Evaluation of Deforestation in the Río Plátano Biosphere Reserve, Honduras.

By

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ABSTRACT

Satellite imagery has been a useful tool in monitoring land cover changes, including changes within protected areas. In the 1980's and 1990's Honduras created over 100 protected areas, yet few resources have been dedicated to their management. This study used Landsat satellite imagery to evaluate deforestation in the Río Plátano Biosphere Reserve in Honduras. The international community recognized the Río Plátano Biosphere Reserve for its ecological and cultural importance with its designation as a UNESCO World Heritage Site in 1982. The reserve was placed on the List of World Heritage in Danger in 1996, and the level of deforestation taking place in the reserve today is uncertain. Landsat TM and ETM+ imagery from 1985-1987 and 2001-2002 were used to conduct a change detection analysis based on an ISODATA unsupervised classification. Specific research objectives include identifying areas in the reserve most affected by deforestation, evaluating the difference between deforestation within the reserve boundaries with an area outside the boundaries, and comparing the levels of deforestation between the internal zones of the reserve. Analysis of the western boundary of the reserve indicated that the boundary was not effective in halting deforestation within the reserve, but may have been effective in slowing deforestation. Furthermore, results showed that deforestation has occurred in each of the three zones of the reserve. The nuclear zone experienced the least forest change, followed by the cultural zone, primarily inhabited by indigenous peoples, and the buffer zone, the site of mestizo colonization.

1. INTRODUCTION

Deforestation in Central America and Honduras has been well documented, although estimates vary (Achard, et al., 2002; Tucker, 1999; Kaimowitz, 1996). Population growth, government policies, land use management, agricultural and infrastructure expansion, external debt, wood export, and wood fuel consumption have all been cited as causes of deforestation (Geist and Lambin, 2002; Rudel and Roper, 1997; Allen and Barnes, 1985). Today, the largest remaining contiguous rainforest in Central America is the Mosquitia, an area extending from the northeastern coast of Honduras to Nicaragua. The Mosquitia has been characterized by relatively low population density and inaccessibility, and its indigenous inhabitants have maintained the forest cover for centuries. Mestizo colonization of the Mosquitia since the 1980's has resulted in conversion of forestlands to pasture and agriculture (Herlihy, 1997). Forest conversion has implications not only for biodiversity, environmental services, and the global carbon cycle, but also for the indigenous cultures that occupy the forests. In response to concerns about the loss of forested areas, the Honduran government established over 100 protected areas in the 1980's and 1990's. One of these protected areas, the Río Plátano Biosphere Reserve, was designated to protect the forests and biodiversity of some 800,000 hectares of the Mosquitia in eastern Honduras. Few government resources were dedicated to its management and its effectiveness is uncertain. Satellite remote sensing has been shown to be effective in monitoring changes in protected areas (Nagendra, 2004; Dodds, 1998). This study combines the use of satellite imagery to detect deforestation in the reserve and compare the rates of deforestation between primarily mestizo populated areas and primarily indigenous populated areas, with an analysis of the literature and theoretical foundations of deforestation, to position the results in the context of the political ecology of Honduran forest management.

Throughout the world, more than 100,000 protected areas have been created in the last century, but it is not always clear if these protected areas are effective in protecting the biodiversity, ecological services, and social services for which they were established (West and Brockington, 2006). People residing in the regions designated as protected seldom had input in the creation, delineation, and management of the protected areas, which often led to negative impacts for the inhabitants (Zimmerer, 2006; Neumann, 1998). Many governments viewed indigenous communal land use practices not only as agriculturally and economically inefficient, but as causes of environmental degradation, and representative of an “early” stage in the evolutionary model of agrarian change (Bassett and Crummey, 1993; Agrawal 2005). The interests of the state and the interests of local inhabitants were often divergent, with the benefits of the protected area unclear or nonexistent for local people (Agrawal, 2005; Neumann, 1998). Furthermore, the rapid creation of protected areas often outstripped the ability of governments to monitor and manage them, resulting in “paper parks” – or parks established in name but not in practice (Nagendra, et al., 2004). The history of protected areas in Honduras in many respects reflects these global trends.

Honduras has a population of 7.4 million and covers some 43,278 square miles, similar in area to the U.S. state of Virginia. With a per capita gross national income (GNI) purchasing power parity of $2,900 (U.S. $, 2005), Honduras is considered one of the poorest countries in the region (PRB, 2005). Despite its relative poverty and chronically troubled government finances, Honduras created over 100 protected areas in the 1980's and 1990's. The study region of this paper, the Río Plátano Biosphere Reserve, is the largest protected area in Honduras. The reserve covers approximately 7% of the country in an area of relatively low population density. It is part of a binational conservation effort known as the Mesoamerican Biological Corridor. The Río Plátano Reserve is currently contiguous with the Tawahka Asangni Biosphere Reserve to the south, which in turn shares a boundary with the Basawas Reserve in Nicaragua. Despite its inscription on the United Nations list of World Heritage in 1982, the Río Platano Biosphere Reserve had very little oversight for the first decade of its existence (Richards, 1996).

While this study applies remote sensing techniques to analyze deforestation in the reserve, it is important to recognize that the use of remotely sensed data is but one of many ways to quantify land cover change. Remote sensing techniques are powerful tools in that they do not require the human resources needed to perform forest mensuration across large areas over time. Remotely sensed data can, as in the case of this study, be used to calculate reflectance values across wavelengths of the electromagnetic spectrum for different land cover surfaces. These values can then be statistically clustered and assigned classes so that one cluster corresponds to dense vegetation, and another to soil or water. Ground data and the application of statistical techniques can then provide a measurement of the accuracy of the overall land cover classification, such as the Kappa statistic. A classified image from one point in time can be compared to a classified image from a later date, and thus land cover change can be calculated across great areas over many years.

On the other hand, there are limitations to what remotely sensed data can provide. It tells nothing of the people living in the area, their land use practices, political economy, or how populations are shifting from one region to another. It reveals *pattern*, but explains nothing of the *processes* that create the patterns it has revealed. It cannot determine *if* a pattern is important, or *why* it would be so.

This study is divided into its respective sections to utilize the strengths of remote sensing and to address its weaknesses. Accordingly, it begins by summarizing the background of forest management in Honduras. Then the focus will shift to the Río Plátano Biosphere Reserve, the people who live within its boundaries and their efforts to organize and establish rights to their land. The framework of political ecology, demonstrating the relationships between state and local governments, non-governmental organizations, private industries, and their influence on the environment, will be used to understand and interpret the remote sensing results.

The background will be followed by an explanation of the methodology used in the remote sensing analysis. This section will review the basic principles of applying remote sensing to the problem of detecting change in land cover and the specific methods applied in this study, including the statistics used to provide measures of accuracy. The results will then be discussed in the context of the research questions.

One key question of interest is: Does a “paper park” necessarily equal an “ineffective park”? The hypothesis is that although the Río Plátano Biosphere Reserve was largely a “paper park” during the study period of 1985-87 to 2001-02, there will be a lower rate of deforestation within the reserve than in surrounding areas. This will be due in part to inaccessibility, but also in large part to the efforts of the indigenous inhabitants of the reserve to protect their lands and culture.

The indigenous people of the Mosquitia have stewarded this land for centuries, but their stewardship has been encroached upon by colonizing mestizo *campesinos* from eastern Honduras. Is there a difference in deforestation rates between the mestizo and indigenous zones of the reserve? This is the second key question of interest. The corresponding hypothesis is that the rate of deforestation will be greater in mestizo dominated areas than in areas primarily occupied and managed by indigenous inhabitants.

Since the boundaries of the reserve have changed over time, it is impossible to fully address the “paper park” question with these data. However, the western boundary of the reserve has remained stable since its inception and provides a study area with which to address how effective “protected area” status has been at limiting deforestation. This boundary is particularly relevant as it is also the site of the mestizo colonization front.

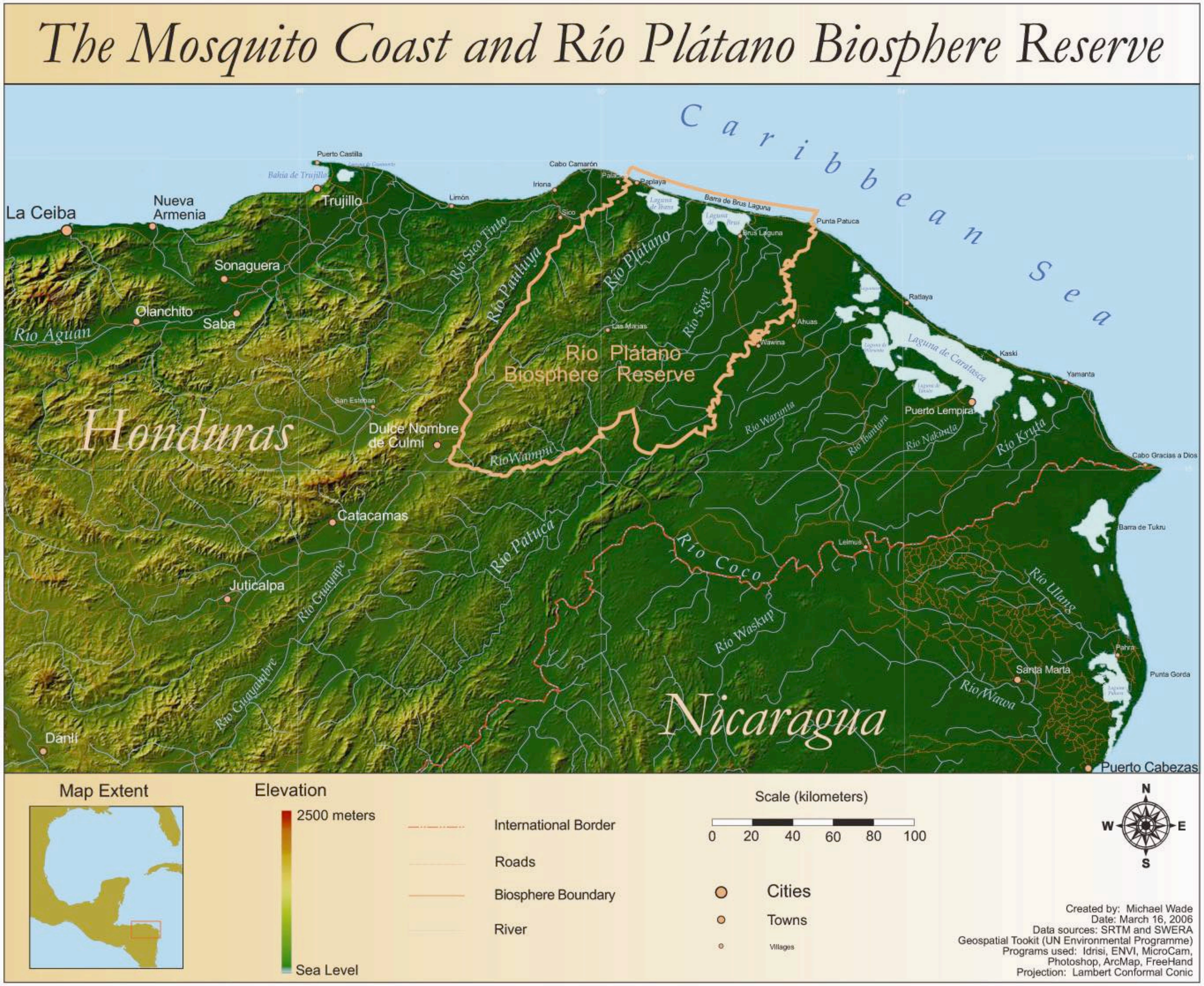

Figure 1: Map of the Study Region

Analysis of deforestation in the internal zones of the reserve will address how land cover change has manifested differently in areas populated by mestizo and indigenous inhabitants. The internal zones of the reserve (buffer, cultural, and nuclear) are the result of a participatory mapping project conducted in the 1990's. The participatory mapping project was a collaborative effort of the Honduran State Forestry Agency (AFE/COHDEFOR), the Social Forestry Program of the German Government (GTZ, KFW), and indigenous Miskito, Pech, Tawahka, and mestizo inhabitants of the reserve (Herlihy, 1998). In this sense, this study treats the zones of the reserve not as strict boundaries, clearly delineated by signs or fences and monitored by the government, for indeed they have not been. Instead, they are treated as areas of land use management - areas the people themselves identified as having been largely under the management of indigenous peoples (the cultural zone) and mestizo (the buffer zone). In this way the zones delineated by the participatory mapping project can be used to study the change in mestizo and indigenous areas between the time periods of 1985-87 and 2001-02.

2. OBJECTIVES

Has deforestation occurred in the Río Plátano Biosphere Reserve? If so, where, and how much? Has the designation of this area as a "biosphere reserve" been effective in limiting deforestation? Is there a difference in the level of deforestation between the internal zones (buffer, cultural, and nuclear) of the reserve? These are the central questions of this research, and their answers will be crucial to effectively protect the ecological and cultural diversity in the reserve. The objectives of this study are:

1. Determine if deforestation has occurred within the reserve, and if so, identify the areas of the reserve that have experienced deforestation.
2. Evaluate the effectiveness of the reserve in reducing forest clearing by a comparison with neighboring regions outside the reserve.
3. Evaluate the difference in forested area change between the biosphere's internal zones.

3. BACKGROUND

3.1 The History of Forest Control and the Creation of Parks in Honduras

Of the 112,498 square kilometers that comprise the nation of Honduras, it is estimated that approximately 88% is best suited for forest (Vallejo, 2003). However, only about half of the terrain is forested (COHDEFOR/FAO, 2005). Pine forests represent 97% of the commercial wood production (Nygren, 2005). Deforestation is considered a problem in Honduras and it is estimated that the country lost nearly 25% of its forests in the 1980's (Tucker, 1999).

Private timber companies dominated the Honduran forest industry until the 1970's. This period was characterized by corruption and mismanagement. Due to the concern over the apparent overexploitation of Honduran forests, the government took action in 1974 and created COHDEFOR (The Honduran

Corporation for Forest Development) (Nygren, 2005). This nationalized Honduran forests, making all trees property of the state, although the land beneath still belonged to the landholders, which included municipalities and private owners. The state not only took ownership of all forests, but COHDEFOR was given power over all aspects of the forest industry including forest management and marketing of forest products (Vallejo, 2003).

Under this new system, municipalities were to be given a small percentage of the revenues of the forest development. However, local citizens were angered by the loss of rights into management decisions on formerly community-held (*ejido*) lands. They felt that their interests, which often involved uses other than logging such as resin tapping, were undermined by a national government under pressure from international lenders to generate revenue to repay debt (Tucker, 1999). Furthermore, communities at the municipal level felt that while they held little power over decisions and saw little economic benefit, they bore the costs of environmental degradation (Tucker, 2004).

The influences of the global shift in economic development to neoliberal policies were felt in Honduras. Neoliberal policies encouraged by the IMF, World Bank and the U. S. government included fiscal discipline, privatization, and private property rights (Peet, 1999). In 1992 the Honduran government passed The Law for Modernization and Development of the Agricultural Sector (Agricultural Modernization Law, or LAM) that decentralized forested land and gave forests back to the original landowners (Jansen, 1998, Vallejo, 2003). The original landowners included municipal or *ejido* landholdings. This followed the neoliberal goals of privatization, decentralization, and establishment of private property rights, as well as fiscal discipline, in that it was thought that community forests could reduce national government expense by taking over forest protection and management responsibilities (Tucker, 2004). Today, approximately 25 percent of forested land in Honduras is privately held (COHDEFOR/FAO, 2005). Of the remaining 75 percent that constitute public forestlands, almost half are *ejido* holdings (Vallejos, 2003).

It is important to put this short historical overview into a theoretical context of forest use. It has been argued that privatization will lead to more efficient use of forest resources and prevent the overexploitation of resources associated with open access areas, a result known as the "Tragedy of the Commons" (Tucker, 1999; Hardin, 1968). Yet it has also been argued that privatization leads to the further impoverishment of marginalized groups and land degradation (Tucker, 1999; Bassett and Crummey, 1993). In the case of Honduras, decentralization occurred largely in the shift of forest resource control from national to municipal hands, and to a lesser extent in the shift to private landowners (although in the municipal holdings individuals are granted usufruct rights to property). The issues of the tragedy of the commons, overexploitation, and marginalization are still important to consider in this national to municipal shift of authority.

One additional but important change in the management of Honduran forest resources has been the creation of protected areas. In the 1980's the number of parks in Honduras increased rapidly. With the passing of National Law 87-87 in 1987, the Honduran government designated all areas at an altitude over 1,800 meters as protected (Pfeffer,et al, 2001). The move was prompted by pressure from the global community's interest in environmentalism, which essentially, Pfeffer et al (2001) argue, has been defined by the experiences and concerns of the First World. This law, along with others that followed, created over 100 protected areas in Honduras. The diverse inhabitants who occupied these lands, relied on them for subsistence, and considered them crucial for their cultural survival found themselves in many ways denied the benefits of the decentralization of forest resources. While municipalities around the country saw their forestlands returned to their stewardship by the Agricultural Modernization Law of 1992, forestlands within designated "protected" areas remained under federal management.

3.2 Indigenous Empowerment and the Struggle for Property Rights in the Río Plátano Biosphere Reserve

As illustrated in the overview of forest resource management at the scale of the state, the struggle between municipal land forest ownership and federal ownership, pressures for development, and international pressure to protect forests have played roles in the continual evolution of forest ownership and management in Honduras. While these changes occurred, so too did developments in the remote, less densely populated region of the Mosquitia among its four indigenous groups. As we shift scale from the state to the region, the prominent actors change from municipalities and the federal government to indigenous rights groups and the federal government.

The Mosquitia is rich in cultural diversity as well as biological diversity. The historical interactions between Europeans, indigenous peoples, and Africans forcibly removed from their homelands by the slave trade have resulted in several distinct cultures. Of the estimated 30,000 inhabitants of the reserve, five cultural groups dominate: the Pech, Tawahka, and Miskito Amerindians, Afro-Caribbean or Garífuna, and “ladinos” or mestizos of mixed Spanish and Amerindian descent (Padilla et al, 2003). Most evidence suggests that the ethnic roots of the Pech and Tawahka are more strongly tied with the Sumu of northern South America and southern Central America than the Maya predominant to the north. The languages of the Pech and Tawahka are considered part of the Macro Chibchan Family, which is found in the northern regions of South America, such as Colombia, and throughout southern Central America in Panama, Costa Rica, and Nicaragua (Herlihy, 1997; House, 1997). The ethnic origins of the Miskito Indians are African, Amerindian, and European, and their language is also related to the Macro Chibchan Family (Dodds, 1998; Herlihy, 1997). The Garífuna (sometimes referred to as “Black Caribs”) are a mix of African and Amerindian influences. They originated on the Caribbean island of St. Vincent and were forced to the coast of Honduras by the British in the late 1700’s (Herlihy, 1997).

The Garífuna and Miskito populate the coastal regions of the Mosquitia. The Garífuna population extends along the north coast of Honduras as far east as Palacios on the western border of the study area. From Palacios eastward the Garífuna population thins and Miskito predominate along the coast eastwards and south into Nicaragua. The Pech occupy inland areas along the Plátano River, and as far southwest as the town of Dulce Nombre de Culmi (Herlihy, 1997). The Tawahka settlements are concentrated along the Patuca River (House, 1997).

While each of these groups has its own distinctive land use systems, they share many common characteristics. First, the federal government has traditionally not recognized their property rights and they often do not have legal titles to the land they work (Hayes, 2007; Richards, 1996). Second, they practice swidden agriculture or shifting cultivation in which they leave fields fallow for years at a time (Dodds, 1998; Herlihy, 1997). Third, they hold some land communally for hunting, fishing, and collecting (House, 1997; Dodds, 1998; Herlihy, 1997). Fourth, the communally held land on which these communities depend often covers a much larger area than the land more easily identifiable as belonging to single households (Richards, 1996; Herlihy, 1997). This last distinction is made to emphasize that it would not simply be sufficient to draw cadastral maps of household parcels and provide titles for the land, because this would fail to recognize the communities' reliance on, and historical claim to, much larger tracts of communally used land.

The indigenous people of the Mosquitia have been actively organizing for thirty years to defend their lands and culture. The Miskito, the largest group in the region, were first to organize to collectively demand rights to their territory. They formed the Unity of the Mosquitia (MASTA) in 1976 with the aim of conserving their cultural traditions (Herlihy, 1997), and which is now a broad federation of Mosquitia indigenous organizations (Brehm, 2000). In the period following the formation of MASTA, a network of non-governmental organizations (NGOs) representing the people of the Mosquitia emerged. The Garífuna founded the Fraternal Negro Organization of Honduras in 1977, the Pech the Federation of Indigenous Pech Tribes in 1985, and the Tawahka the Indigenous Federation of Honduran Tawahka in 1987 (Herlihy, 1997).

One of the most active indigenous groups in the region is the Agency for the Development of the Mosquitia (MOPAWI). MOPAWI was formed in 1985 and represents the indigenous Miskito, Garífuna, Pech, and Tawahka as well as the mestizo population in the Mosquitia (MOPAWI, 2007). MOPAWI works to strengthen the ability of organizations such as MASTA to lobby the federal government for land rights through community education and training community representatives (Brehm, 2000). Furthermore, MOPAWI has served as a primary partner for many international organizations such as the United Nations Environment Programme and the German Social Forestry Program.

The Río Platano Biosphere Reserve was created by a top-down process that did not include the indigenous groups in its establishment (Herlihy, 1997). As a result, the creation of the Río Platano Biosphere Reserve complicated matters for the indigenous groups fighting for recognition of their land rights. Land tenure and property rights in the Mosquitia region were chaotic during the 1980’s and 1990’s (Richards, 1996). The creation of the Río Platano Biosphere Reserve essentially made the lands within the reserve’s boundaries property of the state, leaving issues of previous municipal ownership largely unresolved

(Herlihy, 1997. Richards, 1996). The indigenous inhabitants were essentially granted usufruct rights, but not titles to their land.

This ambiguity of property rights has led to tension between the indigenous populations and mestizo colonists. Indigenous inhabitants were often frustrated by the lack of cooperation from the federal government and made their own explicit delineations of their lands, as in 1985 when, as documented by Dodds (1998), "…Miskito men from various villages formed a large work party to blaze a boundary through the forests from the Río Tinto Negro and to the south of the Laguna de Ibans – this was to serve as a territory marker in case of disputes with in-migrating ladinos".

The efforts to make their voices heard made significant progress in 1992 with the First Congress of Indigenous Lands of the Mosquitia. The Congress raised the awareness of government officials and the Honduran populace of the issues facing the indigenous people of the Mosquitia. It can be viewed as a concrete example of the emergence in Honduras of a wider recognition of the importance of local and participatory management in environmental protection, a recognition that has been developing throughout the world (Ostrom, et al., 1999; Agrawal, 2005). Furthermore, as Herlihy (1997) points out, the Honduran government during this period began to treat protected areas as distinct management units, and see them as at least a small step in recognizing indigenous land rights by "preventing" encroachment by colonization. However, the Río Platano Biosphere Reserve remained poorly demarcated and was allocated only two forest rangers for the entire area during much of the period of this study (Richards, 1998; Herlihy, 1997). Despite the calls for governmental support of indigenous property rights, the reserve remained under COHDEFOR management and the lands mostly owned by the state. As a result, the Río Platano Biosphere Reserve from 1985-87 to 2001-02 was largely "protected" by its inaccessibility and by the indigenous people who resisted encroachment onto their lands. Even today they continue the struggle to obtain the force of law behind their property rights (Hayes, 2007).

The difficulty for indigenous inhabitants of the Río Platano Biosphere Reserve to establish firm property rights is in part the product of two nearly opposing trends in forest management – that of institutional *decentralization* of forest control from the federal government to municipalities, and that of *centralization* of forest control in the form of parks and protected areas. The centralization of forest control in the form of protected areas superseded the decentralization brought about by the Agricultural Modernization Law, and largely denied communities in the reserve the benefits that other municipalities derived from the decentralization process.

3.3 Deforestation

Deforestation has implications for biodiversity, water quality, the global carbon cycle, national economies and sustainability, and for the survival of indigenous peoples of forested regions (Tucker and Southworth, 2005). The causes of deforestation are manifold, far from homogenous, and dependent on local circumstances, although some generalizations can be drawn. Allen and Barnes (1985) identified population growth, agricultural expansion, and the past rate of wood production as strongly associated with deforestation. Kaimowitz (1996) as well and Geist and Lambin (2002), reinforce those findings and add infrastructure expansion, government policies and property rights. Tucker (1999) and Merrill (1995) indicate that in the case of Honduras, servicing government debt may have been a strong driver of logging nationalized forests.

These causes can interact in complex ways and it is not a simple task to untangle the many different proximate and ultimate forces influencing deforestation. Some causes may be present in one area but absent in another; a given force may be a weak influence in one case but a primary in another (Lambin and Geist, 2003). Even contradictory conclusions can be drawn based on individual cases. While Tucker (1999), Merill (1998) and Rudel and Roper (1997) cite government debt as an underlying cause of deforestation in some cases, Rudel and Roper (1997) also go on to point out that government debt can, in other cases, slow the rate of deforestation. In the first case loans are used to finance infrastructure expansion and may be paid for (as in the case of Honduras) with the revenues from nationalized forests. In the second case, when a debt crisis develops, the government imposes austerity measures and curtails expenses related to infrastructure expansion in order to service debt, thus slowing the rate of road building in frontier areas.

Further complicating the issue of deforestation, there are often different estimates of the rate of deforestation given by different studies and organizations (Allen and Barnes, 1985; Kaimowitz, 1996). Table 1 shows the FAO's estimate of forest change in Honduras during the decade of the 1990's as approximately 1%.

	Land area	Forest Cover 2000	Forest Cover Change 1990-2000		Distribution of land cover/use % (1995)		
	´000 ha	´000 ha	´000 ha/year	%/year	Forest	Other Wooded Land	Other land
Honduras	11,189	5,383	-59	-1.03	48.1	0	46.7
North and Central America	2,102,742	549,306	-570	-0.1	26.1	15.9	57.8
World	13,139,618	3,869,453	-9,319	-0.24	29.4	11.2	58.6

Table 1: Forest Cover change in Honduras, North and Central America, and the world for the decade of the 1990's. Source: FAO, 2005

While national statistics are useful to establish a wider context, they reveal little of the regional dynamics occurring in the Río Plátano Biosphere Reserve. By mapping municipal-level demographic data acquired from the International Center for Tropical Agriculture (CIAT), two characteristics of the Mosquitia are clear. Figure 2a maps the population density per square kilometer at the municipality level and illustrates the first characteristic: the general pattern of dense settlement to the east and south, and less dense populations to the west, with the Mosquitia region having low (3-35 inhabitants/km^2) population density.

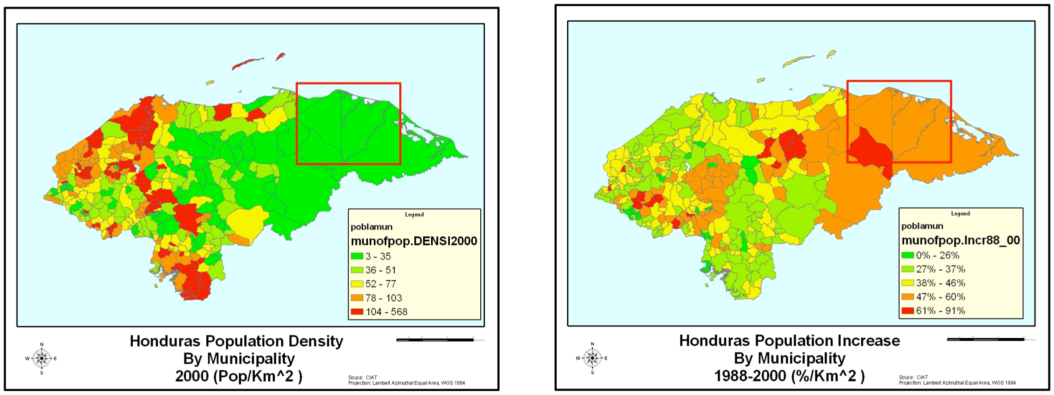

Figure 2: a) Honduras Population Density by Municipality, 2000. b) Honduras Population Increase by Municipality, 1988-2000. The study area is outlined in red. Source: CIAT.

Figure 2b illustrates the second characteristic, that of the relatively rapid population growth of the less dense regions. Most of the Mosquitia experienced a population increase between 47-60% between 1988 and 2000.

This change in population is due to both immigration by mestizo colonists and by natural increases in population of the indigenous groups. Dodds (1998) conducted an analysis of population growth and deforestation in three Miskito communities in the Río Platano Biosphere Reserve. He found that while the Miskito population quadrupled during the period of 1960 to 1996, agricultural area only increased two-fold. He posited that the Miskito adapted their local natural resource management institutions and economies as their population grew, including increased participation in the wage labor market. This suggests that while increases in Miskito population are accompanied by attendant increases in area cleared for cultivation, the relationship may be different than that between colonist populations and forest clearing.

Herlihy (1997) identified the western boundary of the reserve as the “colonization front” of agricultural expansion in the Río Plátano Biosphere

Many mestizo colonists migrated from the more densely populated southern region of Honduras that had experienced soil degradation from years of unsustainable agricultural practices. Richards (1996) described the process of colonization as occurring in three phases “timbermen, *campesinos* (‘small farmers’) and ranchers”. Both Richards (1996) and Merrill (1995) cite corruption in the national forestry agency, COHDEFOR, as allowing for clearing of protected lands. Small farmers move in after the initial clearing and establish *milpas* (small fields of corn and beans), which after a few years they convert to pasture. Land titles are then obtained from lawyers applying questionable practices. Wealthy ranchers from eastern Honduras then eventually purchase adjoining pastures to create large tracts for cattle, virtually securing the permanence of the forest to pasture conversion.

The first “wave” of immigrating mestizos cultivated commercial products such as coffee, maize, and beans that often required forest clearing. Because the subsistence zones of the indigenous people were unmarked, and the ownership of “idle” lands was often ambiguous, many migrants hoped or assumed that the new land titling measures instituted by the 1992 Agricultural Modernization Law (LAM) applied. According to Richards (1998), “…*de facto* possession could be converted into full title after three years, provided the forest was maintained.” This resulted in migrants clearing a small portion of forest for cultivation (or claiming a portion previously cleared), but demarcating, often by fencing off, a much larger forested area. Typically, after several years, large cattle interests would then purchase these fenced lands from the usufruct owners.

These processes influencing land use change threaten both the Río Plátano as a protected area and the cultural heritage and livelihood of its inhabitants. Without individual titles to their land or recognition of the wider communal areas used for hunting and fishing, the indigenous inhabitants have little legal recourse to defend against encroaching colonists who see the land as idle, unoccupied, and open for settlement.

4. METHODS

4.1 Study Area

Designated a World Heritage Site in 1982 by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Río Plátano Biosphere Reserve, centered at approximately 15º 30’ N and 84º 49’ W, covers over 800,000 hectares in the heart of the Mosquitia region of eastern Honduras. Parts of the reserve fall into the three Departments of Gracias a Dios, Olancho, and Colon. Of the 830,000 ha, approximately 196,000 ha are buffer zone, 390,000 ha are cultural zone, and 210,000 ha are nuclear zone, with the remaining portion designated as maritime zone (Figure 3). These zones (termed *macrozonas* in Spanish) were delineated in 1997 partially as a result of the participatory mapping project. They are based on the United Nations Man and Biosphere model and have varying limitations on land use, although enforcement of these limitations has been questionable (Table 2). No logging should occur in the nuclear zone, and settlement was intended to be limited to the original inhabitants. By the 1990’s, some colonists had moved into the nuclear zone, but by 2003 all but ten families had been relocated to areas outside the reserve (Padilla et al., 2003). No new settlements were, in theory, to be allowed in the buffer zone and forest clearing would require exceptional permission by the State Forestry Agency, COHDEFOR (Richards, 1996). The cultural zone was reserved for “sustainable” use by the indigenous people of the area and was intended to protect both material and immaterial components of indigenous culture, such as archeological sites and land use practices (Herlihy, 1997). However, the land use restrictions have generally been poorly defined, communicated, and enforced (Richards, 1996 and Herlihy, 1997). The cultural zone as delineated in 1997 expanded the reserve to include a large portion of coastal savannah to the east.

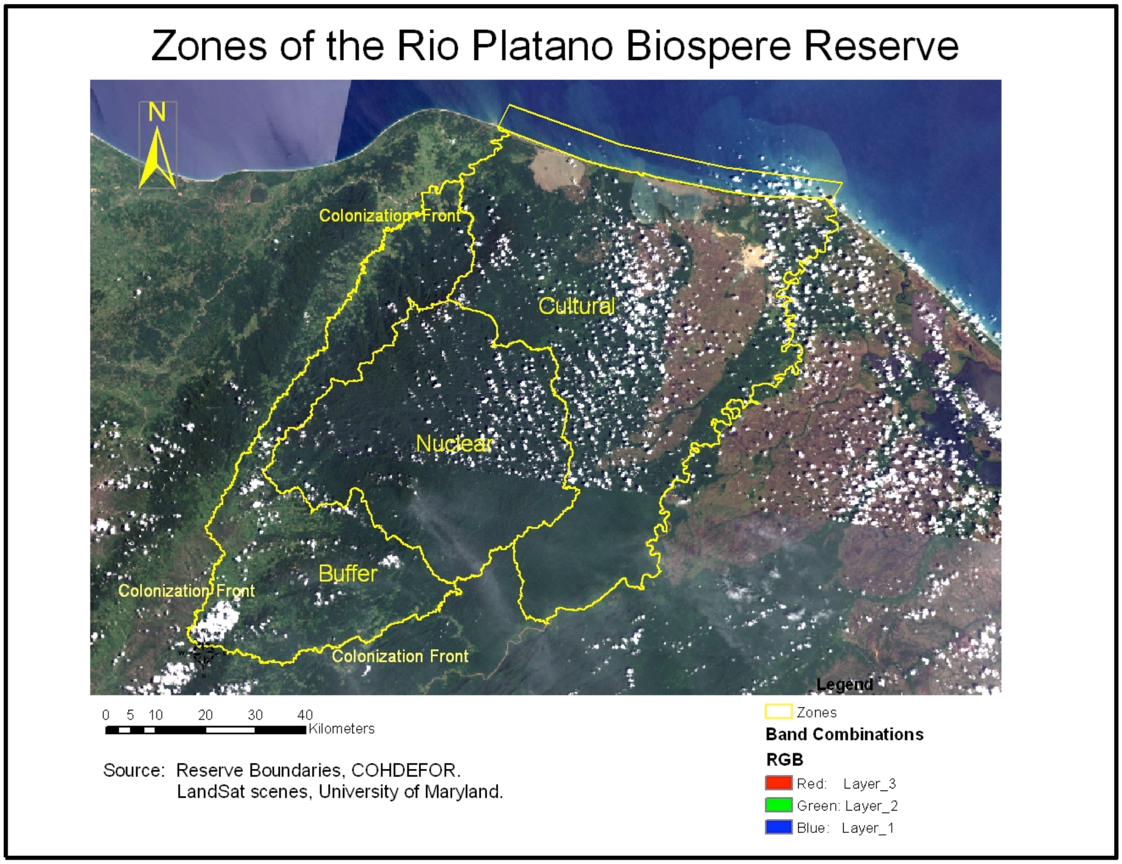

Figure 3: Zones of the Río Plátano Biosphere Reserve. Boundary Source: COHDEFOR. B1- Blue, B2 – Green, B3 – Red. Imagery: Landsat 7 ETM+ data from University of Maryland Global Land Cover Facility.

Forest preservation was the original impetus for the reserve's creation (Herlihy, 1997). The reserve generally protects the watershed of the Río Plátano, although several other rivers lie within or serve as the reserve's boundaries. The Río Paulaya and Río Sigre-Tinto form part of the northwest boundary, the Río Patuca part of the southeast boundary, and the Río Wampu part of the southern boundary. The elevation within the reserve ranges from approximately 1,300 meters to sea level (UNEP/WCMC, 2002). The headwaters of the Río Platano are found in the rugged mountains known as the Sierra Punta Piedra deep within the interior of the park. These mountains gradually give way to the coastal plain and two coastal lagoons, Laguna de Ibans and Laguna de Brus.

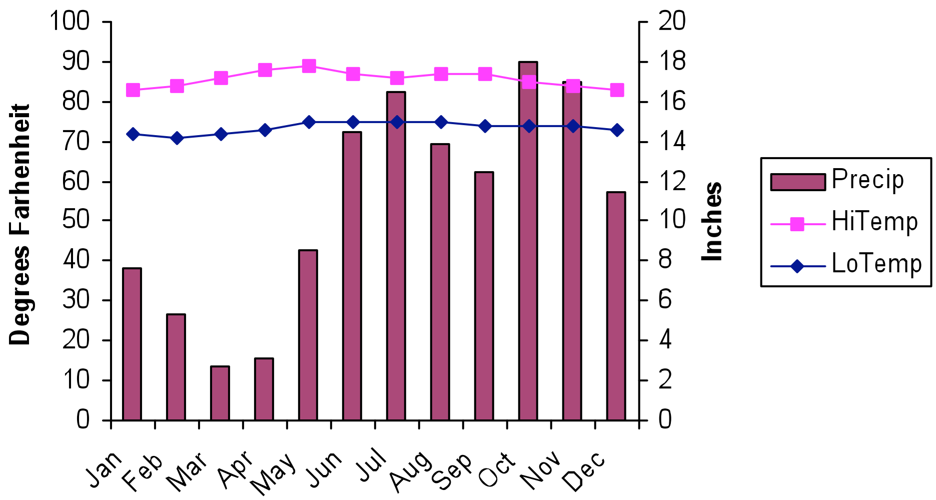

Figure 4. Climograph for Puerto Lempira on the Mosquito Coast. Source: weatherunderground.com.

The reserve receives over 120 inches of rain per year, with the dry season occurring from approximately January to June. Temperatures generally fluctuate between 70 and 90 degrees Fahrenheit (Figure 4).

It is estimated that half of all the ecosystems in Honduras can be found in the reserve (Padilla et al, 2003). These include freshwater and brackish mangroves, humid tropical forest and subtropical wet-forest and coastal savannah (UNEP/WCMC, 2002; Herlihy, 1997). Combined with two other Honduran protected areas, the Tawahka Asagni Biosphere Reserve and Patuca National

Park, and the Bosawas National Park in Nicaragua, the area represents the largest continuous moist tropical forest north of the Amazon (Padilla et al, 2003).

The rain forests of the Río Platano are classified as Broadleaf Evergreen Forest by COHDEFOR. The canopy can grow to 30-40 meters and is composed of species such as red cedar (*Cedrela odorata*), ceiba (*Ceiba pentanda*), brazilian beauty-leaf (*Calophylum brasiliense*), *ficus spp.*, pink trumpet-tree (*Tabebuia rosea*), and mahogany (*Swietenia macryphylla*; *caoba* in Spanish) (COHDEFOR, 2005; House, 1997; Dodds, 1998). Mahogany in particular has been a prized timber tree for centuries (Revels, 2003).

Soils of the majority of the reserve are classified as nitosols under the FAO soils classification system (CIAT, 2000). The FAO classification of nitosols corresponds to the USDA classification of yellow ultisols (OAS, 1987). Nitosol soils are found in the southwestern portion of the reserve, and are characterized by high clay content, high acidity and significant nutrient leaching due to heavy precipitation. This has implications for land use, as once the forest is cleared and the land cultivated, the soil is quickly depleted of nutrients (Harpstead and Hole, 1980). Most relevant to this study, nitosols are the most predominant soil type in the mestizo colonization fronts of the Río Plátano Biosphere Reserve. In the northeastern lowlands the predominant soil types are fluvisols and cambisols (alluvials and brown forest USDA classifications). These are the areas cultivated most extensively by the Miskito and Pech.

The richness in species diversity present in the reserve is considered by the Honduran government one of the primary reasons to preserve the natural habitat

(*Congreso Nacional de Honduras*, 1997). As many as 39 species of mammals, 377 species of birds and 126 species of reptiles and amphibians have been found in the reserve. Large forest mammals include the giant anteater (*Myrmecophaga tridactyla*), jaguar (*Felis onca*), ocelot (*F. pardalis*), puma (*F. concolor*), jaguarondi (*F. yaguaroundi*), while in the canopy one might encounter birds such as harpy eagle (*Harpia harpyia*), scarlet macaw (*Ara macao*), and green macaw (*A. ambigua*) (UNEP/WCMC, 2002; Richards, 1996). The American crocodile (*Crocodylus acutus*) and brown caiman (*Caiman crocodilus*) live in the waterways, and the coastal region is home to Caribbean manatee (*Trichechus manatus*), green turtle *(Chelonia mydas*), loggerhead turtle (*Caretta caretta*) and leatherback turtle (*Dermochelys coriacea*) (UNEP/WCMC, 2002; Richards, 1996). Many of these species are endangered and some, including American crocodile and green iguana (*Iguana iguana*), have been exploited by both mestizo and indigenous peoples for export (Richards, 1996). Although it is illegal to hunt turtles in Honduran waters, the eggs from turtles nesting on the beach are used in a traditional soup, and volunteer groups patrol the beaches to guard nests from May to August.

			Population			
Zone	Area (ha)*	Ethnic Group	1990	1995	2000	Land Use Restrictions
Nuclear	210,000	Ladino		384	568	No clearing, no new settlements.
Buffer	196,000	Pech	149	174	204	No new settlements.
		Ladino	6,763	8,228	10,011	Clearing only by COHDEFOR
			6,912	8,402	10,215	permission.
Cultural		Miskito	12,626	14,780	17,301	Sustainable Use, limited settlement.
	390,000	Ladino	188	229	278	
		Pech	240	281	329	
		Garifuna	445	521	610	
			13,499	15,811	18,518	
Maritime**	33,000					

Table 2: Area and population of the internal zones of the Río Plátano Biosphere Reserve.
Population Data from Herlihy, 1997 (some are estimates)
*Approximate Areas
** The Maritime zone is not included in the change detection analysis comparing internal zones.

As noted previously, an estimated 30,000 people live within boundaries of the reserve. Table 2 shows population estimates for each zone from 1990-2000.

The five primary crops of the Miskito, Pech, and Garífuna are cassava, bananas, rice, beans, and maize. The agricultural plots of these groups are often planted in riverine areas and around villages. The cultivation and fallow periods can vary widely, but two years cultivation before fallow is considered typical (Richards, 1996; House, 1997). As noted previously in the study by Dodds (1998), the Miskito population in particular is increasing rapidly and clears forest for agriculture. Although the Miskito clear primary growth forest, they prefer to clear secondary growth after a period of five years because it is less labor intensive (Dodds, 1998).

Figure 5: Pech men work on *pipantes* – or dugout canoes – along the banks of the Río Plátano. M.Wade, 2000.

Two features of physical geography distinguish the Río Plátano Biosphere Reserve from the many other protected areas of Honduras. One is that, at over 800,000 hectares, it is the largest protected area in Honduras. The second is that a majority of the reserve lies below 1,000 meters, unlike the many protected areas established by the 1987 law protecting all areas over 1,800 meters. Both its size and elevation have critical implications for access. An additional characteristic of the reserve is its low population density and the low population density of the surrounding area. This makes the reserve vulnerable to settlement pressures considering the country's relatively high rate of natural population increase of 2.5%, expected to result in a doubling of population by 2050 (PRB, 2007). As noted in the background section, the Honduras Corporation for Forestry Development (COHDEFOR) manages the reserve, although several indigenous groups, notably MOPAWI, are the principal proponents of establishing indigenous land rights. The reserve was placed on the List of World Heritage in Danger in 1996 due to pressure from encroaching timber and agricultural interests. The Honduran press, such as the newspapers *La Tribuna* and *El Heraldo*, regularly publish articles concerning illegal logging in the reserve.

In the case of the Río Plátano Biosphere Reserve, lack of governmental enforcement of immigration and logging restrictions resulted in the reserve being a “paper park” for much of the study period of 1985-87 to 2001-02. The lands were largely protected by the efforts of indigenous people to secure rights to their lands and resist colonization, most often without legal titles to their property and with unclear jurisdiction and unenforced laws, and during a period of both rapid population growth and a demographic shift of the mestizo population from the west to their eastern lands. What changes in forest cover resulted from the confluence of these forces in action? How effective was “reserve” status on limiting deforestation? Are there differences in the rates of deforestation between the zones under primarily indigenous habitation and those under colonist habitation? Satellite remotely sensed data of the reserve and surrounding area were used to address these questions.

4.2 The Physical Basis for Sensing Vegetation from Space

Satellite imagery is an effective tool for classifying land cover from space (Jensen, 2005; Nelson and Geoghhegan, 2002; Dodds, 1998). Land cover can be classified based on different surfaces’ spectral response curves plotted along wavelengths of the electromagnetic spectrum. Figure 6 illustrates examples of spectral response curves for healthy vegetation, unhealthy vegetation, and soil. Healthy vegetation in particular has a strong response in the Near Infrared (NIR) wavelengths, which correspond to band 4 of the Landsat TM and ETM+ sensors.

NASA launched Landsat 5 in March of 1984. Landsat 5 contains the Thematic Mapper (TM) instrument, which acquires data in 6 bands of electromagnetic wavelength ranges. All of the TM bands except band 6 ("thermal") have a resolution of 30 meters. In April 1999, NASA launched Landsat 7, which carried the Enhanced Thematic Mapper + (ETM+) instrument. The Enhanced Thematic Mapper has an additional band, band 7 or the panchromatic band, that acquires data at a 15 meter resolution (NASA).

Landsat Thematic Mapper and Enhanced Thematic Mapper + Characteristics

	Landsat TM		Landsat ETM+	
	Spectral Range (micrometers)	Pixel Size (meters)	Spectral Range (micrometers)	Pixel Size (meters)
Band 1	.45-.52	30	.45-.52	30
Band 2	.52-.60	30	.52-.60	30
Band 3	.63-.69	30	.63-.69	30
Band 4	.76-.90	30	.76-.90	30
Band 5	1.55-1.75	30	1.55-1.75	30
Band 6	10.4-12.5	120	10.4-12.5	120
Band 7	2.08-2.35	30	2.08-2.35	30
Band 8	None	None	.52-.90	15
Swath Width	185 km		185 km	
Repeat Cycle	16 days		16 days	

Table 3: Landsat Thematic Mapper and Enhanced Thematic Mapper+ Characteristics Source: NASA

Table 3 displays the spectral ranges of the bands and their pixel sizes for both the TM and ETM+ instruments.

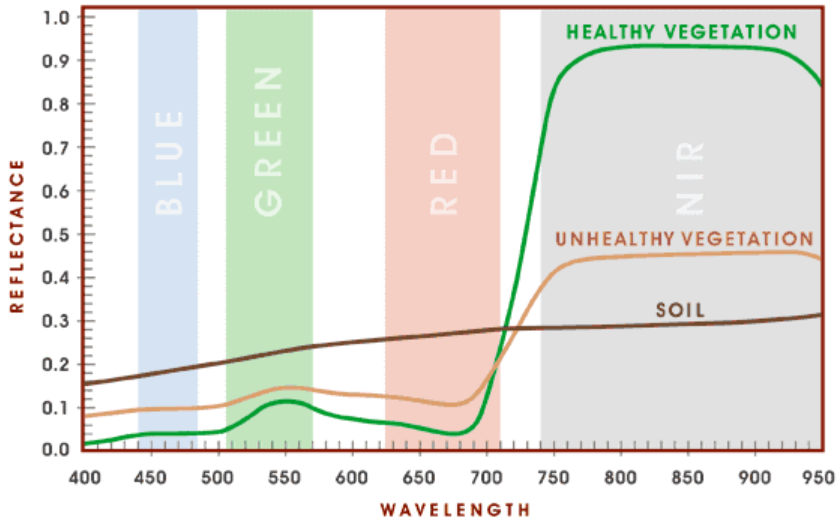

Figure 6: Example reflectance curves of healthy vegetation, unhealthy vegetation, and soil. Source: Utah State University/NASA Space Grant Extension Program.

Many studies have applied these principles to analyzing forest cover change throughout the world, including Guild, Cohen and Kauffman (2004), Nelson and Hellerstein (1997), and Nagendra, Southworth and Tucker (2003).

4.3 *Change detection:*

Several methods for change detection of forest cover have been discussed in previous studies (Nelson et al, 2002; Cropper et al, 2001). After first geometrically and atmospherically correcting the images for comparison, many of these studies use a vegetative index such as the Normalized Difference Vegetation Index (NDVI) to create discrete categories of land classifications. The NDVI is calculated as:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where Red is the intensity value of Landsat TM band 3 (0.63 to 0.69 micrometers) and NIR (near-infrared) corresponds to TM band 4 (0.76 to 0.90 micrometers). NDVI is used to estimate the amount of green biomass (Jensen, 2005). Change detection analysis can be conducted by setting threshold change values of the NDVI and comparing two time periods. In their studies in western Honduras, both Southworth et al. (2004) and Nagendra et al. (2004) found that using images from the end of the dry season will give sufficiently different NDVI values to distinguish agricultural fields from forests.

Two common techniques for using remotely sensed data for classification are supervised and unsupervised classification (Nelson and Geoghegan, 2002). In supervised classification, the user defines training areas of specific land cover classes with which the software then applies a maximum likelihood algorithm to match. The other method, unsupervised classification, is usually preferred when little is known about the land cover being analyzed (Jensen, 2005). It typically involves an ISODATA classification, which is a clustering technique for grouping pixels with similar reflectance values. This is accomplished by minimizing the squared distances between the pixel reflectance values and the cluster center (van Kemenade, et al., 1999). After the cluster analysis is complete, the user must identify each cluster as a land cover class. This is usually an iterative process in which the user may perform many cluster analyses to achieve a satisfactory classification.

When the classifications of both sets of images (time 1 and time 2) are complete, the change detection can be conducted comparing each pixel's land cover class in time one with its land cover class in time two, a process known as post classification comparison (Jensen, 2005).

4.4 Effectiveness of Protected Areas

Bruner et al. (2001) conducted a study of 93 protected areas in 22 tropical countries intended to test the hypothesis that parks are effective at protecting areas from deforestation and unauthorized uses. The results indicated that parks are effective – most effective in preventing forest clearing, but less so with preventing hunting and grazing. Nagendra et al. (2004) studied protected areas in Nepal and Honduras and concluded that, when compared to the surrounding area, protected areas are effective in preventing deforestation. Southworth et al. (2004) showed that Celaque National Park in Honduras experienced less deforestation than the surrounding region.

However, the Cropper et al. (2001) study in Thailand concluded that protected area status had no significant impact on forest clearing. One important reason for this conclusion stems from the methodology used – Cropper et al. did not simply compare regions within the protected areas with those outside the protected area. The study compared regions inside and outside the protected area that also were characterized by similar slope, elevation and other variables. This showed that, while protected areas experienced less deforestation than non-protected areas, this was because the protected areas were characterized by difficult access. Variables such as slope and elevation, not “protected area” status, explained the decreased deforestation.

4.5 Required Data

Four Landsat scenes are required to fully cover the geographical extent of the Río Plátano Biosphere Reserve for one time period. The first four scenes are Landsat (TM) images from 1985-1987. The second four scenes are Enhanced Thematic Mapper + (ETM+) scenes from 2001-2002. Images for anniversary dates were not available, and as a result the images for the 1985-87 time period correspond to the dry season, while most of the images for 2001-2002 correspond to the wet season. This introduces inaccuracy into the analysis because agricultural fields and pasture are more discernable from forest in the dry season than during the wet season. Because of this seasonal difference, non-forest classes such as agriculture or pasture are more likely to be misclassified as forest in the later (2001-2002) classification, which could result in overestimation of forest cover in the 2001-2002 classification.

Table 4 shows the orbital path and rows of the images along with the date of acquisition and the instrument used. Figure 7 shows the geographical extent of the scenes. These data were acquired from the University of Maryland Global Land Cover Facility.

	Cohort Time 1		Cohort Time 2	
Path/Row	Date	Instrument	Date	Instrument
16/49	1/1986	TM	3/2001	ETM+
16/50	1/1986	TM	10/2002	ETM+
17/49	2/1985	TM	7/2001	ETM+
17/50	1/1987	TM	7/2001	ETM+

Table 4: Orbital Path/Rows, acquisition dates, and remote sensing instruments for the Landsat data used in the analysis.

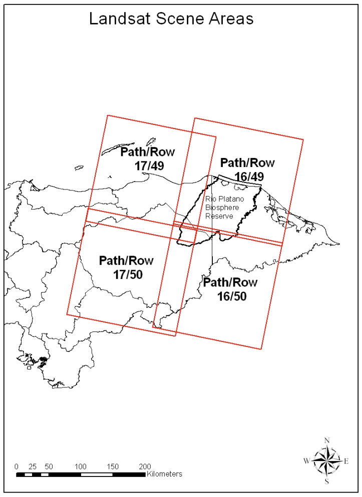

Figure 7: Geographical extent of the Landsat scenes.

In addition to the eight Landsat scenes, topographical maps produced by the Honduras Geographic Institute were obtained for geo-rectifying the Landsat scenes from Dr. Robert Ford (Loma Linda University). For use in the accuracy assessment of the land cover classification, high-resolution aerial photographs were purchased from the USGS. The aerial photos are at a scale of 1:42,000 and were acquired in December of 1998. GIS datasets of the Río Plátano Biosphere Reserve and its internal zone structure were acquired in ESRI shapefile format (ESRI, 2005) from the International Center for Tropical Agriculture (CIAT) and from COHDEFOR produced files provided by Dr. Tanya Hayes (Indiana University).

4.6 Data Processing

Erdas Imagine 8.7 was used to perform the data processing on the Landsat data. All Landsat scenes were georectified to the topographical maps produced by the Honduran Geographical Institute. The Landsat scenes were then subsetted to eliminate areas outside of the study region. The raw digital numbers of the Landsat scenes were converted to radiance values, which in turn were converted to at-sensor reflectance (Jensen, 2005). The atmospheric correction method of dark pixel subtraction was then performed to normalize measurements across the scenes (Chavez, 1998).

The scenes were mosaicked into a 1985-87 mosaic for the initial point in time for the change analysis, and a 2001-02 mosaic for the second point in time. Normalized Difference Vegetation Index was then calculated on the atmospherically corrected images and stacked as an additional layer to the data. The 2001-02 mosaicked image was then processed through ERDAS Imagine's unsupervised ISODATA classification, using bands 1,2,3,4,5,7 and NDVI, with 40 classes and a 95% convergence threshold. These classes were identified as water, forest, non-forest class 1, non-forest class 2, and cloud. Forest was defined as closed canopy forest. Non-forest class 1 was a land cover classification that corresponded most closely to that of tropical savannah (which covers a large portion of the northeastern portion of the cultural zone of the reserve), and bare soil. Non-forest class 2 corresponded closely with agriculture and pasture.

Cloud cover was a challenge with the classification. While the centers of the clouds were readily identified as a separate class during the classification process, the edges of clouds were often confused with other land classes and as a result misclassified. To resolve this, the pixels identified as clouds were extracted, and using ESRI ArcMap 9.1 a 5 pixel buffer was applied around the clouded areas. This was then applied as a mask to the classified image to exclude the buffered, cloud covered areas from the change detection analysis.

The accuracy assessment of the 2001-02 classification was conducted using the 1998 aerial photographs purchased from the USGS. While the time difference of three years introduces inaccuracy to the assessment, these were the only aerial photos of the study region available. A stratified random sample of ground control points was taken from the aerial photographs and compared to the classification result. Several iterations of the classification were performed to achieve an acceptable accuracy rate.

ESRI ArcMap 9.1 was used to perform the area calculations on the classified images, based on shapefiles of the biospheres boundary and internal zone structure. In addition, the biosphere’s western boundary, which has remained unchanged since the beginning of the study period, was buffered in order to compare the rate of forest cover change inside the boundary with the area outside the reserve. This allowed for the comparisons required to fulfill this study’s objectives.

5. **Results and Discussion**

5.1 Accuracy Assessment – Error Matrix

Table 5 shows the results of the error matrix of the 2001-2002 mosaic classification. The columns represent the number of ground control points for each land cover class in the aerial photographs acquired from the USGS. The rows represent the land cover classes as identified in the unsupervised ISODATA classification. The bold numbers in the diagonal indicate regions of agreement between the classification and the reference data (aerial photographs).

The overall accuracy of the classification was 86%, indicating that 86% of the classified pixels from the stratified random sample corresponded to the land classes identified from the aerial photographs. The Kappa statistic was calculated at 81%, a value that indicates strong agreement between the classification and the reference data (Jensen, 2005). The Kappa statistic gives a measure of agreement between the classification and the reference data taking into account chance agreement. Conditional Kappa statistics where calculated for each land class. This was done because exceptionally strong agreement in one class (such as water), will increase the Kappa statistic of the overall error matrix, but the remaining classes may show much less agreement. By calculating the conditional Kappa statistic for each class, the accuracies of individual land classes are clarified.

a)

Error Matrix of 2001-2002 Classification

	Reference Data				
Classification	Water	Non-forest 1	Non-forest 2	Forest	Total
Water	**174**	12	11	3	200
Non-forest 1	0	**154**	26	7	187
Non-forest 2	3	8	**174**	15	200
Forest	1	5	27	**224**	257
Total	178	179	238	249	**844**

Overall Accuracy = 726/844 = 86.0%
kappa statistic = 81%

b)

Producers Accuracy (omission error)

Water =	174/178 =	98%	2% omission error
Non-Forest 1 =	154/179 =	86%	14% omission error
Non-forest 2 =	174/238 =	73%	27% omission error
Forest =	224/249 =	90%	10% omission error

Users Accuracy (commision error)

Water =	174/200 =	87%	13% commision error
Non-Forest 1 =	154/187 =	82%	18% commision error
Non-forest 2 =	174/200 =	87%	13% commision error
Forest =	224/257 =	87%	13% commision error

c)

Conditional Kappa statistics for each land cover class

Water	84%
Non-forest 1	78%
Non-forest 2	82%
Forest	82%

Table 5: a) Error Matrix for the 2001-2002 classification, b) Producer’s and User’s accuracy, c) Conditional Kappa statistics for each land cover class.

Figure 8 shows the change detection map for the Río Plátano Biosphere Reserve and its surrounding area.

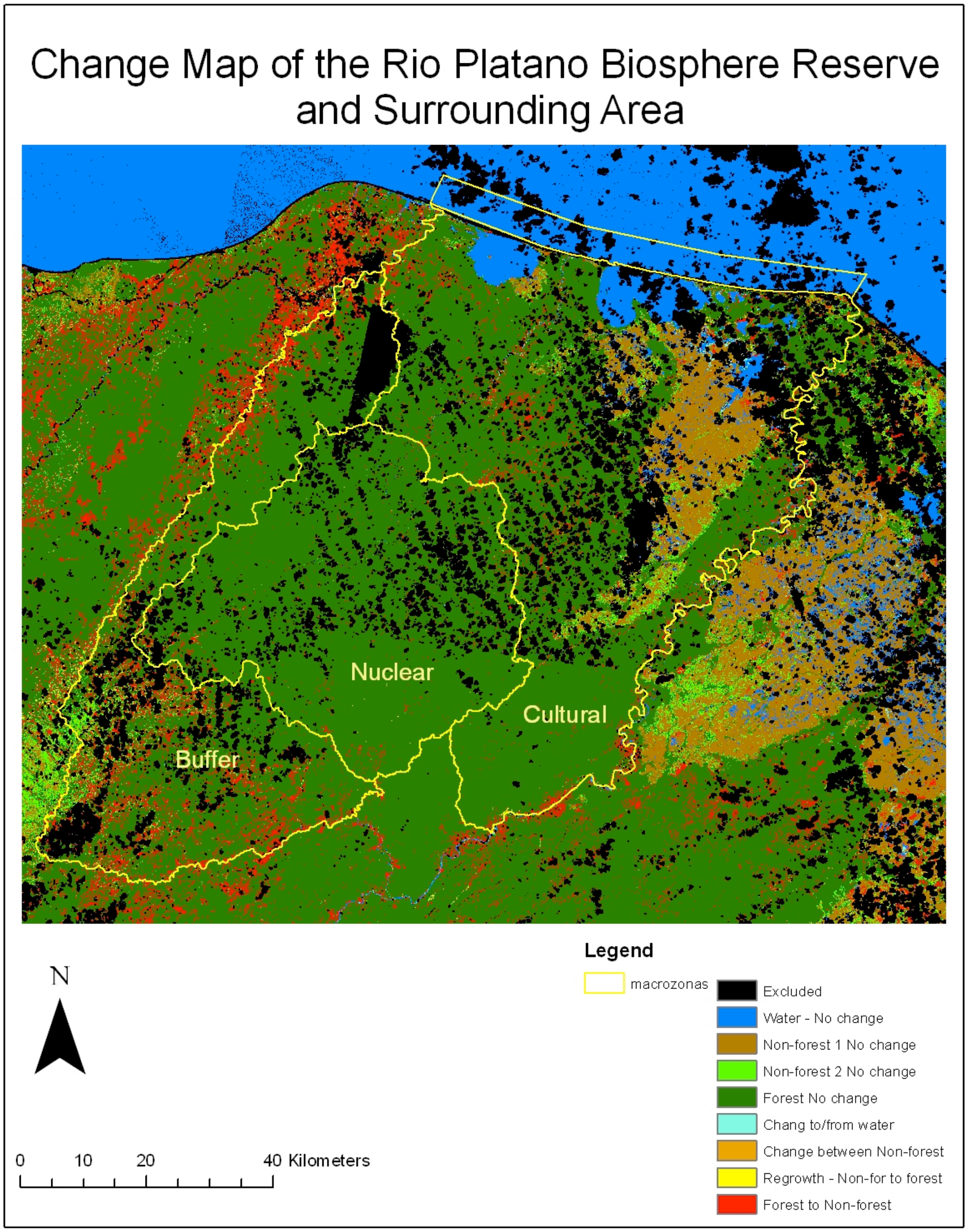

Figure 8: Change Detection Map of the Río Plátano Biosphere Reserve and Surrounding Area, 1985-87 to 2001-02.

5.2 Results for the Entire Reserve

All results, areas, and percentages given in the following summary are after the exclusion of cloud-covered areas. Because of the extent of the cloud cover, approximately 180,000 hectares or 22% of the reserve, it is impossible to determine from these data a more complete estimate of forest cover change. However, relative comparisons can be made between the three zones of the reserve, as well as with areas outside of the reserve.

Results from the change detection analysis indicate that over 38,000 hectares (380 km^2) of forest were cleared during the approximately 15 years between the two classification periods (forest area cleared - regrowth), representing 7% of the forested area of the reserve available for analysis after excluding cloud covered regions. The majority of the clearing occurred along the western border, as expected as this is the colonization front (Herlihy, 1997; Hayes, 2007).

	Area (ha)		
Class	1985-87	2001-02	% change
Water	44,463	44,517	0%
Non-Forest 1	43,049	50,910	18%
Non-Forest 2	14,594	44,257	203%
Forest	547,251	509,673	-7%
Total	649,357	649,357	0%

Table 6: Area (ha) for each of the land classes in the two time periods after excluding clouds. Non-forest 1 corresponds to savannah and bare soil, and Non-forest 2 corresponds to agriculture and pasture.

However, Table 6 gives no indication of what each land class changed to (i.e., forest to water, forest to non-forest class 1). One tool for analyzing change trajectories is the change detection matrix (Jensen, 2005). Table 7 shows the

"From-To" change detection matrix. The row labels represent what each hectare was classified as in the 1985-87 classification and the columns indicate the land cover class in the 2001-2002 classification.

From -To

Change Detection Matrix

Rio Platano Biosphere Reserve (cloud cover excluded)

Area (ha)		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
FROM (1985-87)	Water	43,730	409	120	204	44,463
	Non-Forest 1	405	41,979	597	68	43,049
	Non-Forest 2	173	402	13,059	961	14,594
	Forest	209	8,120	30,481	508,440	547,251
	Total	44,517	50,910	44,257	509,673	649,357

a)

Percent		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
FROM (1985-87)	Water	98%	1%	0%	0%	100%
	Non-Forest 1	1%	98%	1%	0%	100%
	Non-Forest 2	1%	3%	89%	7%	100%
	Forest	0%	1%	6%	93%	100%

b)

Color Key	Description
	Water -No change
	Non-Forest 1 - No change
	Non-Forest 2 - No change
	Forest - No change
	Change from or to Water class
	Change between Non-Forest classes
	Change from Non-Forest classes to Forest (regrowth)
	Change from Forest to Non-Forest 1 or 2

c)

Table 7: a) Change detection matrix, in hectares, for the Río Plátano Biosphere Reserve. b) Change detection matrix in percentage of the 1985-87 classification (should be read along rows). c) Color key. The cells are color coded to correspond to the change detection map legend from Figure 8.

Over the approximately 15 years between the two classifications, 7% of the forested area of the Río Plátano Biosphere reserve was cleared, with the majority of the cleared area corresponding to Non-Forest class 2, or agriculture/pasture. This may indicate a strong reason to question the effectiveness of the reserve. However, some measure of effectiveness can be understood by comparing this figure with national rate. The FAO estimates the rate of deforestation in Honduras during the 1990's as 1% a year (Table 1). With the reserve experiencing a 7% decline from 1985-87 to 2001-02, it experienced a lower rate of forest clearing than the nation as a whole. Furthermore, part of what is now considered protected was not part of the original boundary at the beginning of the study period. The following analysis attempts a more clear evaluation of the reserve's effectiveness at preventing deforestation.

5.3 Comparing Deforestation Inside and Outside the Reserve's Boundaries.

To evaluate the effectiveness of the boundaries and address the "paper park" question, a buffer was created covering 5 km outside the reserve's western boundary and 5 km inside the reserve's western boundary. The reserve's western boundary is delineated almost entirely by rivers, and the buffer was intended to at least partially account for accessibility factors such as slope and elevation. The rates of forest change between the 5 km buffer outside the reserve and the 5 km buffer directly inside the reserve were compared. The results of this analysis showed that 22% of the forested area was cleared during this time period in the 5 km buffer outside the reserve's western boundary, and 18% in the 5 km buffer directly inside the reserve's western boundary.

This suggests at least three possible phenomena. One, that the reserve boundaries were not effective during this time period in *halting* colonization, agricultural expansion, and logging in the reserve. Secondly, that the reserve boundaries may have been effective in *slowing* the colonization, agricultural expansion, and logging compared to areas directly outside the reserve. Finally, the rates of deforestation along the western boundary are greater than the rates found in any of the reserve's zones (buffer, cultural, and nuclear) themselves (see following section). Because rivers essentially delineate the boundary, this suggests, unsurprisingly, that land near rivers are attractive to colonists because of access, soil fertility, or other reasons, regardless of whether they are considered part of a protected area by the federal government.

5.4 Comparison of the Internal Zones of the Reserve

As noted previously, the zones of the reserve were drawn based on a participatory mapping project that included indigenous and mestizo community representatives. These zones then represent, regardless of "protected" status, areas under primarily indigenous habitation and land use management and mestizo habitation and land use management. One of the objectives of this analysis was to compare the rates of deforestation between the zones.

Appendices B and C contain the change detection matrices for the nuclear, buffer, and cultural zones. Figures 9 a) and show the area (ha) and b) percentage of forest cleared for each of these zones.

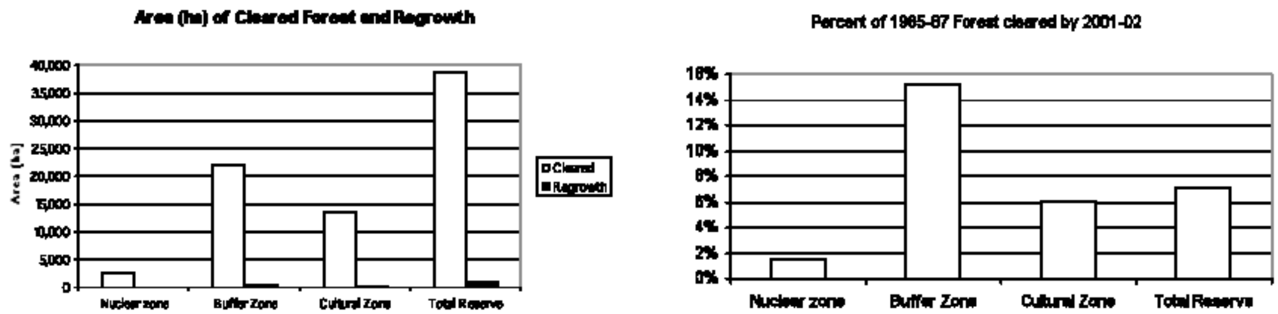

Figure 9: a) Area (ha) of cleared forest and regrowth by zone. b) Percent of forest cleared over the study period.

Several findings are notable from these data. First, the buffer zone, identified as primarily mestizo dominated, experienced over 14% deforestation in this time period. This is near the 1% annual rate the FAO estimates for the country of Honduras as a whole for the 1990's. This may indicate that the buffer zone has experienced a rate of forest clearing at or near the national rate.

Second, the cultural zone, identified as primarily indigenous-inhabited, experienced 6% deforestation. While this is less than half the rate seen in the buffer zone, it is difficult to ascertain any causal relationship from these data. Land use practices in these zones differ, but so too does population. Holding growth rates constant from estimates of population increase in the zones between 1990-2000 from Herlihy (1997), the population in the buffer zone would have increased by approximately 4,700 and the cultural zone by 7,000 between 1985 and 2000. This would indicate a rate of clearing of 4.7 hectares per capita increase in population in the buffer zone compared with 1.9 ha per capita in the cultural zone. A cautionary note about these figures is in order. The results of this study's analysis suggest simply that there are differences in deforestation between the zones. The population statistics are given only as an indication that the rates of deforestation may be different between the zones after controlling for population changes, and are meant to suggest a hypothesis derived from the observations of this study, not as results from the study. Without census data at a sub-municipal level and virtually cloud free imagery (clouds covered 22% of the area in this study), it is impossible to compare the incremental land cover change with corresponding changes in population in a more meaningful way. Furthermore, without detailed cadastral maps it is not possible to show there was a difference in forest clearing on lands given clear titles and those without.

Finally, the nuclear zone has experienced approximately 1% forest cover change, which is the least of the zones and much less than the national average. This would indicate that the buffer and cultural zones may have been effective in limiting deforestation in the nuclear zone. However, the deforestation that occurred in both the buffer and cultural zones points to future threats to the nuclear zone.

6. CONCLUSIONS AND FUTURE RESEARCH

Deforestation has occurred in all three of the zones of the Río Plátano Biosphere Reserve. While the western boundary of the reserve, identified in the early 1990's as the colonization front, has not stopped colonization, it may have been effective in slowing it. Between the study period of 1985-87 to 2001-02, the buffer zone experienced 14% deforestation, the cultural zone 6%, and the nuclear zone 1%, after excluding cloud covered areas. The rate of deforestation in the buffer zone indicates that enforcement has not been effective and that more colonization pressure will reach the nuclear zone as the buffer zone continues to be cleared.

These results highlight the need for enforcement and oversight resources to be put into place in the Río Plátano Biosphere Reserve, as well as continuing work to establish clear property rights for the reserve's inhabitants. Indigenous groups, such as MOPAWI, are working with the state forestry service, COHDEFOR, and the German Development Bank (KFW) to strengthen the institutions protecting the reserve. Since the creation of protected areas under the management of the federal government superseded the institutional decentralization of forest management in the 1990's, policy makers should consider ways to decentralize the management of the reserve by establishing clear property rights, both individual and communal, for the indigenous inhabitants.

There are several areas in which to pursue further research. First, satellite imagery from additional dates would strengthen and clarify the findings. Scenes from additional dates would increase the cloud free area for analysis and add a finer temporal resolution, allowing for a clearer picture of how different management decisions have affected the park, such as the expansion of the cultural zone in 1997. Additional and more recent data would provide not only a more updated analysis but also a trend, indicating whether encroachment into the reserve is increasing, decreasing, or has leveled at a constant rate.

A second area to pursue is an analysis of access, following the Cropper et al. (2001) model, which would incorporate more real-world complexity into the study. This should include variables such as distance to roads, population centers, and rivers, elevation and slope data, as well as sub-municipal census data to understand how population affects deforestation at a detailed scale. This would help isolate the actual effectiveness of the reserve's boundaries, identify causal factors of deforestation, and give insight to the development of land use planning strategies.

Third, incorporating an analysis of government policies and land tenure rights into the future research outlined above would provide a critical link between remote sensing and GIS analytical results and policy. The work of Hayes (2007) on land tenure in and near the reserve would be a valuable complement to a detailed remote sensing analysis. As organizations such as MOPAWI work to strengthen indigenous property rights, the impact of this on land cover change should be monitored over time.

The citizens of Honduras are both proud and aware of the importance of the ecosystems that make up their territory. For many years they have struggled to protect their natural resources with limited economic and institutional foundations to do so. More thoroughly integrating the indigenous inhabitants of the reserve in its management will create additional forces to control deforestation besides the limited, and often ineffective, resources of the federal government. While remote sensing techniques can be powerful tools to identify and quantify the extent of land change, as well as provide the basis for spatial analysis, these techniques cannot provide policy solutions. As Tucker and Southworth (2005) point out, any solution to issues of illegal deforestation will need to be based on an interdisciplinary approach. The efforts of geographers, economists, ecologists, policy-makers, and the local populace must be combined to create a comprehensive understanding of the issue that is greater than its disciplinary components. Furthermore, any lasting solution will likely be built upon the respect and empowerment of those people who have historically stewarded the lands the world now sees so important to protect.

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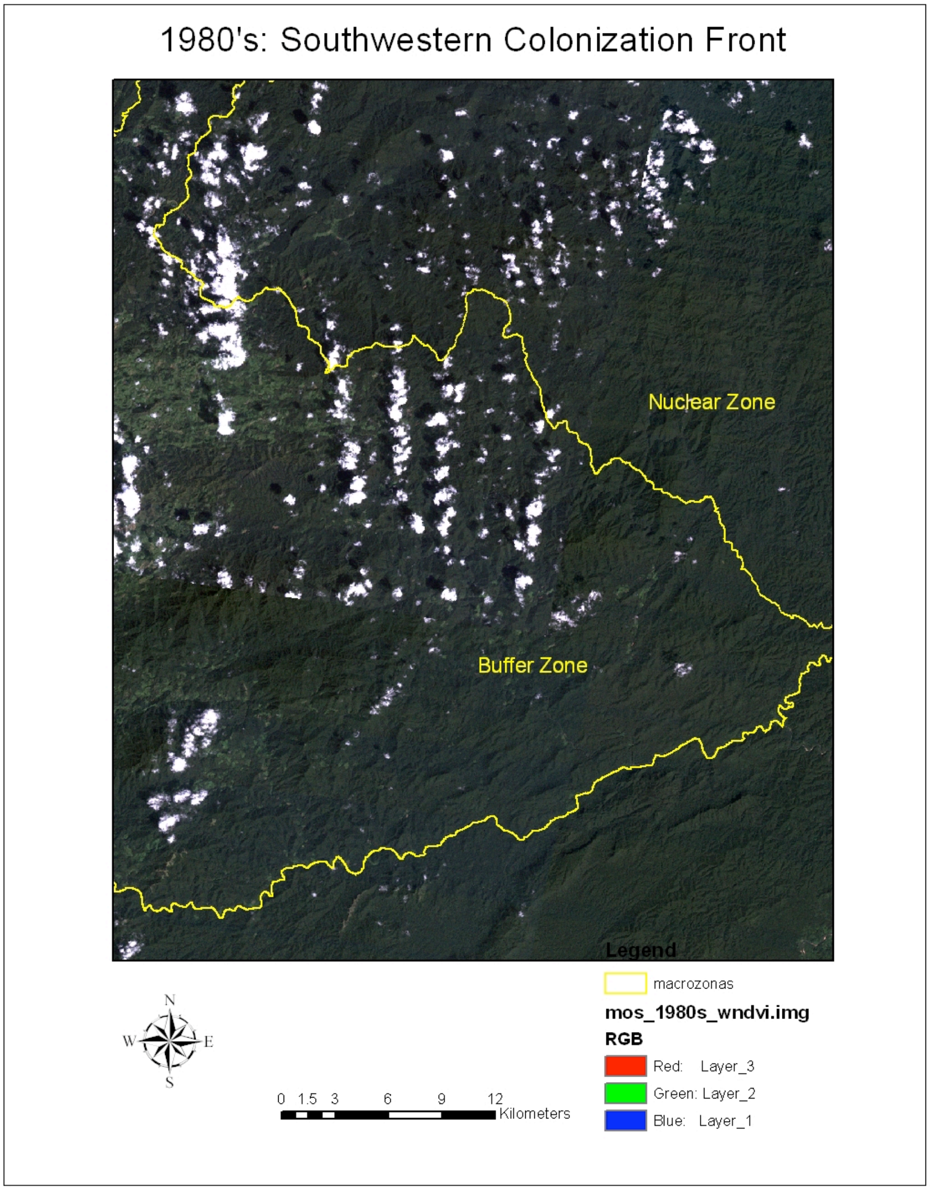
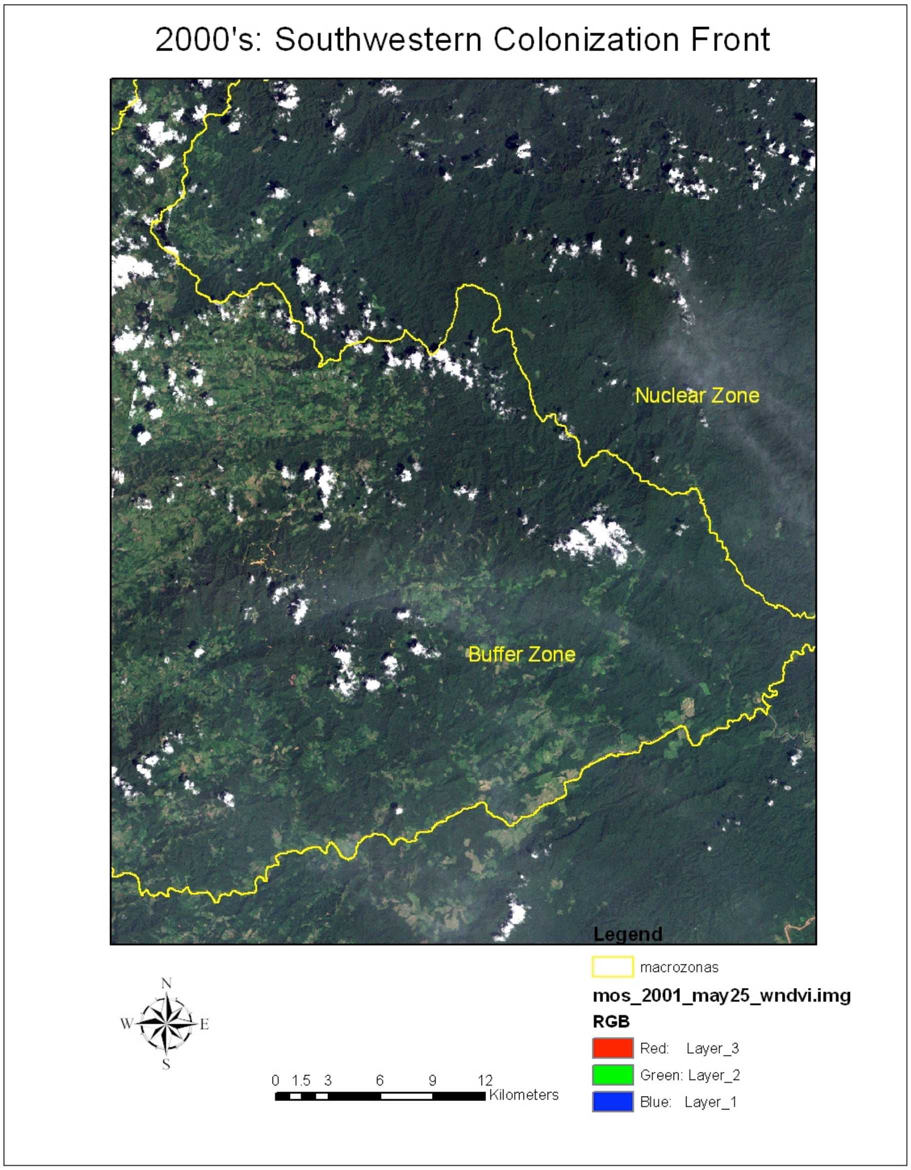


Appendix A 1): Larger scale view of a portion of the colonization region from the Landsat TM 1985-87 mosaic.



Appendix A 2): Larger scale view of a portion of the colonization region from the Landsat TM 2001-2002 mosaic.

From -To

Change Detection Matrix

Nuclear Zone (cloud cover excluded)

Area (ha)

		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
	Water	50	0	2	11	63
	Non-Forest 1	1	22	19	10	52
FROM	Non-Forest 2	1	4	127	63	196
(1985-87)	Forest	30	410	2,271	171,706	174,416
	Total	81	436	2,419	171,790	174,727

a)

Percent

		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
	Water	79%	1%	3%	18%	100%
FROM	Non-Forest 1	1%	42%	37%	20%	100%
(1985-87)	Non-Forest 2	1%	2%	65%	32%	100%
	Forest	0%	0%	1%	98%	100%

b)

Color Key	Description
(blue)	Water -No change
(brown)	Non-Forest 1 - No change
(bright green)	Non-Forest 2 - No change
(dark green)	Forest - No change
(light cyan)	Change from or to Water class
(orange)	Change between Non-Forest classes
(yellow)	Change from Non-Forest classes to Forest (regrowth)
(red)	Change from Forest to Non-Forest 1 or 2

c)

Appendix B: Change detection matrix of the nuclear zone.

From -To

Change Detection Matrix

Buffer Zone (clouds excluded)

a)

Area (ha)		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
FROM (1985-87)	Water	96	6	15	34	151
	Non-Forest 1	14	993	274	31	1,312
	Non-Forest 2	16	286	4,437	573	5,312
	Forest	36	5,139	17,028	123,404	145,607
	Total	162	6,424	21,754	124,042	152,382

b)

Percent		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
FROM (1985-87)	Water	64%	4%	10%	23%	100%
	Non-Forest 1	1%	76%	21%	2%	100%
	Non-Forest 2	0%	5%	84%	11%	100%
	Forest	0%	4%	12%	85%	100%

c)

Color Key	Description
(blue)	Water -No change
(brown)	Non-Forest 1 - No change
(bright green)	Non-Forest 2 - No change
(dark green)	Forest - No change
(light cyan)	Change from or to Water class
(orange)	Change between Non-Forest classes
(yellow)	Change from Non-Forest classes to Forest (regrowth)
(red)	Change from Forest to Non-Forest 1 or 2

Appendix C: Change detection matrix of the buffer zone.

From -To

Change Detection Matrix

Cultural Zone

Area (ha)

		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
	Water	21,032	401	104	154	21,691
	Non-Forest 1	392	40,963	304	28	41,687
FROM	Non-Forest 2	155	112	8,496	326	9,089
(1985-87)	Forest	144	2,573	11,197	213,435	227,350
	Total	21,723	44,049	20,102	213,943	299,816

a)

Percent

		TO 2001-02				
	Class	Water	Non-Forest 1	Non-Forest 2	Forest	Total
	Water	97%	2%	0%	1%	100%
FROM	Non-Forest 1	1%	98%	1%	0%	100%
(1985-87)	Non-Forest 2	2%	1%	93%	4%	100%
	Forest	0%	1%	5%	94%	100%

b)

Color Key	Description
(blue)	Water -No change
(brown)	Non-Forest 1 - No change
(bright green)	Non-Forest 2 - No change
(dark green)	Forest - No change
(light cyan)	Change from or to Water class
(orange)	Change between Non-Forest classes
(yellow)	Change from Non-Forest classes to Forest (regrowth)
(red)	Change from Forest to Non-Forest 1 or 2

c)

Appendix D: Change detection matrix of the cultural zone.