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Deforestation and Land-Use Change in Veracruz, Mexico: A Remote Sensing Analysis

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ABSTRACT

The purpose of this study was to analyze deforestation using multi spectral satellite imagery in a region of Veracruz and Puebla Mexico. A smaller study area in a subtropical region in Veracruz was used to relate changes in forest cover to changes in land-uses within the smaller region. A land-use classification was created for this study that includes fallow/barren, subsistence agriculture, sugar cane, urban/settlement, grazing lands and other vegetation. A change detection was performed to analyze the extent of each land-use encroaching into forests between 1979 and 2002. Another objective of the study is to examine the seasonal variation of forest growth in the study area and how this variation may affect the utility of remote-sensing technology in tracking deforestation. The study area experienced considerable forest change between 1979 and 2002. It appears that land-use change in the region is being driven by socio-economic factors that relate to forest degradation.

CHAPTER 1

INTRODUCTION

Deforestation and loss of vegetative biomass in Mexico has become a problem of major concern that is affecting social, economical and environmental stability. Indeed, much of Latin American forest frontiers have become subject to anthropogenic stresses that relate to land-use expansion into forest ecosystems. Remaining forests are being threatened by land-use expansion. The consequence of this large-scale human encroachment has been linked to ecological degradation and social instability.

On a global scale, “Human populations quickly see the negative effects of deforestation in the form of higher rates of evapotransporation, contaminated water supplies, disease and poor soil quality” (Sader, et al. 1994*,* 24). The total loss of vegetative biomass related to the function of the carbon cycle may have wide-scale global effects on climate. The impacts from conversion of much of the world’s forests resources on the global warming trend over the past 60 years have yet to be fully understood.

In addition, depletion of vegetative resources is associated with erosion, soil degradation, and water quality. These more localized consequences of forest loss on environments not only affect the immediate ecosystems but also have direct consequences on local human populations. Throughout much of the world’s tropics, economic activities are closely related to actions that extract immediate useable environmental resources. For example, the success and profitability of agricultural practices are directly dependent on soil sustainability and water resources. However the clearing of vegetation for the expansion of agricultural and grazing practices can have negative effects on the very resources that are needed to sustain these practices. Tropical

deforestation has been linked to large scale soil degradation in Asia, Africa and Latin America, thus causing agriculturalists to further expand into forest frontiers to maximize crop production (Ochoa-Gaona 2001).

In Latin America many of the tropical soils are classified as andisol soils and retain a very thin A horizon which can become leached as a result of high precipitation and forest clearing for extensive agricultural practices. In such environments, where forests provide the support system and symbiosis of mineral and nutrient cycling that stabilizes tropical soils, agriculture cannot be supported extensively for prolonged periods of time after forests are cleared (Malingreau and Tucker 1988). For example slash and burn agriculture, which has been practiced since the introduction of agriculture in Pre-Colombia America, returns nutrients to soils allowing for the ability to grow crops for a period of time before soils become exhausted. In its traditional form, slash and burn agriculture, where farmers can relocate and thus allow forests to re-grow while a new area is cleared for agriculture, can be a sustainable method of forest management. However when forest clearing exceeds the rate at which forest re-growth can occur, this activity can become unsustainable and forest degradation is inevitable (Ochoa-Gaona 2001).

As socio-economic variables pressure people to encroach into forest frontiers (Deininger and Minten 2002; Scrieciu 2004), tropical soils cannot support intensive land use activities and thus soils can become leeched and eroded. In some cases this leads to a stronger incentive to clear more forests to take advantages of short-term soil productivity that translates into short-term cash crops.

It has been argued that many land tenure systems have encouraged agriculturalists to expand into forest frontiers. In some cases in Latin America rent-tenure systems encourage

agriculturalists to maximize production by giving subsidy incentives to convert forests into "productive" lands or by giving property rights to colonists by clearing lands for agricultural purposes (Southgate 1990). In other cases where small-scale landholders cannot compete in economies that favor crop specific products, they are forced to maximize production to compete in the local and international markets, many times at the expense of natural resources.

Another trend associated with land-use change throughout Latin America and in general the Third World is rural migration into urban centers as a result of agriculturalists not being able to maximize production to meet economic demands (Aide, et al. 2004). These urban landscapes are impacted and are strained to provide for the displacement of human migration from rural regions. Forest re-growth may occur in areas where farmers abandoned their lands (Klooster 2003 b). However, urban development in third world centers have been linked to forest degradation where rural to urban migration can cause urban areas and settlement regions to expand into non-urban landscapes (Barbieri and Carr 2005).

Deforestation in Mexico

Mexico's long history of land-use change and land-tenure policies makes this nation a unique case in the phenomenon of deforestation. Pre-Hispanic cultures had been shaping and impacting natural forest ecology for centuries. After Spanish colonization, lowland regions were converted into grazing lands. By the early 20th century the impact of Mexico's rural population on the country's forest frontiers was clearly evident. Growing rural populations have been shaping forest ecology to such an extent that it is estimated that 60-80 percent of the original native forests have been depleted or transformed. Though estimates vary, some research argues that Mexico has among the highest rates of deforestation when compared to other Latin

American countries (Cairnes, et al. 2001). Much of the research conducted at the national level has documented deforestation at over 1.9 percent per year (Cairnes, et al. 2001).

Even forests that remain intact have been affected by the long history of anthropomorphic activities that have transformed the ecology and species variation of the present forests. For example the savannah forest that exists on the lowland plain along the Gulf of Mexico has been transformed as result of long term grazing activities. Compared to nearby countries such as Guatemala, Honduras, and Nicaragua where rural frontiers were largely inaccessible, Mexico had impacted extensive forest resources early in its history (Goman and Byrne 1998).

Political, economic and social variables have distinguished Mexico's land-use history from other Latin American countries (Klooster 2003 a). In particular the Ejido system in which the majority of rural lands exist through a system of community ownership sets this country apart from other Latin American cases. In contrast to other Latin American systems of land tenure, these lands are neither privately owned nor are they under the complete control and management of federal or state authorities. Management policies concerning forests therefore are ambiguous and resource management has had a long history of policy change that has been influenced by economic and political factors. Consequently, the ways in which socio-economic variables are largely played out are particular to Mexico, and its distinctive policy history (Klooster 2003 a).

Therefore, deforestation in Mexico reflects a complex web of ecological and socioeconomic factors, many of which take on regional components depending on the local ecological setting, land tenure practices, and market conditions. With these regional factors in mind, the analysis that follows will focus on a specific region located in Veracruz, Mexico.

The study area is considered to be an important region for forest and water resources (Zamora and Castillo-Campos 1997). The Sierra Madre plateau is a water recharge region and

supplies the large coastal plain with irrigation for extensive agricultural practices (Marten and Sancholuz 1982). Water resources that flow from the upland zone and down through the dryer lowland region are also essential for overall ecosystem health of the savanna environment. Sedimentation of water bodies and soil erosion has been attributed to forest degradation. This humid region of the state of Veracruz retains some of Mexico's last intact humid forests.

Because of the region's high topographical relief and high amounts of rain in the wet season, the existence of wooded vegetation is crucial in the health and survival of the natural watershed. Soils in the study area, being of fine grained volcanic materials, are easily eroded and washed down slope into rivers.

Deforestation in the study area has been attributed to continuing problems associated with degradation of soils and water resources. Continuing pressures to convert forests into anthropomorphic land-uses activities threaten the valuable natural resources that exist in the region.

Purpose and Objectives

The purpose of this study is to use remote-sensing technology to examine the nature and extent of deforestation in a region of Veracruz, and to relate this forest loss to particular types of land-use activities. With this purpose in mind, specific objectives include: 1) to measure the extent to which deforestation has occurred in the study area; 2) to examine the seasonal variation of forest growth (leaf greenness) in the study area and how this variation may effect the utility of remote-sensing technology in tracking deforestation; and 3) to relate changes in forest cover to changes in land-uses within the smaller study area.

The information relating to land-use change in forested regions in the study area is critical for further research concerning economic and land-tenure variables that are related to

deforestation. The creation of a land-use study maps showing which land-uses have encroached into previously forested regions will provide valuable knowledge on deforestation for the subtropical region of Veracruz Mexico. In addition, this study will examine whether seasonal variation of deciduous forests affects the ability to track and analyze forest change in the study area. Understanding natural seasonal variation, as it pertains to forests, is vital for additional deforestation research that attempts to relate anthropomorphic activities to forest degradation.

The deforestation and land-use analysis will be accomplished in two steps: first, forest change will be quantified using a relatively large study area in Veracruz and Puebla Mexico, and overall deforestation will be analyzed; and second, land-use encroachment into forest resources will be identified through intensive study of a smaller section of the study area. Before proceeding with this analysis, however, it will be helpful to examine in greater detail the historical and policy contexts of deforestation in Mexico as a way of giving greater meaning to the analysis that follows. In addition, since land-cover and land-use changes will be described using remote sensing technology, it is necessary to review briefly how this technology is used in the analysis of deforestation and land-use change, and how it will be adapted to this research.

CHAPTER 2

DEFORESTATION AND LAND-USE CHANGE IN MEXICO, AND ITS MEASUREMENT

In terms of total percent loss of primary forest in the American tropics, Mexico has one of the highest rates of deforestation in Latin America. Because of the more fragmented nature of Mexican forest ecology (Rudel and Roper 1997), the concern of preserving primary and intact forests is of high priority. It has been documented that in tropical regions of Mexico, the rate of deforestation is approximately 559,000 ha/yr (Cairns et al 2001). On a national scale most research has shown over one percent per year of deforestation. However, when analyzing deforestation at regional and state levels, deforestation varies depending on climatic/ecological and land-use variables. For example tropical regions may have a higher rate of forest clearing than temperate or arid zones (Klooster 2003 b).

Large tracts of tropical forest once flourished in the states of Veracruz, Chiapas, Oaxaca and Yucatan. However, extensive deforestation has occurred over the past century as a result of encroachment from agriculture and ranching (Cairns, et al. 2001). These deforested lands have been transformed into agricultural and settlement regions. Only highly fragmented and small patches account for the majority of Mexico's tropical forests (Cairnes, et al. 2001). Along the eastern slope of the Sierra Madre in Veracruz, and tropical regions of Chiapas and Oaxaca, much of the tropical-humid and mountain forests that once covered these regions have been impacted by anthropomorphic activities. (Cairnes, et al. 2001; Gonzalez-Montagut 1999; Ochoa-Gaona 2001).

This long history of land-use change in Mexico has greatly influenced forest sustainability. This unique history is related to land-tenure systems and forest management policies (Klooster 2003 a). To understand the state and nature of land-use expansion as it relates to forest resources, a historic perspective of forest management is necessary.

A Historical Perspective: Mexican Land-Use Change and Forest Management, Nineteenth Century to the Present

Early Nineteenth Century to 1940: Land Redistribution and the Ejido

Nearly 80 percent of Mexico's forests exist within community owned Ejido lands (Bray, et al. 2003). This unique land tenure system sets Mexico apart from all other Latin American countries. The origins of the Ejido system can be traced to the nineteenth century when community lands were distributed to land survey companies under the Porfirio Diaz government. Nearly 90 percent of communally owned lands were transferred to private ownership (Klooster 2003 a). This land-transfer program led to a peasant struggle that ultimately resulted in the Mexican revolution, and to the post-revolution Ejido system of land redistribution back to peasant communities. Indeed, under the Ejido system much of the country's agricultural land came under communal ownership. During the presidency of Lazaro Cardenas, from 1934 to 1940, nearly 18 million hectares of private or state owned lands were placed in the Ejido system. By 1940 nearly 47 percent of the country's agriculture lands were communally owned. (Klooster 2003 a).

During this period of post revolutionary land reform, the forest policies that were enforced allowed professionals (logging companies, large-scale cattle ranchers) to have access to

forest resources on a for-profit basis (Gonzalez-Montagut 1999). Forest conservation became more of a concern as deforestation was recognized as being the result of problems related to water quality, soil degradation, and agricultural production. In 1926, Miguel Angel de Quevedo founded the Mexican forest service, which for the first time included environmental protection polices. Also during this time awareness was raised in the importance of education in conservation and forestry, which led to the establishment of forestry and agronomy schools. The focus of protecting forests was directed at the rural population whom Quevedo saw as a threat to Mexican forest resources (Klooster 2003 a). Therefore even though many of the forested lands were populated by peasants within the communal Ejdio system, they were excluded in the actual decision making, and were viewed as not having the education and capability to properly manage forest resources. Klooster explains that by this time

> the basic dilemma of Mexican forest policy was already established; on one side, a private logging sector with increasingly tenuous access to forest resources, on the other side, an excluded rural population with expanding rates of forest ownership, but few forest management skills and fewer financial resources (Kooster 2003 a,101).

After the Cardenas administration left power, distribution of Ejido lands declined and emphasis shifted toward giving access of resources to large scale land owners and companies for building dams and creating projects that were designed to modernize the country. Land use policies were established to allow private companies to profit from Ejido lands (Klooster 2003 a). Large-scale cattle ranchers, logging companies and commercial agriculturalists were allowed to use communal lands under the "rentista" system, where rents were to be paid to peasant communities for the use of communal lands for the purpose of financial profit. Typically, the contractor received substantial profits and in return was only required to pay a

small percentage of wage labor. This system allowed for legitimized extraction of resources for profit on community lands (Klooster 2003 a).

1940-1960: The Beginnings of Mexican Protectionism

During the 1940s and 1950s, the land-rent tenure mechanism allowed for the certification of commercial land owners to expand their land-uses within community owned lands. Cattle ranchers and loggers were legitimized as forest professionals, thus having official authority to expand their operations into forested frontiers with few or no restrictions (Gonzalez-Montagut 1999).

Land privatization became legitimized and land owners were able to acquire new deeds to clear forests to create plantations or grazing lands. Land owners could convert forests without having to pay for the labor. This was accomplished through a land-tenure system in which peasant farmers were allowed to farm on private plantations in return for the use of grazing areas (Gonzalez-Montagut 1999).

During the 1950s the focus now changed to larger scale projects within communally owned lands and government controlled frontiers that put engineers in charge of managing forest and other environmental resources such as hydrology. Dam projects were initiated and peasant communities were relocated to help modernize Mexico to deal with the growing environmental and social problems that plagued the rural regions.

At the same time there was for the first time an environmental protectionist attitude which led to forest clearing regulations and logging bans in nearly one-third of Mexico's forests (Klooster 2003 a). However the bans and regulatory control were directed towards campesino farmers, and much of the blame for deforestation was placed on subsistence farmers living

within Ejido lands. As Klooster explains "From the 1940s on, Mexican presidents chastised campesinos for slashing, burning, woodcutting and thus causing erosion and siltation of the developing nation's new dams and ambitious irrigation and hydroelectric projects" (Klooster 2003 a, 102).

The observable effects of deforestation and environmental destruction, which were seen as problems by the 1960s, led to Mexican protectionism of forest resources. Policies focused on restrictions and regulations on the subsistence farmer, who was seen as being an obstacle to the modernization of resource management (Clawson and Hoy 1979; Klooster 2003 a).

Land-use expansion continued and deforestation accelerated during this time where permits were given to companies and organizations for the extraction of forest resources or to convert forested frontiers into productive lands. These forest "professionals" were given control over forest resources, and deforestation that occurred was legitimized through newly formed policies that handed out permits to plantation owners, private logging firms and agriculture companies.

This policy led to a mistrust of the forest regulators by small scale subsistence farmers and the lack of involvement of Ejido communities in the overall protectionist effort led to piecemeal forest management and a division between peasant communities and the legitimized "forest professionals" (Klooster 2003 a). This lack of comprehensive forest management led to high rates of deforestation in much of Mexico's last remaining forests during this period.

1960-1980: Rural Development and Credits to Campesinos

Throughout the 1960s the emphasis in rural development policy was on modernization of rural regions. This emphasis flowed from the realization that peasant communities lacked

available resources and technologies for maximizing crop production, new developments in modernizing Mexico's rural regions became the emphasis for rural development. Like the modernization efforts in the previous decade technological and infrastructure implementation was emphasized; however now the focus was to include the peasant farmer to a much greater degree. It was theorized that more conventional and modern methods of agriculture and cattle ranching would maximize production thus relieving poverty and alleviating strain on natural resources (Clawson and Hoy 1979). The thinking was that if production on the farm could be maximized then there would be less necessity to expand land uses into forest resources.

During the 1970s, efforts to maximize production of rural farmers put emphasis on introducing hybrid crops in rural regions to replace natural varieties, and modern technology to replacae more conventional farming methods (Clawson and Hoy 1979).

In Mexico seed banks for specific crops were promoted to small scale farmers. Specific species of seeds were included in a package that encouraged farmers to buy into the programs through a credit system, where those who bought into the programs were guaranteed higher profits in the long term. Seed bank packages and credit programs were funded by agricultural companies and promoted by the federal and state governments and local municipalities (Clawson and Hoy 1979; Gonzalez-Montagut1999). Farmers and ranchers were thus lured into buying hybrid seeds and investing into programs by the guarantee of maximized yields that would result into higher earnings.

The replacement of traditional land uses did not always result in higher yields on the farm. Conventional agriculture techniques being applied to tropical soils in many cases resulted into soil degradation. In some cases farmers rejected the programs for various economic and ecological reasons (Clawson and Hoy 1979).

Also it has also been argued that conventional farming in the tropics introduced a more extensive method of agriculture as a substitute for traditional methods, which utilize and promote intercropping agro-forestry and crop rotation. In many cases agricultural and grazing expansions into forests increased in efforts to conventionalize undeveloped regions in Mexico (Gonzalez-Montagut 1999).

1980-1992: Federal Forestry and Ejido Privatization

During the 1970s community organizations began to develop throughout Mexico, pressuring the government to acknowledge and promote community forest management. Klooster explained "communities focused their demands on President Miguel de la Madrid, who was pressured to promise support for campesino forest production in his 1982 presidential campaign" (Klooster 2003 a, 109). This led to the restriction of logging permits to third parties and gave more powers to Ejido communities to be more included in the management of forest resources in the 1980s..

In 1986 the Federal Forestry Act stipulated greater federal jurisdiction over environmental resources. The 1986 forestry act attempted to control the management of forest resources on a national level. Permits could be given to Ejido communities for legitimized purposes. Forest professionals were to be regulated to a higher degree, and forest policy was to become more comprehensive at a national level to regulate and control resources.

During the1980s some efforts to initiate projects that promote forest sylviculture and reforestation projects were established. The federal government initiated projects that included community involvement. The 1986 Federal Forestry act also gave Ejido communities more power to establish their own logging rights, and private business ventures were promoted

allowing agriculturalists and Ejido loggers more freedoms to manage and profit from their lands. However, it is argued that the liberalization of rural lands may have had negative effects on forests resources (Deininger and Minten 2002). Also the transformation of forest management to communities was not an easy task. Many communities lacked the "internal organization, business management skills, or the equipment needed" (Deininger and Minten 2002 p304) to make the transition.

The 1990s: Neoliberalism and NAFTA

After many years of heavy federal involvement in Mexico's economy, a movement emerged in the 1990s toward increased privatization that resulted in changes to land tenure systems. Ejidos became privatized entities that could compete in the market. Also the sale and rent of Ejido lands became possible.

The privatization policies gave some economic control to communities and individuals within the Ejido; however identification of who actually had control over resources and who was profiting became vague. Ejido individuals now had the right to sell lands, or to work the lands and earn a profit in the market. Ejido communities now had some powers over forest frontiers, leading to the possibility that forests could be utilized for economic benefits or could be cleared to open new agricultural products (Klooster 2003 a).

In 1992, modifications to Mexico's environmental laws included agrarian reform and a forest policy that fit better with Mexico's market economy. The aim was to establish institutions that would facilitate market participation in rural areas to transform rural communities so that they would conform to the "neoliberal vision" (Cornelius and Myhre 1998).

In some respects, the control of rural lands and forest resources was placed under the authority of Ejido communities. This transfer of control, combined with the new emphasis on market economics, facilitated the spread of economic activities to forest frontiers (Taylor 2003). Competitive organizations, such as co-ops and agricultural corporations could work out deals within Ejido regions or utilize or purchase Ejido lands. Thus for the first time since the formation of the Ejido, communities now had the right to sell lands or retain some ownership rights through privatizing lands as business ventures (Cornelius and Myhre 1998).

The long term effect on forest resources of the new privatization policies is not yet fully understood. In cases where community involvement through agroforestry strategies can be used to open new markets for campesinos, pressures on expanding land use into forests frontiers can be minimized. Giving authority to Ejido communities to manage their own lands and create economic strategies to alleviate poverty may reduce the need to expand land uses into forests (Deininge and Minten 1999). On the other hand, a different set of economic incentives may drive the decision-making of communities toward the selling of lands and the opening of new forest frontiers for profit, which may lead to higher rate of deforestation. The ability to privatize rural lands may facilitate the process of converting forested lands into non-forest land-uses, especially if there are no policies in effect that regulate how lands can be bought or sold for these purposes. Many economists argue that new policies have made it difficult for rural farmers to compete in the highly competitive market that favors irrigated farms using higher technology (Klooster 2003 b). Indeed, a growing body of research finds a connection between the latter incentives and deforestation, as is described in greater detail below.

Recent Trends of Deforestation in Mexico

The vast majority of the Mexican deforestation literature relates forest degradation to land-use expansion into forest frontiers, particularly agricultural land-uses as farmers respond to economic incentives to invade forests (Deininger and Minten 1999; Southgate 1990). Much of the previous research that focuses on agriculture encroachment into forests has linked agricultural expansion to economic variables.

Studies that show a relationship between deforestation and economic variables in Mexico use models that have been devised to explain the relationship between resource degradation and economic pressures. Klaus Deininge and Bart Minten in a World Bank project concluded that "poverty is associated with higher levels of deforestation" (Deininger and Minten 1999, 313) and that higher prices on products also created an incentive to clear forests to maximize profits from agricultural crops. They used an economic model to explain the economic incentives causing land-use change. The model, which is similar to other studies attempting to explain the complexity of economic pressures on land-clearing, identifies a number of variables that may cause the actor (farmer) to expand his land-uses into forests. These variables include:

i. work l_w hours in the wage sector -possibly including migration- remunerated at the given wage w;
ii. devote time (l_A) to agricultural production on the "owned" plot a_A which is transformed into output through a standard production function $f(l_A, a_A)$, with output valued at prices p_A that are net of production cost;
iii. devote l_F hours to cutting down trees on forested land to which no clear property rights exist. It is assumed that marketable forest output, which can be sold at price p_F, is generated through the concave function $g(l_F)$ and that additional cleared land (a_F) can be brought into agricultural production during the second period,
iv. use l_I hours to invest in land-augmenting technical change such as irrigation, according to a concave land improvement function $h(l_I)$.

As Deininge explains “we use a simple two-period model that formalizes the relationship between deforestation on the one hand and poverty, government policies, and local land tenure institutions on the other.” (Deininger and Minten 1999, 315). The variables are factored into the equation to explain “incentive based” behavior of the actors (the farmers). Similar to other studies that have been conducted in the tropics, they theorize that price fluctuation of products sold by the farmers and the available economic resources that the farmers possess affect their incentives to clear land. For example when farmers fall into marginal poverty and prices of a given crop rise there will be high incentive to clear more land to take advantage of favorable opportunities (Torres-Rojo 2001; Barbier 2004).

Studies have utilized economic models with remote sensing and GIS data to analyze how rates of deforestation fluctuate over time and to test which variables are causing land-use expansion. Klaus Deininger and Bart Minten in another study, *Determinants of deforestation and the economics of protection: an application to Mexico,* conducted in the states of Chiapas and Oaxaca, found that poverty and land tenure systems play an important role in deforestation. They also concluded that higher price incentives of products and lower wages of on-farm and off-farm labor were linked to higher rates of deforestation (Deininger and Minten 2002).

Remote Sensing: A Tool for Analyzing Forest and Land-Use Change

Remote sensing is a valuable tool for monitoring and assessing land-use and land- cover change. Land-use monitoring is becoming easier as higher resolution data, and better technology allow for more precise delineation of land use types for impact analysis. In remote regions and in third world countries remote sensing applications are useful where data may not exist, and where in-situ data collection may not be possible. As higher resolution data becomes more

available and technology become better for the separation of land-use types, analysis of land use change and its effects on natural resources becomes more accurate (Jensen 1996).

In the tropics and in remote regions where field data may not be gathered, "remotely sensed data provides the primary source of quantifiable data about forest and land cover changes in tropical America" (Sader, et al. 1994, 317). Various remote sensing techniques can be used to derive quantifiable data from raw images that can be used to analyze impact on vegetation over a period of time. The ability to separate forest from other vegetation is necessary in the analysis of forest change. Jean-Paul Malingreau and Compton Tucker utilized the first two channels of AVHRR satellite data to delineate forest from other vegetation biomass for five different years (1981, 1982, 1984, 1985, 1986). This study showed beneficial results for detecting forest from other vegetation rendering a forest to non-forest comparison between all the years (Malingreau, et al. 1989).

The ability to separate land cover types from raw images is essential for analyzing the impact of anthropomorphic activities on forest resources. Clustering algorithms are valuable applications for grouping image data into spectral classes. Arturo Sánchez-Azofeifa et al., for example, estimated forest degradation and fragmentation between 1991 and 1995 by processing Landsat 5 images using supervised classification. The image data were classified into seven classes (closed forest, non-forest, water, clouds, urban area, and cloud shadows) to analyze the extent of deforestation in a neo-tropical region in Costa Rica (Sanchez-Azofeifa, et al. 2001).

Imbernon and Branthomme processed three Landsat MSS images (1973, 1978 and 1987) two Landsat TM images (1993, 1994) and one Spot-XS image (1996) to analyze forest fragmentation in Brazil. An unsupervised classification containing 200 classes was performed, and later recoded into three classes: forest, croplands and other. The recoded image data were

then incorporated into a GIS to separate small crop-lands from large ranching areas. They concluded that crop-lands caused a high rate of fragmentation into intact forests (Imbernon and Branthomme 2001).

While supervised and unsupervised classification applications assist the user to define general classes of spectral data into groups, clustering algorithms are many times not accurate in separating pixels within the image data that retain similar spectral signatures. For example, forests and other vegetation such as agriculture may have nearly identical pixel values, which require the use of other analytical procedures to assign pixels to distinguishable classes.

Indices can be applied to pick out specific feature types that would otherwise be indistinguishable in the raw image data retaining only brightness values captured from the sensors. The 'normalized differentiated vegetative index' (NDVI), which is used for vegetation analysis is effective in delineating forests from other vegetation types (Jensen 1996; Hayes and Sader, in press). NDVI uses the amount of photosynthesis occurring in vegetation as a basis for distinguishing types, combining the reflectance values that are measured in the red and near infrared regions of the energy spectrum. The NDVI can be used to separate forests from other vegetation, or to analyze the health of vegetation, and has emerged as a standard image-processing technique.

NDVI uses a simple mathematical algorithm of these specific bands to assess the "greenness of vegetation". Specifically the equation is as follows: NDVI = (near infrared-visible red)/(near infrared + visible red). The resulting values will yield higher pixel values for healthy vegetation and lower values for non vegetative features. Vegetation therefore can be analyzed in a range of values within the NDVI data set. The data can also be analyzed in an image where a scale of vegetation features corresponds to values that are assigned to the pixels where higher

brightness values correspond to healthier green-biomass. The resulting gray-scale image can be viewed separately or within the image data (as a separate band within the data) that can be used to help delineate ground features.

Hayes and Sader used three NDVI datasets (1993, 1995 and 1997) derived from Landsat TM data to analyze forest change in Guatemala's Biosphere Preserve. They implemented an NDVI change detection to discern the areas of forest change and quantify the amount of forest loss (Hayes and Sader 2006). Using an NDVI within a change detection proved to be beneficial for identifying vegetation types and assessing impact on forest resources.

Change detections using NDVI and more commonly on land-use/land-cover (LU/LC) classes are useful for detecting changes of classes between two or more datasets. LU/LC classifications give the ability to analyze different classes that can be used to assess loss or gain of specific features over a period of time (Green and Sussman 1990).

Matrix change detections allow for pixel-to-pixel analysis of two classified images. Using an (n x n) matrix algorithm, change can be detected (Jensen 1996). GIS polynomial statistics can then be applied, such as the amount of area that has changed from pixel A to pixel B. Other change detection techniques include applications using binary masks and spectral change vector analysis to name a few. The benefit of the matrix approach is that it gives the user a matrix of change between every class, and shows all loss and gain throughout a color specified map of all classifications. This type of change detection allows for a spatial analysis of pixel change for all the specified features types between two or more time periods.

Much of the research concerning image processing used for this study was conducted in the 1980's and 1990s. These image processing techniques were widely used in studies at a time when few or no remote sensing data-sets existed for land-use classifications. The research

conducted for this study faced similar constraints. Given the relative absence of previous studies using remote sensing image data within the Mexican study area described below, this study utilizes similar techniques and relies on these older studies.

Indeed, because of the diverse ecology of the region and the fact that many land-use and land-cover classes could not be delineated using only software applied techniques such as ISODATA (which defines classes using statistical clustering of pixel data) it was necessary to use many image processing techniques. An NDVI, unsupervised classification, and user defined techniques were employed to delineate the various classes that exist within the land-use study area. Details about research methods and study area are provided below.

CHAPTER 3

RESEARCH DESIGN: STUDY AREA, DATA AND METHODS

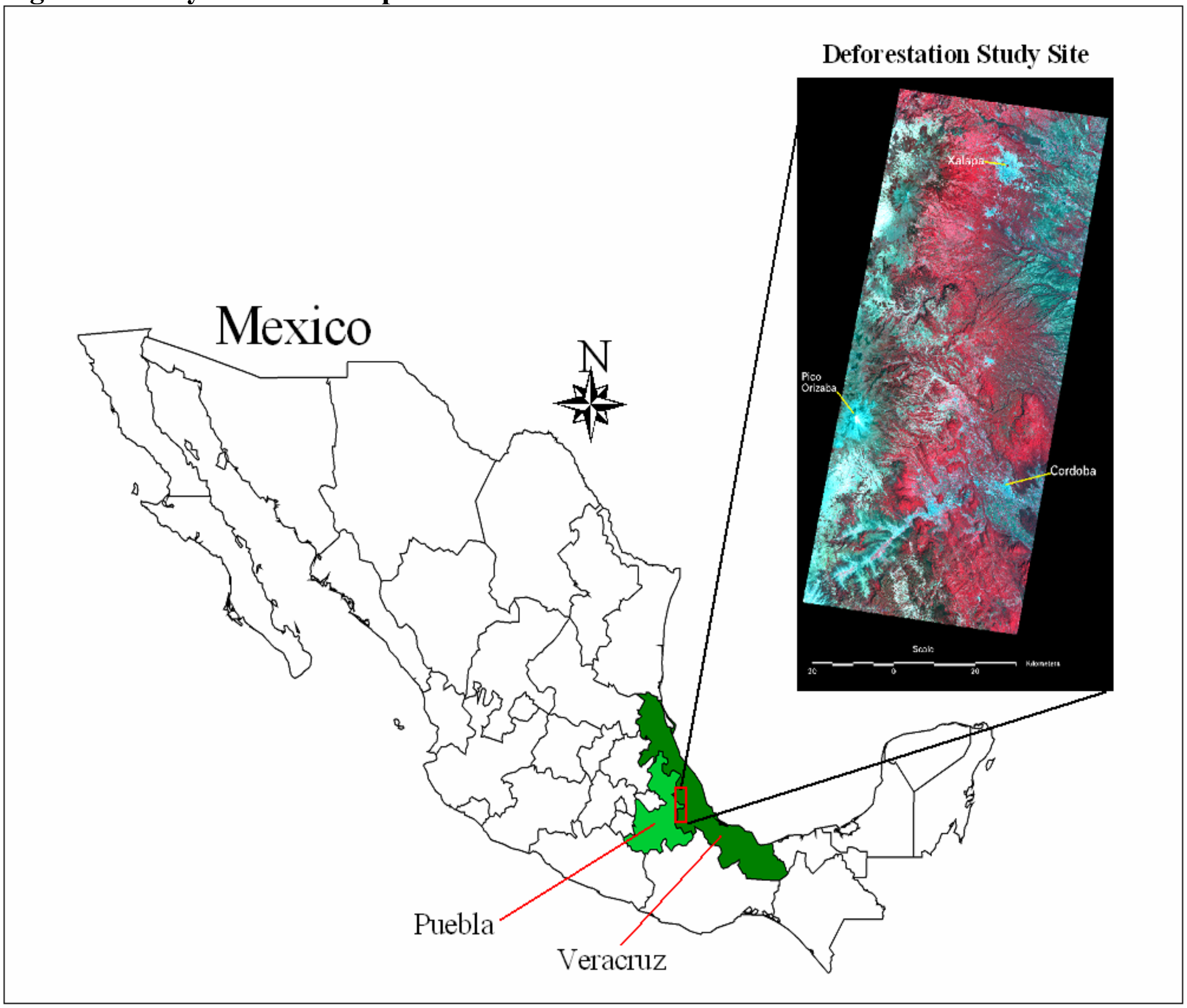
Study Area

This study consists of two areas of investigation. A larger deforestation study site was selected for the calculation of forest loss and gain in a region in the states of Veracruz and Puebla Mexico (Figures 1 and 2). This study site consists of forest and non-forest classifications to analyze overall forest change from 1979 to 2002. A smaller land-use study site, existing within the deforestation study region, was utilized in a region near Xalapa Veracruz to analyze land-use expansion into forests (Figure 3). The smaller study area consists of specific land-use types to analyze more accurately how much each land-use has expanded into regions that were forested in 1979.

Deforestation Study Area

The larger deforestation study area is located in central Veracruz Mexico with a small portion found in the state of Puebla (Figure 3). The study area for the deforestation analysis contains the city of Xalapa to the northeast and extends to the cities of Orizaba and Cordoba to the southwest (Figure 1).

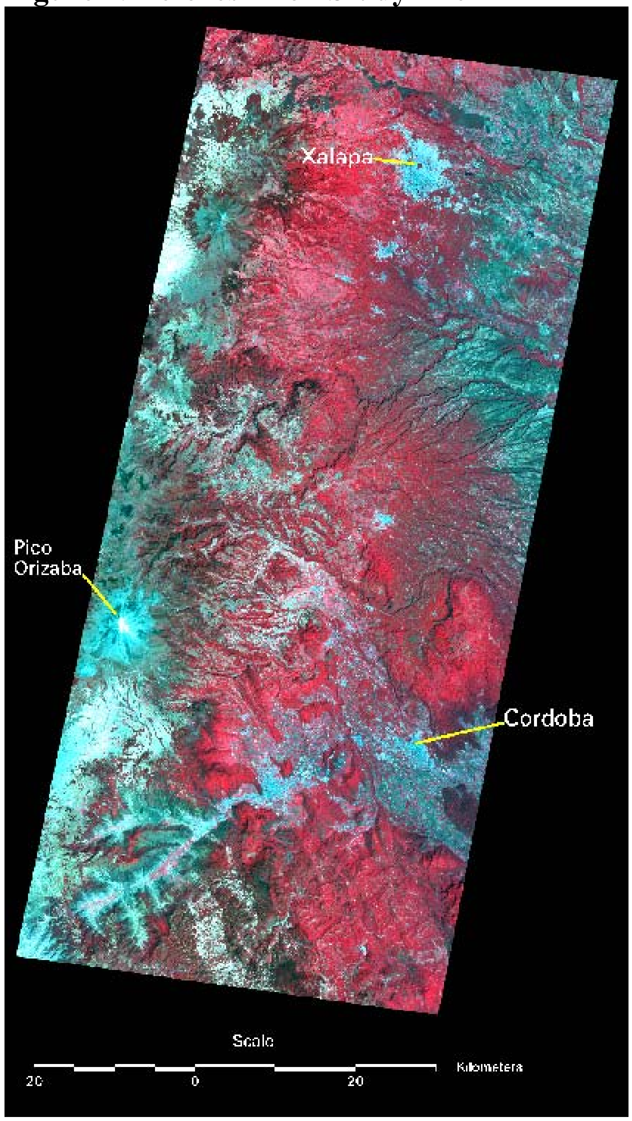
Figure 1. Study Area and Map of Mexico



Deforestation study area (Aster image April 2002). Mexico map created in Arcview.

Climate. The upland region is described as a subtropical and temperate humid zone. Within the study area the region to the eastern extent of the deforestation study area consists of a dryer tropical region in the lower altitudes (Figure 3), where vegetative biomass varies considerably between seasons.

Figure 2. Deforestation Study Area



April 2002 (dry season) Aster Image. Color composite of bands 1,2,3 (green, red, near-infrared).

Within the humid zone, the wet season occurs between April and October. The wettest month is June, averaging 33 centimeters. The dry season extends from November to April with the driest month being February averaging 4 centimeters (The World Meteorological Organization. 2004 a). In the humid subtropical zone season variation is less drastic than in the lower tropical zone which is semi-arid in the dry season where the lowest rainfall month is

March averaging 1.4 centimeters and the highest rainfall month is July is averaging 44 centimeters (World Meteorological Organization 2004 b).

The upland slope of the Sierra Madre ascending from the gulf coast creates orographic climatic conditions where the cooling of rising warm tropical air results in condensation of clouds and precipitation. As a consequence, the upland slope receives rain all year.

The temperate humid zone above 2000 meters retains mixed subtropical temperate and pine species. The highest regions of the study area include the peaks of Pico Orizaba (5,675 meters in elevation) and Cofre de Perote (4,220 meters in elevation) where there exist alpine and subarctic climate zones (Figure 3).

Forest ecology. Tropical dry forests exist in a savanna environment in the lowland coastal plain, and are present to about 900 meters in altitude (Marten 1981). Many species of the scrub forest and oak savannah that exist on the plain, within the far eastern region of the larger deforestation study area, become somewhat dormant during the dry season, and consequently forest greenness varies considerably between the seasons.

Forests that exist within river valleys and along rivers and stream banks retain greenness year-round. The tropical dry savanna forests are a distinctly different forest type that exists in the upland region.

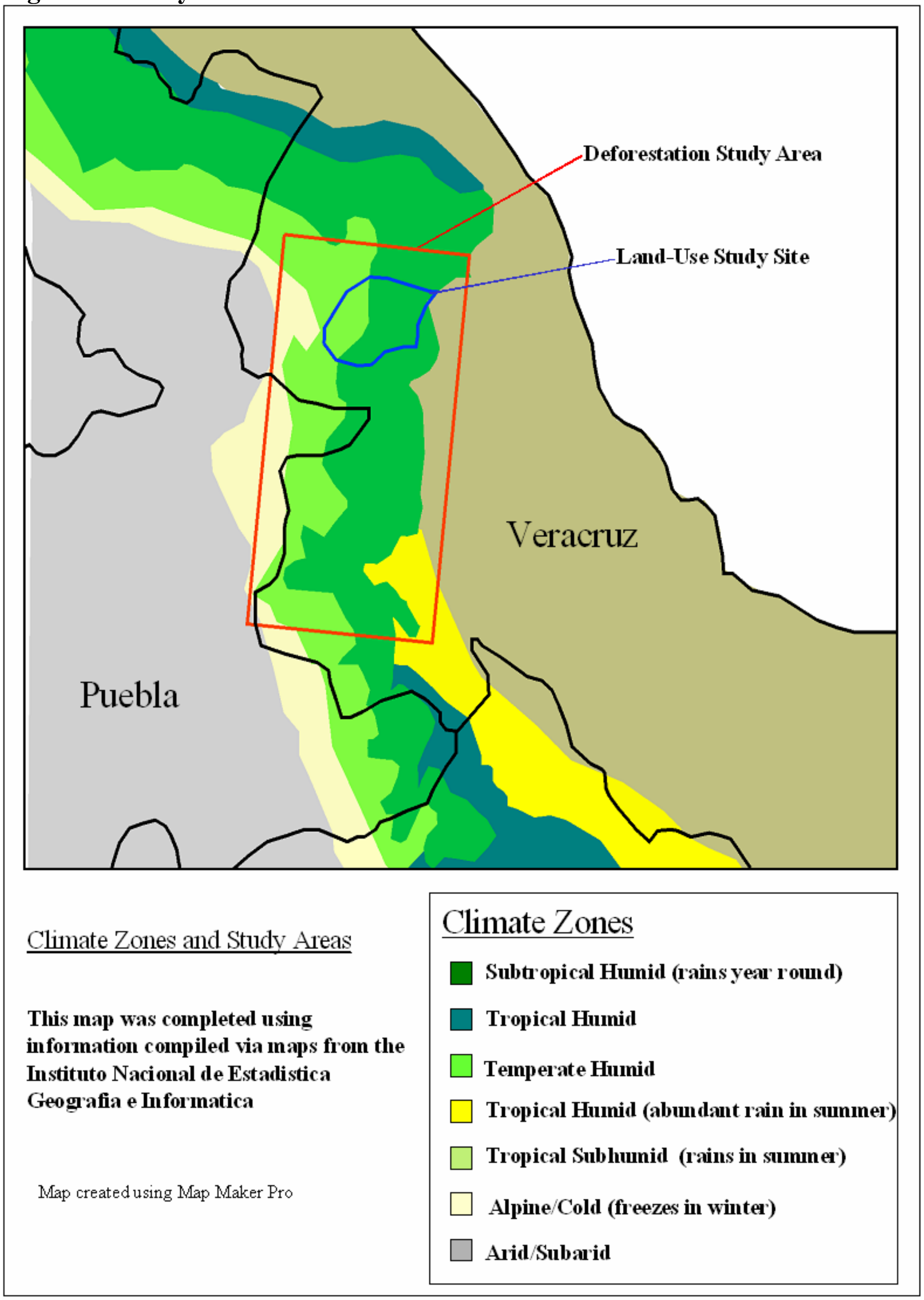
At approximately 1000 meters the subtropical humid zone provides enough precipitation and humidity to support humid forest. Thus the humid sub-tropical forests that exist in the region do not experience considerable seasonal change. The humid zone includes subtropical montane cloud forests. These species exist in the higher regions where clouds form and these plants rely less on precipitation of water and more on high humidity levels in which water is

extracted above ground through the leaf structure of the plant. The remaining cloud forests in the study area that exist northeast of Xalapa are highly fragmented and are among the last cloud forests in Veracruz (Williams-Linera 2002). The remaining cloud forest in the study area exists within the humid subtropical forest that is predominant in the region. The majority of the forest in the humid zone is characterized as subtropical upland forest, with regions where pockets of cloud forest exist.

In the upland temperate zone from about 2,000 to 3,000 meters exists subtropical species mixed intermittently with deciduous and pine tree species. The upland temperate regions also experience rainfall year round and thus the forest remains green throughout the year. Most of the temperate regions retain many subtropical species and thus there is not significant forest variation between seasons. Above the upland temperate zone is predominantly pine forest with some regions where non native pine and deciduous species exist as a result of reforestation projects.

Forest resources in the region are vital to the overall health and sustainability of the region's ecology. Humid tropical, subtropical and temperate forests play vital roles in hydrologic filtering and soil sustainability. Because of the region's considerable topographical relief and high amounts of rain in the wet season, the existence of wooded vegetation is crucial to the health and survival of the natural watershed.

Figure 3. Study Areas and Climate Zones of Central Veracruz and Puebla



Geology. There are numerous calderas in the region, reflecting a volcanic history. In addition, this volcanic landscape has been subjected to severe gradational processes that have cut deep river valleys. The result is a varied terrain and extreme topography that greatly influences vegetation growth and land-use practices.

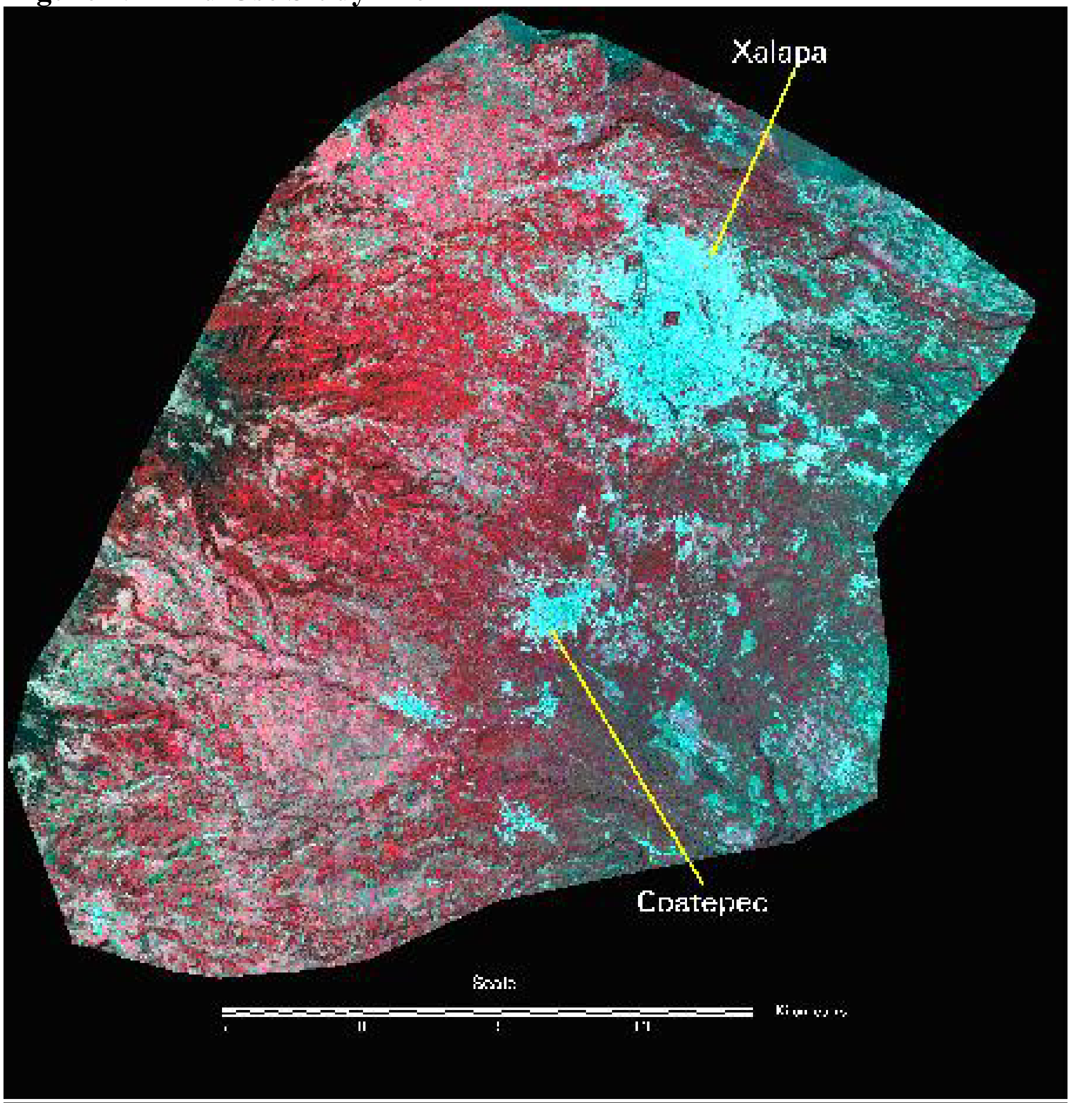
Soils within the humid subtropical zone contain ash layers in the soil horizons as a result of ash flows. The humic-andisol soils contain high amounts of mineral content. The soils in the region provide ideal conditions for agricultural practices and can support a multitude of crop types (Zamora and Castillo-Campos 1997).

Land-Use Study Area

The land-use study site consists of a smaller region within the larger deforestation study area (Figure 4). The smaller study area lies mainly within the humid subtropical zone on the eastern slope of the upland Sierra Madre. The study site also includes an upland humid temperate zone (Figure 3).

The land-use study site is a microcosm of the larger study area except it does not include lowland dry forest. The smaller study site embraces the city of Xalapa (capital of Veracruz) and includes the coffee growing region that exists in the humid subtropical zone lying between Xalapa and the town of Coatepec. This region is also used for sugar cane production. Cattle ranching and subsistence farming also exist in the humid region and in the higher altitudes to the west of Xalapa and Coatepec where temperate and pine forests predominate.

Figure 4. Land-Use Study Area



April 2002 Aster image (dry season). Color composite of bands 1,2,3.

Ecological Problems. The study area exists within a region of Veracruz that is considered to be an important region for water resources. The highlands region above the humid subtropical zone is a water recharge area where many of the region's rivers and streams originate as a result of high precipitation in the upland humid zone. The forests existing here and below in the subtropical zone provide water filtration and maintain natural water flow processes (Munoz 2005). The subtropical humid area is also an important agriculture region where coffee, sugar

cane, and citrus fruits are cultivated. Soil erosion occurring on high sloping terrain threatens the sustainability of agricultural systems. Herbicides and pesticides also threaten water resources that flow to the lowland plain and Gulf coastal waters have experienced fish kills and red tides near the study area due to contaminated rivers that retain high levels of herbicides and pesticides.

Within the land-use study site, urbanization is of great concern as a factor affecting the condition of natural resources. The urban center of Xalapa has nearly doubled in population within the past 23 years. The mountainous terrain in the Xalapa region allows few options for growth. As urban infrastructure expands onto sloping terrain water flow is greatly affected. Urban runoff has been attributed to high levels of pollution in the water shed.

Much of the urban growth occurs into forested regions that are not protected by state or federal authorities. Ejido regions near the city of Xalapa where mixed crops, agrofoersty and forests exist, can be sold to private developers (Munoz 2005). Urbanization continues to expand into forested regions within the Ejido lands as a consequence of escalating land prices due to the need to enlarge space for residential development and economic activity at the expense of forests.

Deforestation in the region resulting from land-use expansion has been attributed to current problems associated with degradation of soils and water resources (Gobierno del Estado de Veracruz 2002). Understanding the nature of land-use change in the study area is important in the analysis of forest degradation.

Historical Land Dynamics in the Land-Use Study Area. In large measure the history of land-use change in the smaller study area mirrors that of Mexico as a whole, with some variation reflecting difference in geography. As discussed concerning the history of land-use change in Mexico, economic factors also played a major role in the study area concerning land-use change,

particular in term of agriculture prices (Munoz A. 2005; Marten and Sancholuz 1982; Zamora and Castillo-Campos). It will be helpful at this point to review briefly the historical land-use circumstances affecting the study area, paying special attention to the economic and policy conditions that were factors in shaping the study area's land-use patterns.

Land use change is influenced greatly by crop prices and ecological constraints, such as terrain and climatic conditions (Marten and Sancholuz 1982). Terrain and climatic variables affect which type of crop can be grown. The study region consists of diverse ecosystems that exist within different climatic zones and varied terrain. Flat and gradually sloping terrain can be used to grow commercial crops of sugar cane for example. Rolling hills and highland regions where lands are flat, or exist on gradually sloping terrain, have been converted to pasture lands for dairy production. Coffee can be grown on high sloping terrain, but is confined within the humid subtropical zone.

By the late nineteenth century, new economic incentives began to impact the land-use dynamics of the Xalapa region as sugar prices increased and sugar became an important export (Hoffmann, et al.1987). The region's good soil and humid subtropical climate were ideal for sugar cane production, although relatively flat ground was required. Much of the region's flatter terrain the within the subtropical zone was therefore cleared for sugar plantations by the middle of the nineteenth century (Hoffmann, et al. 1987).

Cattle ranching also converted large tracts of land as the state of Veracruz became an important producer of cattle by the beginning of the twentieth century (Gonzalez-Montagut 1999). The humid and temperate areas can provide grasses year round without irrigation compared with the lowland savanna plain, where natural grasses become dormant during more extreme intermittent dry seasons. Ranch-haciendas owned by wealthy landowners were put into

production during this time in the southwestern region and near the town of Coatepec. Highland regions northeast of the city of Xalapa were converted into grazing lands for dairy production by the early 1900s.

By the first decade of the twentieth century considerable forest clearing had occurred in the study area (Hoffmann, et al. 1987). During this period of hacienda and plantation agriculture, large tracts of land were distributed to landowners for the production of crops for profit in the state market. Sugar plantations were extensive and this crop required large areas cleared. This system of agriculture promoted large-scale forest clearing and is estimated that approximately 70 percent of forests were cleared in the region for large-scale sugar cane production and cattle ranching (Marchal 1984; Munoz 2005).

Small scale farmers, who had settled in the higher altitudes and in remote regions in more rugged terrain, cleared small plots of land for mix cropping. As more peasants began to lose land rights in the nineteenth and early twentieth centuries, new settlements of rural regions continued (Poleman 1964). They worked the land under a land rent system where haciendas were worked by peasant farmers. The clearing of lands was encouraged by the Hacienda owners, and cattle would be placed in cleared areas. In return campesinos had land rights for subsistence farming.

During the first decade of the twentieth century two factors caused land-use to change considerably. The first was the introduction of coffee in the region as a major crop, due to the favorable international prices (Hoffmann, et al. 1987; Munoz 2005). Coffee had been grown but only as commodity in the local market, and its significance in the region had not become important in the local community until the international prices rose in the early part of the twentieth century. As coffee production was introduced shade-coffee species (coffee beans that

could be grown in shaded conditions) were brought into the region. These species of coffee could be grown within existing forests which provide natural shading for the coffee harvests.

The second major change that affected land-use in the study area was the Ejido land redistribution. Many of the rural regions in the study area were given to peasant farmers after land distribution took place in the 1920s (Marchal 1984). This included regions where sugar plantations existed most notably between Xalapa and Xico. By the 1930s many of these rural regions were now technically in the hands of communities within the Ejido system.

As coffee prices continued to escalate, farmers began replacing sugar crops with coffee. Shade coffee beans were economically favored due to their higher prices and because weeding and clearing of vegetation were not required. As a consequence, forest re-growth was encouraged. Another benefit of shade coffee agriculture is the ability of peasant farmers to grow other products within the forest/shade system. Plantain and citrus trees could be included in a diverse agro-forestry system, providing subsistence crops that could be grown concurrently with coffee. The economic incentives for shade coffee resulted in an agro-forestry system that ultimately led to forest regrowth (Munoz 2005).

During the 1920s substantial forest regrowth began in the region as coffee became the most important crop. Today a good portion of the forest that exists in the region between Xalapa and Xico and the region directly northeast (where there are pockets of cloud forests) are secondary forests that are the result of regrowth due to the coffee industry (Hoffmann, et al. 1987; Munoz 2005). Sugar remained an important product in the region; however as described above coffee planting had many benefits for campesino farmers.

A reversal of this re-growth trend began in the 1940s and 50s as sugar prices began to escalate (Munoz 2005). Also during this time efforts to modernize Mexico's rural regions led to

projects to improve Ejido sugar cane cultivation (Marten and Sancholuz 1982). Herbicides and pesticides were introduced and credits were given to encourage cultivation to take advantage of escalating prices (Hoffmann, et al. 1987; Marten and Sancholuz 1982). These efforts were also implemented in rural Ejidos in regions around the towns of Xico and Coatepec for the modernization of orange fruit cultivation which was promoted for exportation to North America. Areas in the upland temperate regions that grew corn and beans were also included in this effort to modernize leading to the efforts to maximize production (Hoffmann, et al. 1987).

During the 1960s and until about 1975, coffee prices were relatively low and sugar cane and orange cultivation expanded due to higher international prices (Hoffmann, et al. 1987). In the more remote regions maize cultivation was for the most part sold for local consumption. Cattle ranching had become an important economic commodity for the local dairy market for the Xalapa region by the 1970s (Marten 1981). As the city of Xalapa grew into an urban center, a local economy that revolved around the urban center of Xalapa continued to influence land use change in the region (Lopez-Moren and Diaz-Betancourt 1993; Marten 1981).

In 1979 the coffee industry experienced a rise in international prices (Munoz 2005). Coffee production expanded within existing forests. Some sugar cane fields and grazing lands were converted back into coffee plantations (Hoffmann, et al. 1987). Changing from sugar cane back to coffee is a more difficult process because of the time it takes for shade plants to grow before coffee can be replanted (Chavez 2006; Munoz 2005).

During the late 1970s and 1980s some efforts were made to reverse deforestation trends and promote reforestation in the study area. More recently projects have focused on planting pine trees where cloud forests were cleared for cattle grazing and subsistence farming (Marchal and Palma 1984). Credit programs that promoted tree planting and agro-forestry were initiated.

Agricultural credits were given to farmers for preserving forests. A major complaint for credit programs that have been instituted in the region, including recent initiatives for tree plating, is the lack of monetary benefits and the ways in which the economic credits are distributed in that the financial resources were not received by farmers (Munoz 2005; Hofmann, et al. 1987). Overall the programs did not manage to distribute incentives to community inhabitants who have the option of clearing forests for profits. Despite some success through reforestation there has still been considerable deforestation being caused by land-use expansion (Munoz 2005).

Urban expansion surrounding Xalapa has also transformed land-use patterns. Much of this expansion can be traced to migration of peasant farmers to the city. In addition, the appearance of middle-class and upper-class migrants from elsewhere in Mexico has also contributed significantly to urban expansion (Lopez-Moreno 1993). Over the past 40 years the population increased at a rapid pace, transforming Xalapa from a small urban center of just under 100,000 in 1960 to over 212,769 in 1978 (Lopez-Moreno 1993). Today there are approximately 400,000 inhabitants in the greater metropolitan area of Xalapa (Oficina del Programa de Gobierno 2002). This relatively fast population growth has caused the city to expand rapidly, overtaking forest frontiers and agricultural lands that existed on the outskirts of the city.

Coatepec has also grown considerably, and now the corridor that once divided the smaller town from the larger urban center is relatively built up. Lands within this region have experienced escalating land values, creating incentives for Ejido communities to sell lands for development. Within many of the regions where urban land use can expand, coffee agroforestry is being practiced. When the price of the land is worth more than the economic benefit of the crops that can be grown there may be a strong incentive to sell the land (Munoz 2005).

Data

Four 1979 Landsat MSS images were purchased through the United States Geological Service Earth Observation Systems data center and four Aster images were acquired through NASA to be used for the 20001/2002 data set. Each temporal dataset includes images from the wet and dry season for each of the respective years. The 1979 data-set consists of one image captured in March for the dry season and two images, both captured in November of 1979, for the wet season (two images were need for the dry season due to the offset of path and row swath that existed). Two Aster images taken in November were used for the 2001 wet season data set, and two Aster images captured in March of 2002 represent the dry season.

The Universidad Veracruzana (Xalapa Veracruz, Mexico) provided ortho-photos (with a resolution of 1:50,000) that were used to assist in delineation of land uses within the smaller land-use study area. Shape files of land-use classifications also provided by the Laboratorio de Cartografia at the Uinversidad Veracruzana provided assistance for land-use and land-cover identification for image processing of the satellite images

Methods

Preprocessing

As discussed at length above, two study sites were selected: the first covers a much greater area and will be used for a region-wide analysis of forest loss and forest gain, and the second will make use of a land-use/land-cover classification system to examine the nature of land-use encroachment into forests in a small part of the larger study area. Because of time and budget constraints precise land-use classifications are not feasible for the larger study region. Using a smaller region within the larger deforestation study area to examine which types of land

uses exist within previously forested regions allows for a more precise focus on land-use/forest change that represents the larger study area.

A mosaic of the Aster images for each temporal dataset for the larger deforestation dataset (one in the 2001 wet season and one for the 2002 dry season) was completed. The MSS images were co-rectified (in UTM) to the Aster image dataset. This was performed to more precisely match the 1979 dry and wet season MSS data so that a change-detection could be performed for the wet and dry season data sets to separate the seasonal forests into two types. The ASTER images needed no co-rectification as the level Aster 1-B data are precision rectified at sensor and thus has minimal displacement and error for the ASTER datasets.

Image Processing

ISODATA unsupervised classification was performed on the larger forest/non-forest study are of each data set to generate a basic clustering of signatures that could later be broken down into forest/non-forest and later to specific land-use classifications (for the smaller land-use study areas). Ten iterations (cycles) were executed and a spectral distance of .95 was specified. Originally 65 classes were clustered in the 2001 image and 50 classes in the 1979 image using the ISODATA (in ERDAS Imagine 8.6) clustering algorithm for each image. The spectral bands 1, 2, and 3 (green, red and near-infrared) were utilized in the 2001 and 2002 images for the classification process. Bands 1, 2 and 3 were selected for the 1979 images (also corresponding to green, red and infrared energy information). Green, red and near-infrared energy sources are useful in distinguishing vegetation from non-vegetation.

The creation of 60 classes for the 2001/2002 dataset and 50 classes for the 1979 MSS data proved to be the most accurate for the visual delineation of forests from other vegetative

land cover types. The regions where known forests existed were coded as "forest" and the remaining classes were coded as non-forest. An NDVI was used to identify forests and non-forested vegetation. It was discovered that using the NDVI as a band (band 3) with the green and red bands of the original data was beneficial to help delineate forest cover.

User defined image processing proved to be the most accurate for delineation of forests from other land uses. Using the NDVI and the original images, separation of forest feature types was accomplished by selecting forested pixels from the original unsupervised classified image and copying the pixels to the recoded (forests/non-forest) image. In areas where the unsupervised 60 classification image did not delineate forest from other vegetation, a seed pixel approach was utilized on patches of forest in the image to classify such regions that were identified as forest.

A forest/non-forest dataset of each season (one for the wet and one for the dry season) was completed. A matrix change detection of the two forest/non-forest images of each year was accomplished to create a humid forest and perennial/dry-forest image map of each year. The resulting image for each included three classes: tropical dry and deciduous forest, humid and evergreen forest, and non-forest. A second change detection of the 1979 and 2002 forest cover maps was performed for a forest change map to measure and examine deforestation between 1979 and 2002.

Image Processing Methods for the Land-Use Study Area

The study region's diverse array of ecosystems and land-use types results in inconsistent groupings of pixel data when utilizing only an unsupervised classification. In regions where different vegetation features retained the same spectral signatures (such as secondary forests and subsistence farming, which were in many cases grouped together in the unsupervised classification), polygons were manually digitized in ERDAS Imagine, a subset of a given area was created into a separate dataset, and then pixels within the polygon were used to change the pixels on the land-use map to the correct class.

A Normalized Difference Vegetation Index (NDVI) was created from each data set to assist in the delineation of forest from other vegetation. The NDVI was processed into a gray scale image and put into a false color composite by combining the original green and red spectral data (from the original image data) for each dataset. Thus the NDVI was used as a separate band in the original data, which helped distinguish vegetation types. The resulting false color composite provided a useful image for identifying sugar, subsistence agriculture and pastures. Regions that were identified as forest or non-forest were copied from the color-composite image (containing the NDVI band) and pasted onto the forest/non-forest land-use map using the AOI tool in Erdas Imagine 8.7. Creating a color composite image using the NDVI gray scale as a separate band facilitated the separating of forest from other vegetation where the unsupervised classification clustered different classes into the same group.

The NDVI helped with delineating forests from other classes; however, it was not sufficient for separating some land-uses classes that retained similar pixel values in different regions of the image. For example, in the Aster data, sugar cane in the humid/sub-tropical region southeast of Xalapa retain the same reflectance values as some regions containing grazing lands

in the higher humid and temperate regions found northwest of Xalapa and southwest of Coatepec. Similarly some subsistence agriculture found in the humid subtropical region near Xalapa rendered similar pixel values as forests in the lower tropical humid region southeast of Coatepec (within the region that is also extensively used for sugar plantations).

Creating regional subsets and classifying each region separately allowed for more accurate classification of the data. This was accomplished by copying and pasting classes from the unsupervised classification to the new land-use/land-cover map as it pertains to each separate region. Therefore the sugar cane region can be classified as such without incorrectly classifying pasture lands as sugar cane (which have a similar spectral value). Similarly grazing and cattle ranching areas that exist in the higher subtropical regions were delineated by subsetting these regions as separate datasets and pixels that could be identified, as these land-use classes could easily be copied from the subset image on to the land-use map. The pixels in these newly created subset images could be assigned as "grazing lands" without incorrectly changing pixels in other parts of the original image that have similar pixel values.

Land-Use Classifications

The land-use/land-cover classification for the 2002 data set include deciduous forest, humid forest, subsistence agriculture/mixed-crops, sugar cane, urban/settlement, fallow land, and other vegetation.

Forest is defined as any area comprised of one or more 15-square meter pixels using the Aster data, or 60 meter pixels using MSS, in which the majority of land is covered with arboreal species.

The category of subsistence agriculture and mixed crops involves production of crops primarily for consumption by the producer and his family, with some products sold in local markets. For this study area these products include coffee, maize, oranges and dairy, among others. Typically they produce mixed crops on small plots of land, and often maintain small stands of forests where other products are harvested. Unlike many commercial agricultural products, where long rectangular plots of land producing specific crops can easily be identified, the plots of the subsistence agriculturalist are not as uniform within the spectral signatures (of the image data) because they contain mixed crops and forest stands. Delineating these land uses requires user-defined techniques.

Toward this end, a subset of the subsistence agriculture regions was created to separate this land-use classification from other similar land-uses in different parts of the study area. Creation of this subset helped in accurately delineating subsistence agriculture from other land-uses such as sugar-cane production. Typically within the study area the subsistence agriculture regions were located upland from the more topographically level regions where sugar cane was harvested. Therefore the agriculture within these more remote areas along and below the sloping upland valleys and mountains could be safely identified as subsistence agriculture. Field work in the study region confirmed that all areas identified as subsistence farming land-use classes were indeed subsistence agriculture.

Sugar cane was designated as a class because of its importance as a land-use type and its role in the socio-cultural dynamics of land-use change and the deforestation process. Furthermore, sugar-cane production can be delineated using Aster data's higher spatial and radiometric resolution.

Fallow land and bare soil represents areas where there is no vegetation and the land-use that exists there cannot be identified. These regions have a different spectral value and are not consistent with urban/settlement areas. Fallow land could be the result of human and natural conditions. Though typically in the upland subtropical zone fallow lands are the result of anthropomorphic activities.

Urban/settlement includes roads, towns and any regions that could be identified as built-up areas. This land-use class also includes settlement area in rural regions. The spectral signature for this class was easily identified after the completion of the unsupervised classification.

Grazing lands are classified as regions used specifically for livestock production. Farmers utilizing subsistence agriculture and mixed cropping often maintain small-scale cattle ranching within cleared areas; however, this is in contrast with large scale grazing lands where regions are specifically used for animal grazing.

Other vegetation is defined as any vegetation within the study area that cannot otherwise be identified. It is typically found within urban/settlement areas. This vegetation is likely ornamental and consists of non-natural species. Other vegetation also includes plant life in forested regions that is not identified as agricultural.

CHAPTER 4

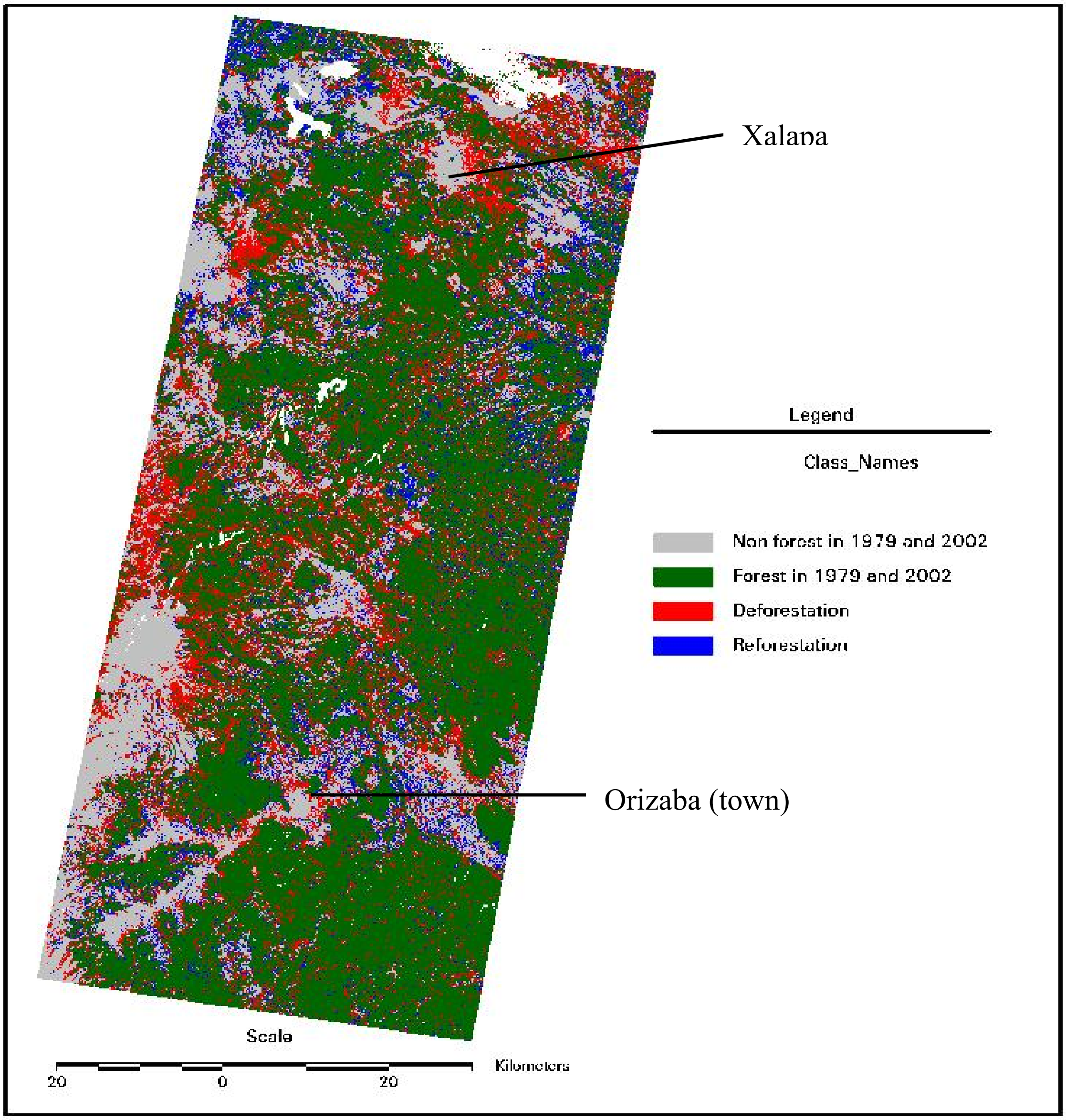
RESULTS AND DISCUSSION: DEFORESTATION AND LAND-USE PATTERNS

Deforestation Study Area

Given the preceding discussion of how land-cover and land-use classes were derived, it is possible now to assess the extent to which deforestation occurred during the period in question in the larger study area. With this discussion serving as a foundation, it will then be appropriate to examine the relationship between forest change and land-use change in the smaller study area.

The larger study region experienced 107,495 hectares of deforestation or 25 percent loss of forest during the 23-year period. This figure is consistent with other Latin American deforestation studies that show deforestation rates of approximately one percent per year. However, the data suggest that the study region experienced 47,449 hectares of forest regrowth. An area of forest re-growth is defined as one in which forest was present in the 2002 image, but not in 1979. Thus, the net loss of forest for the study area was 22 percent (statistics derived from deforestation change detection map, see Figure 5).

Figure 5. Forest Change between 1979 and 2002



Change detection of the 1979 and 2002 forest/non-forest maps

As mentioned above, there was a high amount of reforestation within the deforestation study area. Tree planting projects and protection of rejuvenating forests have been initiated at state and local levels in efforts to reverse deforestation trends. Gain of forests in some areas could also be attributed to abandoned agricultural lands as a result of rural migration of peasant farmers, who

have been abandoning subsistence farming activities to seek wage employment in other regions of the state and in urban centers. Most of the noticeable reforestation exists in the higher humid regions, reflecting a desire to safeguard areas in which rivers and streams originate. This is not to say, however, that these same areas have not also experienced deforestation. Indeed, as indicated in the deforestation change detection image, deforestation and reforestation are occurring intermittently in the same areas.

Also there appears to be substantial urban/settlement growth into forests which is observed in the deforestation change image. This apparent urban growth into forest resources that is observable in and around Xalapa and Cordoba could not be calculated in the larger deforestation study area as there was no delineation of this class. However, the deforestation is noticeable on outskirts of urban areas indicating extensive urban growth into forested regions between the two data sets, as observable on the forest change image (Figure 5). There also appears to be significant growth of small rural towns that exist in previously forested areas in 1979. Though due to the fact that there was not an urban classification for the larger deforestation study site it is not possible to quantify the amount of urban expansion into forests. However, observation of the forest change image indicates significant deforestation around urban areas and settlement regions (Figure 5).

Overall these results show a high rate of forest to non forest, and non-forest to forest change between the two time periods. Given the land-use history of the region – changing from land-use to forest and back to forest again – may be revealing the oscillating nature of forest vs. non-forest land-uses in the study area (Hoffmann, et al. 1987), where some forest are cleared for agricultural purposes and other regions are abandoned or left to rejuvenate.

Seasonal Variation in Both Study Areas

Overall vegetation biomass for all classes of vegetation (agriculture, non forest vegetation and forest) varies considerably between both seasons, which is observable on both temporal data sets (1979 and 2002). Forest variation within the larger deforestation study area experienced a 29 percent variation. In other words, 29 percent of the forest experienced seasonal change as it pertains to photosynthesis activity. Most of the change of forest seasonality is due to the fact that a portion of the deforestation study area exists in the lower slope where tropical dry forests predominate (Figure 6). However seasonal variation was less significant in the land-use study site within the humid zone, where 16% of the forest for the 2002 data-set consisted of forest that experiences seasonal change (Figure 7).

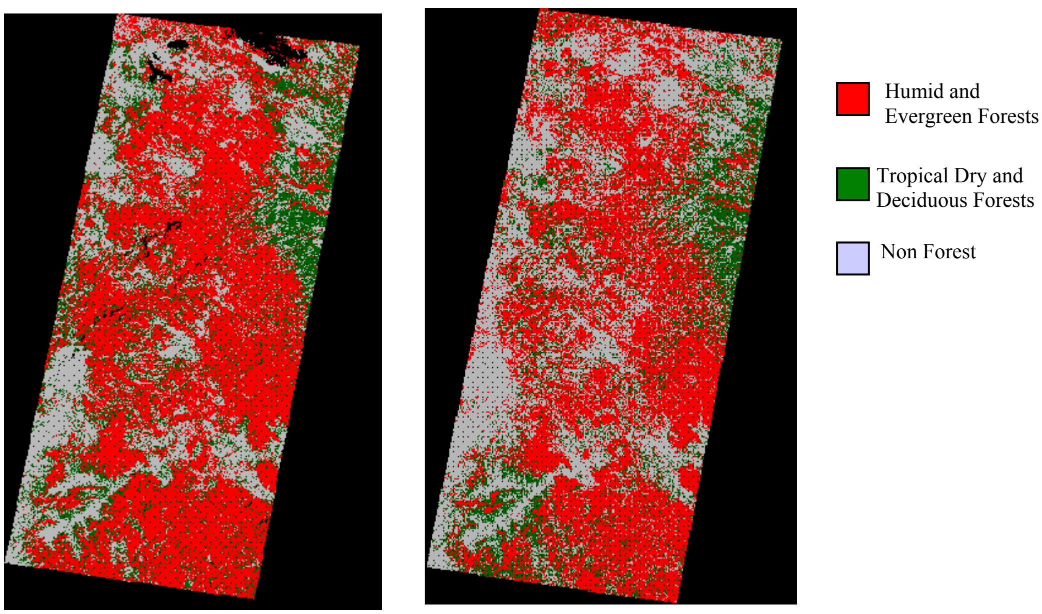
In addition, some seasonal variation of forest types within the humid zones is noticeable on the fringes of urban areas, especially along the outskirts of the urban region in and around Xalapa. This variation could be due to the introduction of deciduous non-native tree species that exist in and on the outskirts of urban landscapes (Garcia-Campos 1993). Also it can be observed that some variation exists in areas where projects have been initiated to replant non-native species of trees.

For the larger study site some natural deciduous species exist in the temperate regions above 2,000 meters in elevation; however, pine forests predominate in these zones with subtropical and deciduous species mixed within the pine forests. Therefore, it appears that seasonal forests change (as it pertains to leaf greenness) does not greatly effect forest detection within and above the humid subtropical zone.

However there is observable seasonal variation within the study area concerning non-forest vegetation. This variation includes agricultural and grazing land uses, which highlight the

effects of human intervention. The fact that the humid forest predominated in this environment – before humans transformed this region – it can be concluded that the variation that exists within the humid region is for the most part due to anthropomorphic vegetation.

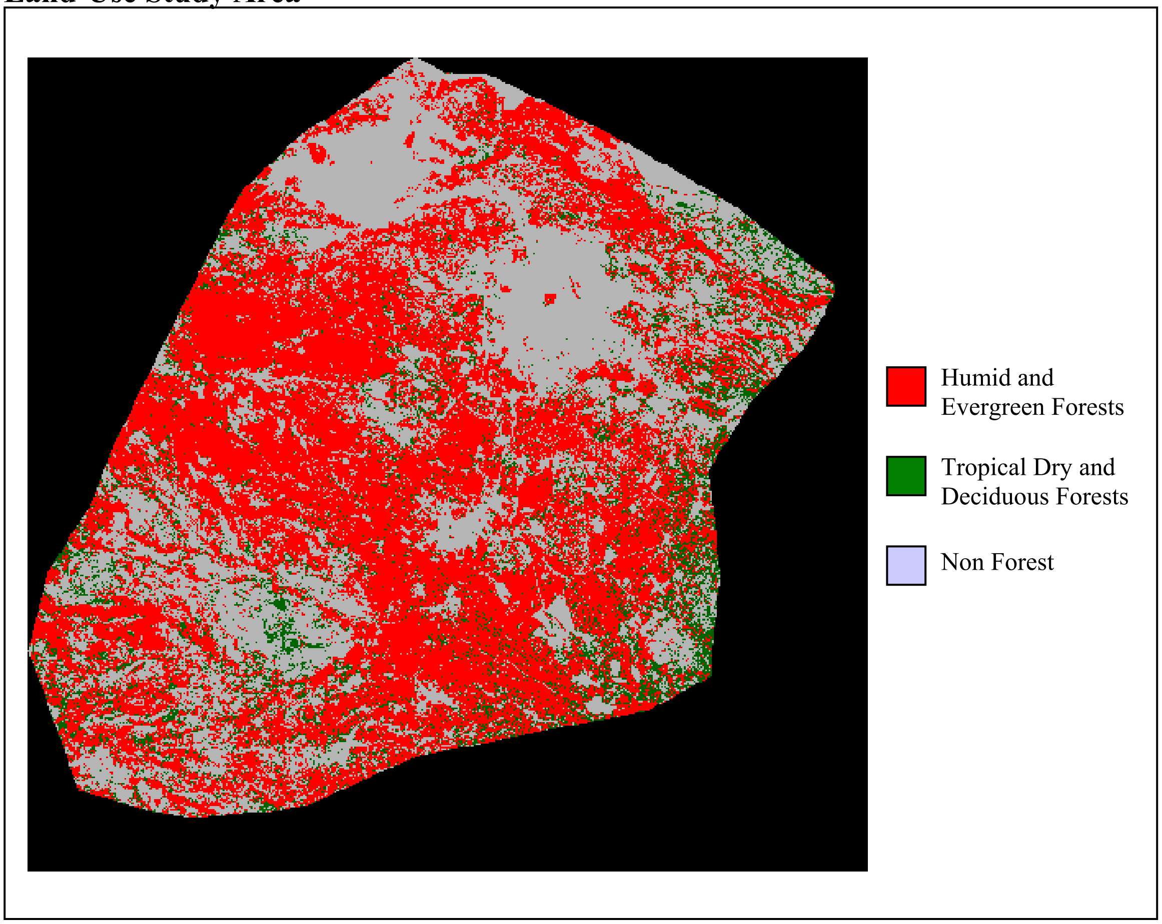
Figure 6. Humid/Evergreen Forests and Dry/Deciduous Forests in the Deforestation Study Area for Each Year



1979 Forest Map. Via change detection of dry season forest/non-forest image and wet season forest/non-forest image.

2002 Forest Map. Via change detection of dry season forest/non-forest image and wet season forest/non-forest image.

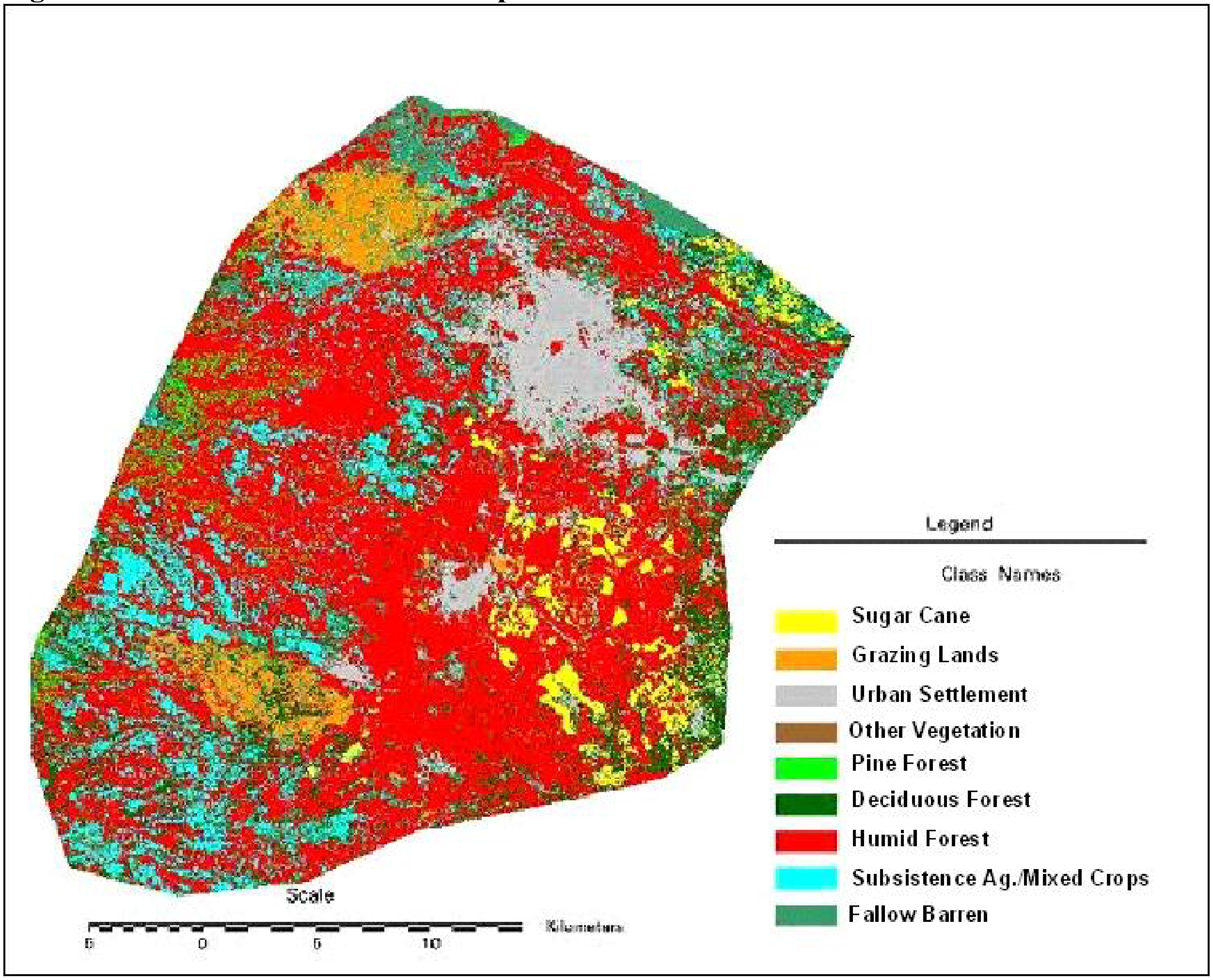
Figure 7. Humid/Evergreen Forests and Dry/Deciduous Forests in the Land-Use Study Area



Deforestation in the Land-Use Study Area

The smaller land-use study site saw a total of 15,661 hectares of deforestation (equaling 18 percent of the forest that existed in 1979). However there was also a gain of 5,982 hectares in reforestation (Table 1). The region therefore experienced a total of 9,679 hectares of forest loss – net loss as revealed in the land-use change map resulting from the change detection of the 1979 forest to non-forest image and the 2002 land-use map (Table 1).

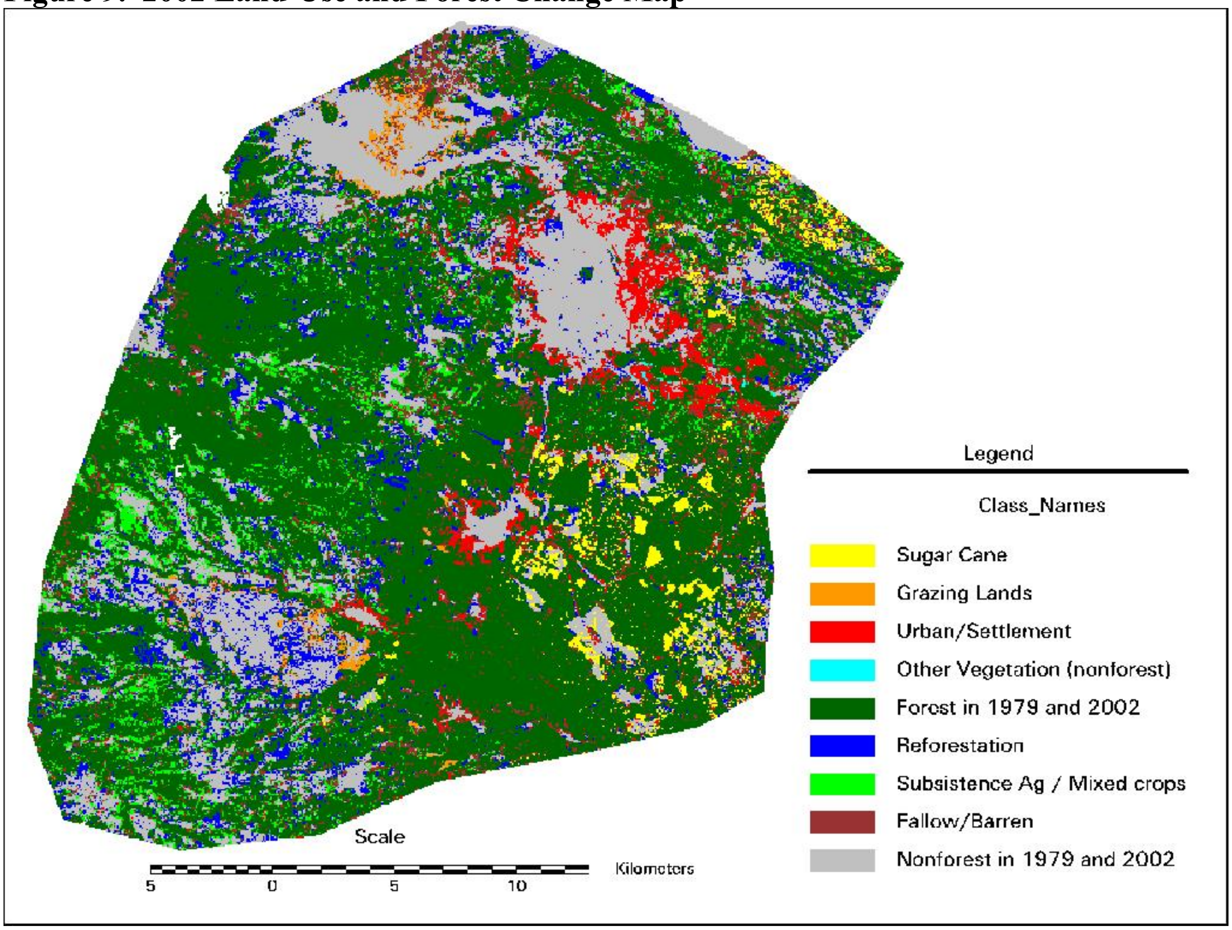
Figure 8. Land-Use Classification Map



The largest increase of non-forest land-use into previously forested regions is fallow/barren lands at 6,075 hectares (Table 1). This land-use classification accounts for anthropomorphic activities that have replaced natural vegetation. Due to resolution limitations, the image data were not in themselves sufficient to identify the specific land-use process that may be causing areas to become barren. The imagery did reveal, however, that the vast majority of the fallow/barren areas that expanded into forested regions were scattered throughout the study area, producing a fragmented and dispersed spatial pattern. Other land uses displayed less

fragmented and more coherent patterns, often with the fallow/barren areas embedded within them. Such a pattern suggests a relationship between the dominant land use in an area and the existence of fallow/barren areas. Field visits to these fallow/barren areas, however, led to the observation that most of the fallow/barren areas were abandoned agricultural plots, overgrazed land, and areas cleared for future urban/settlement purposes (lands in the process of being developed).

Figure 9. 2002 Land-Use and Forest Change Map



Land-use expansion into forested regions and reforestation from 1979to 2002.

Table 1. Deforestation by Land-Use

Class Names	Hectares	Miles sq.	Percent of Deforestation
Fallow/Barren	6,075	23.4	38.8%
Subsistence Ag / Mixed crops	4,381	16.9	27.9%
Urban/Settlement	2,712	10.4	17.3%
Sugar Cane	1,821	7.0	11.6%
Grazing Lands	605	2.4	4.0%
Other Vegetation (non-forest)	67	0.2	0.4%
Total Deforestation	**15,661**	**60.4**	**100**
Reforestation	5,982	23.1	
Total forest loss	**9,679**	**37.3**	

Note: Land-uses causing deforestation in the land-use study area. Figures are from the change detection of the 1979 forest change image and the 2002 land-use study area map.

Despite the fact that other land-uses may lead to the formation of fallow/barren lands, this classification retains unique characteristics as it pertains to ecological issues. Fallow regions cause different types of problems relating to water and soil quality. In the case where agriculture could be the reason for an area to become fallow, defining this region as agriculture would not be accurate considering the definition of "agriculture" where a certain type of agricultural vegetation predominates the given area. Therefore despite the notion that other land-uses may be causing lands to become fallow, the unique characteristics of this land-use/land-cover designates this as a separate classification.

Subsistence agriculture/mixed crops accounted for 4,381 hectares in previously forested areas (Table 1), the second highest amount of all land-uses within deforested regions. Two areas

in particular had noticeable expansion: the upland region to the east of Xalapa in the mountainous terrain of the Sierra Madre and along the eastern slope of the Cofre de Perote plateau directly east of the town of Xico. The rugged topography allows only for small scale farming along marginal sloping terrain, and much of the region east of Xalapa above the subtropical region does not favor commercial coffee and sugar cane.

The region above Xalapa and Coatepec, where subsistence agriculture has encroached into forests, is of great ecological concern as this temperate/humid region (between 2,000 and 3,000 meters in elevation) is a water recharge area, where rivers and streams are initiated. The upland humid forests provide an important function in the process of water flow and filtration (Zamora and Castillo-Campos 1997).

Throughout the regions where a high amount of subsistence farming expansion is observed, there also exists a considerable amount of reforestation. This may suggest a pattern of agricultural/forest rotation where cropping or cattle ranching activities encroach into forests and exhausted lands are abandoned for forest regrowth.

Overall agriculture (including both subsistence agriculture and sugar cane) accounted for the highest amount of land-use expansion into forested regions (6,202 hectares). This supports other research suggesting that agriculture is the main cause of deforestation in Mexico (Ochoa-Gaona 2001).

Subsistence agriculture also includes areas of small-scale cattle ranching or livestock grazing that is done in the context of other land uses such as mixed cropping. Since this grazing is not a primary source of income, and since it does not involve corporations and large estates, it should not be included in the ranching or grazing category.

Regions designated specifically as cattle ranching or grazing within the study area accounted for 4 percent (605 hectares) of the total deforestation in the study area (Table 1). It is observable in the images that cattle ranching expansion occurred within and around regions that were most likely grazing lands in 1979. Thus it was not observable in the image data or in field observations that new frontiers of forest were cleared specifically for cattle-ranching other than outskirts or regions next to ranches and dairy farms that were already in existence in 1979.

Urban settlement accounted for 17.3 percent of the deforestation. However 40 percent of this land-use grew into forests between 1979 and 2002. This urban growth into forests alone suggests a high urban/settlement expansion in the study region. This statistic however does not account for a "total urban growth" as the growth of the total urban land-use was not calculated for this study because the urban class and other LU/LC classes were not processed for the 1979 data-set. The 40 percent of urban growth is *only* occurring into forested regions, indicating that the urban growth rate to be significant between 1979 and 2000, assuming that urban growth will have expanded into other land-uses and land cover types such as subsistence agriculture and barren/follow regions.

Much of the urban expansion into forests has occurred in Ejido regions where agroforestry, focusing on coffee, and subsistence agriculture existed. Rural farmers have little control over the titling of lands if deeds are sold for development. Forest resources too are not protected within Ejido lands and the people who live within the community lands around the urban center of Xalapa, in potential development regions, have little control over the forest resources that exist there. Campesinos utilize and manage forest resources in the region, however they have minimal authority over who has access to forests and as to whether or not forests can be cleared for other land-uses, or sold to private developers.

Within the Xalapa region, if forests are not designated as "protected," these areas can be made available for development with little compensation to Ejido farmers. This reflects the historic trends of forest management of resources within Ejido lands (Klooster 2003 a). Recently during the new "open market" post NAFTA Mexico, Ejido lands could be more easily privatized through private deeds, and thus may have facilitated urban development into rural areas. New laws relating to facilitating deeds for privatizing community lands has made it easier to change land-use activities that promote "economic progress" (Klooster 2003 a).

The ability to sell community lands undoubtedly affect the decisions concerning land-use change within Ejido lands. In the Xalapa region there has recently been a trend of selling Ejido lands to developers for urban expansion. The holders of the deed of the community lands can now do this easier in Mexico's neoliberal economy. These new development regions have resulted in forcing Ejido inhabitants who may receive a small percentage of the property's value to migrate to new rural regions or assimilate in the urban environment. Many times there is no compensation for those merely using the community lands for subsistence farming purposes (Munoz 2005).

Many of these regions that are being developed consisted of fragmented forests with coffee planted under the forest canopy and mixed crops. The agroforestry that exists on the outskirts of Xalapa, especially on the southeastern boundary of the city, is experiencing rapid change to urban development (Chavez 2006).

Urban land-use expansion is of greater concern than other land-use types because of its negative effects on the watershed and soil sustainability. Urban development expansion into forests resources, especially within highly sloping terrain (characteristic of the Xalapa urban landscape) has caused major problems with water flow in the region (Munoz 2005). The total

amount deforestation being replaced by urban development may not be as high compared to other land uses such as subsistence agriculture, however the overall impact on resources being caused by urban encroachment into forests is of great concern.

Similarly sugar cane had a high expansion into forest territories. Commercial sugar plantations accounted for only 11.6 percent of the total deforestation (1,821 hectares). However, 68 percent of the sugar plantations in 2002 exist in regions that were forested in 1979 (Table 2). That is, it had a 68 percent growth into forested areas and thus the highest rate of growth percentage into forests for all land-uses between 1979 and 2002. Despite the fact that the overall deforestation of sugar cane accounts for a small portion (11.6 percent) of the study region, the expansion of sugar cane that had occurred between 1979 to 2002 is significant concerning the growth into forests. From a regional context the sugar/coffee growing regions that exist in the basin between Xalapa and Xico, within the humid zone, are greatly influenced by variables that are related to land-use change from coffee agriculture to sugarcane plantations (Marten and Sancholuz 1982; Munoz 2005; Hoffmann, et al. 1987)

In the subtropical humid region sugar crops replace coffee plantations when sugar plantations become economically more favorable than coffee (Marten and Sancholuz 1982; Munoz 2005; Chavez 2006). The land-use and forest change map (Figure 9) shows expansion of sugarcane into previously forested areas where coffee is harvested under forest canopy.

Table 2. Land-Use Expansion into Forests from 1979 to 2002

Land-use name	Hectares of Land-Use in 2002	Hectares of LU Causing Deforestation	Expansion of LU Within Previously Forested Regions
Sugar Cane	2,685	1,821	68%
Subsistence Ag/Mixed Crops	7,870	4,381	53%
Fallow/Barren	11,153	6,075	49%
Urban/Settlement	6,647	2,712	40%
Grazing Lands	2,929	2,929	20%

Note: Percentage numbers indicate the percent of growth for each land-use into forested regions (from change detection of the 1979 forest/non forest image and the 2002 land-use classification map).

Due to the fact coffee species exist under the canopy of forests there are no accurate maps showing the location and extent of coffee plantations in the study region. However the agricultural department at the University of Veracruz has conducted extensive field work in the region between Xalapa and Coatepec. Dr. Agustin Munoz, chief cartographer and professor of agriculture at the university, has initiated field surveys of coffee species and completed extensive field work in the region. He estimates that 70 to 80 percent of the forests in the subtropical humid region (within the land-use study area) contains planted coffee as understory. In recent years a significant amount of the agroforestry in the region has been replaced with sugar cane when coffee is not economically sustainable, or sugar prices are favorable (Munoz 2005).

Throughout the time period there seems to be a trend to sugar cane expansion. This is occurring despite the normal trend of switching back and fourth between coffee and sugar cane. This could be due in part to the fact that changing from coffee agro-forestry to sugar cane plantations is an easier process when compared to changing from sugar cane to coffee

agroforestry. It is more facilitated because the process involves simply burning forest to clear trees for sugar production. Immediately after forests are cleared, sugar can be harvested. However, when coffee prices go higher and there are economic incentives to change to coffee, it is a more difficult and time consuming process. The procedure of changing from sugar cane to coffee agroforestry requires a mature tree canopy to provide shelter from sunlight for coffee harvest (Munoz 2005; Chavez 2006).

Coffee plantations in the region are found on Ejido and private lands; however, both utilize a similar system where peasant farmers exist within a tenure system constructed so that farmers maintain and work the land for the production of coffee and other products, and function within the subsistence farming definition. Though they sell coffee as a main source of income, they survive in marginal poverty, and as described in chapter 3 for the definition of subsistence farming, they depend on other products for subsistence.

Another strategy practiced by coffee producers in the region is to grow other crops within the agroforestry system, intercropping other products such as banana, plantain and oranges. Some farming systems within the study-area utilize this approach with minimal or no natural tree species; however, this approach also takes considerable time before over-story species are mature enough to act as shade for coffee cultivation. There are advantages to utilizing natural forest overstory for coffee growing as it takes less effort than planting horticulture species for overstory. As mentioned, the forest provides many benefits such as shade, soil maintenance and fuel wood for campesinos. But in areas where forest does not exist, farmers need to decide whether it is necessary to wait for forests to grow back or spend the time and effort planting and maintaining non-natural shade species such banana and orange trees in an agroforestry system.

In either case, changing to coffee from other land-uses where forests are cleared, is a more difficult and time consuming process.

Within the study area the importance of sugar cane and coffee prices affect greatly the economy of the Xalapa region (Hoffmann, et al. 1987; Marten and Sancholuz 1982). Coffee and sugar cane remain among the most important agricultural products in the Xalapa region (Munoz 2005). The pricing of these two products and the land values where these products are practiced influence the decisions concerning land-use change in the study area (Marchel 1984).

The value of land affects the land-use decisions in and around Xalapa where areas can be sold for development. Indeed where lands are worth more than the crops that can be harvested in a given region, there is a great incentive to sell lands. New policies concerning the selling of community owned lands now make this easier (Chavez 2006). Regarding coffee, if the region's land values surpass the value of the coffee crop it most likely will be sold, resulting in forest clearing assuming that the use of the forest is no longer needed (Chavez 2006; Munoz 2005).

Coffee was not designated as a separate land-use within the study area because it exists within forested regions and the image data cannot distinguish coffee crops which are planted under forest canopy. As described above, coffee growers exist within a subsistence farming definition, but because they practice their land-use within the forest defining them as "subsistence" farmers was not accurate. Subsistence farming for this project is defined as a farming system where small plots are cleared for mixed crops that are consumed by the producer and is family and some products sold for income. Farmers existing within the agroforestry coffee system depend more specifically on coffee as cash crop, with other products such as citrus fruits and plantains consumed by the producer or sold for secondary income. Also because the objective of this study is to analyze land-uses causing deforestation, the agro-forestry system

utilized within the study area for coffee production is not causing deforestation, as coffee production exists concurrently with forests.

The region's local economy, including the rural population is still heavily dependent on coffee production (Chavez 2006). However, coffee farmers predominantly operate within the Ejido land tenure system where the inhabitants exist in marginal poverty (Hoffmann, et al. 1987). Low prices for coffee often force these farmers off the land and into the wage economy of Xalapa, thereby contributing to the urban expansion problem described above.

Field observations revealed that coffee is also utilized within much of the subsistence agriculture regions in the outskirts of Xalapa to the east and north of the urban center within the subtropical zone up to about 2000 meters in elevation. This region is higher than the region used for large scale coffee production that exists between Xalapa and Coatapec.

Subsistence farmers in the higher subtropical and temperate also plant coffee within forests by farmers as a secondary source of income (Zamora and Castillo-Campos 1997). When coffee prices drop, and are not advantageous to keep as an income product, regions may be cleared for other land-use practices, such as grazing plots for cattle (sugar cannot be grown here in this higher more rugged terrain). However, in these subsistence farming regions northeast of Xalapa, coffee is not used as a primary source of income. As described the subsistence farmers in these areas use more of a mixed-cropping system with some lands set aside for cattle ranching, and agriculture here can be defined in the more classical subsistence farming system. Therefore coffee is utilized even in these subsistence farming regions in the higher altitudes, and is an important secondary income crop. To an extent the same economic variables relating to coffee and sugar explained above are occurring here (such as cattle grazing) which affects the decisions concerning clearing forest for other land uses (Zamora and Castillo-Campos 1997).

Reforestation in the Land-Use Study Area

As mentioned, there were 5,982 hectares of forest gain between1979 and 2002. There is both forest loss and forest gain within subsistence agriculture/mixed cropping regions. Areas in the 2002 image that are identified as deforestation exist next to forested regions that were non-forest in the 1979 image.

There have been numerous reforestation projects initiated by the government. Reforestation projects northeast of the town of Xico and north of Xalapa may have accounted for some of the gain in forest. Reforestation efforts administered by government and nonprofit organizations within cloud forest regions and the higher temperate areas above Xalapa have been ongoing (Zamora and Castillo-Campos 1997). Such efforts in the 1990s include projects that have introduced non-native tree species (such as coniferous pine species) within fragmented cloud forests near the city of Xalapa, and in the higher temperate regions (field observations revealed significant planting of non-native pine species northeast of Xalapa).

The land-use and forest change image (figure 9) show reforestation in the subhumid and temperate areas above Xalapa and in the cattle ranching lands west of Xico. However within these same areas where forestry projects have resulted into reforestation there is also evidence of continued deforestation that has occurred within natural forests and around the same regions. The area within the cattle ranching lands north east of Xalapa, where there is reforestation, also shows a high rate of the follow/barren land-use replacing forests.

CHAPTER 5

SUMMARY AND CONCLUSION

The large study area and the smaller land-use study site experienced considerable forest change between the two temporal data sets. The overall deforestation of the larger forest change study site indicates a continued trend of deforestation for the region.

Within the larger forests change study-site some variation of forest is attributed to seasonal variation of the small portion of lowland savannah forest. However, forest variation accounted for small percentage of the total amount of forest within the land-use study area, therefore the forest change of the study area is not greatly influenced by seasonal climatic variables. It is advised that studies attempting to monitor forests or analyze vegetation should use data from the wet season as there exists some forest variation within the urban region of Xalapa and some variation being caused by non-native tree species as a result of reforestation projects. Also considering the significant variation of non-forested vegetation such as agriculture and pastures between seasons it is recommended that the wet season be used for vegetation monitoring.

Deforestation and Land-Use Change

The study areas seem to be following the trends of Mexico's land-use change history of being driven by external factors. Field observations and the literature suggest that land-uses are being affected by agricultural prices, land prices, and policies concerning land tenure. All land-use activities in the study area contributed to deforestation, though each land use differs greatly as to the underlying causes that relate to land-use change and land-use expansion.

Barren lands accounted for the largest amount of deforestation, and this land-use is not easily linked to such external factors. However, this classification may be the result of other land-uses that were being identified as barren-lands. Higher resolution data and more time spent in the field to verify which land-uses are causing barren lands needs to be utilized to better understand what specific activities are causing barren lands. Considering that this classification accounts for 39 percent of all deforestation in the study area it is essential to better understand the causes of barren areas and the relationship this classification has with other land-uses. The fallow/barren classification is also of concern because of the negative effects it has on the study area. Within the subtropical humid region, where rainfall is constant year round, barren regions can have negative effects on water flow processes and soil sustainability. This is especially true on sloping terrain where lack of vegetation can create substantial erosion.

Small scale agriculture and mixed crops (including small scale cattle ranching) as expected accounted for a good percentage of deforestation. This is consistent with past studies suggesting that agricultural expansion into forests have been responsible for high rates of deforestation in Mexico.

Agricultural expansion has caused considerable deforestation in the study area, and the pressures relating to expansion could be attributed to many causes. The regions classified as subsistence agriculture and mixed crops consist of a wide variety of products that are utilized for consumption and for income. Linking subsistence agriculture with specific variables that relate to the deforestation (such as economic or land tenure) would require further investigation concerning the various crops and products (including dairy and logging activities) and how they relate to expansion into forests. The vast majority of the literature concerning subsistence agriculture in Mexico links land-use expansion with economic and land-tenure variables.

Considering the economic pressures that exist with the coffee and sugar production, which was discussed in chapter 3, it is expected that economic factors are related to the need to expand subsistence agriculture into forests.

The expansion of subsistence agriculture in the region is of concern as it relates to the conservation of forest resources in the upper subtropical and temperate region. This upper region as mentioned is an important “recharge” zone. North and northwest of Xalapa reforestation projects have been initiated to help resolve the problems related to water resources (erosion, pollution, and drying up of streams). Still, reforestation efforts may not have been successful when small scale farming continued to expand into forests in the same region.

The expansion of sugar cane into forested regions is significant. Historically, expansion of sugar cane relates to change from coffee agro-forestry to sugar production. Within the study area coffee and sugar cane production exist in the same growing region, except for highly sloping terrain where coffee can be harvested but sugar cane cannot be produced on a large scale. In the Xalapa, Coatepec and Xico region, where the majority of coffee is produced, sugar plantations also exist, taking advantage of the favorable terrain and subtropical humid climate. Both coffee and sugar cane are important economic products for the region, but the significant growth of sugar cane in the region indicates an overall diminishing coffee agro-forestry land-use. Considering that the great majority of forests existing in the humid region are concurrent with coffee understory, the change from coffee to sugar relates directly to deforestation.

Within the subtropical humid region coffee appears to be an important land-use activity that encourages forest preservation. Also coffee is identified within the socio-cultural identity of the Xalapa region. Within the study area there is great effort to preserve the coffee “culture” as it pertains to the business and ecological aspects of the region. For the most part coffee is

revered as an important resource for the Xalapa region. The tourism industry, coffee distributors, and the rural population that harvests this product, all depend on this land-use activity to some degree.

Yet the local beneficiaries have little control over external factors relating to the viability of this land-use. Field work in the region and conversations with various farmers revealed that coffee producers average \$120- \$150 per year in income. Coffee farmers do not have decision making powers related to setting prices within local or national markets. Therefore within the subtropical humid regions the sustainability of coffee agroforestry is greatly influenced by external economic variables.

The majority of these coffee plantations reside within Ejido lands, and the agro-forestry system managed by small-scale farmers is dependent on international coffee prices. When prices fall below the threshold in which farmers can sustain enough income to survive, there is great incentive to change land-use activities, or migrate to urban centers to find wage labor. The people holding deeds to these community lands can sell the properties to private parties or change to another land-use such as sugar cane. Because of the framework of the land-tenure system, however, wherein people retain rights to use community lands for economic and subsistence purposes, but do not individually own the land, the great majority of the inhabitants are not included in the profits when lands are sold. Mexico's new liberalized system concerning the privatization of lands and the ease at which these community lands can be sold for profit pave the way for forest clearing for other land-uses.

Land values in the region have seen an escalation due to the demand for development of residential, commercial and industrial land-uses. Rural regions containing forests and agroforestry practices can easily be cleared for such development when deeds are sold to private

developers. In and around Xalapa there is little opposition to development into rural regions, as the change in land-use generates money for the local governments at the municipal and state level. Projects are legitimized and promoted as “economic development” in the region. They provide jobs, new housing and businesses for the growing urban region.

The 40 percent expansion of the urban classification for this study occurred into areas where a substantial amount of the forests were maintained within Ejido lands. Forests resources in these community lands are not “protected” and in many cases are not considered “forests” if they are being used with other land-use purposes such as coffee. These regions are not seen as deforestation if they are being classified as “agriculture”. However the definition of agriculture does not take under consideration the overstory canopy that exists above the agricultural products. Such agroforestry regions are considered forest for this study.

There has been little participation in Mexico of the rural Ejido population concerning forestry management policies. Forested resources within community lands can be extracted, cleared, or utilized by non Ejido organizations or other enterprising parties. Within the study area encroachment into forests via development for urban infrastructure is legitimized by local governments in the name of progress. This legitimized deforestation has occurred and is occurring despite great efforts to protect forest resources and invest in reforestation projects. As the state governments and local municipalities helped (and continue to help) fund and manage reforestation projects in the subsistent agriculture regions to the North of Xalapa and near the towns of Coatepec and Xico, there was at the same time large scale clearing in the southeastern region on the outskirts of the urban area of Xalapa. These new developments in this region can be defined as middle to upper income residential zones, shopping malls and entertainment centers. This southeastern region of Xalapa has experienced, and will continue to experience,

considerable urban expansion as there are no efforts to protect forested areas in outlaying rural regions that lie within Ejido community lands.

Another effect of this expansion is the result of rural populations being pushed into smaller regions on the outskirts of the newly developed urbanization. These people in the past were living a subsistence farming lifestyle within the rural regions outside of the city's jurisdiction. Now, as their regions have been engulfed by the urban infrastructure, they have become more dependent on the urban environment for survival.

Three such areas were visited during field research. One in particular was a coffee agroforestry region that was cleared for Xalapa's largest ever housing development (Lomas Verdes, existing in the most southeastern region of the city). Within months of the clearing of trees inhabitants were displaced because of development in previously forested areas where small scale grazing and agroforestry was practiced. The inhabitants have formed a small community in a remaining patch of forest near the subdivision. This new community lacks sewerage or drainage, and the inhabitants have no access to utilities. Within a two month period the number of houses within the "community" has nearly doubled from 17 to 36. The urbanization of Ejido and privately owned rural lands can result into a chain reaction and cause even more resettlement when people are displaced and forced to live in illegitimate communities. Though not recognized by the official census of Xalapa, they are dependent on the urban infrastructure and to some degree participate in the urban economy and overall socio-cultural makeup of the urban area.

Therefore the dynamics of urban growth and land-use change in the region can trigger a multitude of results that can lead to degradation of natural resources that once existed in the

region. These pressures to expand land-uses or change land-use activities have also had negative affects on the local populations that depend on the natural ecosystem.

Remote Sensing and Image Processing for the Study Areas

Using two study sites to analyze forest change provided the ability to analyze deforestation at two different scales. The larger study site shows the extent and location of deforestation in a larger scope. The smaller land-use study site representing a smaller sample area exemplifies the extent and amount of deforestation as it pertains to each land-use.

The smaller land-use study site shows similar results concerning seasonal variation of forests. Within the humid subtropical zone remote sensing studies using image data can be accomplished in both wet and dry seasons.

Having both wet and dry seasonal image-data allowed for more accurate image processing of land-use classifications. Forest delineation was easiest accomplished in the dry season, when most other land cover classifications where at lowest levels of greenness activity. The humid subtropical forest within the region retains greenness throughout the year therefore making it easy to classify forest vegetation from other land cover classifications.

Wet season data contains classifications that have similar spectral signatures when photosynthesis activity of vegetation is at a peak during the rainy season. It was difficult to distinguish grazing grasses from sugar cane, and some agriculture was difficult to delineate from other vegetation features using only the wet-season image data. Using dry season data, these vegetation classes could be delineate as they retained different spectral signatures.

Using Landsat MSS image data from 1979 is useful for long-term analysis of forest change. Utilizing the higher resolution Aster data for the 2001/2002 data set to accomplish a

land-use map to be compared to the forest/non-forest data from 1979 allowed for maximum use of higher resolution data. Unlike most previous studies that accomplish land-use classifications to the extent that the lowest resolution data can delineate classes, this study attempted to extract the most amount of information from the higher resolution data. These data were then compared to the forest classification of the lower resolution data.

The drawback to this method of processing one data set of a higher number of land-use classifications, to be compared with data with fewer classifications, is the inability to compare land-use change as it pertains to every class between both data sets (1979 and 2002). However, the objective of this study was to analyze land-use change as it pertains to deforestation. Having to sacrifice the ability to compare land-use change of every class, for the benefit of utilizing a more accurate land-use map to show more precisely the land-uses encroaching into forested regions, proved to be a useful method for analyzing deforestation in the study area. The ability to retain a more precise land-use classification for the higher resolution data, and relate this higher resolution to the lower resolution data retaining only forest and non-forest, allows the benefit of maximizing the capabilities of the different data sets. The methods utilized for this study to analyze which land-uses have encroached into previously forested areas proved to be useful for the purposes of this study.

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VITA

Mark Dalrymple was born March 24th 1971. He grew up in Aspen Colorado and graduated from Colorado State University with BA in Anthropology. After graduation Mark worked in Medellin Colombia as an English instructor and returned to the US where he worked as an Archaeologist in New Mexico, Texas, and later at Mesa Verde National Park. Mark's interest in using GIS and remote-sensing for land-use analysis led him to pursue a Masters degree at the University of New Orleans. At the University of New Orleans he worked at the Coastal Research Laboratory processing satellite imagery for wetlands monitoring. In 2002 he was awarded a fellowship through NASA's Graduate Student Research Program to conduct a project in Xalapa Mexico concurrent with his thesis. Mark spent most of his time in Xalapa Veracruz conducting field research and writing his thesis. He plans to pursue a PhD to continue his research in Xalapa Veracruz.