HUMAN-ENVIRONMENTAL IMPACTS IN IXTACCIHUATL-POPOCATEPETL NATIONAL PARK, MEXICO

By

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CHAPTER 1

Introduction

The relationship between humans and the environment is a topic garnering much attention throughout the world. Since the industrial revolution, various social/ environmental movements have grown causing people to start questioning the sustainability of the earth's resources. From this questioning, support for stability and preservation rather than change and consumption has also arisen. Some would call this movement "environmentalism", and its supporters "environmentalists", or "preservationists". Particularly in this century, many organizations and institutions have been created to redirect and better manage our use of resources in an attempt to slow the pace of change accompanied with the world's population explosion and the increase in consumptive habits. Obviously, this has caused a worldwide debate that will persist well into the future.

This debate is central to many disciplines in the academic world; environmental biology, environmental history, cultural ecology, and many other fields are attempting to document human interaction with the environment in the hope that we will be able to assess our actions to help society make better-informed decisions in the future. It is important that this literature attempts to remain unbiased in terms of taking a position on human interaction with the physical environment. Whether it be conservation or consumption, the issue at hand is how humans have influenced or continue to influence the environment, and the consequences of this interaction.

Purpose of Study

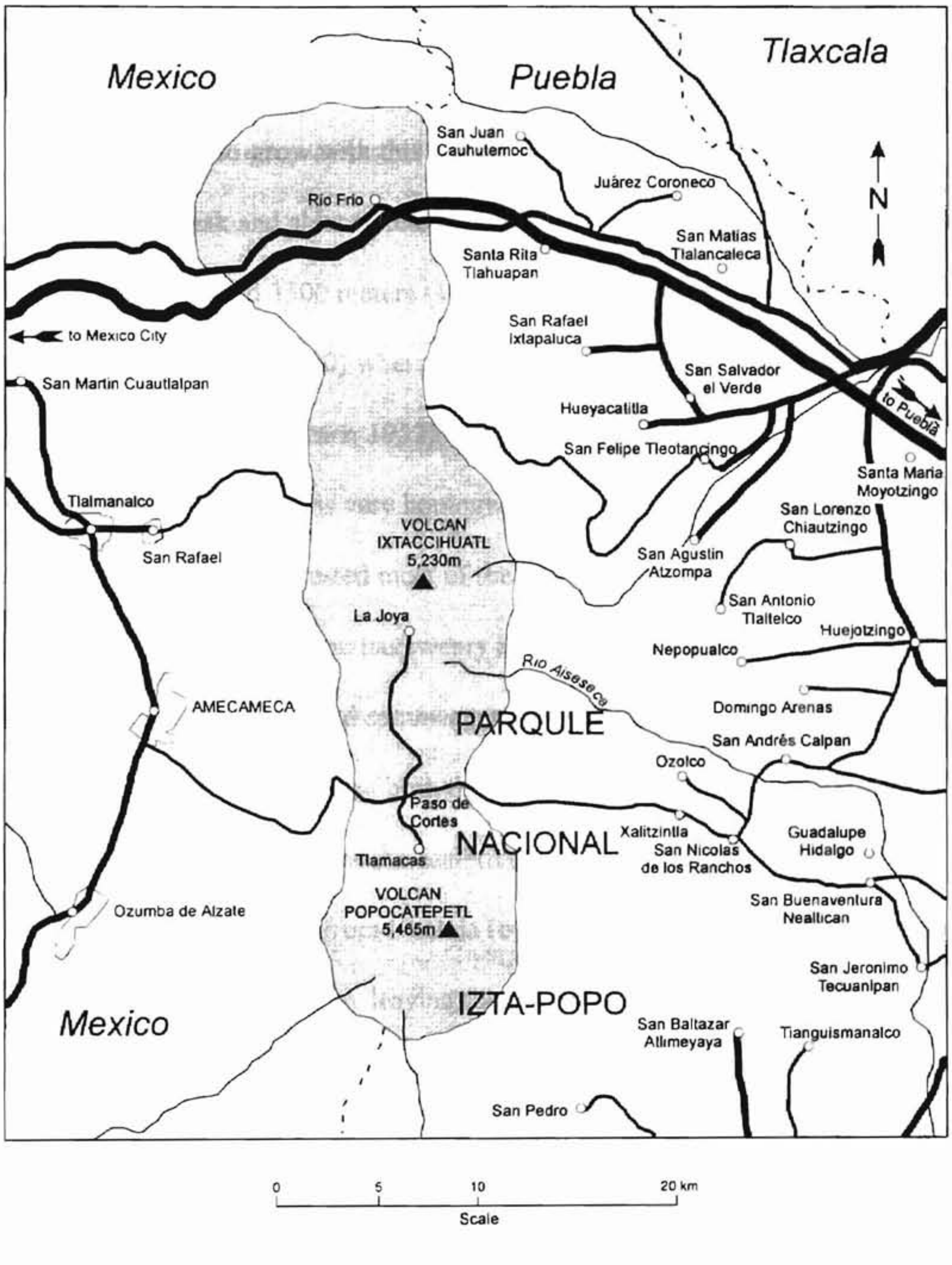
One entity within which society has attempted to limit human interaction is a national park. There are currently over 2,700 national parks in more than 120 countries. This represents a large part of the earth's surface that has been dedicated to protected status. These lands, in theory, are intended to represent islands of stability untouched by human interference. However, with world population nearing six billion people, the attraction to these lands is growing. National parks are not only characterized by great beauty, but usually possess great amounts of natural resources that humankind seeks to exploit.

The purpose of this study is not to argue the detrimental effects of human encroachment into national park lands, nor advocate limiting access to these lands and their resources. This study seeks to analyze the effects that humankind has had within a national park and how this impact has affected the physical landscape of a park and its surrounding area. The surrounding area is included because it borders the park and therefore incorporates physical and human elements in direct interaction with the park. The park selected is in a developing country because there is a significant difference in national park lands in developed countries and lesser developed countries. Lesser developed countries which have received international pressure to preserve and protect areas, have devoted many acres this century to national park status (Lightfoot, 1994). However, because their economies are generally more fragile than developed countries, they are limited from locking up precious natural resources, which often occurs when land is legally protected. Therefore many of the parks exist only in theory, and protection laws designed to protect parks are often overlooked, or poorly enforced.

Study Area

The area chosen for this study is Ixtaccihuatl-Popocatapetl National Park (Figure 1). It is located sixty kilometers east of Mexico City and forty-five kilometers west of Puebla. The park boasts two of the three highest peaks in Mexico, which are both volcanoes. The summit of Ixtaccihuatl, usually referred to as Ixta, reaches 5230 meters (17,158 feet), and Popocatepetl or Popo towers to an elevation of 5465 meters (17,930 feet). The volcanoes are considered by local people, including many in Mexico City and Puebla, to be sacred. The local residents believe that many years ago Popo was a warrior in love with a woman named Ixta who was the daughter of a local emperor. While Popo was away in battle, Ixta falsely received word of his death. Upon hearing this, Ixta took her own life knowing she could not live without her love. Popo returned only to find his love dead. In a fit of anger and sorrow, Popo built two mountains, on one of which he laid his love, and on the other he forever stands holding her funeral torch. Thus came the Nahuatl Indian words, Ixtaccihuatl, meaning 'sleeping woman', and Popocatepetl, meaning 'smoking mountain'. Ixtaccihuatl has four peaks which resemble human features. These peaks running from north to south are called La Cabeza (head), El Pecho (breast), Las Rodillas (knees), and Los Pies (feet). As for Popo, it has been periodically venting smoke and ash for centuries, and continuously since its December 21, 1994 eruption which claimed the lives of four people. Today, many of the local people truly

Location of Ixtaccihuatl-Popocatepetl National Park



Source: Instituto Nacional de Estadistica Geografia e Informatica (INEGI).

Figure 1

believe that whenever Popo vents steam from its crater, it is out of anger.

Another unique attraction in this park is the world's highest pine forest, which lies on the volcanoes' slopes. The vegetation within the park consists mostly of pine, fir, alder, oak, subalpine prairie, and alpine meadow. The forest normally starts around 2300 meters (7,500 feet) where it consist of an oak-alder composition. At around 2500 meters (8,200 feet), pine begins to grow with this oak-alder forest upward until 2800 meters (9,200 feet). Here the oak and alder species discontinue, and fir begins in the more moist parts of the park. At around 3500 meters (11,500 feet), the forest consist solely of pine upwards until 4000 meters (13,100) where this gives way to the alpine meadows that consist mainly of bunchgrass (Sears, 1952).

Around the park the land is very homogeneous consisting mostly of cornfields and beanfields. These fields are harvested most of the year, except for the winter, which is rather dry for the region. The region has twenty to forty inches of rain annually, most of which falls during the late spring and summer months.

The park can be accessed from both the western and eastern slopes. However, the road from the west is paved, whereas the eastern road is a rough, single lane dirt road. In summer 1996, a route was paved from Cholula (on the east side) to the small village of Santiago Xalintzla, but it stops there, leaving the old dirt road for access to the park. The western entrance to the park consists of several small buildings used by the forest service. Only one of these buildings is staffed, and not consistently. The eastern entrance has a building as well, but once again this is usually not staffed. Within the park, the main station is located at Paseo de Cortes. Here lies one of only two monuments in all of

Mexico paying tribute to Hernan Cortes. This station is large and has bathrooms, but because of Popo's activity it has recently been all but shut down. It is staffed by one employee of the park service. The park has a 98 bed lodge directly south of Paseo de Cortes called Tlamacas. This is the primary place for visitors to stay while at the park. However, since the 1994 eruption it has been shut down and is off limits to civilians. North of Paseo de Cortes a dirt road runs the distance to La Joya, a parking lot from which trails lead up to the summit of Ixta. In addition, a television and microwave station are near La Joya. Currently, this facility provides rooms for visitors wishing to view the peaks or ascend Ixta's slopes.

The volcanoes are situated running north/south along the border between the states of Mexico and Puebla. There are eighteen recognized municipios (equal to U.S. county) on the east side with a combined total population in 1995 of 332,000 people. On the western side, in the state of Mexico, there are four recognized municipios with a combined total population of 110,000 people (INEGI, 1996). These municipios are considered by the Instituto Nacional de Estadistica Geografia e Informatica (INEGI) to be in the park's hinterland, thus possibly affecting the resources in the park.

Statement of Problems and Objectives

Ixtaccihuatl-Popocatepetl National Park encloses land that has been set aside as a protected area to limit human interference with the natural landscape in an effort to help preserve the current ecosystem. This park is an ideal choice for studying human interaction with national park lands because of its location. One of the world's largest population centers (Mexico City) is situated at its western doorstep, and on its eastern side lies another large city (Puebla). This study will attempt to answer four primary questions: (1) how have humans impacted the environment in the park, (2) what types of activities have most effected change, (3) how has this impact altered the landscape through time and, (4) what is the likely future of landscape patterns considering present land use and park policy?

The primary objectives of this study are to examine the historical record of the past few decades to determine if humans have, in fact, significantly altered the landscape in Ixtaccihuatl-Popocatepetl National Park. By reviewing the literature dealing with national parks the following hypotheses are posited to test the impacts that humans have had in the park:

1. Large numbers of people visit the park each week for recreational purposes. These people have an impact by consuming fuelwood and leaving waste behind.

2. A large part of the forest is being consumed by illegal logging which is still permitted in the park.

3. Vendors selling products to tourists consume the parks resources and also leave waste behind.

4. People residing in and adjacent to the park clear the forest to provide land for agricultural production.

5. Local residents in the surrounding villages are clearing the forest for fuelwood.

6. The forest service encounters many difficulties in attempting to manage the park's resources and in limiting human encroachment.

CHAPTER 2

Literature Review

This review is divided into five parts: (1) an overview of national parks in Latin America and research supporting conservation, (2) literature that points out the benefits and costs associated with national parks, (3) literature involving methods used in environmental research, (4) a sample of articles surveying image processing methods to be used for this research and, (5) a collection of articles discussing various methods to assess human impacts on landscapes.

Overview of Latin American National Parks

"The Tropical National Parks of Latin America and the Caribbean: Present Problems and Future Potential" by Alan L. Eyre (1990) presents a good overview of national parks throughout Latin America; what a national park is, why they are needed, and some of the major problems they face.

A national park is defined as

> a relatively large area where one or several ecosystems are not materially altered by human exploitation and occupation, where plant and animal species, geomorphological sites and habitats are of special scientific, educative, and recreative interest or which contains a natural landscape of great beauty, and where the highest competent authority of the country has taken steps to prevent or to eliminate as soon as possible exploitation or occupation in the whole area to enforce effectively the respect of ecological, geomorphological, or aesthetic features which have led to its establishment, and where visitors are allowed to enter, under special conditions, for inspiration, educative, cultural, and respective purposes (IUCN 1971, 13).

In summary, the purpose of Eyre's study was to give an overview of the development of national parks in Latin America; the purpose they serve, why they need to be studied, and their current status.

Two hundred million people now residing in Latin America look to the national parks as a way out of the city and a place to enjoy various recreational activities (Eyre, 1990). In Central America, 75 of the protected wildland areas are being settled in and exploited by indigenous peoples (Herlihy 1990). According to Eyre, the need for national parks plays a role in the conservation of the biosphere. National parks serve many roles such as helping to preserve the genetic diversity critical to the delicate tropical biomes and to the balance of nature, helping to forestall climatic change, and provide a limited-use area for recreation (Eyre 1990).

There has been significant progress in the development of national parks in Latin America in the past couple of decades. The total area of parks has grown with the number of parks increasing from forty-eight in 1971, to one hundred and sixty-eight in 1990 (Eyre 1990). Many countries have devoted a large proportion of their land to national parks. Honduras and Costa Rica serve as excellent examples. When combined, the two countries' parks account for eighty-five percent of the total protected land in Central America (Herlihy 1990). The following table illustrates the change in the number of parks per country for selected countries throughout Latin America from 1971 to 1990. Although it does not represent area, it does illustrate how significant the concept of dedicating land to national park status has been in the last two decades.

Table 1

Number of National Parks in Latin American Countries (After Eyre 1990)

Country	1971	1990
Bolivia	0	5
Brazil	7	25
Colombia	13	26
Costa Rica	0	14
Cuba	0	4
Dominican Republic	1	5
Ecuador	1	7
Guatemala	4	5
Honduras	0	3
Mexico	13	30
Panama	0	4
Venezuela	7	27

Notice that Mexico and Venezuela have increased their number of parks dramatically. Sheer number of parks alone, however does not represent the efforts these countries are putting into effective conservation. Some have large numbers of parks, but how many of these parks are actually serving their purpose is another matter. Many of these parks are considered to be "paper parks":

> About two percent of the world's rainforests have been declared nature reserves or national parks. The vast majority of these are completely unprotected, and some are leased for logging or other disturbing activities. Brazil has one of the most impressive systems of protected areas in all rainforest countries. But only one of the national parks has a director, guards, rangers, and the money to carry out essential works, such as marking the boundaries. The rest are what is known in the trade as 'paper parks' (Caufield 1984, 234).

Paper parks are those officially protected as national parks, yet lack the enforcement to prevent illegal activities from taking place.

According to Chris Park (1994), the establishment and management of national parks plays a crucial role in the goal of a perpetually sustainable environment. The interest in Latin American national parks is relatively new and should tie in well with the sustainable development theme. These types of studies increased dramatically during the 1980's. Gary Hartshorne worked on conservation throughout Central America, Tosi and Morales assessed the situation of forests in Costa Rica, and Dickinson completed a comprehensive study on the inventory of natural resources in Honduras (Herlihy 1990). *Defending the Land of the Jaguar: A History of the Conservation in Mexico* (1995) by Lane Simonian is a recent publication that comprehensively details the known history of conservation in Mexico. It does so by recognizing the leaders involved in the conservation movements, their individual political and social influence, and how this has shaped present day policy and attitudes.

Benefits and Costs of National Parks

There are many books that take a two-sided view towards the establishment of protected areas; discussing the impacts in a cost/benefit fashion. *Economics of Protected Areas: A New Look at Benefits and Costs* (1990), by John Dixon and Paul Sherman, is of this nature. The authors present both the costs and the benefits of establishing and managing national parks and other protected areas. They point out that this trend is a relatively new one, evident only in this century. Some of the benefits associated with national parks discussed by the authors are recreation, watershed protection, ecological processes, biodiversity, education and research, consumptive benefits, non-consumptive benefits, and future values. The costs are identified as direct costs involved with establishing and maintaining parks, and opportunity costs involving the benefits society loses when an area is protected, such as lost resource consumption.

Economics of the Environment (1977), by Robert and Nancy Dorfman is a collection of articles that illustrates the use of resources from an economist's point of view. Although this collection does not deal directly with national parks, it is included in this literature review to support the position that a human encroachment study in a national park is needed. The fact that a controversy over preservation exists merits the need for these studies to see if national parks are, in fact, helping to preserve the environment in Latin America.

Many economists believe, as stated above, that the environment needs to remain healthful for the economy to thrive, yet flow of resources should not be restricted. This is the goal of sustainable development. By protecting some of our lands, we are nourishing the environment, but still allowing for the flow of resources, mainly outside the park.

Areas protected by national park status are lands "where one or several ecosystems are not materially altered by human exploitation and occupation" (IUCN 1971, 13). This guideline as set out by the IUCN was added for the preservation of certain areas, thus working toward achieving the goal of sustainable development. Humans do, in fact, occupy national parks, and they do affect the ecology of these protected areas. But what is their impact, and is the impact affecting the goal of preservation and sustainable development in the area?

Methods in Environmental Research

An article by Chris Park in *Progress in Physical Geography* titled "Environmental Issues" (1994) has helped illustrate some general topics involving environmental research. Although the article is not directly intended for national parks, it did lead to information on what tools are available for research emphasizing sustainable development, a concept largely associated with national parks. This article summarizes directions of research in environmental issues and the direction the field is moving, by sampling a few of the recent publications in various subfields of environmental research. The current focus of environmental research seems to be in environmental management and the tools used to make decisions in this process.

The article points out that the United Nations Conference on Environment and Development has aided the environmental cause by providing five formal documents on climate change, biodiversity, forest principles, and other environmental issues on which researchers can base their work. This has been a "catalyst" in the new environmental research which seems to be centered on sustainable development and conservation. The focus is on implementing programs to conserve our earth for future generations (Park 1994).

There are a number of environmental concerns that the research will be focusing on in the future. The first concern mentioned by Park (1994) is global warming, which has been at the top of the list of environmental concerns for the past decade. Most research on this subject deals with policy making, and concentrates on prevention. Biodiversity and species extinction is another area of focus that this research is concentrating on. Research in the future will concentrate on populations, and solutions designed to prevent the loss of species. The last concern mentioned has to do with trade relationships and their effect on the environment. The proposal here is for complete reform of trade relationships (Park 1994). Many developed countries implement environmental policies and regulations in their own country, and then manufacture and assemble products in developing countries specifically to avoid their country's own environmental regulations.

In order for sustainble development to be implemented the necessary tools must be available for researchers to do their job. This has been a significant area of growth, which has greatly aided in the process of environmental management. Park discusses some of the main tools used in environmental decision-making. These tools might aid in the research of national parks and help increase the role that national parks play in sustainable development. The first tool discussed by Park is an Environmental Impact Assessment(EIA). This is a procedure used to assess the impacts of developments on the environment, providing rationale as to whether these developments are acceptable. Another tool that is used to study environmental impacts is known as environmental modeling. Environmental modeling uses a computer to simulate conditions and outcomes. This is a very popular direction of research shown by the growing number of published models. Environmental auditing that is based on an analysis of the impact of all activities that may have an impact on the environment is yet another important tool aiding the cause of sustainability (Park 1994).

The last tool discussed by Park involves the incorporation of various technologies to aid in environmental management. One of the principle components of the technological tools is the incorporation of a Geographic Information System (GIS). A GIS can be used to manipulate physical and socioeconomic data to develop long-term management strategies for the environment (Park 1994).

One tool not discussed by Park, which works hand-in-hand with a GIS, is remote sensing, or image processing. Human-encroachment studies are concerned with change, and the field of remote sensing is well-suited for identifying change across space through a process known as change detection analysis. The basis of this technique is that "changes in land cover must result in changes in radiance values and changes in radiance due to land cover change must be large with respect to radiance changes caused by other factors" (Singh 1989, 989). Change detection analysis is useful in the assessment of deforestation, vegetation changes, and other factors that human occupation could have caused.

These tools all seem to provide a solid framework for a working methodology in environmental research. One of the main problems that still exists is the availability of accurate data. In evaluating change of landscapes, researchers are limited by the availability of data from the historical record. One form of data that has increased our knowledge about the earth is satellite imagery. The next section will discuss this form of data and its use in evaluating change in landscapes.

Image Processing Techniques

Coinciding with the world's population explosion is the need for the careful management of our natural resources for future generations. Remote sensing and a GIS, are some of the newest tools developed to help us achieve the goal of economic growth with sustainable development (Park 1994). Specifically, the application of change detection in monitoring natural resource change is very useful for monitoring the environment. This process has given us the ability to forecast the results of human action upon the environment. As the body of literature on change detection grows, so will humankind's historical record of the extent of our action upon the environment. With this historical knowledge we will be able to make better-informed environmental and economic decisions in the future.

This section starts out with a discussion of some of the problems associated with remote sensing in developing countries, then offers an overview of remote sensing in forested areas. Afterwards, a section is included covering some of the literature that deals with change detection in a generic sense and concludes with a section identifying some of the common applications associated with change detection of forest environments on a local, regional, and global scale.

Remote Sensing in Developing Countries

Since the early 1970's humans have been acquiring digital imagery of the earth's surface from space. This data is readily available for most parts of the earth. However, in developing countries the technology is not as easy to apply as in developed countries, as pointed out by Petera and Teteishi (1995); "On the technological side, remote sensing and GIS have various problems common to the entire world, but on the application side the problems are much more severe in the developing world". There are many problems associated with performing remote sensing processes in developing countries that are not encountered in the developed countries, especially the United States where the technology has advanced at the most rapid rate.

One of the main problems that developing countries encounter is low economic strength (Petera and Tateishi 1995). The satellite imagery itself is relatively inexpensive when considered that most of the resource monitoring will be done by either governments, academia, or corporations. However, the lack of hardware and ancillary data to facilitate the processing of these images could be a costly investment for most developing countries. The United States is fortunate to have agencies such as the Bureau of Land Management (BLM), or the United States Geological Survey (USGS) that provide necessary ancillary data to aid in such processes as rectification, and registration of satellite imagery. In addition, most developed countries have an archive of publicly accessible aerial photographs to aid in image interpretation. Another benefit associated with remote sensing and GIS in developed countries is the availability of ancillary data in digital format such as TIGER files or Digital Line Graph's (DLG). This technology is not available in most developing countries which can make image processing more time consuming. It also makes it more difficult to achieve a higher confidence of accuracy.

Most developing countries do not have an organized grid system sectioning off the land. Most topographic maps are outdated, or are of too small a scale to be useful. Aerial photographs exist, but time and place of imaging is often sporadic and limited, or the photos are not available to the public. Another problem associated with performing remote sensing in developing countries is field work. Ground truthing, performed to verify the accuracy of imagery, is often very difficult in developing countries because of the lack of access to training sites or sample sites. This can be inhibited by lack of roads, military blocks, disease, or many other factors not common in developed countries. Specifically, in change detection methods where ground truthing is limited to historical data and personal interviews (Prins and Kikula 1996), accurate communication is essential. This communication is often misinterpreted from language barriers like dialect differences, which commonly exist in developing countries (Perera and Tateishi 1995).

Some of the problems that exist in developing countries also exist in developed countries. In general, wherever you are performing the study, limitations will exist and researchers will have to use available data and deal with these limitations on an individual basis. Currently, these limitations are being addressed as the technology advances. For example, the newest SPOT satellite has been designed with an on-board registration of all spectral bands. Perhaps in the future most satellites will collect imagery with on-board rectification which would increase the accuracy of image processing.

The application of remote sensing in developing countries has proven to be very beneficial and will only become more useful in resource management in the future. One area in remote sensing that has shown growth is the monitoring of forest vegetation.

Remote Sensing of Forest Vegetation

The article, "Use of Digitally Processed Satellite Images in Studies of Tropical Rain Forest Vegetation" (Tuomisto et al. 1994), points out the value of using satellite images in studying tropical rain forests. Satellite images proved useful in vegetation and geologic studies of areas which have poor accessibility. A Landsat MSS image was analyzed to find the best methods for identifying different vegetation types and geologic formations. The authors point out that, in their study, the best results were obtained using enhanced color composites and PCA of areas where the vegetation was known. The digital classifications they performed were far less successful. Another article titled "TM Digital Processing of a Tropical Forest Region in Southeastern Mexico" (Garcia and Alvarez 1994) proved to be much more successful in achieving an accurate land classification. The increase in accuracy is more than likely attributed to the increased spatial and spectral resolution of Landsat TM over that of Landsat MSS. The authors also used 103 ground samples and aerial photography to help improve the accuracy of the classification. Fourteen different classes were identified using a hybrid (supervised/unsupervised) classification with an accuracy of 84.4 per cent. The authors then used a GIS to compile a land use and vegetation map. The authors illustrate in this study that the finer resolutions associated with TM data render it more useful in applications where vegetation is significantly heterogeneous than that of imagery with coarser resolution. However, Landsat MSS has been useful for classification studies where less precision is needed. "Forest-Type Stratification and Delineation of Shifting Cultivation Areas in The Eastern Part of Arunachal Pradesh Using Landsat MSS Data" (Roy *et al.* 1985) is one such study in an inaccessible area where broad forest-type mapping was successfully done using Landsat MSS data.

A few of the more recent publications such as "Mapping Forest Vegetation Using Landsat TM imagery and a Canopy Reflectance Model" (Woodstock *et al.* 1994) illustrate some new methods in analyzing forest vegetation with remote sensing tools. In this article the authors use a combination of image segmentation and classification to estimate tree size and cover for individual forest stands. From these estimates, general-purpose vegetation maps useful in land management applications are produced. From the same model, the author published another paper titled "Mapping and Monitoring Conifer Mortality Using Remote Sensing in the Lake Tahoe Basin" (Macomber and Woodcock 1994). This article illustrated that stands of coniferous forest can be effectively mapped and inventoried. These techniques have been created for applications in developed countries; however in the right situations they could be useful in the developing world as well.

Several books offer insight into remote sensing of forest vegetation exist in the literature. *Remote Sensing and GIS in Ecosystem Management* (Sample 1994) has a whole section dedicated to the management of forest ecosystems using remote sensing. There are three chapters covering topics ranging from the economics, planning, and the application of remote sensing to ecosystem management.

Remote Sensing and Geographical Information Systems for Resource Management in Developing Countries by Alan Belward and Carlos Valenzuela (1991) has a chapter dedicated to remote sensing for tropical forest monitoring. This book approaches forest monitoring on a local scale, regional scale, and a global scale. One area this book does not cover is the problems associated with remote sensing in developing countries. It will occasionally make inferences about difficulties that one may encounter, but there is no mention of the problems discussed earlier.

Satellite Remote Sensing of Natural Resources (Verbyla 1995) is another book that offers some insight into the remote sensing of forest ecosystems. Although it does not specifically dedicate a chapter to the topic, it still offers the best explanation and organization on the techniques involved in image interpretation.

Change Detection

Change detection is a remote sensing process that determines difference in land cover between multitemporal data sets. This can be used in a variety of applications including: the monitoring of deforestation, monitoring vegetation change, determining urban growth or recession, monitoring climatic change, and monitoring geologic change. The preceding are just a few of the specific applications associated with change detection. These specific applications can each be categorized into two broader groups that either deal with monitoring the change in natural resources, or monitoring the change in man-made features. Often the two are unavoidably combined in the process.

The data available for monitoring these changes comes in many different forms and is dependent upon where the study area is located and for what dates the study will span. Generally, data gathered should be consistent between the different dates of data acquisition with the same spatial, spectral, geometrical, and temporal characteristics (Lillesand and Kiefer 1994) in order to exclude differences in these factors between multitemporal images.

There are many forms of remote sensing that could be used in change detection. Two of the most commonly used include photography, and digital imaging. These two forms are best utilized from either an airborne platform or from space. Normally, digital imaging is associated with satellites acquiring images from space, and aerial photography is associated with the airborne platform. In recent years, the use of satellite data in change detection embodies most of this literature. There are three different sensors that have historically been used successfully for change detection. These include the Landsat satellites, SPOT satellites, and the AVHRR sensor aboard the NOAA satellites. Satellite images are readily available for most of the world from about 1972 onwards and are improving in terms of ease of use and quality as the technology advances with time.

There are several different methods of performing the change detection process. Ashbindu Singh (1989) does an excellent job of discussing the different methods in an article titled "Digital Change Techniques Using Remotely Sensed Data". In this article, Singh discusses univariate image differencing, image regression, image ratioing, vegetation index differencing, principal components analysis (PCA), post-classification comparison, direct multidate classification, change vector analysis, and background subtraction. In this review some of the most commonly used methods will be discussed. Singh is quick to point out that errors are involved with all of the methods of change detection, but points out that various techniques are being developed to deal with these errors such as the on-board registration on SPOT's newest satellite.

The first technique discussed is univariate image differencing, otherwise referred to as temporal image differencing (Lillestrand and Kiefer 1989). This technique involves the registration of two or more images from different time periods. Each individual pixel is subtracted from the same registered pixel on one of the other images to produce the output that identifies areas of change. Subtracting large digital numbers (DN) from small ones results in a negative number, which would be of little use for display purposes. To deal with this a constant is added to get rid of the negative numbers. Areas with no change will yield a DN close to the mean value and areas of change will be located in the tails of the histogram distribution.

Image ratioing is another method commonly used for change detection discussed by Singh (1989). Two separate registered images from different dates are ratioed against each other using individual bands. Areas experience no change if the reflectance is nearly equal in each image after the ratioing process has been completed. On the other hand, areas experiencing change will yield a value greater or less than one after being ratioed, with the interpretation depending on the characteristics of the bands being used. Vegetation index differencing is a form of image ratioing that Singh (1989) discusses. It is in this section where he points out that ratioed images have some important properties:

> First, strong differences in the intensities of the spectral response curves of different features may be emphasized in ratioed images and, secondly, ratios can suppress the topographic effects and normalized differences in irradiance when using multidate images (Singh 1989, 994)

These properties can help when dealing with scene illumination problems and topographical problems.

The next method discussed is image regression, which is the process of regressing one image's pixels against another image's pixels of a different time. A thresholding technique is then used to define areas of change. The regression technique accounts for differences in the mean and variance for pixel values of different dates so that atmospheric and solar illumination effects are eliminated or reduced (Singh 1989). The article reported that this procedure performed better than the univariate image differencing discussed earlier.

Another method discussed is principle components analysis (PCA). This is a technique developed to remove redundant data between bands for analysis. In change detection studies the principal components for two or more dates are found with the major changes occurring in the first couple of components and the minor changes are highlighted in the later components. How much information that is implied about change depends on the intrinsic dimensionality or number of bands in the data set (Singh 1989).

Probably the most commonly used method of change detection is post-classification comparison. This is a technique that involves the separate classification of each image and then the registration of the images to each other. The images can then be coded similarly and overlaid to identify the areas of change. As stated earlier, there are problems associated with all of these techniques and in post-classification comparison the fact that the two images are classified independently and then overlaid can significantly decrease accuracy. As Singh illustrated in his article, "for example, two images classified with 80 per cent accuracy might have only a 0.80 * 0.80 * 100 = 64 per cent correct joint classification rate" (Singh 1989, 996). To deal with this problem the images must be carefully classified in the first place. A working knowledge of the area will help increase the accuracy of the initial classification which will increase the accuracy of detecting areas of change. In addition, accuracy can be increased by decreasing the number of classes necessary for the application.

The final method discussed is change vector analysis. This technique is used to identify the direction and magnitude of spectral change between two dates on a pixel by pixel basis from two bands. The vector connecting the two points from each pixel is used to do this by establishing a threshold point of change. The threshold is determined by the analyst, which can lead to somewhat subjective conclusions if a the threshold is not derived by some standardized method.

As illustrated, there are a number of change detection techniques available to the analyst. The best method depends on the individual application that is being sought, and often a combination of these methods will produce the most desirable result.

Change Detection of Forested Environments

"An Assessment of several Linear Change Detection Techniques for Mapping Forest Mortality Using Multitemporal Landsat TM Data" by John Collins and Curtis

Woodcock (1996) is one of the more recent articles that discusses some techniques for monitoring forest canopy changes. Three different change detection methods were examined, including the Kauth-Thomas transformation, Gramm-Schmidt orthogonalization, and multidate principal components analysis. The authors also tested to see if preprocessing of the image had an effect on the results by performing the test with three different preprocessing methods, including: no preprocessing, matching DN's of invariant features between the two images, and full radiometric correction and matching DN's. The authors concluded that the Kauth-Thomas wetness method is the best technique to determine forest change, and that preprocessing the images had little effect on the results.

The following two articles present a good example of the application of change detection on a large scale study area that proved to be very successful. Both studies were conducted in developing countries as well. "Digital Change Detection of Forest Conversion of a Dry Tropical Indian Forest Region" by Unni and Jha (1994) uses Landsat MSS scenes from 1982 and 1989 to determine the change in vegetation cover. The study area covers the Sobhadra district, Uttar Pradesh, the Singrauli coal fields, and part of the Sarguja district in Madhya Pradesh, India. As stated earlier, this part of the world is developing, thus the authors had to overcome some major difficulties to achieve their results, but it does illustrate that these methods can be applied in developing countries. The authors used the following materials and methods: satellite data of the same or similar phenology which the authors point out as being critical, ancillary data collection including maps and field observations, geometrical correction referenced to ground control points, normalization for atmospheric and seasonality conditions, and a variety of change detection methods. The authors point out that the two images must be registered to each other with an accuracy of one pixel or less or errors from the registration could be misinterpreted as land cover change. The authors then explain their methods of image rectification and image registration, which is useful to readers who are not familiar with remote sensing techniques. The change detection method employed by the authors in this study was image regression. In addition, they performed image differencing and PCA to compare the results of the change. The authors found that the overall accuracy of their results was 74.8 percent. They present their results in a tabular form with the areal values and percentages of land change. The results of this study illustrate that change detection of forested environments can be performed fairly accurately even in the developing world with limited data and hardware resources.

"Deforestation and Regrowth Phenology in Miombo Woodland - Assessed by Landsat MSS" (Prins and Kikula 1996) also does a good job of illustrating change detection methods of forest lands in a developing country. In this study the authors use seven Landsat MSS images to assess the deforestation and regrowth patterns of Miombo woodland in southwestern Tanzania from 1972 to 1988. The authors used the post-classification method of change detection to determine the areas of deforestation and regrowth. The spectral signatures of either cleared area or covered area was fairly easy to classify because the area is very homogeneous. Either wooded or cleared grasslands make up most of the study area. The authors performed ground truthing through a series of personal interviews and training sites to become familiar with the area. The study once again confirms that in the right situation change detection is very possible in the developing world. Currently Landsat MSS has been used significantly more than TM data in change detection because of TM's relatively recent birth. In the future, as spatial and spectral resolutions increase, images will offer more information. However, from 1972 to 1993 Landsat MSS successfully acquired data that bestows a wealth of information about our earth in this time period.

On a smaller scale, an article is included that discusses the application of change detection on a global level. "Modeling of Global Change Phenomena with GIS Using the Global Change Data Base" (Hastings and Liping 1994) addresses how an integrated global data base originally designed for regional study is being applied to study global change. The article discusses how the World Data Center for the past fifteen years has been building a Global Change Data Base (GCDB) including information ranging from elevation, population distributions, water monitoring, land cover, vegetation, and etc. From a remote sensing perspective it discusses how they have collected an archived data base of AVHRR data with 1.1km spatial resolution to aid in global change detection.

The final article, "Seeking the Truth in Kathmandu; Fieldwork as an Essential Component in Remote Sensing Studies" (Craven and Haack 1987) stresses the importance of ground truthing to validate remotely-sensed data, and improve accuracy. It points out that remote sensing studies are very valuable if they actually reflect the conditions of the earth's surface. The article deals with measuring the growth of an urban area, Kathmandu, through the use of remote sensing techniques. In addition, to improve the accuracy of the remotely-sensed data, reference points were collected in the field. This article provides justification for fieldwork to help improve the accuracy of any change detection study whether in an urban environment or a forested environment.

Probably the most commonly used application of change detection in forested ecosystems in developing countries is the monitoring of deforestation. Along with deforestation comes other changes that can be monitored with remote sensing such as clearing practices, surface energy interactions, or fire dynamics (Belward and Valenzuela 1991).

The numerous applications all occur at different scales including the local scale, the regional scale, and the global scale. On the local scale the change is mainly concerned with human activity (Belward and Valenzuela 1991). How humans affect the clearing process, the shifting of cultivation, or logging activities are all phenomena that change detection can help address at the local level.

On a regional level the change in developing countries is concerned with large area change. The agent of change in regional studies is deforestation itself rather than human impact. For instance, how a deforestation front is impacting the climate or economy within a region is a common question that might be addressed at a regional scale using change detection.

On the global scale change detection is concerned with assessing the condition of the whole planet. How is the reduction of forest affecting the hydrological cycle of the planet, or how is it affecting the exchange of oxygen and carbon dioxide in the earth system? These are questions that remote sensing and change detection are attempting to answer.

As the world develops and the population of the earth continues to grow there is widespread support for maintaining a balance with nature. Change is inevitable, and therefore change detection methods have been developed to help us assess the degree of change and the impacts of these changes. The monitoring of the earth's forest is one area that has room for improvement, especially in developing countries, and it appears that we are moving in the right direction with the advent of new technologies.

Human Impact Assessment

Most change detection studies involving image processing techniques identify the change but give no explanation for their occurrence. The difficulty in assessing the causes of change may be a significant reason for this. Interviews and field work observations seem to be the best methods currently available to assess human impacts on landscapes, as this section will illustrate. Field work can be a time consuming and expensive process, which probably has played a role in the absence of causation in change detection studies involving image processing.

One study, "Analysis of Human Impact on a Forested Landscape of Central Italy with a Simplified NDVI Texture Descriptor" (Ricotta *et al.* 1996) attempts to identify human impact on a landscape by using image processing techniques and *a priori* knowledge. The authors base the human impact on the non-forest classes that are "closely related to human activities" (Ricotta *et al.* 1996, 2871).

"An Analysis of Land Use/Cover Change Using the Combination of MSS Landsat and Land Use Map--A Case Study in Yogyakarta, Indonesia" (Dimyati *et al.* 1996) is another study utilizing image processing that attempts to evaluate change and provide additional analysis. This study uses two Landsat MSS scenes, one for 1972 and one for 1984, to perform change detection. Through field work, additional analysis is offered concerning settlement patterns. The newly settled areas all seem to have taken place within close proximity to roads throughout the study area. This study briefly discusses the methods used to acquire information about settlement patterns. It continues with an evaluation of the change and probable causes, although not directly indicated by the author.

There are many studies that deal with human interaction with national park lands. However, very few depend on remote sensing techniques. Instead, they incorporate historical data and field work for analysis. "Historical and Contemporary Human Disturbance in the Upper Barun Valley, Makula-Burun National Park and Conservation Area, East Nepal" (Byers 1996) incorporates various techniques such as pollen analysis, carbon 14 dating, historical documents, and the current land use of local people to evaluate the human impact within a national park. The change in the landscape of the park predominantly was forest land that has been converted to pasture land. This change was assessed through observation and interviews.

Another study that identifies human impacts on a landscape is "Human Impact trend in Crete: the Case of Psilorites Mountain" (Lyrintzis 1996). The change was evaluated using land use records and census data, which exist for the past forty years. This study illustrates that human impact can be assessed quantitatively if a good historical record has been documented. The authors mention nothing about field work in assessing the human impact, which seems to be livestock raising on land that has been converted to ranges from forests.

Many articles discuss human activities in protected areas that address environmental impacts from a management perspective. The methodologies in these studies seem to employ field work to assess the changes in the area as well. "Protected Areas, People and Incentives in the Search for Sustainable Forest Conservation in Honduras" by Michael Richards (1996) is a study that approaches land cover change from this perspective. During field work, various government officials were interviewed, as well as local farmers, resource managers, and park staff. This study identifies two protected areas in Honduras and evaluates the condition of these parks in terms of management practices and protection policies. The author points out that the only benefit that a forest has to the local people of the region is what lies under its soil (Richards 1996). The human issues Richards discusses deal with settlement, land tenure, and management and conservation interventions.

The literature reviewed in this section depends largely on field work for data collection to assess the physical changes in protected areas and the human role in this change. In the future, studies will be able to incorporate image processing to facilitate this process. By being able to show government officials, resource managers, park personnel, and local farmers in these regions physical evidence of the change that has occurred, better conclusions can be made about the causes of these changes.

CHAPTER 3

Methodology

This chapter will discuss the methods employed to identify the impact that humans have upon the environment of Ixtaccihuatl-Popocatepetl National Park. The first part of this chapter discusses the various sources of data utilized for analysis of the physical change in the landscape. The second section discusses the data used to measure the impact that humans have played in this landscape change. The third section provides justification for this field work. The chapter concludes with a discussion of the methods of change detection chosen to measure the physical change of the landscape and the construction of the database used to accomplish this measurement.

Data Sources

To assess change over time in landscapes, researchers must seek out the historical record as a gauge of measurement. This historical record is encompassed by many different forms of data and whenever possible these must all be combined to evaluate change comprehensively; whether the data is in a written piece of literature, perhaps a photograph, a physical measurement in static time, or the accounts of human memory, each can be assessed to help give a more complete description of change.

In assessing the impact that humans have had over time in Ixtaccihuatl-Popocatepetl National Park, it is first necessary to determine the length of time to be used in evaluating the change. This is largely dependent on the available data.

Human occupation in the region extends back at least 5000 years, and humans have been using resources near the summits of the volcanoes for 1000 years, if not longer. There are accounts of human occupation as far back as 900 A.D. on the northeast ridge of Ventorillo on Popo's slope (Secor 1981). Here a small structure that is believed to have been built by the Aztecs has been excavated. This is the highest structure to have been found in the region. European written records exist as far back as October of 1519, when Hernan Cortes set out to climb over the mountains to reach the valley of Mexico and described the event in a letter (Morris 1928). However, the national park was not established in the area until February 11th, 1948 (INEGI 1996), so only data since 1948 was sought.

The next step was determining the type of data to be used to evaluate the physical change and the type of data available to measure the human impact. Written description of the park through time is one form that could be useful. Unfortunately, there is little applicable published information about the park since its establishment. One form of available data, which provide archival information about physical landscape in the park, is remotely sensed imagery. Aerial photography and satellite imagery are two such forms. These data can be used to determine changes in landscapes through time. Aerial photographs are useful by providing visual information; however, it is difficult to measure change quantitatively from these. In addition, no photographs could be found during the two fieldtrips to the area, not even at Compania Mexican Aerofoto in Mexico City. Satellite imagery of the earth's surface, including the study area, has been available since the early 1970's and this is the form of data that has been chosen to measure changes in landscape through time. These data are limited by atmospheric conditions and spatial, spectral, radiometric, and temporal resolutions.

A combination of resources is available to measure the human impact on the environment. Written records exist in various forms but are used sparingly. Field work provided the majority of the data for measuring the human impact. The field work sessions will be discussed later in this chapter.

Two Landsat MSS images were used having similar phenology (same season) with nearly a decade of separation. Landsat images use four bands of information, with bands one and two imaging in the visible portion of the electromagnetic spectrum and bands three and four imaging in the near infrared portion of the spectrum. These bands can be used to highlight different information in the image.

Criteria used in the selection process of the images was based on availability and quality of the images. Since 1972 the Landsat satellite has been collecting images of the study area every 16 to 18 days. This yields over 500 images of the area; however, cloud cover and atmospheric conditions, along with mechanical error, can render images useless. The atmospheric interference is worse in mountain ranges where orographic uplift and related moisture are common. This left only a few images to choose from and in the final selection process two images were selected. The first image chosen was acquired on March 2, 1979 (Figure 2), and the second, used to compare with the 1979 image for change detection purposes, was acquired on March 7, 1989 (Figure 3). By using images of similar phenology, problems that occur with seasonality differences are minimized.

1979 False Color Composite Image

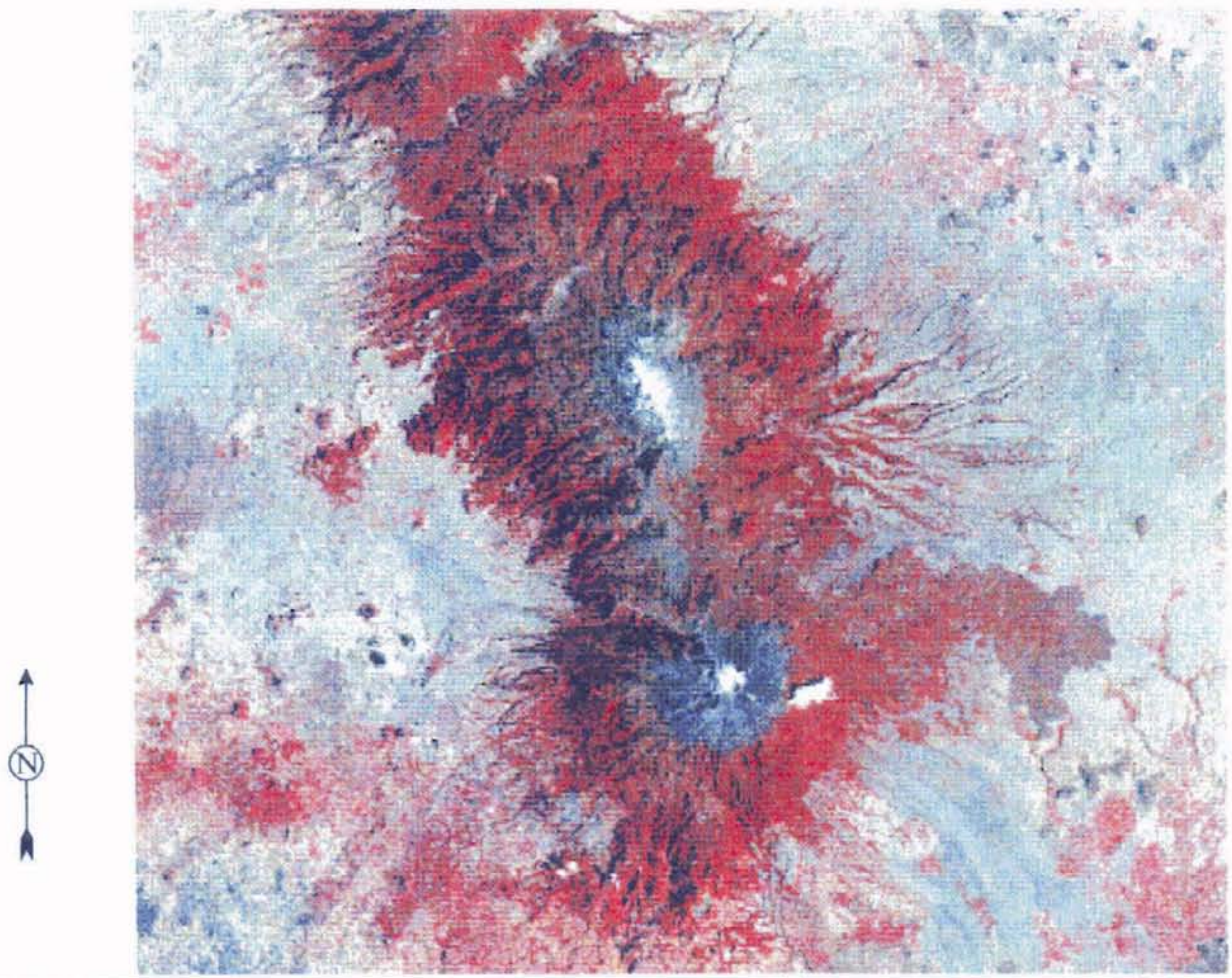


Figure 2

1989 False Color Composite Image

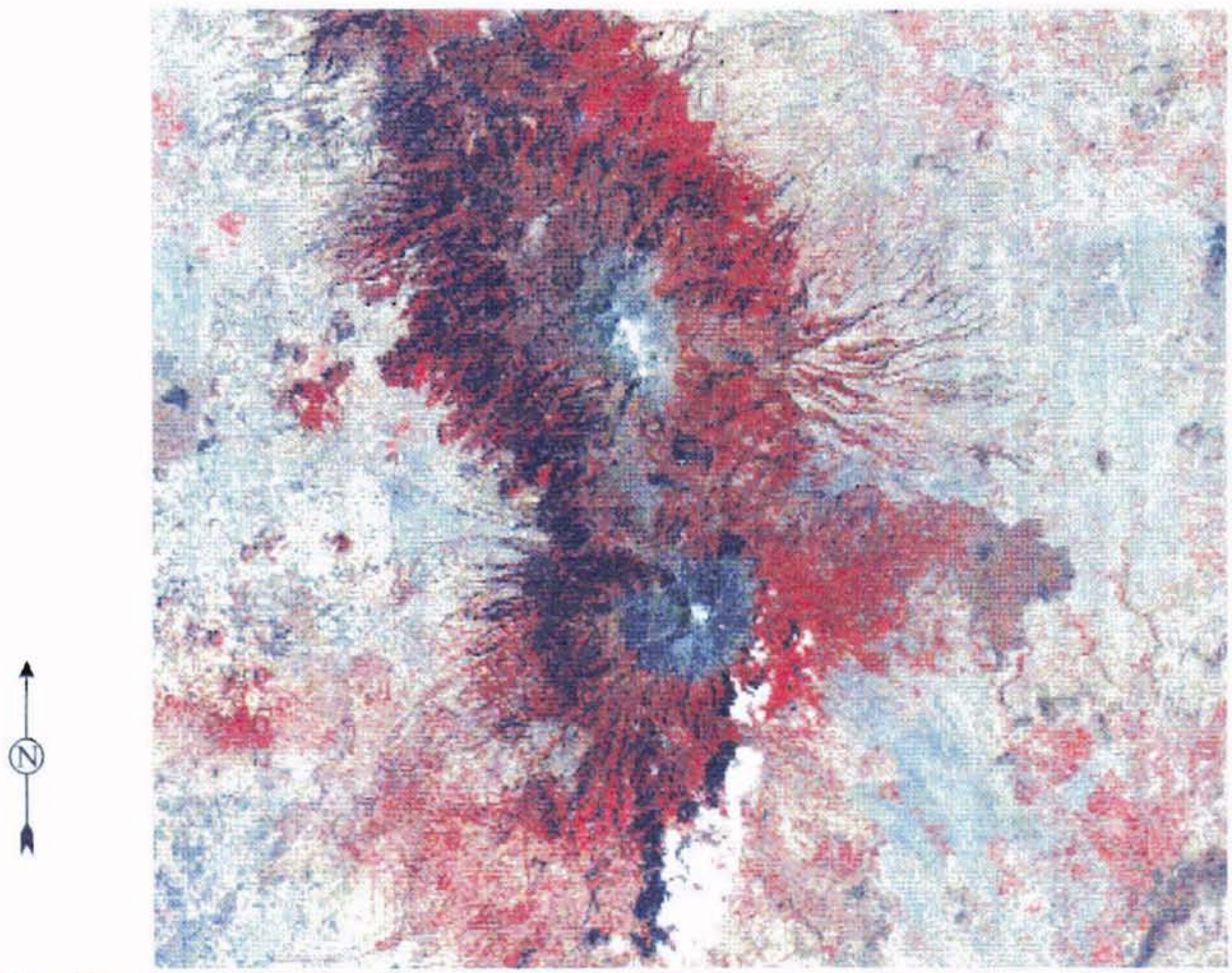


Figure 3

Landsat MSS data were chosen due to their availability, low cost, and temporal length of coverage, allowing for a longer time period with a greater number of images than any other existing satellite platform available in the public domain. Landsat MSS data has a resolution of eighty meters, and this has historically been acceptable, especially when trying to identify change in forested landscapes, as the following paragraph illustrates:

> In many situations, especially in the early stages of deforestation, we are dealing with a somewhat diffuse process which can only be resolved if means of observation of a certain resolution are available. This is verified in the case of the slow movement of a deforestation front where rates of advance can only be measured if data at a resolution of a few hundred meters are available (Belward 1991, 255).

Within these parameters the Landsat MSS image resolution of eighty meters is sufficiently acceptable for this study.

Both Landsat scenes selected were less than ten percent cloud covered. However, both scenes do have clouds covering part of the park. The 1989 scene is significantly worse than the 1979 scene, but it only covers a relatively small area on the southeast side of Popo. This cloud covered area was assessed by the surrounding pixels. The region itself is very homogeneous with little variation in agriculture and forest structure. This significantly increases the accuracy of the image processing performed. With low amounts of atmospheric interference and fairly simple image processing methods employed, the Landsat scenes were processed (through methods discussed later) to provide a measurement of Landscape change.

Field Work Sessions

In all, over a month and a half was spent in the study region, including eight days in or near the park conducting field research. Fieldwork sessions were conducted during July and August, 1996 and March of 1997. The field research was designed to accomplish two main goals. One goal was to gather data to aid in the analysis of the change in the physical landscape, and the second goal was to gather data to explain the human presence and impact within the park.

In order to facilitate the image processing to identify the physical change of the landscape, ancillary data were collected in the field. Several maps were collected from the the National Institute of Geographic Statistics and Information (INEGI) in Puebla. Of these, four are 1:50,000 scale topographic maps that cover the entire extent of the park. These topographic maps are the largest scale available for the area that are laid out in a usable form with an universal transverse mercator projection, Clarke 1866 spheroid, and 1927 North American datum. These data were used for navigation in the region and for rectification of the Landsat scenes. In addition, six 1:250,000 scale thematic topographic maps were acquired. The maps offer many details about the park, including information about geology, soils, vegetation, forestry, and land use.

In addition to the maps, ground control points were collected using a Global Positioning System (GPS). The GPS used has an accuracy of 100 meters which is close to the resolution of the images. At individual latitude/longitude points, a brief description of the landscape was recorded. Even though these points are considered only to be absolute ground truth for 1996-1997, these data, combined with the historical record and personal interviews, aided in the processing of the images.

The goal of measuring human influence within the park was a seemingly easier process, but in the long run required more complicated and time-consuming procedures. The primary method employed to gather this information was personal interviews. The area surrounding Ixtaccihuatl-Popocatepetl National Park is full of rural villages with native people who enjoyed talking about their land and the lands of Ixta-Popo.

An interpreter was hired from Puebla to aid in the interviewing process. The interpreter, Jose Luis Zahuita, is a twenty-two year old engineering student from the Universidad de Puebla. Jose has two years of English language training in the United States and a solid grasp of the methods of science. Jose's assistance also helped to ease tension and fear (on my part and theirs) when approaching the local people. This helped interview subjects to relax and provide more accurate answers.

No pre-set criteria were used for choosing the people to be interviewed. Instead, any person encountered who would take the time to converse about their livelihood was questioned. If a person consented, the conversation was noted with a pen and paper. If it seemed a person was in a hurry or hesitant, then they were questioned, but nothing was recorded. This method is appropriate for the region due to its homogeneity of people. Most interviewed had lived in the region all of their life, practicing subsistence farming and some commercial agriculture on land that has been passed down through the family for many generations. Almost all farmers grow corn and beans, and raise chickens and other livestock.

In order to compare and contrast responses from local residents, interviews were conducted with the forest service as well. During field work, the forest service was initially in a period of transformation because of the resignation of the head of the organization. However, time was later spent interviewing them during field work. At this time, forest service personnel were happy to talk about the condition of the park. Questions were asked regarding park policy, and management practices within the park.

A general list of questions is given in Appendix A that formed the structure of the interviews with the locals and the forest service. Included with this appendix, a detailed explanation is given identifying what these questions were attempting to answer. In general the questions were attempting to measure the agents of change in the park.

Field Work Justification

Field work was necessary in this study for three reasons. First, it was necessary to obtain a working knowledge of the area to see what elements exist in the landscape. This is to provide a means in which to ground truth the classification procedure. By collecting ground control points, noting observations, and verifying these points with personal accounts, a reasonable accuracy can be achieved in the image processing (discussed later).

Second, it was necessary to travel to the region to collect ancillary data to aid in the completion of the project. These data consist of several maps and books that were collected in the field. These data were not readily available in the United States, so field work was necessary to obtain them.

Last, it was most important to gain a first hand experience with the range and intensity of various human activities that take place in the park. Through observation and interviewing an intimate familiarity was obtained regarding the types of human activities that take place in the park and adjacent areas.

Change Detection Methods

Although several different methods exist for change detection, as illustrated in the literature review, a post-classification comparison was chosen as the best method for this application. This is a technique that involves the separate classification of each image used in the analysis and then registration of those images to each other. This method was chosen for several reasons including:

> Post-classification comparison holds promise because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates. The method also bypasses the problem of getting accurate registration of multidate images (Singh 1989, 996).

Most importantly, the fact that atmospheric differences can be eliminated using this method was a factor influencing the selection of this procedure.

In addition, the coarseness of the classification desired allowed for this method to be employed with confidence of accuracy. Coarseness, in this case, refers to the low number of classes desired to identify change. Since the park mainly consists of forest vegetation, only a forest/non-forest classification is of utmost importance, however other classes such as agriculture may be of use to this study. Although accuracy with confidence cannot be assigned a value because the images are archived data, it can be significantly improved by limiting the number classes. For example, a much higher level of accuracy can be achieved if a single "forest" class is used, as opposed to breaking this class down into different types of forest such as light, mixed, or dense forests.

The data acquired through processing provides a quantitative view of change, and can be manipulated to identify the areas of landcover change in order to facilitate further field work. The historical record of the area provides data that helps to explain what role humans have played in this landscape transformation. Combined, the two provide a description of how human action affects the environment of national park lands.

Database Construction

Two raw Landsat MSS images were used to form the initial database. The first image was acquired on March 2, 1979 (Figure 2) and the second on March 7, 1989 (Figure 3). The format of these data is in digital numbers (DN). The DN value measures the average radiance value within an eighty meter by eighty meter raster on the earth's surface and assigns it a value ranging from zero (no radiance or total absorption) and 64 (total radiance or reflection). This DN value is then used to provide information about the landscape.

The image processing software used to perform the processing techniques for this study is Erdas Imagine. This software platform is Unix-based and the processing was performed on a SunSparc I workstation in the Center for Applications of Remote Sensing at Oklahoma State University.

Landsat MSS images are shipped to the customers in an uncorrected format. This means that the analyst must project the images onto a flat surface to eliminate distortion associated with the spherical shape of the earth. In addition, by projecting the images onto a flat surface using a known grid system, real world coordinates are tied to the images, allowing for quantitative spatial analysis.

This rectification process was accomplished with the use of four 1:50,000 scale topographic maps encompassing the area of the park. These images were scanned into Erdas Imagine and assigned coordinates by using the latitude/longitude tags on the maps. These tags are known points on the maps which allow the software to project it onto a coordinate system. Erdas Imagine allows the analyst to rectify images to a geographic coordinate system by projecting it to a known grid system, in this case a Transverse Mercator projection, spheroid Clarke 1866, and datum North America 1927 equal to the projection of the topographic maps.

Once the topographic maps were geometrically rectified they could be used to match ground control points of known locations on the topographic map with ground control points on the 1989 image. The raw 1989 image was rectified to the topographic maps; the second image could be rectified to this image rather than the topographic maps. The ground control points need to be easily identifiable on the images and with Landsat MSS's resolution of eighty meters by eighty meters, this task can be difficult. Natural features such as rivers were avoided since the earth's processes are continuously changing their positions. The majority of the ground control points used were road intersections since these points are held to a relatively fixed position. This task was hindered by Mexico's poor road network and the coarseness of the image's resolution, but enough points were acquired to confidently rectify the images. Erdas Imagine has a utility that allows a gauging of the accuracy of rectification. This utility measures the Root Mean Square (RMS) error and allows you to rectify the image when this value is less than one. Both images were rectified with less than a 0.5 RMS value.

After the images had been geometrically corrected and tied to a coordinate system, the classification procedure was performed. A hybrid unsupervised/ supervised classification was utilized. An unsupervised classification clumps similar pixels into an analyst-specified number of groups, whereas a supervised classification utilizes user defined signatures for the classification.

For this study's purpose, only five classes were desired which included: forest, agriculture, bare fields, bare land, and clouds/ice. These five classes represent the basic landscape of the park and surrounding area including, most importantly, forest/nonforest classes. Through field work and the classification process it was determined that two different bare classes were needed; bare field and bare land. Bare fields consist of signatures that encompass the uncultivated agricultural fields in the area at the time of scene acquisition, which constitutes a majority of the scene's landscape. Bare land includes that area around the peaks of the volcanoes, land characterized by ash, and land that consists of sand dunes.

In addition, some farming takes place during March, the time of scene acquisition; usually irrigated agriculture near the surrounding villages, which was uniquely identified by an individual signature. Due to the predominantly rural landscape in the scene and to the coarseness of the imagery, urban landscapes were not included. The small villages that show up in the scene are characterized by agriculture signatures associated with the backyard irrigated fields and bare field signatures associated with the dry landscapes of the rural villages at the time of scene acquisition. A water class was excluded as well due to the lack of large bodies of water in the study area.

Twenty initial classes were selected for the first unsupervised training procedure. This procedure assigns a signature to the individual signal clusters and then these signatures are analyzed and regrouped by the analyst. In Erdas Imagine, the user can visually combine similar classes to represent individual classes. The classes were combined based on the five desired classes and then this was checked against the field observations for improved accuracy. It was determined that the unsupervised classification performed fairly well; however, there were obvious pixels misclassified and these pixels were assigned the correct signature through supervised training.

The supervised classification was performed using the signatures from the unsupervised classification and added training signatures. Sites that were obviously misclassified, such as pixels effected by the shadow of the mountains, were trained as the proper class. Training involves selecting seeds or polygons of a known class to help increase the accuracy of the classification. This allowed for a highly sensitive fine tuning of the classification.

The hybrid unsupervised/supervised classification was performed in identical fashion on each image, which yielded a classified image for 1979 (Figure 4) and one for 1989 (Figure 5). Visually comparing the two images revealed that the forest had

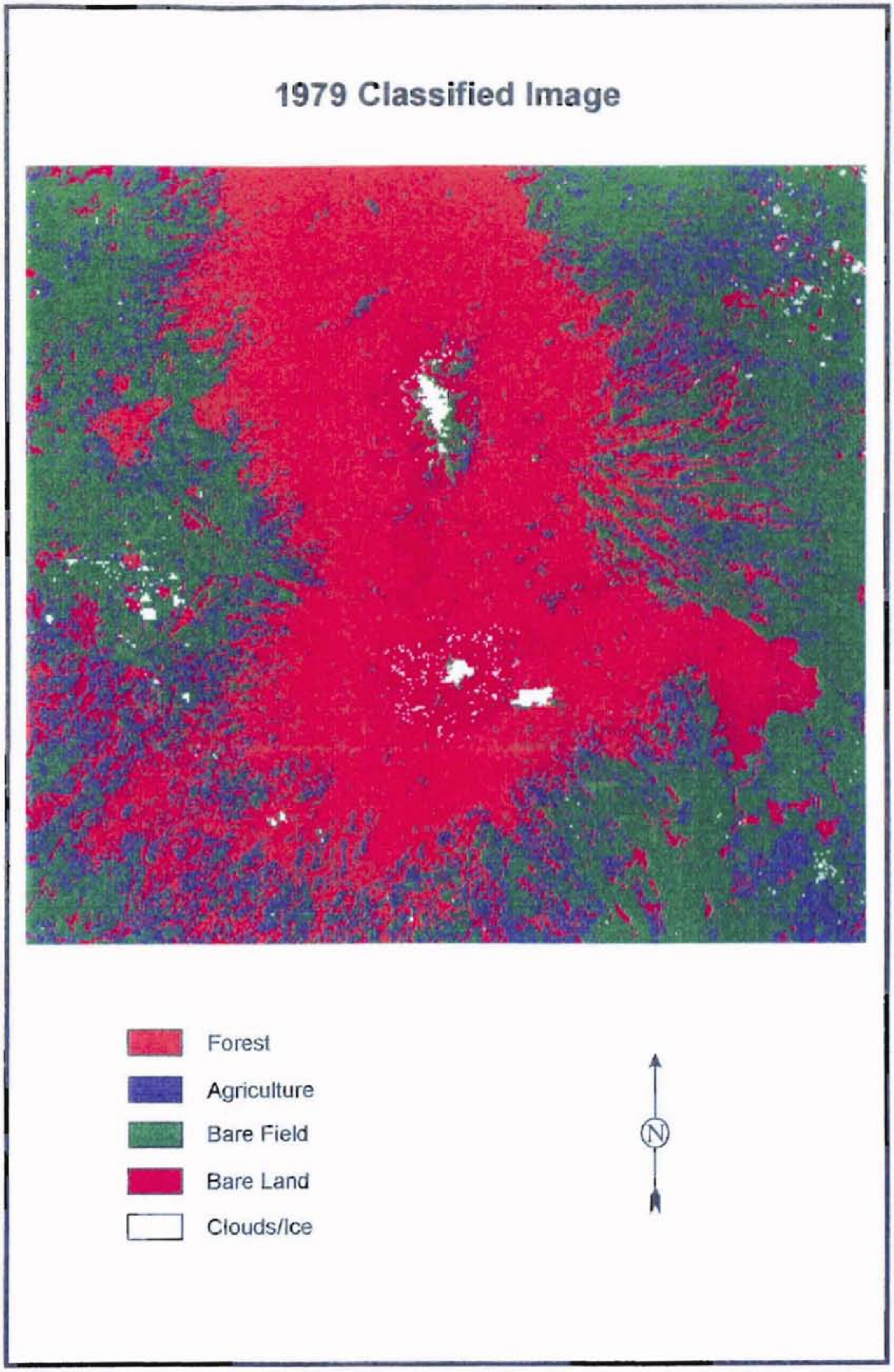

1979 Classified Image
Forest
Agriculture
Bare Field
Bare Land
Clouds/Ice
N

Figure 4

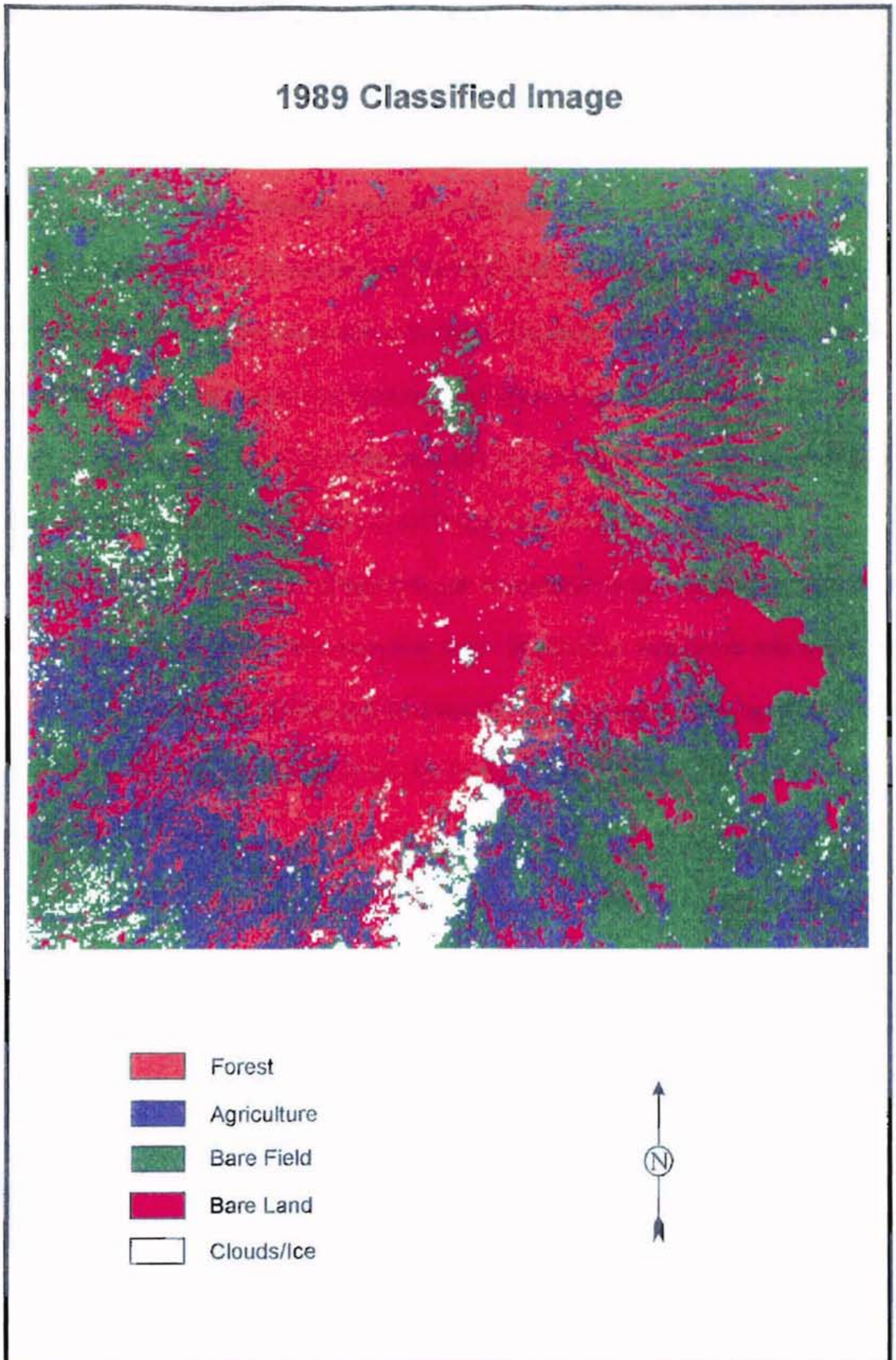

1989 Classified Image
Forest
Agriculture
Bare Field
Bare Land
Clouds/Ice
N

Figure 5

decreased since 1979 and that the bare land had increased. However, it was difficult to ascertain the amount of change that had occurred by visually comparing the two images. To quantitatively illustrate the physical change to the landscape of the park and surrounding areas, change detection methods were performed.

A post-classification comparison of the 1979 and 1989 images was utilized for change detection. First, each image was recoded to highlight an individual class in each image and then the images were overlayed to detect the change in that class. Next, the individual classes of each image were matrixed (an Erdas Imagine tool) against each other to determine what each individual class in 1979 had changed to by 1989.

The overlay and matrix processes provide a quantitative and qualitative description of the pattern of change in the landscape over time. In addition, field work was necessary to expand knowledge of this pattern and to assess the human impact as an agent of change. The results of these processes and the field work are presented in the following analysis chapter.

CHAPTER 4

Analysis

This chapter will begin with an analysis of the change detection processes and results used evaluate the physical change in the landscape over time in Ixtaccihuatl-Popocatepetl National Park. The second part of the chapter explains the role that humans have played as an agent of change in the landscape.

Analysis of Physical Change

Post-classification comparison was the change detection method chosen to measure the physical change in the landscape. The Erdas Imagine Modeler utility allows this process to be performed in many different ways. For this study, an overlay process and matrix process were performed to provide the quantitative and qualitative description of the landcover change. The overlay process was designed to highlight the areas of deforestation and reforestation, and the areas of no change. The matrix process was also performed to provide additional information about the total change in land cover.

In the first process, each image was recoded to highlight the forest and non-forest classes. Since the park's vegetative environment mainly consists of forest and bare land, identifying the change in the forest structure would help identify the landscape change in the study area. An overlay function was employed to accomplish this task. To perform the overlay the images first needed to be recoded. Since the park lies completely within forest, a forest class is most useful for this study. The recode is illustrated in Table 2.

The recode was set up this way in order to identify areas of deforestation, reforestation, as well as those areas that experienced no change in forest structure. The images were overlaid using an addition function. Thus, areas that experienced deforestation would have a value of one in the output image, reforested areas would have a value of two in the output image, and areas where the forest experienced no change would have a value of three in the output image.

The quantitative results are displayed in Table 3 and are visually illustrated in Figure 6. As illustrated, the areas of deforestation greatly outnumber the areas of growth. Reforestation pixels account for 2.6% of the scene, whereas deforestation pixels account for 10.5% of the scene, illustrating that the people in the region are consuming significantly more forest than they are planting.

Figure 6 illustrates the location of reforestation and deforestation. Notice that the volcanic peaks show up as black spots in the middle of the forest. The southern black void represents Popocatepetl and the northern void represents part of the bare saddle between the volcanoes and Ixtaccihuatl. This image can be referenced against the raw images (Figure 2, and Figure 3) for a better understanding of the change. It is noted that the cloud cover from both images has caused some misrepresentation on the southeastern side of Popo. However, some deforestation took place here and is evident in spots where cloud cover did not interfere. In addition, the southeast side of Popo shows a large area of reforestation that is misrepresented. Evaluating this area from its surrounding pixels and combining matrix analysis, illustrates that deforestation did occur here.

Table 2

Image Recodes of Land Cover Classes Designed to Highlight Forest/NonForest

1979 Image			1989 Image		
CLASS	VALUE	RECODE	CLASS	VALUE	RECODE
Forest	1	1	Forest	1	2
Agriculture	2	0	Agriculture	2	0
Bare Field	3	0	Bare Field	3	0
Bare Land	4	0	Bare Land	4	0
Cloud/Ice	5	0	Clouds/Ice	5	0

Table 3

Change in Forest Cover from 1979 to 1989

CLASS	CLASS VALUE	PIXELS	HECTARES	PERCENT
Other	0	472,343	302,304	68.6
Deforestation	1	65,333	41,814	9.5
Reforestation	2	17,788	11,384	2.6
No change	3	133,355	85,348	19.4
Total		688,819	440,850	100

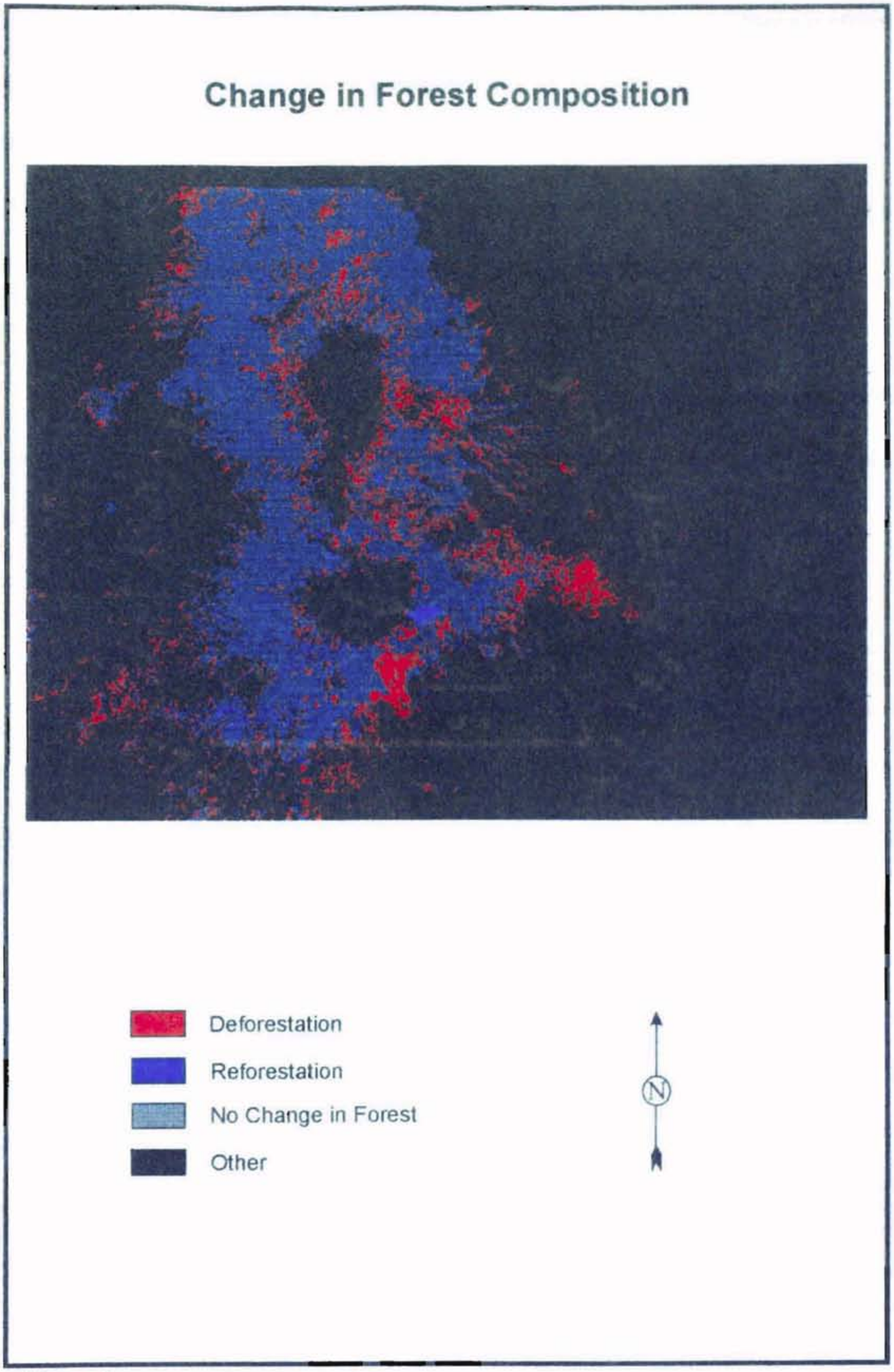

Change in Forest Composition
Deforestation
Reforestation
No Change in Forest
Other
N

Figure 6

The remaining image illustrates that there is loss of forest surrounding the edges of the whole stand of trees, possibly signaling human encroachment into the forest. In addition, a large stand has been cleared on the eastern edge of Ixtaccihuatl and along the eastern route of Paseo de Cortes. There is also evidence of deforestation along the treeline at the base of both volcanoes; however it seems that Ixtaccihuatl is experiencing more forest loss.

The second process performed was a matrix overlay. This is a process that allows the analyst to identify what each class from the 1979 image had changed to by 1989. The results are presented in Table 4. This allows for additional analysis in assessing the landscape change in Ixtaccihuatl-Popocatepetl National Park.

The main point of this matrix is to see what classes the forest has changed to and how much total forest is involved in this change. In addition, an image is tied to this data allowing for visual interpretation (Figure 7). This matrix is very useful because it not only enables the user to assess total land cover change, but it also allows the user to assess the accuracy of the classification.

Accuracy can be checked by examining the numbers in Table 4 . For example, it is highly unlikely that land used for agriculture in 1979 has been replanted with trees and changed to forested lands in 1989, just ten years later. As Table 4 illustrates, the classification is consistent with this logic. The total amount of land that changed from agriculture to forest is 2,665 hectares out of 440,327 total hectares. These pixels account for 0.6 % of the total number of pixels. The pixels could be a product of misclassification or perhaps were actually replanted fallow land. Along with this, it is also highly unlikely

Table 4

Change in Land Cover From 1979 to 1989

1979 Class	1989 Class	# Pixels	hectares	percent (0.0)
Forest	Forest	133,355	85,349	19.4
Forest	Agriculture	11,151	7,137	1.6
Forest	Bare Field	2,391	1,530	0.3
Forest	Bare Land	46,915	30,026	6.8
Forest	Clouds/Ice	4,872	3,118	0.7
Agriculture	Forest	4,164	2,665	0.6
Agriculture	Agriculture	41,133	26,326	5.9
Agriculture	Bare Field	45,483	29,110	6.6
Agriculture	Bare Land	20,778	13,298	3.0
Agriculture	Clouds/Ice	3,807	2,437	0.6
Bare Field	Forest	837	536	0.1
Bare Field	Agriculture	27,248	17,439	4.0
Bare Field	Bare Field	188,145	120,415	27.3
Bare Field	Bare Land	21,273	13,615	3.1
Bare Field	Clouds/Ice	10,335	6,615	1.5
Bare Land	Forest	12,197	7,806	1.8
Bare Land	Agriculture	25,907	16,581	3.8
Bare Land	Bare Field	18,586	11,895	2.7
Bare Land	Bare Land	61,179	39,155	8.9
Bare Land	Clouds/Ice	2,806	1,796	0.4
Clouds/Ice	Forest	590	378	0.1
Clouds/Ice	Agriculture	276	177	0.0
Clouds/Ice	Bare Field	1,808	1,157	0.3
Clouds/Ice	Bare Land	1,962	1,256	0.3
Clouds/Ice	Clouds/Ice	800	512	0.1
Totals		607,998	440,327	100

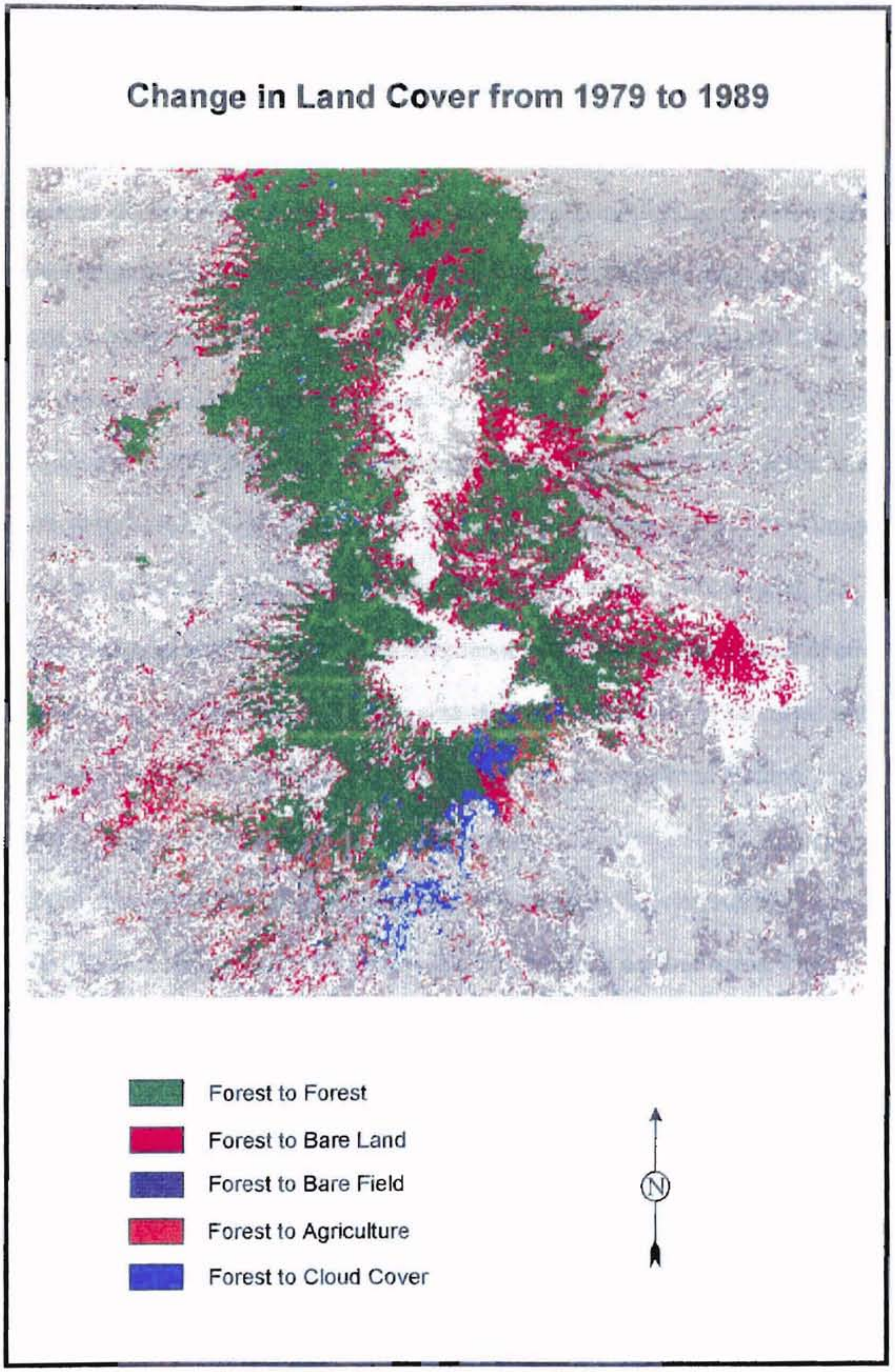

Change in Land Cover from 1979 to 1989
Forest to Forest
Forest to Bare Land
Forest to Bare Field
Forest to Agriculture
Forest to Cloud Cover
N

Figure 7

that bare fields have changed to forest. The matrix shows that 536 hectares changed to forest, which is less than 0.125% of the total amount of pixels.

Another item examined was the areas of no change. It is logical that if the classifications were performed accurately, each class should have a large number of pixels that remained unchanged. This is verified by 85,349 hectares of forest remaining unchanged, as well as 26,326 hectares of agriculture, 120,415 hectares of bare fields, and 39,155 hectares of bare land remaining as such.

Notice that 29,110 hectares of agricultural land has changed to bare fields, and 13,298 hectares have changed to bare land. This accounts for almost 10% of the image. This could be a result of: (1) agricultural land that is being shifted to fallow land, (2) agricultural land that has been overused and rendered useless, or (3) it is a result of error from the cloud interference. In conjunction with this, 17,439 hectares of bare field and 16,581 of bare land changed to agriculture. This may also be a result of shifting agriculture or land that had been cleared for agriculture.

In all, the matrix follows a logical pattern with some obvious errors, but as illustrated these are slight and associated mostly with the cloud covered areas. The physical landscape of the park and surrounding area, overall, will be assessed using a combination of both processes of change detection. A majority of the analysis was done assessing the change in forest since this constitutes the principal landcover of the park and is the class that experienced the most change in the park. Based on change detection data, 41,800 hectares were deforested from 1979 to 1989, 11,400 hectares were reforested, and 85,300 hectares underwent no change. Analyzing the deforestation using the matrix shows that of the 41,800 hectares of deforestation, 7,200 hectares became land devoted to agriculture, 1,500 hectares became bare fields, 30,000 became bare land, and 3,100 hectares were unidentifiable because of cloud cover.

These numbers signal that a large amount of the park and surrounding area has been cleared and is no longer being used, and a smaller percentage has been cleared for agricultural purposes. For the second part of the analysis, data derived through field work will be used to explain the role that humans have played in this transformation and discuss the changes that imagery is unable to detect.

The Human Impact

A month and a half was spent in the field in order to evaluate the impact that humans have had on the environment of Ixtaccihuatl-Popocatepetl National Park. During field work, local residents, and employees of the forest service were interviewed in an effort to measure how humans have impacted the physical structure and form of the landscape.

It is evident that the surrounding region of the park has a very rural, low-income population. Many of these people practice subsistence agriculture, growing most of their food in their backyards or nearby plots. To people living near the park the mountains are sacred and provide them with resources that they depend on for their daily survival. Many people fear gods associated with the land and believe that Popo is steaming now not only out of anger for his lost love, but in disgust with its visitors. Even so, the locals are the ones largely responsible for the recession of the forest boundaries. Yet, most of the local people think the environmental conditions of the study area have changed for the better. They look to the forest as a source energy, and rely on this ecosystem to remain healthy and survive.

This section will test the hypotheses of the study to evaluate the different ways that humans have affected the environment of the national park. To evaluate a hypothesis, a combination of image processing and personal interviews was used. A general discussion of the method of questioning is provided in Appendix A. The six hypotheses concerning forces responsible for forest and related environmental impacts include recreational influences, logging of the forest, vending within the forest, clearing of the forest for agriculture, cutting forest for fuelwood, and forest management.

Recreation

A trip to the volcanoes provides an excellent opportunity to take in one of the most spectacular views in all of Mexico. From the acclimation lodge located at Paseo de Cortes, one can see both peaks clearly. The park also offers many trails for hiking, including paths that lead up to the summit of both peaks and trails throughout the forest. In addition, the park offers a place to stay for visitors, which is called Tlamacas. This is a ninety-eight bed facility with bathrooms, water, and a restaurant. Unfortunately, because of Popo's continuous venting of a smoke, access to the lodge and to Popo itself has been restricted since 1994 by the forestry service. Lodging still exists at the television and microwave station on the western slope of Ixtaccihuatl and at the Buenavista Turistica facility on the eastern slope along Paseo de Cortes.

The main recreational activities taking place in the park are mountain climbing and hiking, camping, and picnicking. It is a destination where mountaineers can reach two of the highest peaks in Mexico. With the closing of Tlamacas and Popo, tourism has decreased significantly in the area. The forestry service estimates that the park typically receives 500 visitors per week totaling around 26,000 people per year. This estimate is for people who visit the park, but is not an estimate of the number of people who actually stay in the park. This number has significantly decreased since the eruption in 1994. The forest service estimated that when Tlamacas was open, approximately 100 people stayed in the park per week and the visitors totaled 1,000 per week.

In any event, the visitors are not allowed to cut the forest for fuelwood, but are allowed to gather wood that has either fallen or has already been cut. There is a significant amount of trash along many of the trails throughout the park, but it is difficult to assess whether this came from tourists or local people. Campsites are scattered sparingly throughout the park; most have a fire pit and seem to be relatively clean.

It is evident that people occupy the park for recreational purposes mainly to see the peaks and climb to their summits. There is also evidence of camping activities taking place. These events are not currently thought to be altering the physical landscape of the national park significantly but, in combination with other factors, seem to have an effect. In the past, they seemed to play a more influential role, most significantly in the building of structures such as Paseo de Cortes and Tlamacas to provide lodging for visitors. These structures, built for the purpose of recreation, altered the physical landscape. There are structures that have helped to preserve the park as well. The numerous huts and shelters on these mountains limit the human impact of climbers to small areas instead of creating new campsites whenever groups or individuals climb the peaks. The hypothesis that recreation is significantly altering the environment of the park cannot be confirmed. The impact of recreation in the park is currently limited to basic fuelwood consumption, and the disposal of waste.

Logging Activities

This factor has the potential to be one of the most influential human activities impacting the park. Logging can destroy large stands of trees in a short amount of time. People were very cautious when talking about this subject so it is difficult to ascertain the actual impact that this has had on the landscape of the park. Another factor hindering recovery of information regarding logging is that the borders of the park beyond the entrances along the road are not delimited and even the local park personnel are confused about specifically which areas of land fall within their jurisdiction.

According to the personnel in the area, they prohibit any cutting or burning of the forest by individuals other than themselves, and the prohibition seems to be enforced within close proximity of Paseo de Cortes. However, only a few kilometers from Paseo de Cortes a large clearing was discovered with a lumbering road leading up to it. Lining this road were stumps and loose logs, and in the clearing the smaller trees remained which indicates selective clearing of forest in the recent past. Throughout the remainder of the forest (at least areas accessed through field work) similar clearings existed. In addition, several logging trucks and lumbering roads were observed throughout the park.

As stated, this was a sensitive subject among the people interviewed, but the people who did comment mentioned logging activities of local paper factories and a few persons mentioned that there was significant clear cutting occurring on the southern slope of Popo in the recent past. The imagery does show some deforestation on the southern side of Popo (Figure 7). Unfortunately, clouds interfere in the 1989 scene, making it difficult to see the extent of this clearing. It was evident that clearing had also taken place on the southeast side, but people were unwilling or unable to talk about it.

The impact that logging has had in the region is difficult to ascertain. However, from the data it is evident that logging takes place in the forest surrounding Ixtaccihuatl-Popocatepetl National Park and that there is a reasonable chance that this activity has encroached into the park.

Vending Impacts

Vending activities in the park have coincided with the recreational activities. With a large part of Mexico's economy involving the informal sector, sidewalk vending or merchandising is a common occurrence. With large numbers of tourists visiting the park, local residents have ample opportunity to sell goods to visitors. This draws the vendors, usually people from the local villages, into the park to sell goods either to make a living, or to help supplement the family income.

These vendors line the paved road from Amecameca on the western side ascending into the park. There are dozens of clearings where vendors have staked their claim to sell food and novelty items. At almost all of these vending sites, a group of people can be found around a campfire, awaiting hungry or curious visitors that stop along their way to or from the park.

It is thought that these vendors have impacted the landscape throughout the park by spreading waste and by the consumption of fuelwood. The impact of vendors, like the impact of recreation, is a factor in overall landscape change; they constantly consume firewood for their campfires, which are used to provide heat to deal with the cooler temperatures at these higher elevations. Furthermore, they provide goods to the park visitors who have littered the landscape with trash. However, compared to the impact of other human activities in the park, the environmental impact of the vendors is not too great. Thus, the hypothesis that vending activities significantly alter the environment within the park cannot be confirmed.

Agricultural Clearing

The amount of deforested land that has been converted to agriculture from forest in the study area is 8,700 hectares out of 41,814. This takes into account the land classed as agriculture and that classed as bare fields that are used in the right season for agriculture as well. This accounts for twenty-one percent of the total amount of deforestation. Most of this lies on the southern and southwestern slope of Popo and on the eastern edge of the forest. However, conversion to agriculture does not account for the majority of the clearing within the park. The only agricultural activities which are obvious within the park are the cows and sheep which are occasionally seen grazing on the alpine meadows. Thus, the hypothesis that agricultural clearing has significantly altered the physical landscape within the park cannot be confirmed.

Fuelwood Cutting

It was originally thought that, because the western entrance to the park is the one that most visitors enter, the western side of the study area would be experiencing the most change. On the western side, in the state of Mexico, there was a combined total population of 110,000 people and on the eastern side, in the state of Puebla there was a combined total population of 332,000 people in 1995 (INEGI 1996). Obviously, with larger populations comes a greater amount of consumption. There are many more villages scattered across the entire eastern slope of the mountains which depend on the forest as a source of energy. Accompanied with this larger population has come the depletion of a large amount of forest resources. There is strong argument that this is the reason for the cleared areas on the eastern slope.

In support of this argument, it may be pointed out that a political border between the states of Mexico and Puebla splits the park into a western and eastern side. It seems that the enforcement of the park policy is limited to the western side and less attention is given to enforcement on the eastern slope. In addition, the two states' administrative practices may be different, and during field work this was verified. Not one authoritative figure, either the military or the police, was encountered on the eastern slope, whereas dozens were encountered throughout the western side, especially in Amecameca, the center of information about the park, and the place through which most people pass when accessing the park.

The eastern slope has a greater population experiencing less interference from park officials and government officials. The east side is more rural, and less developed. With development of areas adjacent to the park comes technology, like natural gas lines, and towns like Amecameca on the western slope shift away from their dependence on the forest as a resource. But the villages on the eastern slope remain less developed and still dependent on fuelwood. On any given day, the eastern Paseo de Cortes route is filled with local people descending the slopes of the mountains with bundles of wood either carried on their back, or carried by mules and horses. This is not a common occurrence on the western slope.

A qualitative assessment of probable causes indicates that fuelwood cutting seems to be most significantly impacting the physical landscape and is believed to be the main factor in the depletion of the forest within the park and the surrounding region, especially on the eastern slope and along Paseo de Cortez.

Forest Service Management

The forest service in Ixtaccihuatl-Popocatepetl Park exists to manage the park resources in order to help the park achieve the goal of preservation. According to the forest service, they employ over 500 employees who are involved with maintaining and managing the facilities and resources within the park. Of these, many are uneducated laborers hired from surrounding villages to help replant trees in July, August, and September.

The park is currently in a stage of forest recuperation designed to promote reforestation. They replant trees, remove dead trees and clutter, and are attempting to clean up the trash spread throughout the park. In all, a total of 11,000 hectares of land was reforested between 1979 and 1989 and most of that area lies within the park (Table 3). Park service personnel have stated that reforestation efforts accelerated in the last couple of years, and since the closing of Tlamacas they have been able to spend more time on reforestation efforts. The forest service does seem to have good intentions, but also encounters many obstacles.

One of the main problems is that the employees do not seem to have a clear idea as to where the actual borders of the park are. In addition, lack of easy access to most of the park allows people to exploit the resources of the forest without any interference from the forest rangers. Another problem encountered is lack of adequate funding to maintain facilities and to employ qualified personnel. The park service personnel efforts seem to lie on the western side where most of their time is spent. In fact, the eastern entrance is never even staffed.

Based on the field observations and conversing with residents and park personnel, the hypothesis that the park service encounters many difficulties in limiting human impact is accepted. Although they have good intentions, they are limited by lack of adequate funding, and insufficiently trained personnel.

Summary of Human Impact

Several studies exist addressing human impacts on landscapes and many of these deal with protected areas. Alton Byers (1996) assessed human impacts and disturbance in Makula-Barun National Park, Nepal. This study found similar activities to have affected the landscape in his study area. Byers assessed the physical change within the park through carbon 14 dating and pollen analysis and relied on historical records and field work to assess the human influence in this change. He found that tourism has had a significant and recent impact in the park and surrounding areas. In addition, it seems that pasture development and timber harvesting by local residents in adjacent areas has caused a significant reduction of the forests.

Richards (1996) found commercial log extraction to be a problem in several protected areas throughout Honduras. He also identified a major cause of deforestation to be fuelwood cutting, and conversion of the forest to pasture land. The two parks where Richards conducted most of his field work had problems with the boundaries of the park and indigenous land rights and claims. Many of the local people near the parks attempted to take title to the land by building fences and trails, or marking the trees by peeling off their bark. Arthur Morris (1997) identifies fuelwood consumption to be a major problem in the highlands of Ecuador. He points out that approximately 90% of the forest extracted in developing countries is for fuelwood consumption. Wunder (1996) illustrates that in areas where technologies exist, such as bottled gas and electricity, fuelwood consumption has little impact.

The primary human impact in Ixtaccihuatl-Popocatepetl National Park is the consumption of the forest for fuelwood. This seems to be the case in the studies that have been done in many other parts of the world as well. The main area of change seems to have occurred on the eastern slope where a larger population exists that is less developed. This is consistent with Wunder's (1996) findings that less developed areas have a greater impact on forest resources through fuelwood consumption. In addition, Ixtaccihuatl-Popocatepetl National Park has had problems enforcing park policy because of the confusion over the boundaries of the park. The national parks in Honduras seem to be experiencing similar problems over boundaries and enforcement of park policy (Richards 1996).

Overall, from 1979 to 1989, a total of 30,800 hectares of forest was removed in the park and surrounding area. This has altered the physical landscape and environment within the park. In addition, humans have built structures, trails, and roads since the birth of the park in 1948. With this development people have gained easier access to the park, therefore easier access to its resources. All the human factors discussed have played a role in the physical change of the park.

The people care deeply about the condition of the land and have a deep respect for the gods associated with the forest and the volcanoes. They depend on the resources for their livelihood, and even if the lands were not protected, they would have to manage its resources. Nevertheless, in less developed areas adjacent to the park, people still need the wood to provide energy necessary for survival, especially on the eastern side where alternative energy sources are lacking.

CHAPTER 5

Conclusions

Summary

National Parks are a relatively new concept, gaining most momentum in the twentieth century. This concept has stirred controversy in the world between people who believe that protecting the land involves locking up precious natural resources, and those people who advocate preservation to help slow the pace of change. In either case, these lands do exist and have altered the earth's physical landscape and our perception of land much the same way that staking claim to land has done.

National park land has been protected in an effort to slow the pace of change to the earth's ecosystems, which has accompanied the earth's population explosion in this century. Approximately six billion people now occupy the earth, exerting pressure on our environment through increased consumption. It is believed that national parks are helping to preserve biodiversity and help forestall climatic changes that are a result of this population pressure. However, the fact that a majority of national parks have an abundant supply of natural resources and attractive landscapes has meant that they are attractive to many people; people interested in illegal exploitation of the park's resources, people searching for a home, people looking to capitalize on the people visiting the park, or people seeking out a place for recreation. Human occupation of theoretically protected land raises the question whether protection of this land is in fact preserving the land, or on the contrary, does protection promote activity and change in national parks, thus effectively eliminating preservation?

This study singles out one national park located between two large metropolitan areas in a developing country. Being located between two large urban areas, one of which is thought to have the largest population in the world (Mexico City), Ixtaccihuatl-Popocatepetl National Park receives many visitors each year. The large number of visitors hinders the goal of protecting this area from human exploitation and occupation. A large rural population surrounds the park and, although there are no signs of permanent residence within the assumed park boundaries, it has been shown that humans do in fact exploit resources from this park. Resource exploitation has impacted the landscape over time, since the birth of this park, and this paper has documented historical data to show the pattern of change over the past two decades.

Measuring change in a landscape over time has become a simpler task since the launch of the Landsat satellite in 1972. As this technology develops, spatial, spectral, radiometric, and temporal resolutions will make the task of measuring landscape change more accurate and easier. Studies similar to this one complete the historical record by providing documentation that explains the agents of change. Change detection is one method that has been developed to help detect the physical change of landscape, but little effort has been expended to document the agents of change in conjunction with these methods.

Human beings are, without doubt, the most influential earth shapers and earth movers of all species known to date. To evaluate their impact on the landscape, a large number of large scale studies as well as small scale studies need to be performed in the manner of this report so society can answer questions concerning human relationships with the environment. This study evaluated various human impacts, through a combination of image processing and field work. During the field work sessions, the local residents were interviewed in an informal manner to provide a description of what activities have caused the changes in the landscape.

Ixtaccihuatl-Popocatepetl National Park has experienced a depletion of forest land, caused by a variety of human activities. Most notably on the eastern edges of the park, where most human activity takes place, a large amount of forest has been cleared over time through a combination of recreational, vending, logging, agricultural, and fuelwood cutting activities. The most influential change has came from the need for biomass by the rural populations surrounding the park. The largest need for fuelwood is found on the eastern edge of the park where most people in the area live. In addition, fuelwood cutting has occurred in areas that have the easiest access with the least interference from authorities in charge of maintaining the resources of the park.

The forest service is attempting to regenerate this forest by planting pine trees throughout the park. To accomplish this, the park employs a large staff throughout the summer to plant trees and clean up trash spread by its visitors. The park maintains a regular staff to enforce the policy of no cutting or burning of the forest as well. However, the forest service encounters many obstacles to this effort. Probably the largest obstacle is a lack of funds to employ educated personnel to aid in this process. There is also a lack of funds to evaluate the change in land cover.

Ixtaccihuatl-Popocatepetl National Park has undergone changes in its landscape since its institution. The park management is working to preserve this forest by preventing human activities, specifically, the cutting of the forest. However, their occupation and enforcement of park policy does not seem to exist throughout the entire park, leaving a large percentage of the land open for exploitation by humans. The forest has been experiencing encroachment, most significantly on the eastern edge where little forest service enforcement occurs.

The implications of this change illustrates that the protection of land is a difficult task. With the dedication of this land to protected status, roads were built and paved, providing access to the park, which has increased the number of tourists and local residents visiting the park. The park also provides places for people to stay while visiting the park, thus, perhaps promoting human activity rather than prohibiting activity. The fact is that human activity is taking place and people are exploiting its resources. This leads to further questions that seek to answer how the landscape would have changed if it were not a national park? Perhaps an unanswerable question.

Suggestions for Additional Research

This report could be treated as a case study that attempts to evaluate whether national parks are serving their purpose. In addition, it can be used as a case study to help explain the role that humans have played in national parks. Throughout the world similar studies are needed in order to evaluate the whole concept of national parks in many areas. Studies are needed to determine if national parks are indeed slowing the pace of humaninduced change to earth's systems, and to assess the desirability or wisdom of such land preservation practices. Studies are needed to evaluate the impacts of national parks on the economy. And studies are needed to evaluate the role and severity of human activity in all parks.

Additional research is also needed in Ixtaccihuatl-Popocatepetl National Park. With additional funding, current Landsat or SPOT scenes could be used to evaluate the physical change of the landscape up to the present. Once these changes have been evaluated, the role of various agents of change could be assessed through more field work. With more time spent in the field, additional questions could be answered.

One issue that was addressed here, but could be significantly expanded, is an evaluation of the eastern/western dichotomy in the study area. How have differences between the state of Puebla's administrative and land use practices, versus Mexico's administrative and land use practices, shaped human activity in the region?

Another question that could be explored is how local myths, rituals, and religion have influenced human behavior and activity in the region. A majority of the local residents seem to believe that these mountains and its forests are sacred. Has this in any way inhibited or promoted use of the resources in the region? Finally, additional research is needed to elaborate on the impacts of technological advancements in the area and how this has shaped human activity. Is the introduction of new transportation or energy technologies in the region helping to slow fuel consumption of the forest?

Many studies exist that identify human impacts in national parks and protected areas (Byers 1996, Richards 1996, Morris 1997, Wunder 1996, Lyrintzis 1996). Most of these studies depend on field work to assess these impacts, but few utilize remote sensing data to evaluate the physical change in a landscape. The use of remote sensing to evaluate land cover change through time is evidently very useful to society. The importance of this study is that it not only assessed the land cover change, but evaluated the agents of change as well. It has also illustrates the importance of field work to gain an intimate understanding of this change and the reasons for its occurrence.

For field of geography, specifically cultural ecology, this study provides a method for assessing human impacts in protected areas. In the future, with the advancement of remote sensing technology, society will be able to use this along with intensive field work to effectively document the relations between humankind and the environment.

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APPENDIX A

Field Work Sessions and Interview Procedure

One field session was spent in the field during July and August, 1996, and another during March, 1997 which coincided with the date of scene acquisition for both images. This helped in the classification procedure by allowing for the landscape characteristics at the time of scene acquisition to be viewed.

A field assistant was hired to help travel around the study area, and communicate with the people interviewed. The field assistant's name is Jose Luis Zahuita. Jose is a twenty-two year old college student whom I lived with during my first two weeks in Puebla. He spent two years studying English in the United States so his English is very good. Being an engineering student, Jose has a solid grasp on the methods of science which helped him understand what I was researching, and more importantly the methods I was using to gather data. Jose is a local, and even if I could speak Spanish fluently, he would have been hired to help ease any tension of unfamiliarity among the interviewees and myself.

The following is a general list of questions that formed the structure of the interviews during field work. This provided an understanding of land use of the park and surrounding area. In addition, the questions asked attempted to answer two general questions: 1) how has the landscape has changed, and 2) what role did human activity play in this change?

The questions were organized by categories starting with Settlement and Barriers to Movement. These questions addressed the reason for settlement either in or near the park. The second, third, and fourth categories; Land Use/Agricultural Issues, Land Use/Forest Cover/Water Issues, and Tourism Issues attempted to answer how human activity has affected land use in and around the park. The last two categories, Forest Service/Government Relations and Forest Service, attempted to identify the forest service's role in the changes that occurred within the park.

Settlement & Barriers to Movement

When did you settle here?

Why did you choose this spot to settle on?

Did you encounter any obstacles in trying to settle here?

Does the national park make this area more or less attractive for settlement?

Land Use Agricultural Issues

Have you noticed many major changes since you first settled here in the quality of crops ?

How good were the crops then and how good are they now?

What types of crops do you grow presently, and do you or have you ever changed?

Are you still growing the same crops that you were when you first settled?

Do you sell much of your produce?

Where do you sell it?

Land Use/Forest Cover/Water Issues

Has there been more land available for farming, or has more land been cleared for agricultural use?

Was this clearing this size when you first settled here?

When was it cleared?

How is the quality and availability of water? Has the water quality changed over time?

Do you use any form of irrigation? If so, what type, and why?

Have you noticed any soil erosion or runoff since you first settled?

Do you think the forest has shrunk or grown over the past few decades?

Tourism Issues

Has the number of tourist increased or decreased in the past few decades?

Do you feel the tourist are a good thing or bad thing for the park and the land?

Do you think the visitors to the park use much of the forest for their campfires?

ForestService/Government Relations

Does you have any relations with the forest service?

Do you ever talk to the forest service?

Do you think the forest service is helpful?

How do you see the park in the future?

Park Service

How long have you been employed by the forest service in Ixta-Popo National Park?

What changes in land-use have you noticed since your employment began in the park.

with respect to local settlement?

with respect to agriculture?

with respect to the forest?

with respect to the quality and quantity of water?

to the quality and condition of the soils?

What is your relationship with the settlers within the park?

Is there any data available for the number of visitors to the park ?

Has there been changes in park policy since your employment began?

What are the policies?

APPENDIX B

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 01-13-97 IRB#: AS-97-040

Proposal Title: HUMAN-ENVIRONMENTAL IMPACTS IN IXTACCIHUATL-POPOCATEPETL NATIONAL PARK

Principal Investigator(s): Dale Lightfoot, Luke Marzen

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Since this study will utilize a very unobtrusive interview protocol and the identity of the participants will be known only to the researcher, no risk is posed for participants. Therefore, the study should be classified as "EXEMPT" and allowed to proceed.

Signature: [signature] Date: January 14, 1997

Chair of Institutional Review Board

cc: Luke Marzen

VITA

Luke J. Marzen

Candidate for the Degree of

Master of Science

Thesis: HUMAN-ENVIRONMENTAL IMPACTS IN IXTACCIHUATL-POPOCATEPETL NATIONAL PARK, MEXICO

Major Field: Geography

Biographical:

Personal Data: Born in Charles City, Iowa, on January 29, 1971, the son of Louis Erma Marzen.

Education: Graduated from Hampton Community High School, Hampton, Iowa in May 1989; received Associate of Arts degree from North Iowa Community College in May, 1992; received Bachelor of Science degree in Geography from Northwest Missouri State University in May, 1995; Completed the Requirements for the Master of Science degree with a major in Geography at Oklahoma State University in May, 1997.

Professional Experience: Teaching Assistant, Department of Geography, Oklahoma State University, August, 1995 to May, 1997.

Professional Membership: Association of American Geographers.