothesis is that the presence of forest within *colonos'* farms will have a positive relationship with malaria prevalence, because anopheles breeding sites tend to be in forested areas with clear still water, and the proximity of breeding areas to *colonos'* houses increases their exposure to mosquitoes. The same positive relationship with malaria is expected for secondary forest, and annual crops, because anopheles need shady places to rest, as well as clear standing water; these conditions are likely to exist within these land use/land cover types. Also, swampy areas are likely to be related to malaria presence within the household members, because swamps seem to be the ideal breeding sites of anopheles. Conversely, it is expected that

pasture will have a negative relationship with the prevalence of malaria within the *colonos*, because these areas likely do not offer a breeding place to anopheles mosquitoes, therefore they do not imply a risk of malaria transmission to *colonos*.

Topography is used in this study to determine whether a farm with flat terrain is associated with the prevalence of malaria. Malaria is reported mostly in lowlands of tropical areas (WHO, 2008; OPS/OMS, 2003; Foley et al., 2007) where there is an absence of steep hills. However, history reminds us that malaria is not confined to the tropics; it is also present in higher latitudes, such as England until the end of the XVIII century (Harrison, 1978; Meade et al., 2000), and higher altitudes, as the lower part of the Andes (McMichael, 2004; Levi-Castillo, 1954). A new binary variable was created; which was coded as flat (1) and others terrain conditions (0). It is believed that farms composed of relatively flat topography tend to concentrate more water in ponds if they are close to rivers, or even during and after the rainy season, when compared to the hilly or rolling farms; therefore, these ponds may represent suitable anopheles breeding sites.

#### **3.1.4 Results: Cultural Determinants of the Prevalence of Malaria**

The *colonos* in the agricultural frontier of the Northern Ecuadorian Amazon reported higher numbers of malarious households in 1990 than in 1999. The scale of analysis was at the *finca madre* (farms without any subdivision) for the 1990 and at the household level for 1999. The prevalence of malaria was measured based on whether a household had at least one member with malaria in the 3-month period prior to the survey interview, see Table 3.2.

Table 3.2. Number of observations in 1990 and 1999, farm and household, respectively; Malaria prevalence in 1990 and 1999.

	1990 (finca madre level)	1999 (household level)
Number of observations (finca-madre or household)	356	641
Number of self-reported Malarious households	89	45
Percentage of Malarious households	<b>25%</b>	<b>7%</b>

A similar pattern is seen in the number of malaria cases – in 1990, the surveyed *colonos* reported 150 malaria cases, while in 1999, there were 61 reported cases. The frequency of malaria cases reported at the farm level in 1990 and by household in 1999 is described in Table 3.3.

Table 3.3. Frequency and percentage of malaria cases self-reported in 1990 at the farm level, and in 1999, at the household level.

Number of self-reported malaria cases per household	1990 (finca madre level)		1999 (household level)	
	Frequency	Percentage	Frequency	Percentage
1	54	60.7	35	77.8
2	23	25.8	5	11.1
3	8	9.0	4	8.9
4	2	2.2	1	2.2
8	1	1.1		
10	1	1.1		
Total	89	100	45	100.0

While looking at the prevalence of malaria in the study area, at the province level, Sucumbios has 4 times greater self-reported malarious farms in 1990 than Orellana.

Conversely, Orellana in 1999 has reported one more case of malaria than Sucumbios. A summary of these numbers with frequencies is in Figure 3.1.

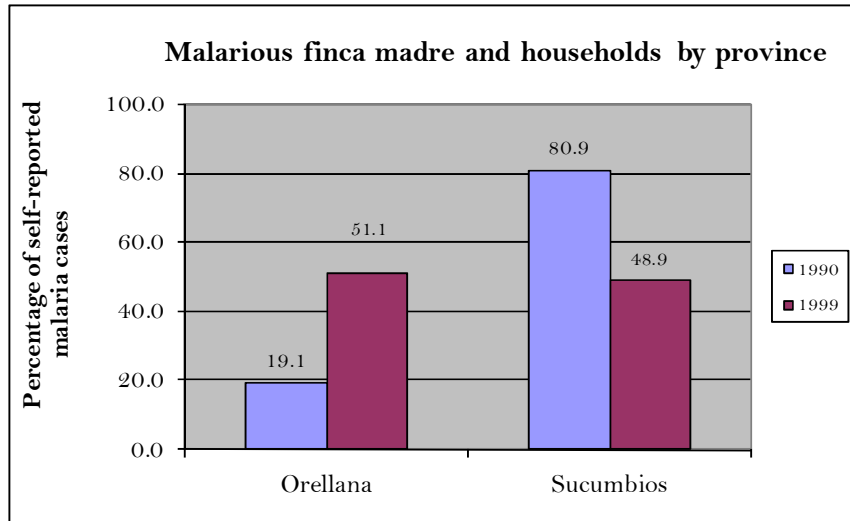


Figure 3.1. The percentage of self-reported malarious households by province for 1990 and 1999.

The cultural and biophysical determinants of malaria that are part of the logistic regression include socio-economic, demographic, land use, and topography, see Table 3.4. For a more detailed description of the variables refer to Appendix B.



Table 3.4. Dependent (presence/absence of malaria) and the independent variables used in the logistic regression model.

Name variable (name in the model)	Variable description	Variable Type
Malaria (yes_malaria)	Presence of malaria within at least one member of the farm in 1990 and of the household in 1999.	Dependent variable
Education hh (educhh)	Level of education of the household, using the highest level of education of the head or wife.	Socio-economic
Acquisition of the farm (yearf)	Year of acquisition of the farm.	Socio-economic
Household income (log_hhinc)	Net household income. It takes into account remittances, off-farm employment, and income of selling products from other farms that the household members own. To have a normally distributed distribution of the variable, the natural logarithm was applied.	Socio-economic
Female member of association (membera)	Any member of household belongs to a social organization (religious, economic, sports, etc.)	Socio-economic
House type (housetype)	Wall type of the house, using wood, bamboo, and cement as types.	Socio-economic
Well	As a type of water sources for drinking water.	Socio-economic
River	As a type of water sources for drinking water.	Socio-economic
Latrine (latri)	Latrine as the type of human waste disposal	Socio-economic
Region male was born (born_a)	It indicates which region of the country (Coast, Andes, or Amazon regions) the head of the household was born.	Demographic
Head's age (jage)	Age of household head	Demographic
Number people (nump)	Number of people living in the household at the time of the interview; includes children and adults.	Demographic
Flat farm (flat)	Topography of the farm	Topography
Perennials, secondary forest & pasture, forest, swamps	Land use type for the farm where the household existed and the interview took place. The values are percentage of land use type controlling for farm size.	Land use

The variables that help to explain the prevalence of malaria in survey households in the agricultural frontier of the Northern Ecuadorian Amazon in 1990 are education of the household, house type, land use types (i.e., forest, perennial crops, secondary, pasture, and

swamp), and age of the head of household. The results of the logistic regression model for the year 1990 are presented in Table 3.5. These variables have a p-value of 0.05 or 5-percent alpha level, and they have a negative relationship with malarious households. The model implies that the greater the level of education, the less malaria will be experienced by household members living in the house. Contrary to what was expected, house type, wood or bamboo, prevented family members from becoming infected with malaria. All land use types are negatively related with malarious households in 1990. Age of the household also implies that the older the head of the household, the less malaria will exist among household members because they learned how to prevent themselves and their families against anopheles bites. Income and drinking water sources also are important, but with a p-value of 0,1 or only at the 10-percent alpha level. The results indicate that the higher the income of the household, the less malaria will be self-reported because there are means to protect and/or treat family members. Obtaining drinking water from a well indicates a greater occurrence of malaria reported in the household. This is likely that wells are good environments for anopheles breeding, therefore, *colonos* collecting their water risk being bite by mosquitoes and getting infected with the plasmodium.

Table 3.5. Socio-economic, land use/land cover change, and physical factors contributing to the prevalence of malaria in the Northern Ecuadorian Amazon, finca madre level 1990

	Coefficient	Std. Error	Z-value	P-value (P> z )	95% Confid. Interval	
<b>Socio-economic factors</b>						
<b>Education hh</b>	<b>-1.282061</b>	0.4439766	-2.89	<b>0.004**</b>	-2.15224	-0.4118826
<i>Income hh (logarithm)</i>	-0.2431063	0.1432412	-1.7	0.09*	-0.52385	0.0376413
<b>Housetype</b>	<b>-0.400804</b>	0.1914489	<b>-2.09</b>	<b>0.036**</b>	-0.77604	-0.0255711
<b>Age of hh head</b>	-0.0242179	0.0100622	-2.41	<b>0.016**</b>	-0.04394	-0.0044964
Year acquisition	0.0006115	0.0180059	0.03	0.973	-0.03468	0.0359024
Latrine	0.0691107	0.0925779	0.75	0.455	-0.11234	0.2505601
Number people	0.0212001	0.0398168	0.53	0.594	-0.05684	0.0992396
Member association	-0.0295691	0.0597716	-0.49	0.621	-0.14672	0.087581
<i>Well-source</i>	0.491919	0.3214414	1.53	0.126*	-0.13809	1.121933
River-source	0.0604607	0.3071848	0.2	0.844	-0.54161	0.6625318
Born Andes	-0.0957884	0.3705462	-0.26	0.796	-0.82205	0.6304688
<b>Land use/land cover</b>						
<b>Perennials</b>	<b>-0.0608995</b>	0.0182744	-3.33	<b>0.001**</b>	-0.09672	-0.0250824
<b>Pasture/Secondary forest</b>	<b>-0.050686</b>	0.0146225	-3.47	<b>0.001**</b>	-0.07935	-0.0220264
<b>Forest</b>	<b>-0.0535165</b>	0.0146944	-3.64	<b>0**</b>	-0.08232	-0.0247161
<b>Swamp</b>	<b>-0.0552668</b>	0.0240108	-2.3	<b>0.021**</b>	-0.10233	-0.0082064
<b>Farm topography</b>						
Flat	0.4077676	0.3921055	1.04	0.298	-0.36075	1.17628
Constant	6.791994	35.60073	0.19	0.849	-62.9842	76.56814

Significance levels: \*\* = p<0.05; \* p<0.1

Number of observations: 346. Chi<sup>2</sup> with 16 degrees of freedom: 38.91. P>chi<sup>2</sup>=0.0011.

Pseudo R<sup>2</sup>=0.0585.

The results for 1999 are less definitive. The cultural determinants that seem to be statistically related to the prevalence of malaria in the agricultural frontier of the Ecuadorian rainforest are perennial crops, latrine, and number of people living in the household. Perennials and latrine have a significance level of 5-percent, while the number of people in the household has a p-value of 0.1 or an alpha level of 10-percent. The more perennial area (coffee and cacao) that exists on a farm, the less malaria among members of the household exist. A similar negative relationship exists between latrine and malaria: the more latrines,

the fewer the malaria cases will prevail within the household members. Number of people is positively related with malaria prevalence, the more people living in the household, the more likely self-reported malaria will be reported in the household. Table 3.6 presents the results of the logistic regression model for 1999. The results showing less or no explanatory power for the relationship between the socio-economic and land use factors with the prevalence of malaria may be due to fewer numbers of self-reported malaria cases in 1999.

Table 3.6. Socio-economic, land use/land cover change, and physical factors contributing to the prevalence of malaria in the Northern Ecuadorian Amazon, household level 1999

	Coefficient	Std. Error	Z-value	P-value (P> z )	95% Confid. Interval	
<b>Socio-economic factors</b>						
<b>Education hh</b>	-0.101692	0.4193166	-0.24	0.808	-0.92354	0.7201533
<i>Income hh (logarithm)</i>	-0.005323	0.1349256	-0.04	0.969	-0.26977	0.2591264
<b>Housetype</b>	-0.135006	0.2240827	-0.6	0.547	-0.5742	0.3041885
<b>Age of hh head</b>	-0.010145	0.0145027	-0.7	0.484	-0.03857	0.0182794
Year acquisition	0.0013822	0.015833	0.09	0.93	-0.02965	0.0324143
<b>Latrine</b>	-0.945456	0.4918693	-1.92	0.055**	-1.9095	0.0185898
<i>Number people</i>	0.0800545	0.0491568	1.63	0.103*	-0.01629	0.1764
Member association	-0.015251	0.3881803	-0.04	0.969	-0.77607	0.7455682
<i>Well-source</i>	-0.070441	0.4147571	-0.17	0.865	-0.88335	0.7424684
River-source	0.1936034	0.4455395	0.43	0.664	-0.67964	1.066845
Born Andes	0.2725778	0.3681341	0.74	0.459	-0.44895	0.9941073
<b>Land use/land cover</b>						
<b>Perennials</b>	-0.025003	0.0097463	-2.57	0.01**	-0.04411	-0.0059004
Pasture/Secondary forest	-0.006992	0.0083089	-0.84	0.4	-0.02328	0.0092929
Forest	-0.003704	0.0085261	-0.43	0.664	-0.02041	0.0130072
Swamp	-0.006402	0.0146123	-0.44	0.661	-0.03504	0.0222377
<b>Farm topography</b>						
Flat	-0.092009	0.4572275	-0.2	0.841	-0.98816	0.8041405
<b>Constant</b>						

Significance levels: \*\* = p<0.05; \* p<0.1

Number of observations: 615. Chi<sup>2</sup> with 16 degrees of freedom: 66.31. P> chi<sup>2</sup>=0.00. Pseudo R<sup>2</sup>=0.0585.

It is important to note that in this research children were not found to be the most affected population with malaria. Also, when comparing prevalence of malaria by gender, no significant difference between women and men was found, though men were consistently more prone to infection. Though in 1999 those households that self-reported malaria among their members, the males were more affected than females by 13 percent. These demographic characteristics, gender and age, of the *colonos* that has been infected with malaria are described in Figures 3.2 and 3.3 for both years, 1990 and 1999.

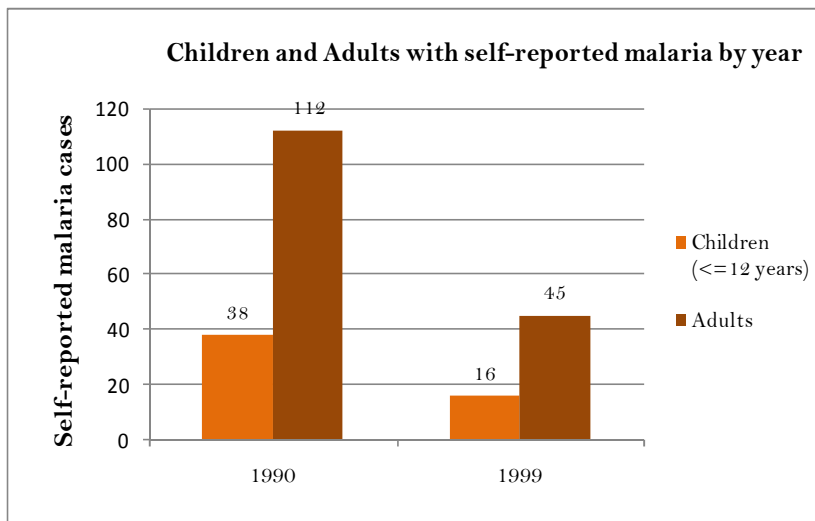


Figure 3.2. Age of *colonos* infected with malaria in 1990 and 1999.

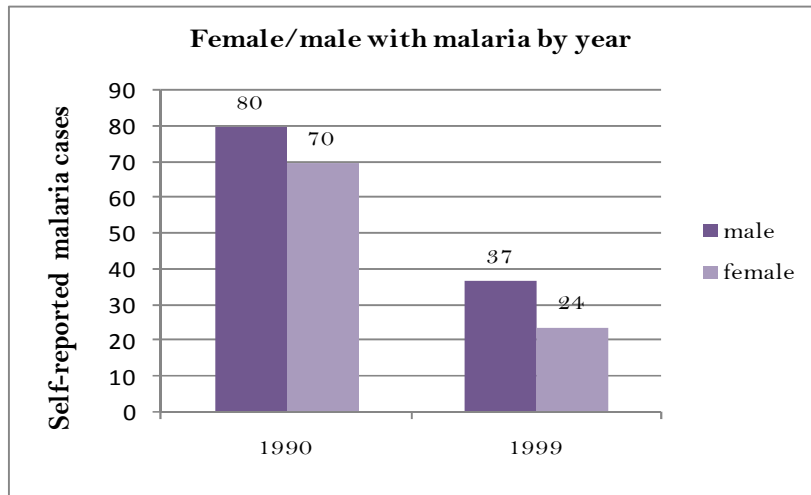


Figure 3.3. *Colonos* infected with malaria by gender in 1990 and 1999.

### 3.2 Pattern Metrics of the Northern Ecuadorian Amazon Land Cover

#### 3.2.1 Satellite Imagery

Another spatially-explicit way to analyze the dynamic changes of land use/land cover through time is by using ecological patterns metrics and remote sensing techniques to understand the composition and spatial organization of classified land-cover types on survey farms. Remote sensing imagery and tools are used in this research to determine the composition and spatial configuration of land use/land cover patterns on survey farms in the Northern Ecuadorian Amazon, and to study links to the prevalence of malaria. The NASA Ecuador project has assembled a rich spatial dataset that includes a satellite image time-series and GIS coverages describing geographic features of the Amazonian landscape. Two Landsat TM images for 1986 and 1999 were used in this analysis: see Table 3.7. The Landsat images were selected because of their spatial and temporal characteristics – they completely cover the study area, Sucumbios and Orellana, and they link in time to the 1990 and 1999 socio-

economic and demographic surveys. The 1986 image was the best available to measure changes in the landscape for 1990, because the Ecuadorian rainforest is generally covered by clouds that affect the visibility and analysis of the rainforest. These images have been pre- and post-processed through a standard suite of operations that include geographic and geometric rectification, supervised and unsupervised classification, and accuracy assessment by the spatial analysis team of the NASA project (Messina, 2001; Frizzelle, 2003). Using the classified satellite images, a recoding or reclassification process was used to describe three land use/land cover classes (forest, non-forest, water), allowing measurement of spatial variation throughout the Amazonian landscape; see Table 3.8.

Table 3.7. Landsat image characteristics.

<b>Path/Row</b>	<b>Landsat sensor</b>	<b>Date</b>	<b>projection</b>	<b>Datum</b>	<b>Spatial resolution (meters)</b>
9/60	TM	23Aug86	UTM	NAD83	28.5
9/60	TM	15Nov99	UTM	WGS84	28.5

Table 3.8. New scheme of land coverage of the Northern Ecuadorian Amazon.

Class type old	Class #	Class type used	Class #
Unclassified	0	Unclassified	0
Primary Forest	1	Primary Forest	1
Succession (secondary forest)	2	Non-forest: Succession, Pasture, Agriculture, Urban, Barren	2
Pasture	3		
Agriculture	4		
Urban/Barren	5		
Water	6	Water	3

The resulting recoded image contains the selected land use/land cover classes, primary forest, non-forest, and water. The reclassified images, Landsat TM with a spatial resolution of 30 x 30-meters, are shown in Figure 3.4 for 1986 and 1999.

### The Northern Ecuadorian Amazon

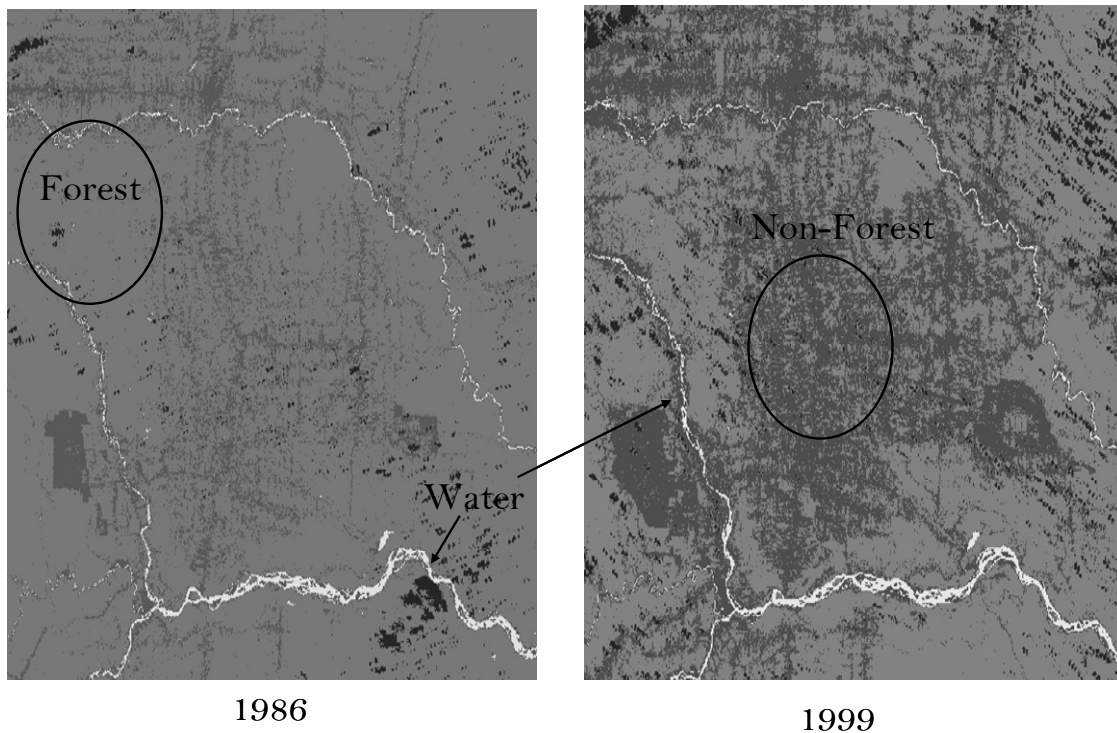


Figure 3.4. Land cover change in the study area: Northern Ecuadorian Amazon. Class types: Forest, Non-Forest, and Water.



### 3.2.2 *Finca madre* (farms) GIS-Coverages

Another important spatial dataset used in this analysis of land use/land cover change and the prevalence of malaria is the NASA project farm boundaries, shape files that describe the outline of survey farms, see Figure 3.5. This GIS coverage was created at the Spatial Analysis Unit at the Carolina Population Center by digitizing maps acquired at IGM. These farms are known as the *finca madres*. This coverage was used to clip the Landsat satellite image and obtain small farm-shape polygons that contain satellite image information using ArcGIS software: see Figure 3.6.

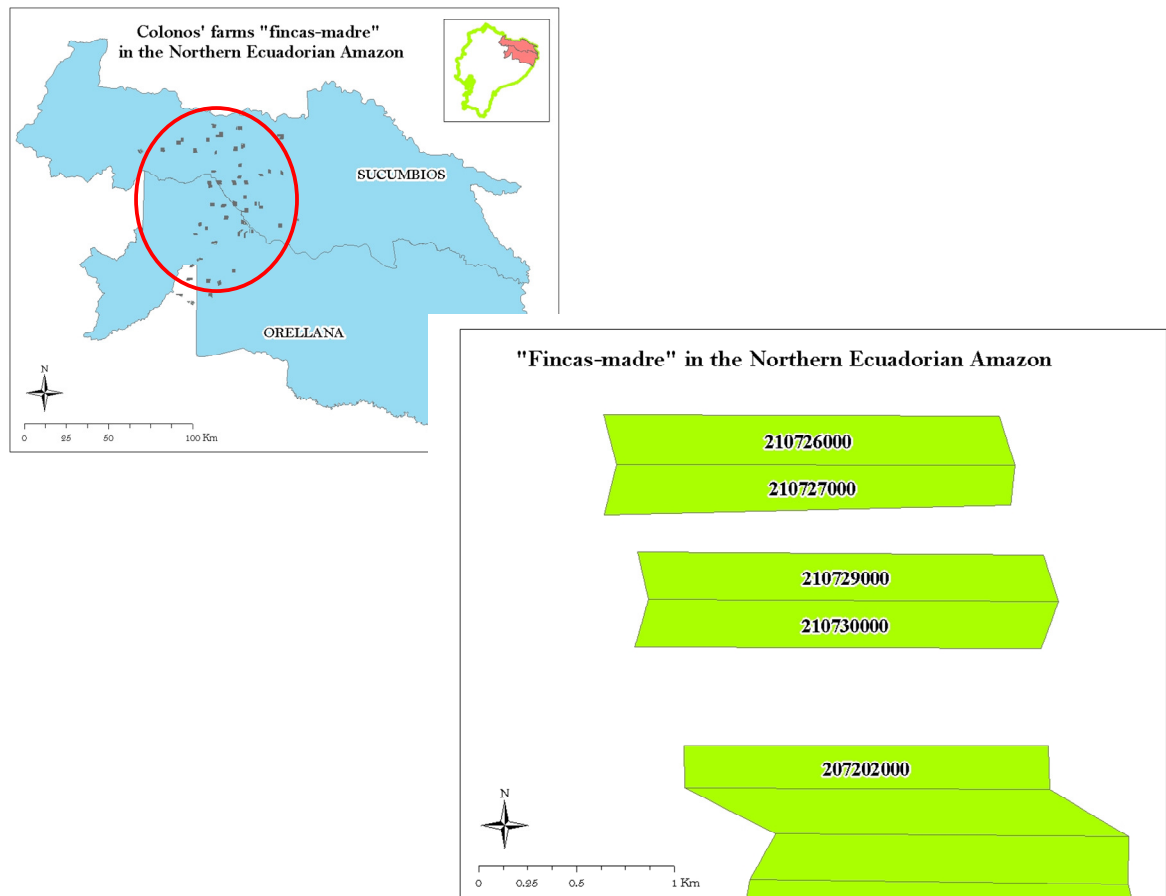


Figure 3.5. Farms, or *finca madre*, of the *colonos* in the Northern Ecuadorian Amazon.

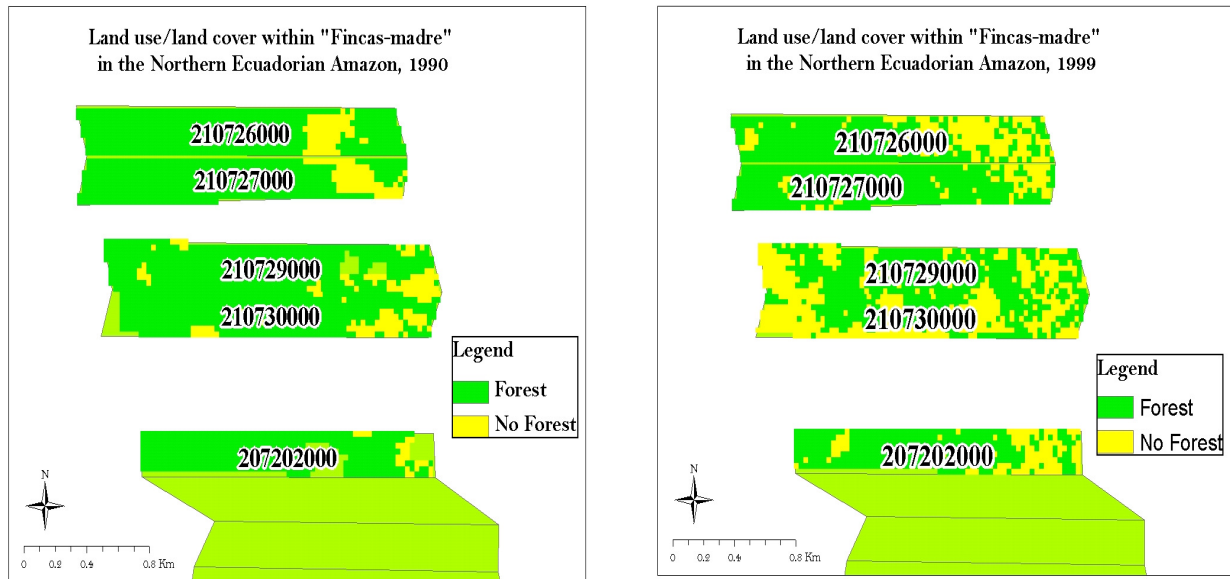


Figure 3.6. Farms with forest and non-forest classification in the Northern Ecuadorian Amazon; left side *fincas-madre* in 1990, right side *fincas-madre* in 1999.

### 3.2.3 Results: Ecological Pattern Metrics of the Northern Ecuadorian Amazon

An analysis of the landscape comparing malarious and non-malarious households through time makes it possible to explain whether or not the spatial structure and composition of the landscape is related to the prevalence of malaria in the Northern Ecuadorian Amazon. Specifically, the research here investigates links between the spatial dynamics of deforestation occurring at the level of *fincas madres* as well as at the landscape level (e.g., changes in the size and/or number of land use/land cover patches through time). It is hypothesized that the spatial distribution of malaria prevalence (based on self-reports) is linked to the spatial dynamics resulting from the processes of deforestation and agricultural extensification in the study area prior to and during the 1990's decade. In addition, I observe a "malaria frontier" cycle in the Northern Ecuadorian Amazon, in which malaria cases were high in the first years of settlement, but after more intense forest clearing, in the 1990's, decreased because anopheles breeding places were less likely to be close to *colono* houses, so

family members were bitten less; however, malaria has not disappear because *colonos* continue clearing further areas of forest and work with crops where anopheles mosquitos live.

Ecological pattern metrics were used to measure the classified land use/land cover types to determine the composition and spatial configuration or structure of the study area. Patterns can be analyzed at three different scales – the patch, class, and landscape levels (McGarigal, 2002). While patch-level metrics describe the spatial character of each homogenous land use/land cover patch, class-level metrics describe the spatial organization of land use/land cover types of a single type, whereas landscape-level metrics describe the spatial structure of all mapped land use/land cover for some defined areal extent, such as a farm or an entire province ( McGarigal, 2002). Acknowledging that ecologic patterns are scale dependent (Walsh et al., 1999; Walsh et al., 1997), pattern metrics were computed at the landscape level. Landscape metrics integrate all patch types over the total extent of the study area. The metrics used in this study help to discern how the forest, non forest classes within each farm has changed during the 1990s, and to determine how these cover changes, composition and spatial organization, are related to the presence of malaria in Northern Ecuadorian Amazon.

It is important to be aware that an appropriate application of pattern metrics begins with a thorough understanding of how the metrics are selected, calculated, and interpreted (McGarigal, 2002). Riitters et al. (1995) suggest a redundancy in the calculation of pattern metrics due to a strong correlation between many of the core metrics. Also, the edges of the

satellite image (or edges of farm boundaries) can be problematic to deal with, particularly, if the cell size is relatively large (e.g., above 30 x 30 m.). In such circumstances, the software will drop that part of the satellite image, therefore losing important information for the calculation of pattern metrics within farm boundaries (Erlie, 2008).

The landscape-level metrics used in this analysis are the Number of Patches (NP), Patch Density (PD), Landscape Shape Index – Mean (SHAPE\_MN), and Aggregation Index (AI). NP is the number of patches of forest that exist within each survey farm in the Northern Ecuadorian Amazon. PD informs us about the state of fragmentation of the farm landscape for the dates assessed. This metric is similar to NP but it informs us the number of patches that exist per 100 hectares, therefore, comparison between areas with different dimensions can be done. The Landscape Shape Index measures the patch edge complexity of land cover types for each farm landscape. This measure describes patches complexity. Lastly, AI is a measure of the clumpiness of Forest and Non-Forest types at the farm level. A less deforested landscape will have a measure close to 100, because the patches of land use types are bigger than a landscape that has been cleared and has smaller patches of different land uses.

Using the satellite image classifications and the shapefiles of the survey farms, Fragstats software was run to derive the selected ecological pattern metrics at the farm level. Every farm *-finca madre-* has its own pattern metrics values of NP, PD, SHAPE\_MN, and AI. In this analysis, transformations of the cell size of the satellite image was not necessary because the pattern metrics results using both methods (a cell of 30 meters-, and reshaped cell of 1 meter), did not result in any variation. The *finca madre* that have self-reported

malaria presence within at least one of the members of household were summarized as malarious households; the same has been done for those non-malarious households. A summary of the landscape metrics for 1990 and 1999, of those *finca madre* having malaria and not having malaria is presented in Table 3.9.

Table 3.9. Pattern metrics at the landscape level (mean values).  
Comparing malarious households between provinces in 1990 and 1999.

1990	Sucumbios		Orellana	
	Malaria	Non-malaria	Malaria	Non-malaria
NP	11.1	11.5	9.3	7.3
PD	23.3	24.1	24.0	17.0
SHAPE_MEAN	1.4	1.4	1.4	1.5
AI	87.4	87.6	87.8	90.3
1999	Sucumbios		Orellana	
	Malaria	Non-malaria	Malaria	Non-malaria
NP	21.7	24.5	22.8	20.0
PD	48.7	52.9	46.5	48.6
SHAPE_MEAN	1.4	1.4	1.4	1.4
AI	75.0	72.2	75.4	75.7

The pattern metrics indicate that the prevalence of malaria over time within the *colono* households is related to increasing number of patches. Thus, Sucumbios had 4 times greater malaria self-reported households than Orellana in 1990, and it is reflected in the higher number of patches that Sucumbios had than Orellana did. The same relationship, of malaria in households and a landscape with more patches, can be seen for 1999, Orellana has slightly higher self-reported malaria in households than Sucumbios, and Orellana has higher number of patches than Sucumbios. When comparing within the same province malarious and non-malarious households, Orellana follows the pattern of more patches within those

farms that self-reported malaria. But, an opposite pattern shows for Sucumbios in each year, i.e., non-malarious households have more patches in their farms; however the number of patches within each type of household varies slightly.

Patch density results imply that the lower the PD number, the fewer patches of the land use/land cover class types that exist in an area of one hundred hectares, which means a less deforested landscape. The classes analyzed were forest and non-forest. Overall, the results of patch density imply that in the study area, self-reported malaria in households is related to a landscape that has fewer patches of forest and non-forest every one hundred hectares. The results are representative for both years. In 1990, Sucumbios has more self-reported malarious households than Orellana, and the landscape was less patchy of forest and non-forest. In 1999, Orellana had more self-reported malaria in households than Sucumbios, and Orellana had a landscape with less patches than Orellana. However, when comparing malarious and non-malarious households in Orellana in 1990, self-reported malaria in households is associated with a landscape with higher number of patches than those households that did not report malaria.

The metric, Shape Area - Mean Index represents the higher the metric, the more complicated form of the farm landscape. Results of this research showed that there is not a relationship between complex spatial structure of the rainforest landscape and malarious households in either year.

The Aggregation Index implies that the closer to 100, the more aggregated is the patch class, which means a less deforested landscape. Households with malaria are likely to occur on farms that have more patches of forest and non-forest, or the landscape is less aggregated. Thus, in 1990 Sucumbíos had more self-reported malaria than Orellana, and the Sucumbíos landscape metric suggests that it is less aggregated than those farms in Orellana. The same occurred in 1999, Orellana had more self-reported prevalence of malaria and its landscape was less aggregated (or with more patches) than Sucumbíos. In both years, results indicate the same relationship of self-reported malaria and a less aggregated landscape. These results agree with the metric number of patches reported above, as a more patchy landscape has the likelihood of more self-reported malaria. However, the aggregation index metric of Sucumbios in 1999 had a different pattern of relationship between malarious households and a more aggregated landscape.

During the 1990s, households with self-reported malaria had a pattern in the land use/land cover change over time. It is a patchy and aggregated spatial structure and mostly agricultural land type composition. In Sucumbios, malarious households have more numbers of patches –forest and no forest–in both years than non-malarious households. Similar spatial structure was derived for Orellana in both years, malarious households were related with higher numbers of patches within farms. Overall, the aggregation pattern metrics suggest that malarious households have a less aggregated landscape (or more patches) of forest and non-forest within farms in both years in Sucumbios and Orellana.

In sum, the prevalence of malaria within the agricultural frontier of the Northern Ecuadorian Amazon has cultural and environmental implications. Socio-economic and

demographic factors (i.e., education, household income, housing conditions, and household age) are important household factors associated with the prevalence of malaria within their members. The decline of the prevalence of malaria in the Northern Ecuadorian Amazon is related to a landscape that has become more fragmented due to deforestation and agricultural extensification on household farms during the 1990s. Therefore, malaria is a "maintained" disease, influenced by population-environment interactions, which needs to be understood through the local cultural, socio-economic, and demographic contexts that intersect with land use/land cover states, conditions, and spatial organization for achieving more effective anti-malaria campaigns.



## CHAPTER 4

### **Epidemiology of Endemic Malaria in the Northern Ecuadorian Amazon**

The results presented in the previous chapter suggest that the prevalence of malaria in the *colonos* living in the agricultural frontier of the Northern Ecuadorian Amazon has interwoven cultural and environmental determinants. These determinants are particularly related to land use dynamics, i.e., composition and spatial structure, and social adaptive processes, i.e., health adaptability. The *colonos* who settled in the Ecuadorian Amazon Basin during the 1970s and 1980s were mostly from the Sierra, i.e., the Andes (72%) (Bilsborrow et al., 2004; Tamariz et al., 1997). In this new agricultural frontier, the colonists also faced a “frontier malaria” (Sawyer, 1999; Castro et al., 2006), so that during the first years of settlement malaria was more common among this non-immune population. The prevalence of malaria decreased during the 1990s because much of the forest located close to the *colonos*’ dwelling units had been cleared. Therefore, the forest/non-forest edge was displaced further from the houses, along with the anopheles mosquito, which lowered the contact between *colonos* and mosquitoes. The forest clearing has implied changes in the composition and spatial pattern of forest/non-forest on the farm. In addition, this pattern of decrease in self-reported malaria through the 1990s may be due to adaptive cultural behaviors protecting these *colonos* and their family’s members from infection with malaria. Results indicate that lower prevalence of malaria in 1990 was linked to the age of the household head and the

level of the parents' education in each household. This study proposes that malaria rates can be reduced and even prevented if the elements of transmission –humans, environment, anopheles, and plasmodium types- of this disease are understood at local levels and influenced by national/international policies.

#### **4.1 Settlers' Socioeconomic and Demographic Characteristics and the Prevalence of Malaria**

Because of changes in the *colonos'* cultural conditions and practices, the prevalence of malaria declined through the 1990s in the Ecuadorian rainforest. The socioeconomic variables that made an important contribution to decreasing the presence of malaria among *colonos* population were higher levels of education and of household income, and better living conditions (i.e., latrines in 1999). Conversely, source of drinking water (i.e., wells) was linked to malarious households in 1990. Age of household head and number of people living in the house were demographic variables that affected the prevalence of malaria in the agricultural frontier. The older the household head was, the less malaria was self-reported in 1990. The more people living in the same dwelling unit, the more malaria was reported in 1999. The logistic multivariate regression model had low explanatory power for 1999 data, possibly partially a result of the smaller sample size (the small number of cases of self-reported malaria within households, n=45). Thus, education, household income, house type, source of drinking water, and age of the household head were all not statistically significant in the 1999 logistic multivariate regression model.

Even though the education variable was not related to learning about the malaria cycle and how to avoid it in the Northern Ecuadorian Amazon, higher levels of education among the parents in 1990 led to more informed decisions about behavior and living conditions that prevented household members from becoming infected with malaria. Although higher education levels, i.e., completion of primary and some secondary school, have been reported for the *colonos* in 1999 compared to 1990 (Bilsborrow et al., 2004; Carr et al., 2006), in 1999 education was not important in reducing the number of malarious households. This decrease may be related to the high level of accumulated deforestation on the farm by 1999. This result is similar to reports showing higher incidence of malaria among household members in mainly rural areas where education levels are low to minimal (Castro et al., 2006; Aguilar et al., 1994; Castro et al., 2001; Franco et al., 1987).

Higher household income was also related to less likelihood of malaria in 1990. The implication is that better off *colonos* made housing improvements, such as the construction of latrines and better walls the existence of which led to less malaria reported by households in 1999 (see discussion below). Another factor that may have favored a lower prevalence of malaria for households with higher income is a higher education level among its members, which had had a negative effect on malaria prevalence. However, in 1999 household income did not affect the prevalence of malaria. The relationship between better-off households and lower malaria incidence or prevalence has been debated in the worldwide literature. Some authors argue that malaria exacerbates the impoverished conditions of poor populations, who are mostly located in rural tropical areas (Franco et al., 1987; Sawyer, 1993; Aguilar, 2007). Others suggest that poor countries as well as poor communities and poor housing conditions

are the perfect socio-demographic condition that enables epidemic or endemic malaria to exist and thrive (Sawyer et al., 1987; Sachs et al., 2002; McMichael, 2004; Meade, 1980; WHO, 2008; SNEM, 2007). Blaming poverty is not going to prevent people from getting infected with malaria. Indeed, regardless of socio-economic status, poor and wealthy people, become infected with malaria. However, social inequalities are meaningful because they modulate the prevalence of malaria in areas lacking basic services, which in turn favors the thriving of anopheles mosquitoes in these areas.

The prevalent house type in the NEA in 1990 was wood and bamboo (nearly 85 percent) of the survey dwellings. This type of structure had favored the absence of malaria in *colonos* households. This result indicates that anopheles bites to humans occurred mainly outdoors; therefore, spraying inside houses as an anti-malaria policy may not be cost-effective anymore, unless a broader human “activity space” is included. In 1999 neither cement nor bamboo and wood houses were related to lower levels of prevalence of malaria. This result contrasts with other studies on South America, which indicate that housing conditions (e.g., wood wall type) are related to higher malaria rates as well as endemism (Barbieri et al., 2005b; Aguilar et al., 1994; Franco et al., 1987; Prothero, 1995). It may be that before 1990 most houses already had experienced high incidence levels, whereas by 1999 malaria had a prevalent but lower incidence because forest edges were more distant from *colonos*’ houses. See Figure 4.1: house types of the study area, wood and cement.



Figure 4.1. House types existing in the study area. Left wood house type, right cement house type. Fieldwork, summer 2007, P. Polo.

The presence of latrines in 1999 is linked to lack of malaria but there was not association in 1990. The increasing tendency through time of latrine use in the *colono* population is evident, 13- percent in 1990 and 31-percent in 1999. This housing improvements has led to fewer self-reported houses with malaria in 1999, than in 1990. This result agrees with the malaria literature showing that an improved sewage system is a factor that lessens the malaria burden (Prothero, 1995; Kroeger et al., 1991; Franco et al., 1987; Dutta et al., 1978). See Figure 4.2: latrine types in the study area.



Figure 4.2. Latrine types existing in the study area. Fieldwork, summer 2007, P. Polo.

The existence of a as the source of drinking water was associated with malaria in households in 1990. This suggest that the areas surrounding water wells are good environments for anopheles breeding, that household members collecting drinking water come in contact with anopheles, increasing likelihood of infection. In the study area, using a-water well as a source of drinking water has more effect on the presence of malarious households than closeness to a rivers. This shows that the anopheles biting pattern seems to be persistent outdoors. Aguilar et al. (1994) reported that *colonos* who obtain their drinking water from rivers have higher malaria rates. Other studies report a more general conclusion that deficient drinking water services or the absence of them is related to higher malaria rates and prevalence (Franco et al., 1987; Kroeger et al., 1991; Prothero, 1995; Dutta et al., 1978). See Figure 4.3: river as a source of drinking water.



Figure 4.3. River where *colonos* get their water for consumption. Fieldwork, summer 2007 P. Polo.

Age of household head was related to fewer malaria cases within each dwelling unit in 1990, but this factor is not significant in 1999. The frontier malaria theory (Sawyer, 1999; Singer et al., 2006) seems to be related with this phenomenon, because the *colonos* may have developed through time effective adaptive behaviors that prevented them from becoming infected with malaria. Therefore, the self-reported prevalence of malaria in the agricultural frontier of the study area has declined from 1990 to 1999.

Although the population increased in the Northern Ecuadorian Amazon in the 1990s, mainly due to incoming migration (Bilsborrow et al., 2004; Carr et al., 2006), malaria prevalence in households decreased during the same period. Human fertility also was high, though it decreased in the decade (Carr et al., 2006), and contributed also to the prevalence of this disease in the northern Amazon region of the country. See Figure 4.4: a *colono* family of the study area. However, self-reported malaria in households were related to larger household

size and the increase in human density in 1999. This result, i.e., higher incidence and prevalence of malaria where there is higher human density, is a well-known pattern in the global malaria literature (Worrall et al., 2005; Barbieri et al., 2005b; McMichael 2004; Aguilar, 2007, cited in OPS/OMS, 2007; Franco et al., 1987).



Figure 4.4. *Colono* family living in the study area, summer 2007, P. Polo.

An account of the prevalence of malaria, however, is not solely defined by its cultural determinants. It is also essential to study the surrounding landscape through which malaria transmission happens. The analysis of how land use/land cover change has affected the prevalence of malaria in the Northern Ecuadorian Amazon is developed in the next section.



## 4.2 Linking Land Use/Land Cover Change to the Prevalence of Malaria

Land use/land cover changes may have contributed to reduce the prevalence of malaria within the *colonos*' households during the 1990s. Forest, perennial crops, fallow, and pasture as land use/land cover types were related to the absence of malarious households in the Northern Ecuadorian Amazon in 1990, whereas in 1999 only perennials was linked to a reduced prevalence of self-reported malaria. These results contrast with other literature finding a positive relationship between deforestation and land use change, and higher malaria incidence and/or re-emergence (Yasuoka et al., 2007; Vittor et al., 2006; Barbieri et al., 2005b; Meade et al., 2000; Zimmerman, 1992; Walsh et al., 1993). However, the results of the pattern metric analysis indicates that through time the prevalence of malaria has declined in concert with an intensive deforestation process in the study area, at a rate of about 1-2 percent annually in the Northern Ecuadorian Amazon region (Mena et al., 2006; Sierra, 2000). Land clearing in the area has been driven primarily by agricultural extensification by *colonos*, farm subdivision, logging, cattle activities, road building, and the direct and indirect effects of urbanization (Bilsborrow et al., 2004; Pichon, 1997; Tamariz et al., 1997). Therefore, to understand the prevalence of malaria in the agricultural frontier from a land use/land cover change perspective, it is necessary to approach it as a change process that is space and time dependent.

In 1990, the presence of forest did not contribute to the prevalence of malaria, while in 1999 a relationship between forest and malaria did not exist. This negative relationship in 1990 may be related to the distance of *colonos*' houses to forest edges. Some farms in the study area were established in the early 1960s, and about 45-percent of the farms in the study

area were established prior to 1990. Therefore, if the *colonos* have encroached into the forest and the rate of forest clearing on farms is high, as it was at about 3-percent annually in the area during the 1990s (Bilsborrow et al., 2004), *colonos*' exposure to breeding sites could be reduced over time. Again, it seems that the “frontier malaria” cycle is part of the colonization process of the Ecuadorian Amazon. Thus, it seems that deforestation and agricultural extensification had influenced high epidemics during the first years of establishment, prior to the 1990 data collection campaign, but during the 1990s forested areas have receded, and the incidence and prevalence of malaria were lower at the time of assessment, though still endemic. See. Figure 4.5: non forested areas around dwelling units.



Figure 4.5. Forest and agricultural land are far from dwelling units in the study area, summer 2007, P. Polo.

Perennials, i.e., coffee and cacao, also represented a “protective land use” factor against malaria in 1990. See Figure 4.6: coffee plantation in the study area. Even though coffee or cacao plantations can offer ideal shading for anopheles breeding or resting, the

presence of mosquitoes is feasible only when there is clear standing water in addition to shade. The linkage between both crops –coffee and cacao- with the presence of malaria among the people in the surrounding areas of the plantations was reported by Fonaroff in Trinidad (1968) and Yasuoka et al. in the world (2007). These environmental conditions that favor the presence of anopheles may not have been present in the Northern Ecuadorian Amazon in 1990, or if present, they may have been far located relatively far from the *colonos*' dwelling units. The anopheles flight range is about 3-km (interview with SNEM personnel, field work, summer 2007), and if perennial plantations are more than that distance from the farm, the presence of malarious households is less likely. In addition, farmer's working hours are an important factor that prevents their exposure to the anopheles biting time. The *colonos* usually start their day very early in the morning, around 6 am, and end the day around 3-4 pm (field work, summer 2007). Anopheles heaviest biting activity starts at 6 pm and goes until 8 pm (interview with SNEM personnel, field work, summer 2007). All of these environmental and behavioral factors contribute to perennial crops being a factor that prevents the prevalence of malaria within the *colonos* population in the agricultural frontier. "Prevents" is used here to mean that the spatial association between land use and contraction of malaria is negatively related as a consequence of the creation of the forest/non-forest edge and the timing of farmer activities in a possible "bite zone".



Figure 4.6. Coffee plantation in the study area. Fieldwork, summer 2007, P. Polo.

Pasture areas also did not represent an ideal environment for breeding sites of anopheles within the agricultural frontier of the Northern Ecuadorian Amazon, and neither was it associated with malarious households in 1990. See Figure 4.7: pasture in the study area. The literature suggests that an intermixed land use type, such as pasture and fallow, can constitute breeding sites for anopheles (Guimaraes et al., 2004). Although intermixed patches of pasture and fallow are present within the agricultural frontier of the Northern Ecuadorian Amazon (Bilsborrow et al., 2004), they do not seem to affect the prevalence of malaria. In addition, pasture on *colonos'* farms decreased from 1990 to 1999 (Bilsborrow et al., 2004; Barbieri et al., 2005a). Finally, if pasture or intermixed pasture and secondary forest are breeding sites for anopheles in the agricultural frontier, the presence of cattle may divert the anopheles to bite them rather than humans, who can be more distant from these land use types, particularly, during the optimum biting time.



Figure 4.7. Pasture in the study area. Fieldwork, summer 2007, P. Polo.

Fallow was associated with the decline of malaria in the agricultural frontier in 1990, but this land use type had no effect in 1999. The literature about the re-emergence and prevalence of malaria is associated with locations where secondary growth or reforestation has taken place (Eisenberg et al., 2007; Vittor et al., 2006; Molyneux, 2002). In the Northern Ecuadorian Amazon, fallow in 1990 within *colonos* farms was only about 5-percent of the land use, increasing in 1999 to only about 6-percent (Bilsborrow et al., 2004, Barbieri et al., 2005a), however, still fallow has not represented a desirable site for anopheles to breed or rest within. In addition, though about 41-percent of the *colonos*' farms have been reported as flat surfaces, the anopheles seem to need more than the combination of fallow and flat surfaces to maintain the transmission of malaria in the agricultural frontier.

Contrary to what was expected, swampy areas also were associated with an absence of malarious households in 1990. This could occur because the notion of swampy areas that

the surveyed *colonos* have is different from those places where anopheles mosquitoes breed. While anopheles need shade and clear standing water for their reproduction (interview with SNEM personnel, field work, summer 2007), a swampy area can indicate an intermittent condition occurring through seasonal flooding, which may not have clear water and shady conditions. In addition, the lack of association between the prevalence of malaria and swamps is explained by the low presence or complete absence of swampy areas within the *colonos*' farms. Swampy areas represent only 1-percent of the land use/land cover types in the area. The prevalence of malaria and swamps in 1999 were also not related, although, world-wide, malaria outbreaks, re-emergence, and prevalence have been reported when humans live near swampy areas (Yasuoka et al., 2007; Walsh et al., 1993; Vittor et al., 2006; Barbieri et al., 2005b; Guimaraes et al., 2004).

#### **4.3 Landscape Pattern Metrics and Self-Reported Malarious Households**

When analyzing malaria and landscape dynamics in the Northern Ecuadorian Amazon, it can be stated that the prevalence of the infection within *colonos* households during the 1990s has been influenced by the dramatic landscape modifications that have occurred. The drivers of change have been listed as a process of deforestation and agricultural extensification tied to increasing colonization, road building, and oil exploitation (Bilsborrow et al., 2004; Walsh et al., 2002). Landscape dynamics in terms of high number of patches per farm was related to self-reported malarious households in the agricultural frontier in both years 1990 and 1999. However, from 1990 to 1999, the number of self-reported malaria in households decreased, but the number of forest patches nearly doubled. It appears that anopheles is a faster adaptive vector that can use disturbed or transformed breeding sites

in the absence of optimum or bountiful pre-existing forested conditions; thus malaria incidence rates has decreased but still continues being prevalent. Therefore, prior to 1990 when intense and widespread forest clearing was occurring, rural households, mainly *colonos* were closer to anopheles breeding sites, and this resulted in a greater presence of malarious households in 1990 than in 1999. But, in 1999 the new rate of deforestation dropped but the accumulated and increasing deforestation over time meant that most households were farther away from new areas being cleared on farms, this factor decreased the exposure of *colonos* to anopheles mosquitoes, in turn malaria decreased but has been not eliminated.

The degree of landscape fragmentation, or patch density, among households with self-reported malaria was slightly lower than in non-malarious households, when comparing provinces within each year, 1990 and 1999. However, in 1999 the Northern Ecuadorian Amazon was more fragmented than in 1990, while the presence of malarious households decreased. It is suggestive that the prevalence of malaria in the Ecuadorian rainforest is less dependent on land use types – e.g., forest or non-forest - than the timing of forest change. This implies that malaria prevalence in the Ecuadorian rainforest seems to respond to the “frontier malaria” event. During the first stages of land clearing, there is a higher presence of malarious households, but after the deforestation rate has decreased, malarious households are still present, but fewer in number. Patch density when compared among malarious and non-malarious households in each year suggests that self-reported malaria is related with a less fragmented landscape. These results do not agree with the metric number of patches, which suggest that malaria is related with a patchier (or more deforested) landscape. This metric does not seem to be the best tool to analyze land use/land cover dynamics and its link

to malaria prevalence within a defined unit area –one hundred hectares, because malaria is not constrained by abstract areal units.

The Shape Mean metric, which measures the complexity of the land use/land cover shapes, overall, was not related to the presence or absence of malaria in dwelling units, when comparing across provinces in the same year, and within provinces over time. Overall, the lack of variation in relation to the complexity of the shape of land use/land cover over time is noteworthy, as this finding is a product of the generalized nature of the satellite classification and the application of ecological pattern metrics that were used to assess the composition and spatial organization of forest and non-forest cover types. In reality, the Ecuadorian rainforest is a highly diversified landscape, with the human-managed portion of the Northern Ecuadorian Amazon substantially varied.

Patch clumpiness, or high number of patches, when compared among provinces in the same year accounts for the presence of malaria in households. The patchy, or less aggregated, landscape pattern is also present in the farms of self-reported malarious households in the same year in each province. Over time the landscape of the study area had become less aggregated, similarly to what had occurred with the incidence of malaria, but still it is prevalent. The process of deforestation that has undergone in the study area has shaped the prevalence of malaria. Thus, at the beginning of the 1990s, the area faced high deforestation rates and the prevalence of malaria was also high because *colonos* were in frequent contact with anopheles living sites. At the end of the 1990 decade, the landscape has been largely cleared; along with it fewer self-reported malaria cases were recorded. It seems that



anopheles have learned to live and breed in less homogenous and smaller forested sites. In addition, *colonos* still were working their farms, and had contact with anopheles, though in a less frequent mode. This human and anopheles adaptive behavior had led to shape the prevalent character of malaria.

The contrasting results derived from the pattern metrics applied to the landscape to measure the links with malarious and non-malarious households may be a result of various factors. First, it may be related to the data sample, the low number of self-reported malaria cases (about 89 in 1990 and 45 in 1999) among the interviewed dwelling units are not representative. Second, it can resemble that Sucumbíos is in the second stage of the frontier malaria cycle, an area already highly deforested, with declining incidence of malaria, but the disease is still prevalent. Last, another influencing factor must lie in the land use/land cover class types used in the pattern metrics analysis -they were only forest and non-forest-, which highly simplifies the tropical landscape in the agricultural frontier of the Ecuadorian Amazon.

On the other hand, analyzing the spatial distribution of malarious households in the agricultural frontier of the study area, these had a clumpy spatial effect in 1990. But this effect was diluted by 1999. Therefore, malarious households seem to follow the same spatial configuration of land use/land cover transformation pattern through the 1990s, particularly patchiness. This parallel malaria-land use pattern implies that, in 1990 anopheles used to live in a more aggregated (clumpy) environment, and that *colonos'* activities and/or dwelling units were closer to breeding sites. Thus, the prevalence of malaria in 1990 was higher than

at the end of the decade. The decline of self-reported malaria in households over time indicates that deforestation and agricultural extensification is an on-going process in the Northern Ecuadorian Amazon that operates at the farm level. But it is more obvious and widespread in 1999 than in 1990, as a consequence of the aging of the farm (deforestation continues over time) and socio-economic and demographic processes that affected changes in land use/land cover in the years between the two household/farm surveys. These two factors, land use and cultural practices plus anopheles' adaptive behavior to a more patchy and less clumpy landscape had shaped an irregular spatial distribution of malarious households, less clumpy and none homogenous in 1999. But, still households that self-reported malaria in 1999 are close to water bodies as rivers or to forested areas. See Figure 4.8: spatial distribution of households with self-reported malaria in both in both years.

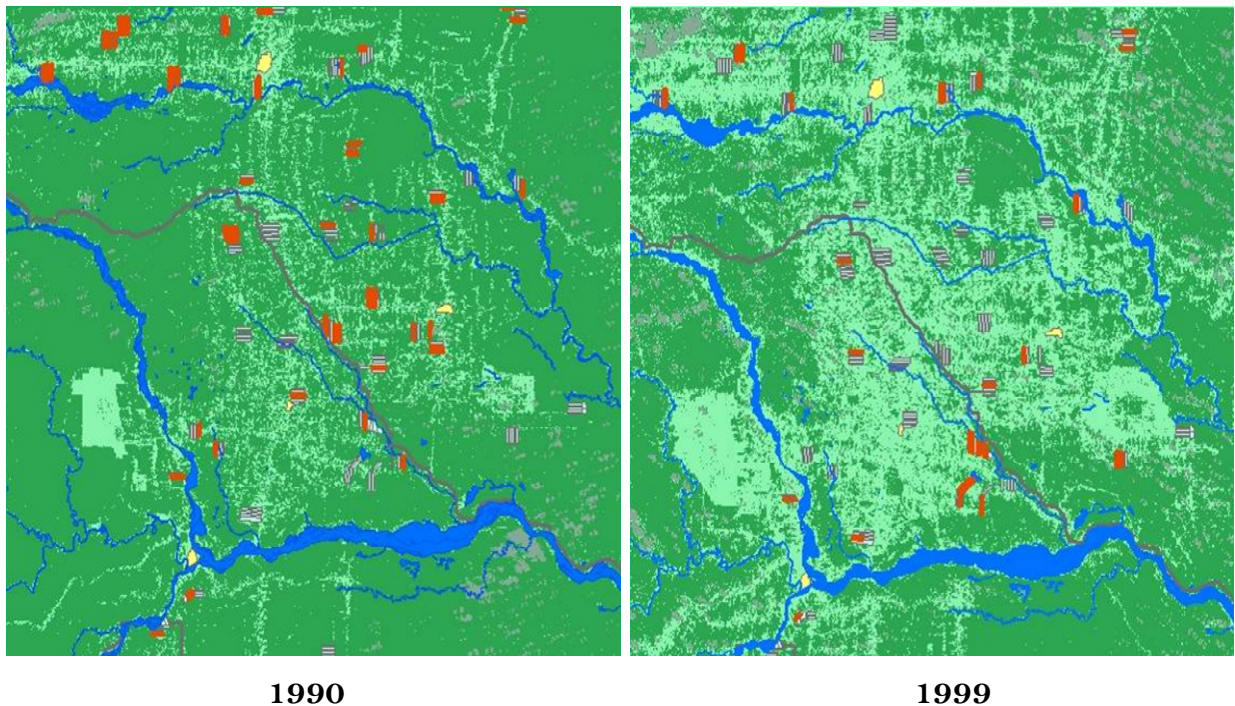


Figure 4.8. Spatial distribution of households that have self-reported malaria in the study area. Left side, in 1990, households with malaria have a clustered/clumpy pattern; right side, in 1999, there is not a particular aggregation spatial pattern, but households with self-reported malaria mostly are close to forest patches or rivers.

#### **4.4 Malaria in the 1990s in the Northern Ecuadorian Amazon: the *Colonos*, the Tropics, and the Anopheles**

The colonization process have shaped the land use/land cover patterns in the Northern Ecuadorian Amazon, which in turn and along with *colonos*' behavior have become the ideal factors that characterize the prevalence of malaria on the agricultural frontier during the 1990s. It is good that self-reported malaria in households decreased from 1990 to 1999, even though *colonos*' decisions and actions were not intended to prevent malaria from occurring. However, malaria is still endemic in the area. The decrease of self-reported malaria has been a by product of changes in proximate factors and distal forces i.e., higher levels of education of the household parents, higher household income, mature household head, increased use of latrines, and improved house type. Contrary to expectation, the house type, mainly wood and bamboo, may also be another factor related to decreased malaria, and this suggests that anopheles biting activity usually occurs outdoors. Conversely, households that rely on a well as the drinking water source and those families that have had a high density of household members have had an increase in the prevalence of malaria.

The ecological pattern metrics confirm the land use/land cover results of the logistic regression model through time. Comparing the models, 1990 and 1999, indicates the importance of land use/land cover fragmentation at the farm level as a factor influencing the prevalence of malaria in the agricultural frontier of the Northern Ecuadorian Amazon. Prior to the 1990s, a “frontier malaria” situation led to higher prevalence rates of malaria. In the first few years of forest clearing, there were more self-reported malaria households, but over time, due to larger cumulated areas being cleared, the number of malaria households

decreased, but did not disappear. The early period of frontier malaria occurred due to the closer proximity of *colonos*' activities and houses to anopheles breeding sites during the first stages of colonization prior to 1990. However, the forest/non-forest line has been pushed further from the *colonos*' dwelling units; malarious households have, therefore, decreased from 1990 to 1999. In addition, the spatial composition and configuration of the landscape of the Northern Ecuadorian Amazon is not a stationary process. This dynamic pattern of deforestation and agricultural extensification has led to a lower prevalence of malaria in the agricultural frontier.

## CHAPTER V

### Fundamentals of Malaria in the Northern Ecuadorian Amazon

#### 5.1 Conclusions

This research has examined the hypothesis that the occurrence of malaria in the Northern Ecuadorian Amazon is contextual and deeply rooted in landscape dynamics as well as human practices and ecology. The rise of malaria in the Northern Ecuadorian Amazon has occurred within the context of oil exploitation and colonization. Attracted by the opportunity to own land, groups of *colonos* have settled along and near roads constructed to access the oil reserves of the area and lay pipelines for oil extraction. Both, the oil industry advancing deeper into the rainforest and the *colonos* settlements have modified the spatial structure and composition of the landscape. Wide deforestation through the Amazonian landscape is the result of oil companies' activities. The *colono* modification of the Northern rainforest resulted from their spontaneous colonization, settling on newly created household farms, and on subsequent land changed through deforestation and agricultural extensification. These modifications of the landscape through the expansion of the agricultural frontier have triggered an adaptive response by the anopheles mosquito that spreads malaria, and shaped its prevalent character. The prevalence of malaria in this area assessed in 1990 and 1999, showed an association with the percent deforestation on household farms, the spatial structure or organization of forest and non-forest on farms, and the socio-economic and

demographic characteristics of the household in the two survey years. While some cultural practices and land change processes have protected the *colonos* from anopheles bites and the contraction of malaria, others have increased their exposure.

To examine the relationship between malaria occurrence and land use/land cover change, socio-economic and demographic characteristics of survey households, and *colonos* cultural practices, a logistic regression model was developed to examine the prevalence of malaria at the household and farm level. The analysis suggests that as the forest is cleared to support subsistence and commercial agriculture and household dwelling units are constructed, the incidence of malaria initially increases and then declines. More cases of malaria were reported at the household farms in 1990, when many households were in the early stages of clearing land for farms, than in 1999, when much of the farm land had already been cleared during the earlier stages of settlement. One explanation for this decline is that household members of frontier farms are geographically closest to anopheles breeding sites immediately after deforestation through the creation of a localized forest/non-forest edge (i.e., a fragmented forest ecotone); but these breeding sites retreat from primary human activity space with time as the forest/non-forest ecotone is “pushed” further from the position of the household dwelling unit and the location of the primary family activity space as a consequence of agricultural expansion through extensification processes. The analysis also indicates that the existence of forest, fallow, pasture, or perennials (coffee and cacao) within a *colon* farm is associated with a reduced incidence of malaria in 1990. Contrary to expectation, the existence of swampy areas within a farm was not associated with any increase of self-reported malaria. At the end of the 1990s, only farms with perennials continued to be associated with a lower incidence of malaria. The “aging” of the farm and the

farm household is part of the story of colonization and the establishment of household farms in a frontier setting, in which early arrivals obtained land along newly formed roads and began the deforestation process on household farms. By 1990 and more so by 1999, the process of agricultural extensification had altered the landscape matrix at the farm level and cleared forest further from the dwelling unit over time. The loss of forest and the spatial “homogenization” of the landscape, i.e., areas close to the dwelling unit, from one dominated by forest to one dominated by agriculture changed the location habitat for the anopheles mosquitoes and thereby reduced the potential for contact with members of the household farm population over time.

While self-reported cases of malaria in households decreased from 1990 to 1999, deforestation and agricultural extensification processes increased, thereby generating a less aggregated landscape or with smaller forest patches remaining. A patchy configuration of forest and non-forest seem to be the ideal breeding or resting places for anopheles in the study area because an intermixed landscape offer shade and sun rays that support anopheles survival. These optimal breeding/resting places have become less proximal to *colonos*' activities or houses over time; therefore, self-reported malarious households declined, but the ailment is still persistent in the agricultural frontier. Thus, the dynamic spatial composition and configuration of the landscape have defined a clumpy spatial distribution of the prevalence of malaria in households in 1990, but in 1999 the trajectory of malarious households declined and showed no spatial pattern.

The socio-cultural factors examined, generally, represent an asset among those *colonos*' households that have been self-reported as free of malaria. Overall, malaria in the frontier is mostly present within the economically active population, over 12 years old. Men are slightly more affected with malaria than women, likely because of their activities that draw them from the cleared land around the dwelling unit and into a more fragmented forest/non-forest mix. In 1990, malarious households tended to decrease when the level of education of the household parents was higher, the household had higher incomes, and wells were used as a drinking water source. At the end of the decade, there was a significant increase in the use of latrines by *colonos*, which may have buffered them from contracting the malaria plasmodium.

The adaptive behavior of the household head through learning from experiences has constituted an important demographic factor that reduces the exposure of family members to primary anopheles habitats, leading to a reduction of anopheles bites from occurring. The prevalence of malaria has decreased even though the agricultural frontier has experienced high population growth, mostly due to im-migration; however, the fertility rate, although still relatively high, has declined during the 1990s. Both high im-migration and fertility led to a greater number of households being formed on existing and new farms, pushing the forest edges away from *colonos*' dwelling units and their activities; this in turn contributed to a decrease in the presence of malaria in households.

This analysis relied upon a longitudinal survey of farms assessed in 1990 and 1999. While new households were formed on the survey farms by 1999, additional, newly



developed farms were not studied. Interestingly, a declining prevalence of malaria pattern is associated with house types of bamboo and wood, suggesting that the feeding activity of anopheles mosquitoes is mostly exophagic, the biting occurs outdoors.

This research has explored the social and environmental determinants of the prevalence of malaria at the farm and household level as well as at the landscape, i.e., province, scale over time by using a rich social and geo-spatial data set. The longitudinal socio-economic and demographic data and the satellite image time-series data were used to understand the links among people, place, health, and environment. The cultural determinants of the prevalence of malaria were studied by using a logistic multivariate regression model. The prevalence of malaria was measured using self-reported cases to identify when at least one member of the household had malaria in the previous three months at the time of the interview. The results from the 1999 logistic regression had less explanatory power about the prevalence of malaria than those for 1990, mainly due to fewer self-reported malaria cases. Satellite imagery and GIS layers were integrated to perform the landscape pattern metrics analysis. The landscape level analysis, using forest and non-forest as land use/land cover classes, has been important to determine the spatial distribution of malaria, defined as “clumpy” with a declining timeline trajectory. The results indicate a decline of malaria in households during the 1990s, an observation that is confirmed in reports by SNEM -malaria incidence plummeted during this decade. However, the ailment has not been eradicated. Malaria is locally maintained through landscape dynamics and cultural practices, and national and regionally influenced with policies. These are factors that the anti-

malaria campaigns at national and international levels must take into account and study if they are to be successful locally.

Land use change in association with the emergence of infectious diseases and the cultural ecology of disease are crucial perspectives for addressing the research questions posed in this study. Through forest clearing, *colonos* have encroached on the rainforest and transformed the nature of population-environment interactions and feedbacks, resulting in anopheles mosquitoes being closer to *colonos*' activities and their dwelling units, thereby, changing the incidence of malaria and contributing to the possibility of epidemics. A complementary perspective offers cultural ecology of disease in assessing how the prevalence of malaria is shaped in the area. *Colonos*, mostly from the Andes, have had to adapt to a new and different environment, and this adaptation has altered their socio-cultural practices that also has promoted the prevalence of malaria, particularly, in frontier settings and during initial settlement periods. Over time the *colonos*' behavior -intentional and not-- has led to a prevention and reduction of anopheles bites, and reports of malaria have decreased, but the disease is still prevalent. Nevertheless, while landscape modifications carried out by *colonos* as well as *colonos*' behavior have shaped the prevalence of malaria, other factors are also crucial to understand and learn about. Factors such as anopheles' ecology and behavior, anti-malaria policies and campaigns, and household life cycles must be studied to address a comprehensive analysis of the prevalence of malaria in the agricultural frontier.

Currently, malaria in the Northern Ecuadorian Amazon is still endemic. Agricultural activities are becoming more commercially oriented, mainly the cultivation of single crops in extensive areas. The land use/land cover change continues, but now the increasing stakeholders are agri-business and larger companies. For instance, African palm is a central plantation-style crop being grown in the Northern Ecuadorian Amazon. *Colonos* family size is decreasing and grown children migrate mostly to nearby urban areas or to the main cities of the country to make a living. Within *colonos*' farms, secondary forest has increased from 1990 to 1999, and this trend doubtless continues. At the same time, more roads have been built, while the quality of others has been improved. Therefore, population mobility is easier within the area; travel to and from other parts of the country has increased and will continue to do so. In addition, anopheles living in the Ecuadorian rainforest are highly adaptive, as the results presented in this research suggest. These human-environmental interactions are dynamic and complex, and it is likely that their interplay within the agricultural frontier will further shape the prevalent character of malaria. Therefore, malaria can be seen as a persistent challenge to the health and well-being of people living in the agricultural frontier of the Northern Ecuadorian Amazon; however, malaria seems to be a preventable disease, and anti-malaria policies must be based on the cultural and environmental circumstances in which malaria has become entrenched.

Malaria's re-emergence in Latin American and elsewhere has been reported since 1970. Drug and spray resistance, population mobility, and proximity to anopheles breeding sites, as well as landscape modification are mentioned as factors shaping the increasing incidence of malaria cases as well as its endemism. Despite numerous and diversified anti-

malaria campaigns launched around the world, the disease continues its rampant march, affecting human health and well-being and even causing deaths. Fighting the anopheles mosquitoes and the plasmodium is not enough. What is necessary is to understand the context of malaria happening. An interesting proposal that takes into account contextual cultural and environmental elements in the occurrence of malaria is the concept of the “frontier malaria,” coined by Sawyer (1993), which well describes the prevalence of malaria in the agricultural frontier of the Ecuadorian rainforest. During the first years of settlement, prior to 1990, extensive deforestation occurred, which caused anopheles mosquitoes breeding sites to be closer to *colonos* activities and dwelling units, therefore, high rates of incidence of malaria were reported. However, during the 1990s, the prevalence of malaria decreased along with the retreat of forest edges, which increased the distance between anopheles breeding places and colonos dwelling units and activities.

This study indicates that reducing the burden of malaria in Ecuador requires more than spraying houses and administering free malaria drugs; rather, a comprehensive approach is needed that includes an understanding of the people living in malarious areas and how the surrounding environment supports or constraints malaria epidemics, prevalence, and reemergence. Thus, it is important to continue studying the local pattern-process relations of malaria, but also to monitor its occurrence and distribution at global levels. Disruptions of ecosystems are likely to continue around the world, and land use/land cover change patterns are described as a central element of landscape dynamics.

## 5.2 Recommendations for Policy and Future Research

Regarding human health, studies on a local level are necessary and important if the intent is to contribute to improved anti-malaria policies. This research has found that malaria in the agricultural frontier of the Northern Ecuadorian Amazon has decreased, because *colonos* have learned to protect themselves from anopheles biting; but the reduction in the prevalence of malaria has also occurred through the deforestation and agricultural extensification and the change of the fragmentation pattern of the landscape. However, malaria still affects *colonos* health and overall their well-being as it has not been eradicated. Therefore, it is suggested that research projects and the SNEM personnel learn the activities of people getting infected with the malaria plasmodium, including their living status in the region and their geographic activity space on the farm and elsewhere, including the movement of seasonal workers from and to the Northern Ecuadorian Amazon. It is crucial to know more about the malaria vector, the anopheles mosquitoes, and their reactions to the environmental disruptions and changing patterns. Finally, although anti-malaria campaigns started in Ecuador in 1948, malaria continues affecting populations. Studying the results of these efforts to eradicate or control malaria can contribute to “lessons learned” of what was effective and what needs to be avoided in future activities.

Self-reported data are a good source of information to support studies. The reliability and confidentiality of these data types range between 67 to 81 percent (Castro et al., 2006; Kroeger et al., 1995). Even though it has been suggested that wealthier families or individuals tend to report their health status as less satisfactory than their poorer counterparts do (Worrall et al., 2005; Quiroga et al., 199), self-reported data are a good source of

complementary information, and in some cases the only kind available. This research has shown that self-reported malaria prevalence rates conform with the malaria incidence trajectories during the 1990s in the Northern Ecuadorian Amazon, as reported by SNEM. In addition, SNEM (2007) acknowledges that for every clinical reported malaria case, six cases are not reported. Therefore, we need to understand that we need to understand that we have been studying the “tip of an iceberg”. It is suggested that the under-reported nature of malaria needs to be included in policy assessments of eradication and education programs in the Ecuadorian rainforest and elsewhere around the world, where such data are used as the primary or secondary source.

Human health is a complex area that is barely understood, even with recent scientific advancements. Biomes, like the tropical rainforest, are also complex due to their high biodiversity and dynamic processes. No single study is going to get an integrated picture of all the events and how they are related when studying the incidence of a disease. However, comprehensive studies that integrate proximate and distal factors at various spatial scales are feasible. In this research, Audy’s (1971) health definition was key to understand that the adaptive and responsive behavior of colonos examined along with land use/land cover dynamics have influenced the prevalent character of malaria.

A complementary interpretation of the reduced prevalence of malaria in 1999 (compared to the higher prevalence rates seen using the 1990 longitudinal survey) may be reflected in the Household Life Cycle Theory. In the agricultural frontier of the Northern Ecuadorian Amazon, deforestation occurred through decisions made at the household level

for their initial engagement in subsistence agriculture. As the household aged and new sources of income arose, the agricultural strategy was manifested through the cutting of forest on the farm for the creation of cash crops and pasture for cattle. The net spatial effect was a “pushing” of the forest/non-forest edge further back from the household dwelling unit for economic and demographic reasons, which, along with the adaptive behavior of the *colonos*, has mitigated the prevalence of malaria at the farm household level. The current stage of land use/land cover change in the Northern Ecuadorian Amazon allows to us state that fallow succession will reforest the landscape cleared initially for agriculture, thereby once again increasing the habitat for mosquitoes and altering the prevalence rates of malaria at the household level. On the other hand, a greater portion of the members of the household may be engaged in off-farm employment in local and more distant communities when the reforestation of the farm occurs in a sufficiently substantial way.

A different perspective of the same problem, the epidemiology of malaria over time and across space, can be assessed with the lenses of political ecology, because malaria extends beyond the tropical and poor rural peasants’ livelihoods. Traditional political ecology studies concentrated on how environmental consequences are linked to political and economic forces working at different scales. If a political ecology framework is used to understand the prevalence of malaria in the agricultural frontier of the Northern Ecuadorian Amazon, political and economic powers need to be studied. Such studies should focus on the institutional responses that the SNEM has had to the epidemic and endemic character of this ailment. Since its creation in 1948, the anti-malaria goals of the SNEM have changed from eradication to simply control and prevention with little or no knowledge about the local

cultural and environmental determinants of the disease. In addition, despite the fact that the Ecuadorian Amazon provides substantial amounts of oil and agricultural products to the national and international markets, the rural populations in the region remain poorly served in basic services, such as potable water, sewage, and health. Therefore, making failed anti-malaria campaigns accountable and a contributing element to current policy making in SNEM and the Ministry of Public Health. Politics, ecology, and economics need to be integrated to study the prevalence of malaria in the Northern Ecuadorian Amazon.

Human health status will continue facing the constant risk of malaria, locally and globally. Local, national, and international development projects need to take into account the likelihood of malaria epidemics and endemism as a result of project implementations. Last, it is crucial that health policies are developed and deployed, taking into account the local environment as well as the socio-economic factors of local people as part of the production of malaria, but also considering that the prevalent character of this ailment is externally influenced by policies at regional and national level.



## Appendix A

### Interview to *colonos* living in the Northern Ecuadorian Amazon

#### Entrevista a colonos del Nororiente Ecuatoriano.

##### Personal

Edad    Sexo  
Nivel de educación (ninguno, primario, secundario, universitario, otro)  
Provincia    Cantón                          Parroquia                          Comuna/Cooperativa

##### Trabajo

Cuales es su ocupación (esposo, esposa, otros miembros de la casa)?  
Lugar físico donde la desempeña su trabajo?  
Que horas comprenden la jornada de trabajo?  
Desde cuando realiza esta actividad?  
Tiene alguna otra actividad laboral?  
Cuanto tiempo permanece en su casa?  
Trabaja en su casa?                          Que hace?  
Cual es su ingreso mensual?  
Cuanto dinero necesita su familia al mes para vivir (comer, vestirse, salud, educación, otros)

##### Infraestructura de casa (Fotos)

De que material es su casa (techo, paredes, piso, ventanas)?  
Como esta constituida su casa (cocina, número de cuartos, baños)?  
Si no posee baño, letrina, donde realizan sus necesidades?  
Cuántas personas viven en su casa?  
Es usted propietario de la vivienda?  
Que vegetación existe en el perímetro de su casa?  
Tiene jardín?  
Tiene animales domésticos?                          Cuales?

##### Deforestación, y uso del suelo

Cual es la dimensión de su finca?  
Es usted propietario de la finca?  
Cuanto tiempo es dueño de la finca?  
Que productos cultiva en su finca?  
Cual es la temporalidad de cultivo de estos productos?  
Que extensión de la finca aun tiene árboles?  
Ha talado/cortado árboles recientemente (últimos 10, 5, 1 año)?  
Tiene cuerpos de agua cercanos a la finca?                          Cual es la distancia hacia ellos, cuanto tiempo demora en llegar a ellos?

##### Salud

De donde obtiene agua para consumir en su casa, aseo personal, lavar la ropa, sanitario?

Que sucede con la basura que generan en su casa?

Cual es la alimentación suya y de su familia diaria-básica?

Ha tenido alguna vez malaria usted?

Ha tenido alguna vez malaria alguien de su familia?. Quien? Edad? Sexo?

Cuales son los síntomas que usted sintió cuando usted tubo malaria (fiebre, dolor de cabeza, escalofríos, otros )?

Realizo algún tratamiento para curarse de la malaria usted (o el familiar enfermo)?, Cual?,  
Donde acudió?

Como se ha protegido usted para evitar la malaria? (repelentes, medicamentos)

Tiene su casa mallas en las puertas para evitar a los insectos? Estado

Tiene toldos en las camas para evitar la picadura de insectos? Estado

Cuantas veces ha tenido usted (o algún miembro de la familia) malaria?

Cuando están enfermos donde acuden?

La salud en general suya y de su familia es ahora mejor o peor que hace 20 años, 10 años, 5 años, 1 año?

Que ha implicado el estar enfermo de malaria para el desarrollo de su vida normal?

**Appendix B**  
**Dependent and the independent variables used in the logistic regression model.**

Variable	Name variable	Variable type	Variable description	CODES
Malaria	yes_malaria90 yes_malaria99	Independent variable	Presence of malaria within at least one member of the household.	1=self-report of someone in the hh <sup>1</sup> has been infected with malaria. 0=no malaria.
Education	educhh90 educhh99	Socio-economic	Level of education of the household parents, using the highest level of education of head or wife.	0=none; 1=primary; 2=secondary & technical; 3=university; 4=other; 98=do not know; 99=missing
Head age	jage90 jage99	Demographic	Age of the household head	
Nr. of Inhabitants	nump_90 nump_99	Demographic	Number of people living in the household at the time of the interview; includes children and adults.	
Farm age	yearf_90 yearf_99	Socio-economic	Year of acquisition of the farm.	
Head born	born_a90 born_a99	Demographic	Province of birth of the head of the household.	1= head born in the Andes; 0= any other
Household income	log_hhinc_90 log_hhinc_99	Socio-economic	Net household income. It takes into account remittances, off-farm employment, and income of selling products from other farms that the household members own. To have a normally distributed distribution of the variable, the natural logarithm was applied. Average rate of exchange: 10,000 sucres=1 USD.	
Social Membership	membera_90 membera_99	Socio-economic	Any member of the household belongs to a social organization (religious, economic, sports groups, etc.)	Yes=1; No=0
House type	housetype_90 housetype_99	Socio-economic	Wall type of the house	1=cement; 2=bamboo; 3=wood; 4=other; 9=missing
Drinking water	well_90 well_99 river well_99	Socio-economic	Sources for drinking water.	Yes=1; No=0
Latrine	latri90 latri99	Socio-economic	Latrine as the type of human waste disposal	Yes=1; Other sources= 0
Land use/land cover class types	pperennial_90 psecpas_90 pforest_90 pswamp_90 pperennial_99 psecpas_99 pforest_99 pswamp_99	Land use/land cover	Land use type for the farm where the household existed and the interview took place. The values are percentage of land use type controlled for the farm size.	Perennials=Coffee and cacao were included under this category. Each variable was calculated as percentage of the total hectares of each farm.
Topography	flat_90 flat_99	Topography	Type of farm's surface	Flat=1; Others=0

<sup>1</sup> hh=household

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