AN EVALUATION OF THE RESOURCES OF THE MOSQUITIA REGION OF HONDURAS BY MEANS OF REMOTE SENSING AND GIS

by

JUAN CARLOS TORRES

A RESEARCH PAPER

submitted to

THE GEOSCIENCES DEPARTMENT
OREGON STATE UNIVERSITY

in partial fulfillment of the
requirements for the
degree of

MASTER OF SCIENCE

GEOGRAPHY PROGRAM

June 1997

Directed by
DR. A. JON KIMERLING

TABLE OF CONTENTS

Maps and Figures

ABSTRACT

The Mosquitia Region of Honduras is part of the largest wilderness area in Central America. In terms of biodiversity the area is rich in ecosystems including pine savannas, tropical rain forests, and wetlands. These ecosystems are rich in millions of species including rare and endangered. Honduras faces an economic, social, and political crisis without precedent in its history. A lot of the crisis has to do with resource allocation and land tenure. Most of the land well suited for agriculture is concentrated in a few hands. The Mosquitia Region is seen as the last frontier by thousands of landless farmers coming from the poor and eroded lands of southern Honduras. This study evaluates the impact of deforestation due to subsistence and extensive agriculture in the areas around and inside the Mosquitia Region by means of remote sensing and GIS. A change detection analysis is carried out for the years of 1965, 1986-89, and 1995 using land use maps, topographic maps, and LANDSAT TM data. In addition the study examines the relationship between proximity to rivers and deforestation. The study concludes that significant and accelerated change is taking place in the study region, and that there is a linear relationship between proximity to rivers and deforestation.

BACKGROUND

Honduras Environmental Crisis

Honduras is well known as the poorest country in Central America. With a land area of 112,492 square kilometers it is the second largest republic in Central America. The country faces many economic challenges, including an external debt of around seven billion dollars. Lack of education is widespread with more than half the population being illiterate. The agriculture sector is underdeveloped and per capita income is only 900 U.S. dollars per year. To make things worse, there is widespread corruption, high levels of crime, and limited access to health services. Around 70% of the population lives below the level of poverty and life expectancy is very low. Inflation in Honduras was reported to be 21.3%; the highest in Central America (HTW 1996, WWW).

Land tenure has long been a traditional issue in Honduras. Even though the population of the country is only 5.5 million people, land ownership is concentrated in a few hands. Estimates indicate that 4% of the population owns about 60% of the country (Tear Fund 1997, WWW). The only high quality land of the country is owned by transnational companies and a few land owners.

The topography of the country makes agriculture difficult. Around 80%of the country is mountainous and the poor soils of the hilly lands are easily eroded. This leads to migratory slash and burn cultivation. The population growth of around 3.5% per year is creating an unprecedented pressure on the resources of the country. Deforestation of the highlands is accelerated and migration from the already eroded lands is increasing. Land reform programs in the 1970's were unsuccessful. The idea was to redistribute land in Honduras to make land tenure more egalitarian. The process failed for several reasons including corruption and the distribution of lands that were not suitable for agriculture. Current estimates place the deforestation rate in Honduras at 3,000 sq. km. per year (Johnson 1997, WWW). At this rate there will not be any forests remaining in 20 years. Broadleaf deforestation is the most severe, 65,000 to 80,000 ha. per year, followed by pine forest deforestation of around 15,000 ha. per year (Richards 1997, 1-3). Between 1964 and 1986 Honduras lost 25 percent of its forests (Uttley 1993, cited by Richards 1997, 1). Efforts to protect the remaining forests have been undertaken, including the designation of protected areas and the creation of national parks. However, the conflict between preservation and deforestation seems to have reached a critical point.

The Mosquitia Region, a Land of Conflicts

The Mosquitia Region of Honduras is the largest frontier in Central America. Located in northeast Honduras, it covers an area of 20,000 sq. km. The importance of the area is increased due to the existence of indigenous groups that still preserve their ancestral ways of life. In terms of natural resources the Mosquitia Region possesses the largest forests in Honduras. This has attracted people from other regions of the country who are motivated to exploit this vast resource. In 1980 the Honduran government created the Rio Platano Biosphere to protect the largest area of virgin forest left in the country. An area of 525,000 hectares was the first biosphere reserve in Central America and Honduras' largest. The area is rich in insects, mammals, birds, amphibians, reptiles, and other species included on the list of endangered or threatened species.

There are many threats to the Rio Platano Biosphere Reserve. Powerful Honduran and international logging interests seek the extraction of valuable species such as mahogany.

The best documented incident occurred in 1992 when a US-based logging company, Stone Container Corporation was interested in exploiting the vast forest of the Mosquitia including areas of the Rio Platano Biosphere. The Honduran government was willing to grant a 40 year concession to log more than a million acres of pine. In return, the company was to create 3000 jobs and invest 15 million dollars (Rainforest Alliance 1996, WWW). Fortunately, opposition by environmental groups, Indians, newspapers, and people from all sectors of Honduras made President Rafael Callejas back away from the decision to allow timber operations in the region. It was a response without precedent in the country's history. For the first time people from all social classes united to protect their natural heritage (Rainforest Action Network 1992, WWW). Presently, the most severe threat to the region is the advance of a colonization front made up of landless farmers coming from southern Honduras. This group of farmers comes from the already deforested southern region where soils are poor and eroded almost to the point of desertification. They see in the Mosquitia Region and particularly in the Rio Platano Reserve the last frontier of free land for the taking. In addition, powerful cattle ranchers, mainly from the Olancho Department, promote deforestation by encouraging landless farmers to move into the reserve. When the landless have cleared the lands the ranchers buy it cheaply and the farmers continue to move on. The devastation in the region surrounding the area is really dramatic (see figure 1). Numerous incursions have already occurred in the nucleus of the Rio Platano Biosphere. Some evaluations in the area have reported coffee plantations in the reserve (Hernandez 1996, personal communication). There is virtually no vigilance from the Honduran government and timber extraction in the area continues. Recently, Honduras This Week, a newspaper on the Internet, reported

Agricultural Colonization Front and Deforestation
Olancho Honduras 1993

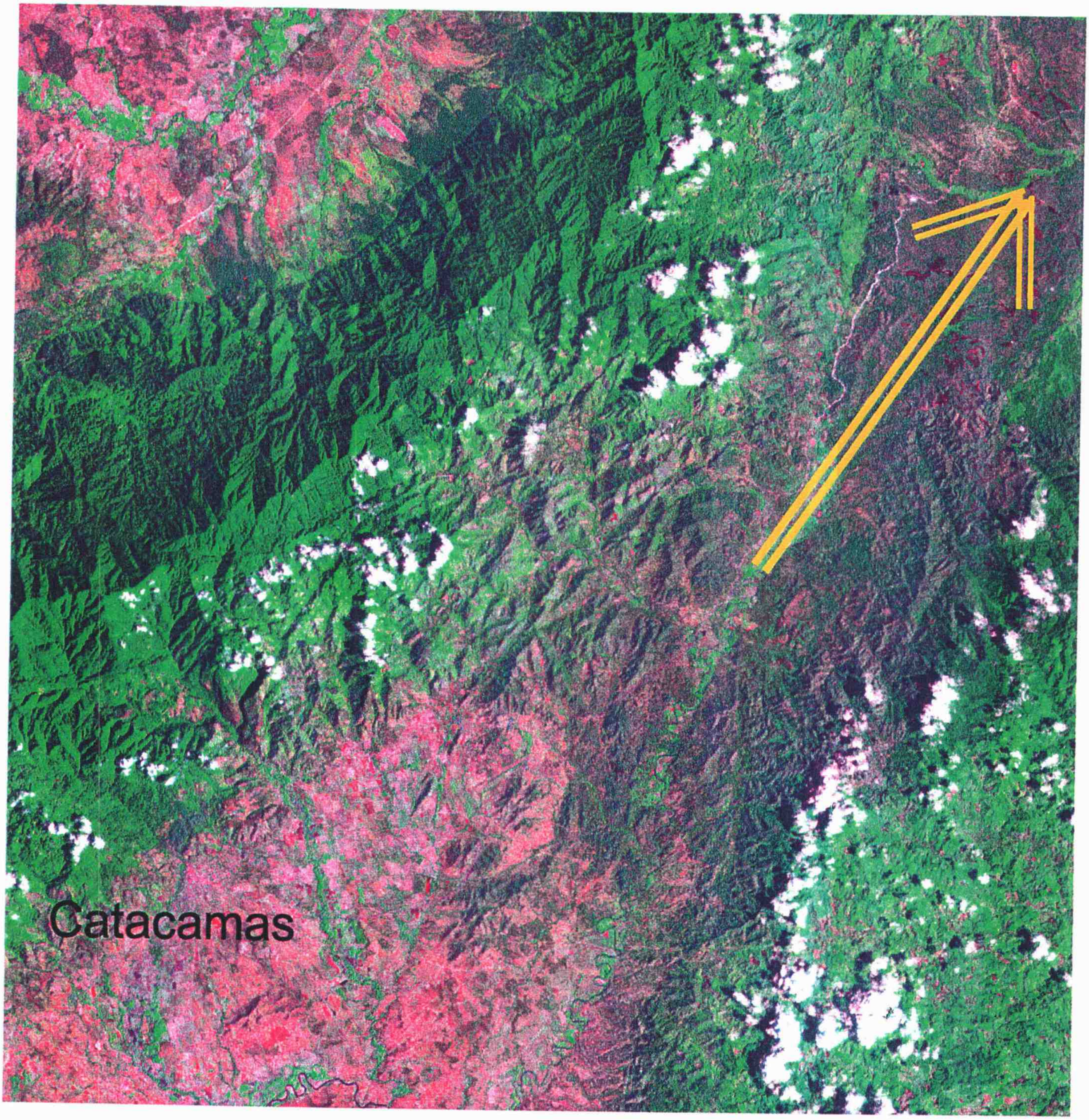
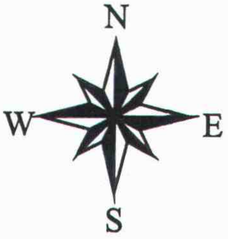


Figure 1

LANDSAT TM bands 7,4,3
shades of green represent vegetation
light and dark pink and red represent deforestation
dark violet indicates burned areas.
The yellow arrow shows the
direction of the colonization front
towards the Rio Platano Biosphere.
By Juan Carlos Torres 1997



that the inhabitants of Palacios, a small village close to the mouth of the Rio Platano, could not believe it when they saw thousands of feet of mahogany logs being floated down the Paulaya and Rio Tinto Rivers. Later they learned that the local authority in charge of protecting the area had given permission to timber companies to cut the logs (HTW 1997, WWW).

The influence that timber interests have in the Honduran government is notorious. Many of the members of the national congress are also loggers (Rainforest Alliance 1993 WWW). They will not enact any legislation oriented to the protection of forest. Since the military are also involved in cattle ranching and logging, they intimidate the peoples from the forests and do not help to enforce the protecting laws. In spite of the many threats to the area, the Rio Platano Biosphere still constitutes the only buffer to the interior of the Mosquitia Region.

OBJECTIVE

This study seeks to evaluate the resources of the Mosquitia Region by means of remote sensing and GIS. Change detection techniques are used to evaluate change in the region during the years of 1965, 1986, and 1995. Attempts are made to characterize the magnitude of change in the region in the aforementioned years. Results of the study include maps and graphs depicting the change in the area. The emphasis of this study is the change due to conversion to agriculture and deforestation. In addition, I attempt to evaluate the spatial pattern of the deforestation. Usually, one of the first steps of deforestation is the opening of roads that allow the access of people to the forested areas. That is not the case in the Mosquitia Region. The lack of roads in the area has made people look for alternative ways of access to the area. In this study, I evaluate proximity to rivers and deforestation.

LITERATURE REVIEW

Tropical deforestation is occurring at unprecedented rates. Current estimates vary, but several studies place it between 100,000 to 165,000 sq. km. per year (Skole and Tucker 1993). The implications of tropical deforestation are so severe that it threatens the survival of thousands of species and plays a key role in global climatic change and the increasing green house effect (Skole and Tucker 1993). Other effects of the depletion of rain forests have to do with the impact on indigenous populations. Rain forests are homes for ancient cultures whose existence is being threatened by the destruction of their resources and their ancient and sustainable way of living.

Obtaining accurate and up-to-date information about the tropics is the first step in assessing the damage taking place and to take measures to protect biological diversity. Quantifying the forests' resources requires measuring and mapping. The fact that the tropics cover extensive areas and are located in the poorest areas of the planet makes obtaining information sometimes impossible. Traditional approaches to land evaluation include land surveys and the use of photogrammetric techniques. These techniques are expensive and require the training of personnel and facilities that poor countries can not afford. In addition, aerial photography-based evaluations produce vast volumes of photographs that usually require manual interpretation and lots of time to process. The time span between aerial missions often results in information that is out of date and does not reflect the most recent changes taking place.

Satellite remote sensing has been used throughout the world to evaluate, monitor, and classify natural resources. As a result there is a broad body of literature dealing with the results of such studies. Of particular interest for this study are those papers dealing with the application of remote sensing in the tropics. The application of remote sensing in the tropics presents some unique challenges including data availability, cloud coverage, confusing spectral signatures due to the number of tree species present in a small area, and ground truthing under difficult conditions. Nonetheless, resource inventories have taken place and several of them have been able to classify land uses with different degrees of resolution and accuracy. Among the most successful and better documented studies are those dealing with monitoring rain forest depletion in the Amazon Region of Brazil and in equatorial Africa. Large scale assessments have been undertaken in these regions using coarse resolution sensors, among them the Advanced Very High Resolution Sensor (AVHRR) (Chuvieco and Martin 1994), (Blasco 1990) (Stone et al., 1994). Nonetheless, making decisions based on data provided by large resolution sensors can be risky. Skole and Tucker (1993) carried out an assessment of the deforestation in the Amazon using LANDSAT MSS data and concluded that previous studies of the region based on AVHRR data had overestimated deforestation by as much as 50 percent. AVHRR data were never intended for land classification. Their main use was to be a meteorological tool. Perhaps the best use for these data would be to obtain global or possibly continental estimates.

There is a robust body of literature assessing the relationship between spatial resolution and classification accuracy. One of the findings of these studies is that classification accuracy is improved at resolutions between 15 m and 75 m (Moody and Woodcock

1994, 585). Other issues associated with the use of AVHRR data had to do with poor pointing, poor calibration, and non-optimized band specifications. In addition, the data are often limited by a lack of adequate pre-processing procedures such as atmospheric corrections, cloud screenings, image to image registration, and insufficient resources for ground based validation efforts (Moody and Woodcock 1994, 585-86). In spite of these limitations AVHRR data can provide the best temporal resolution of any other satellite sensor. Almost every part of the globe can be monitored daily providing updated information. The ability to create monthly composites from the data guarantees that within a certain period we can obtain cloud free data for any area of interest in the tropics.

On the other hand, finer resolution sensors such as the LANDSAT thematic mapper (TM) and multispectral scanner (MSS) offer the advantage of improved spatial (30 m and 79 m respectively) and spectral resolution. Objects on the ground are easier to detect. The broad range of areas within the electromagnetic spectrum in which these sensors operate makes these type of data well regarded in the remote sensing community. In relation to research in the tropics, there is a growing body of research dealing with LANDSAT data. Again, most of the studies focus on the Amazon region of Brazil where most of the world deforestation is taking place. The data obtained from these sensors have been merged in powerful Geographic Information Systems (GIS) what have allowed sophisticated spatial analysis of the deforestation. Among the best studies are those of Sader and Joyce (1988) dealing with deforestation in Costa Rica. Deforestation in the Philippines was analyzed by Liew et al., (1992). Both studies merge LANDSAT data with other data sources to evaluate the relationship between road building and deforestation. Boyd et al., (1996) have studied forest regeneration in tropical forests using TM data. Tropical deforestation and habitat fragmentation have been measured using a combination of MSS and TM data for the Amazon Region by Skole and Tucker (1993). Deforestation in the Guinea highlands of West Africa was evaluated using MSS data (Gilruth and Hutchinson 1990). Berta et al., 1994 used multidate MSS data to analyze forest degradation in equatorial Africa.

Study Area

The present study focuses on the Gracias a Dios Department in the Mosquitia Region of Honduras. The Mosquitia Region also covers some areas of the Departments of Olancho and Colon. The Department of Gracias a Dios was selected due to data availability and also for the scientific impact that the present study may have. The area of the Mosquitia Region in Colon and Olancho has been better documented, particularly the area of the Rio Platano Biosphere. In addition, the area in Colon and Olancho is already protected (in spite of the many threats). In contrast, the interior of the Department of Gracias a Dios is virtually unprotected. The study area encompasses an area of 19,000 sq. km. The physiography of the area is characterized by traverse ranges that descend from the central cordillera of Central America into the Caribbean lowlands.

The area is drained by several rivers including the Rio Tinto Negro (formed by the Rio Sico and Rio Paulaya), the Rio Platano, the Rio Patuca, the Rio Warunta, the Rio Cruta, and the Rio Coco (border with Nicaragua) (Dodds 1994, 71). In the coastal area there are several lagoons, many of them connected to rivers and some to the ocean. Among the largest lagoons are Laguna de Caratasca, Laguna de Ibans, and Laguna de Brus. The climate of the region can be described as humid tropical with an annual precipitation between 2,000 and 3,000 mm. The mean temperature for the area is between 18° and 24° Celsius. According to Koeppen classification the climate of the area falls into the category Afw. The precipitation in the area follows the pattern of the intertropical convergence zone (Wilson and Meyer 1982, 12).

The soils of the region have been described as being comprised of hydromorphic soils on the low-lying coastal lands, alluvial soils inland behind low-lying coastal lands, and intensively weathered soils subject to erosion in the highlands (Steves 1964, 308-311 cited by Dodds 1994). In terms of biodiversity the study area is rich in ecosystems including pine savannas, wetlands, rain forests, and grass savannas. The tropical rain forest area is composed primarily of broadleaf evergreen species. Among the most common rain forest species are mahogany (Swietenia macrophylla), rubber (Castilla elastica), cortes (Tabebuia guayacan), and San Juan (Vochysia hondurensis). In addition, ephiphytism is very common including species of Bromeliaceae, Araceae, orchids, ferns and mosses (Agudelo 1987, 9 cited by Dodds 1994, 75). The pine savannas are characterized by stands of Pinus caribea var. hondurensis, amid sedges (Cyperaceae), and grasses (Tracchypogon, Paspalum, Aristida, Leptocoryphium) (Parsons 1955, 55). Other common species in the pine savanna are palmetto or tique stands, Cratella americana, Micronia spp., Byrsonima crassifola, Calliandra houstoniana, and less commonly, Quercus, Crescentia, and Mimosa (Parsons 1955, 49 citted by Dodds 1994). The vegetated wetlands are characterized by several species including red mangrove (Rhizophora mangle), white mangrove (Laguncularia racemosa), and Coccoloba uvifera (Brunt 1981, 45).

Fires play an important role in the region. Parsons (1955) provides a classical study of fire in the pine savannas of the region. The pine areas of the Mosquitia Region have similar climate to the areas occupied by tropical forest. According to Parsons, this area is probably the rainiest area in the New World with a savanna type vegetation. The fact that islands of hardwoods occur within the areas occupied by the pine savanna suggests that geology alone is not the explaining factor for the distribution of vegetation (Parsons 1955, 44). He postulates that fire has played an important role in forming the extensive pine savannas of the region. According to Parsons, where soils are poor pines begin to colonize. Fires then prevent the colonization by deciduous trees that otherwise would shade the pine. The fires are both natural and anthropogenic, lighting being the main source of natural fires. In addition, the natives of the area habitually set fire to the savanna to hunt, improve grazing, or simply for excitement (Parsons 1955, 46). In Parsons' view, hurricanes also help open up what originally was dense canopy forest trees. When the original tropical forest is opened it becomes more susceptible to fires. Parsons' hypotheses have been recently challenged by Wilson and Meyer (1982). They argue that the native population of the area is too small to maintain such large savannas. In addition, hurricanes are not very frequent in the area. They suggest an alternative explanation based on edaphic factors. Pine occurs in ridges composed of coarse gravel while lower areas support sedges grasses and palmetto. Fires allows pine to predominate over broadleaf species in the ridges, but the lower areas are probably natural savannas (Wilson and Meyer 1982, 15-16).

METHODS

Data Acquisition and Processing

This study uses several sources of data:

a. A map of forest cover in 1965 made by FAO. This map presented some challenges including lack of information about the projection used, the wrong scale, and some misclassification of land uses. In order to use this map it was necessary to reproject and reclassify it.

b. Map of land use in 1986-89 based on the interpretation of LANDSAT TM data made for the Honduran Corporation of Forestry Development by GAF, a German Company. The digitized map was acquired without editing. It had to be cleaned, edited and labeled.

c. 1995 LANDSAT TM images for the study area. They were rectified and made free from systematic errors. They were already projected to the Traverse Mercator Projection. I examined them and concluded that atmospheric correction was not needed.

d. Map of Indian Lands 1992. Although this map was designed to map the extent of the Indian lands in the area, it also shows the land use of the area as obtained from land surveys.

e. Topographic Maps from the Honduran National Geographic Institute. These maps were derived from aerial photographs at scale 1:50,000 taken in the 1960's. They were used to verify the classification of the 1986-89 map.

Steps

The first step was to digitize the 1965 forest map. It was digitized using the ADS module of the ARC/INFO software. Before digitizing some editing was necessary. It was noted that some of the features of the area were not included in this map, including water bodies. To remedy this situation, and in an effort to create the change detection, these features were added to the map. Since the border of the area was not very well delineated the border of the 1986 map was used. After the map was digitized it was edited in ARC/INFO using the ARCEDIT module. Labels were added for the different land use classes and topology was built using CLEAN and BUILD. Finally, the map was projected to the Universal Traverse Mercator Projection (UTM), zone 16, NAD27, and the Clark1866 spheroid using the PROJECT command. The 1965 map distinguishes six different classes: dense pine, sparse pine, tropical forest, mangrove, water and other uses. To be able to compare the 1965 map and the 1986 map it was necessary to reclassify the 1965 map. Mangrove was reclassified as vegetated wetland. Even though mangrove is common in the area, it has never been the dominant class. The area portrayed as mangrove in the 1965 map is composed of several wetland species and mangrove is only one of them. The area classified as other uses corresponds to savanna and vegetated wetland in the 1986 map. This area was also reclassified as savanna and vegetated wetland.

The 1986-89 map had to be cleaned in ARCEDIT. A hard copy of the map was obtained through a friend in Honduras and it was used as a reference to clean, edit, and label the digital map. After the topology was built, the map was projected to the UTM Projection, zone 16, NAD27, Clark1866 spheroid.

To produce the 1995 map for such a vast area several approaches were undertaken. Initially I developed a supervised classification using the least correlated LANDSAT TM bands (7,4,3). The idea was to produce an independent classification and then compare it with the 1986 and 1965 maps. Some problems arose with this approach. First, since I was using two full LANDSAT TM scenes the volume of data was enormous and the processing time was very long. Second, the classified image needed to be converted into vector format to be able to do the analysis. With the conversion came the difficult task of eliminating small clusters of pixels that were not significant enough for the scale of the study. Finally, I decided to try a new strategy. I looked at the study area using only one of the TM bands at a time. I knew from experience that the near-infrared and the mid-infrared bands are particularly sensitive to vegetation stress. Band 4 and 5 proved to be the best for detecting stress and deforestation in the area. From these two bands, I decided that band 5 was the best. To improve visual discrimination, I applied a linear filter using the default linear filter in Imagine 8.2. Next, I exported both the 1986 map and the enhanced 1995 TM images into ARCView and overlaid the 1986 map on the enhanced 1995 TM band 5. After that, a hard copy of the resulting overlaid map was produced. Next, those areas that had changed were identified, delineated, and finally digitized using the ADS module in ARC/INFO. The resulting map was cleaned, edited, labeled and projected to the same coordinate system as the other two.

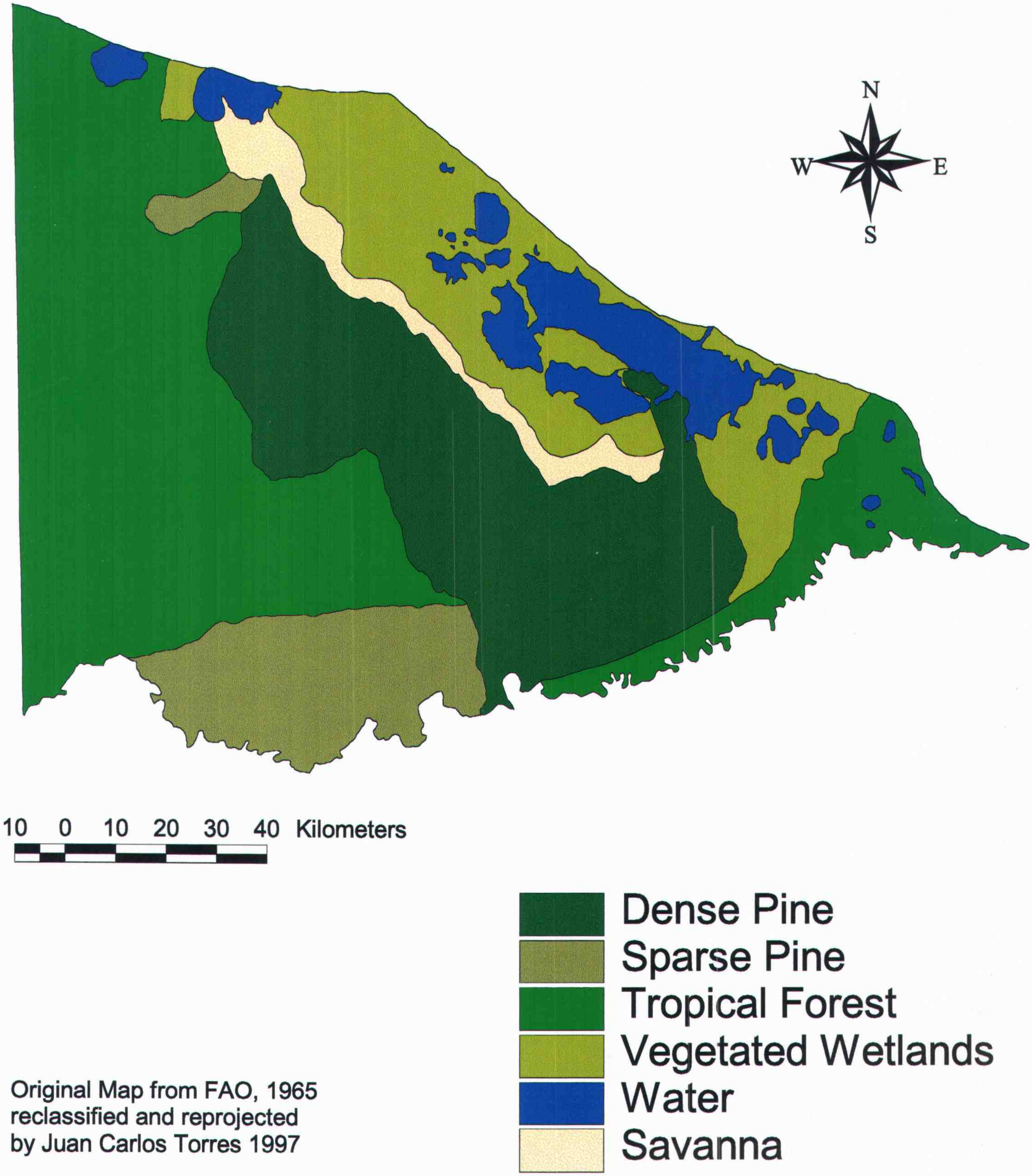
Change Detection

From the beginning of the study the idea was to quantify the amount of change in the Mosquitia Region. Of particular interest was the creation of a matrix showing change from one class to another. Vector GIS provided only marginally useful for this type of analysis. It was possible to quantify the total change in the area but what had changed from one class to another seemed a better task for raster GIS. Each of the coverages was imported into ERDAS Imagine 8.2 raster GIS software. After verifying that the process could be successfully done the analysis started. The MATRIX command in Imagine allows the user to overlay two raster coverages and produces a third that is the combination of the inputs. A matrix of the classes of each coverage is produced in such a way that there is only one possible combination for each of the classes. By looking at each of the resulting classes and the number of pixels in each of them, it is possible to infer the change that has taken place and the total area of the change. For this study, the 1986 map was overlaid on the 1964 map and a matrix of change was generated. Next the 1995 map was overlaid on the 1986 map to assess the change for this period. After the change maps were produced, they were exported back into ARC/INFO as vector coverages. Since I was interested only in change due to subsistence and extensive agriculture, the polygons that met these criteria were selected using TABLES and the command RESELECT. Finally, the coverages were exported into ARCView to create the final map composition.

Assessing the Relationship Between Rivers and Deforestation

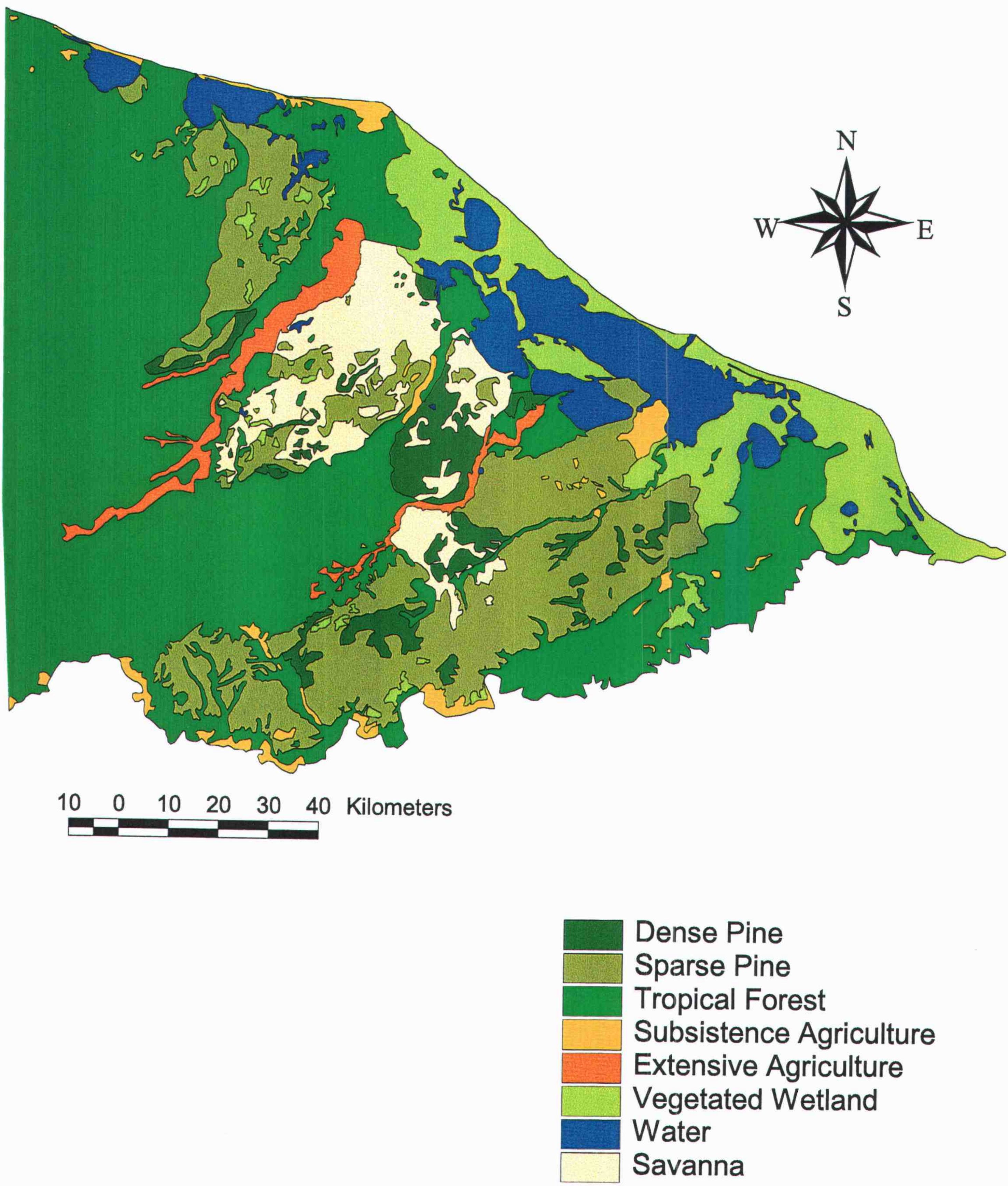
In the early stages of this study one pattern began to emerge, that of an association between proximity to rivers and deforestation and disturbances in the region. It looked as if all the deforestation was limited to areas next to rivers (see maps 2 and 3). Numerous studies have found a linear relationship between roads and deforestation in other

Land Use of La Mosquitia 1965

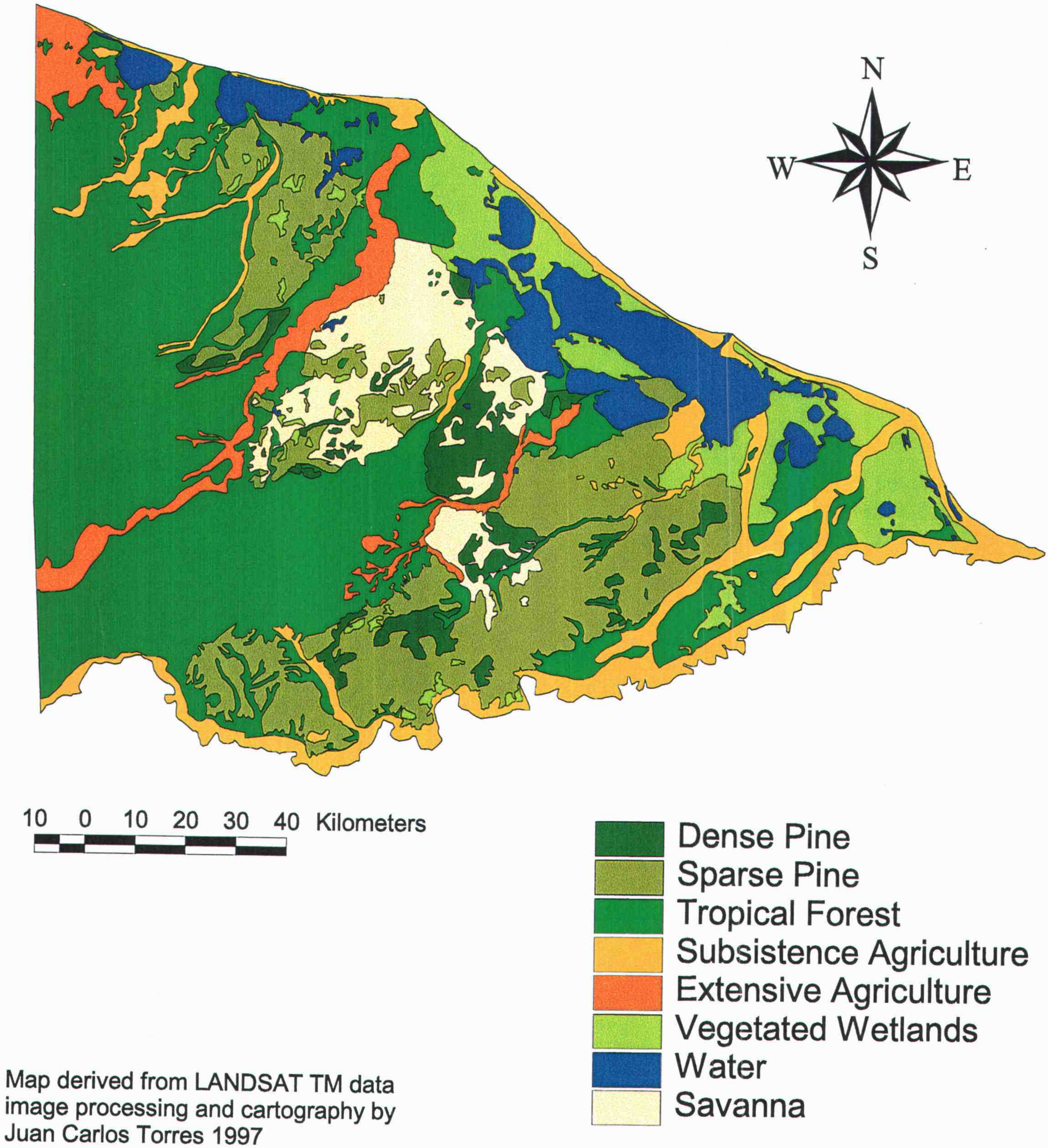


Original Map from FAO, 1965
reclassified and reprojected
by Juan Carlos Torres 1997

Land Use La Mosquitia 1986-89



Land Use La Mosquitia 1995



countries (Sader and Joyce, 1988) (Dawning et al., 1993). In the Mosquitia Region, the lack of roads has led to the use of rivers as major means of transportation. In addition, the areas along the rivers are very fertile due to annual flooding. Many valuable species such as mahogany occur close to the rivers, which at the same time provide a means to transport logs.

To assess this relationship an analysis was undertaken. First the main rivers of the area were digitized. The coverage containing the rivers was edited and georeferenced in ARC/INFO to the UTM Projection, zone 16, NAD27, and Clark1866 spheroid. Sixteen different buffers, each 500 meters from the center of the rivers were created using the BUFFER command. Each of the buffers was overlaid onto the 1995 map using CLIP. The CLIP command allows the user to overlay two coverages, one is the input, the second is the clip, and creates a third coverage that contains the area that is clipped from the first coverage. After the buffered areas were used to clip the 1995 map the deforested area inside each of the buffers was calculated using TABLES. Finally a linear regression analysis was performed for proximity to rivers and deforestation using Microsoft Excel.

RESULTS

I feel that the results of the study were successful. Figure 2 summarizes the change in the Mosquitia Region for the period of 1965 to 1986-89. The area occupied by dense pine in the 1965 map seems to be an area of major change with a reduction from 421,307 hectares in 1965 to 73,114 hectares in 1986-89. The area of sparse pine in 1965 increased in the 1986-89 map. It grew from 168,815 hectares in 1965 to 321,291 ha in 1986-89. The tropical rain forest area also experienced an increase from 679,607 ha. in 1965 to 846,894

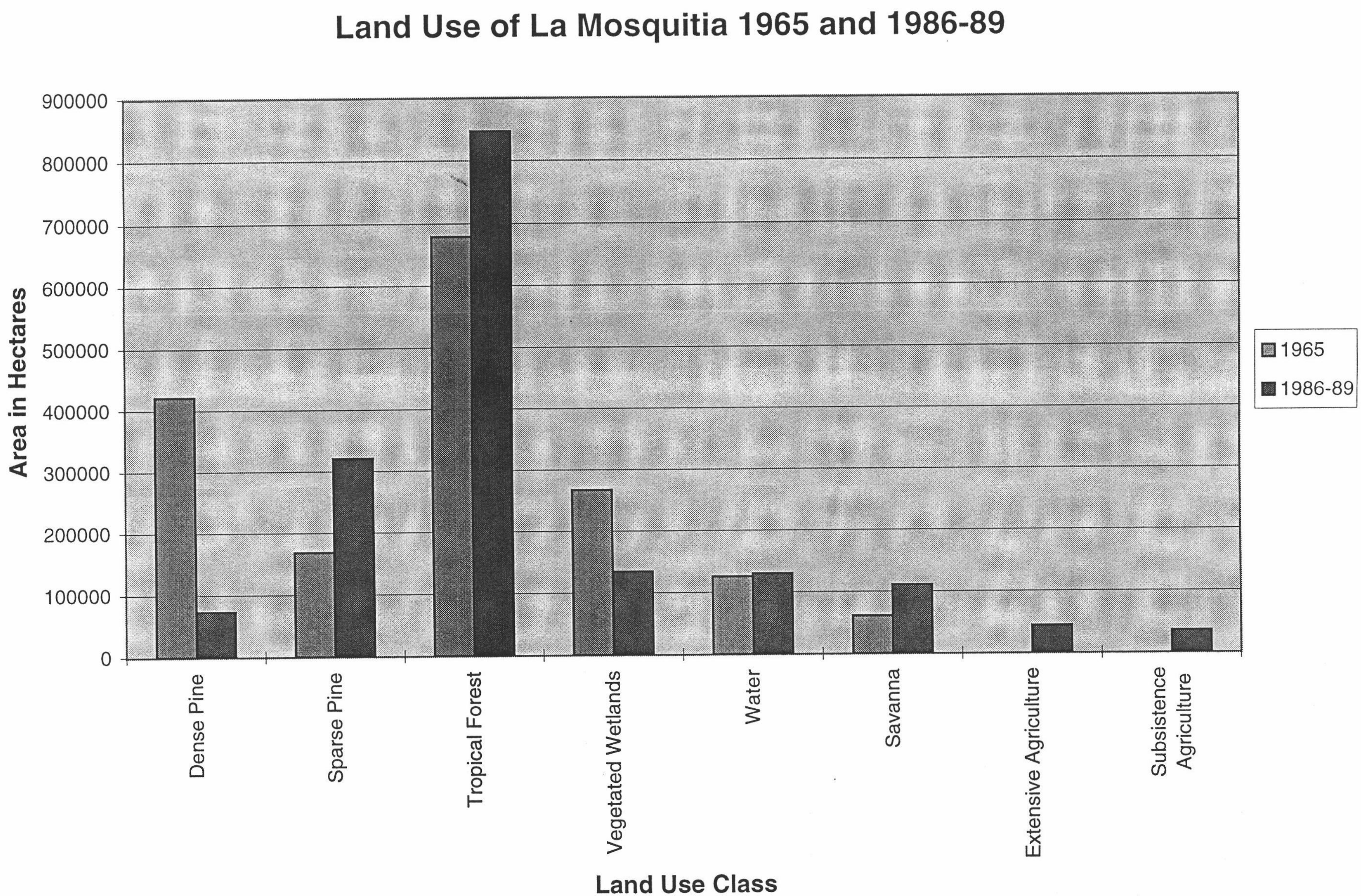

Land Use of La Mosquitia 1965 and 1986-89
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Area in Hectares
1965
1986-89
Dense Pine
Sparse Pine
Tropical Forest
Vegetated Wetlands
Water
Savanna
Extensive Agriculture
Subsistence Agriculture
Land Use Class

Figure 2

in 1986-89 period. Likewise the savanna area showed an increase from 61,073 ha. in 1965 to 110757 ha. Vegetated wetlands decreased from 267,240 ha. in 1965 to 171,028 ha. Two new classes are reported in the 1986-89 map, subsistence agriculture and extensive agriculture. For the purpose of this study subsistence agriculture is defined as being used for the purpose of feeding a family without any excess for commerce. Subsistence agriculture is characterized as being low impact and where only small parcels of land are cultivated and not major clear cutting of forests occur. Extensive agriculture is characterized by having a stronger impact on the land and the resources of the area. Areas are clear cut to grow crops and raise cattle. However, extensive agriculture is labor intensive and does not make use of mechanized equipment and high volumes of fertilizers as opposed to intensive agriculture. The area of subsistence agriculture in the 1986-89 map is 35,439 ha. and the area of extensive agriculture 44,140 ha. The area occupied by water remained the same for the period.

For the period from 1986-89 to 1995 the change for the area was as follows (see figure 3). The area of dense pine changed from 73,114 ha. in 1986-89 to 73,196 ha. in 1995. The area of sparse pine changed from 321,291 ha. to 321,388 ha. The area of tropical rain forest experienced the greatest change. It decreased from 846,894 ha. to 706,357 ha. The area of subsistence agriculture increased from 35,439 ha. to 175,114 ha. The extensive agriculture area increased from 44,140 ha. to 81,807 ha. The area of vegetated wetlands decreased from 171,028 ha. to 134,466 ha. The savanna and the water covered areas remained unchanged for this period.

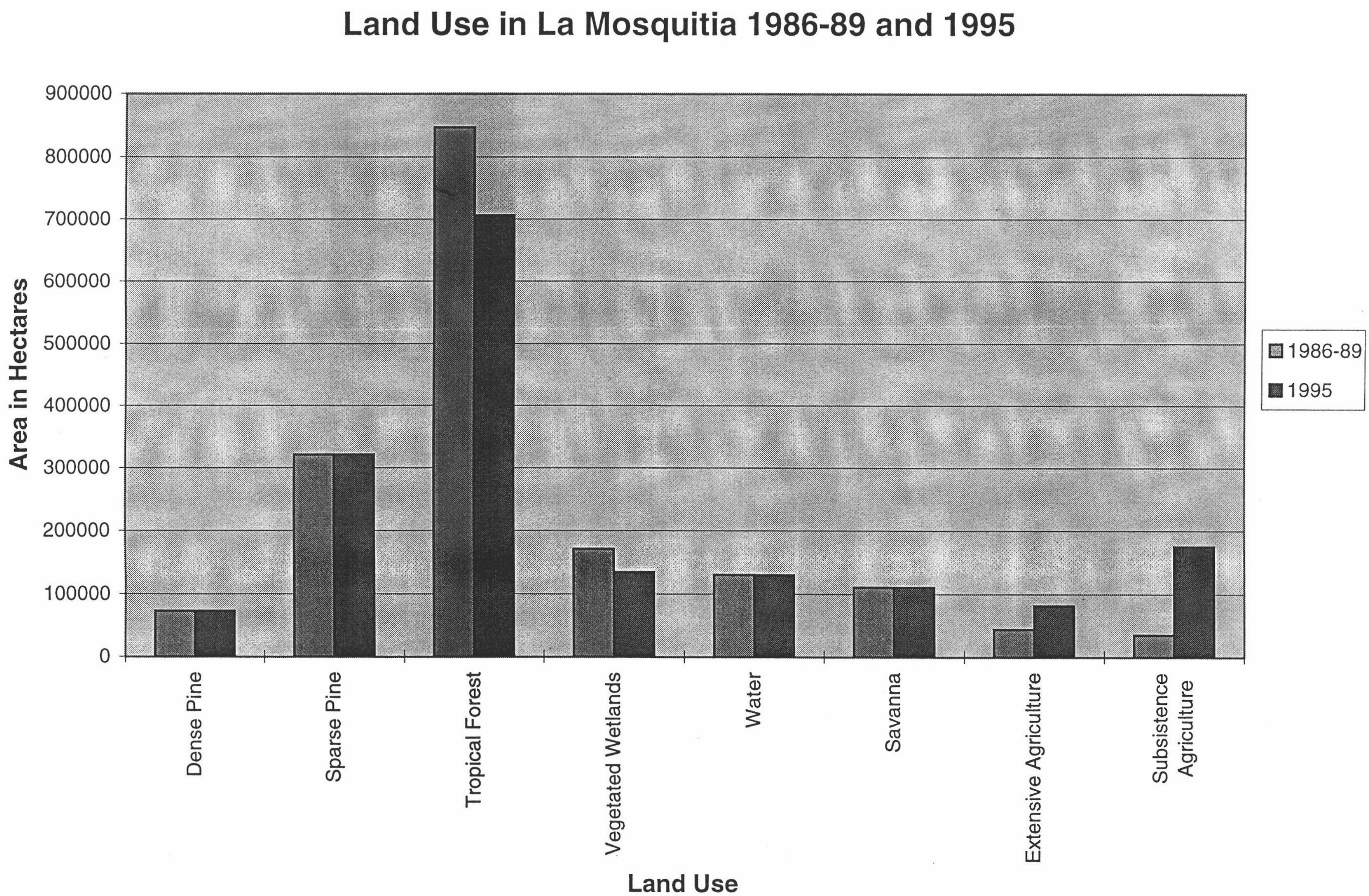

Land Use in La Mosquitia 1986-89 and 1995
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Area in Hectares
1986-89
1995
Dense Pine
Sparse Pine
Tropical Forest
Vegetated Wetlands
Water
Savanna
Extensive Agriculture
Subsistence Agriculture
Land Use

Figure 3

Matrix of Change

The objectives of this study were not only to quantify the area of change but also to determine what part of the change was due to conversion to agriculture. As explained before, the MATRIX command in Imagine 8.2 allows the user to combine two maps and produces a matrix that is the combination of the inputs. The resulting matrix allows the user to evaluate the change from one class to another. Map 4 shows the change in the Mosquitia Region between 1965 and 1986-89 due to subsistence and extensive agriculture. Table 1 shows the of change in hectares for that period:

Table 1.

Land Use in 1965	Total Area Changed by 1986-89	Area Changed to Subsistence Agriculture	Area Changed to Extensive Agriculture
Dense Pine	26,224	9,111	17,113
Sparse Pine	11,291	11,291	0
Tropical Forest	18,686	2,894	15,792
Vegetated Wetlands	15,739	7,701	8,038

Map 5 shows the areas of change in hectares for the period of 1986-89 to 1995 due to subsistence and extensive agriculture. Table 2 summarizes the change for the period.

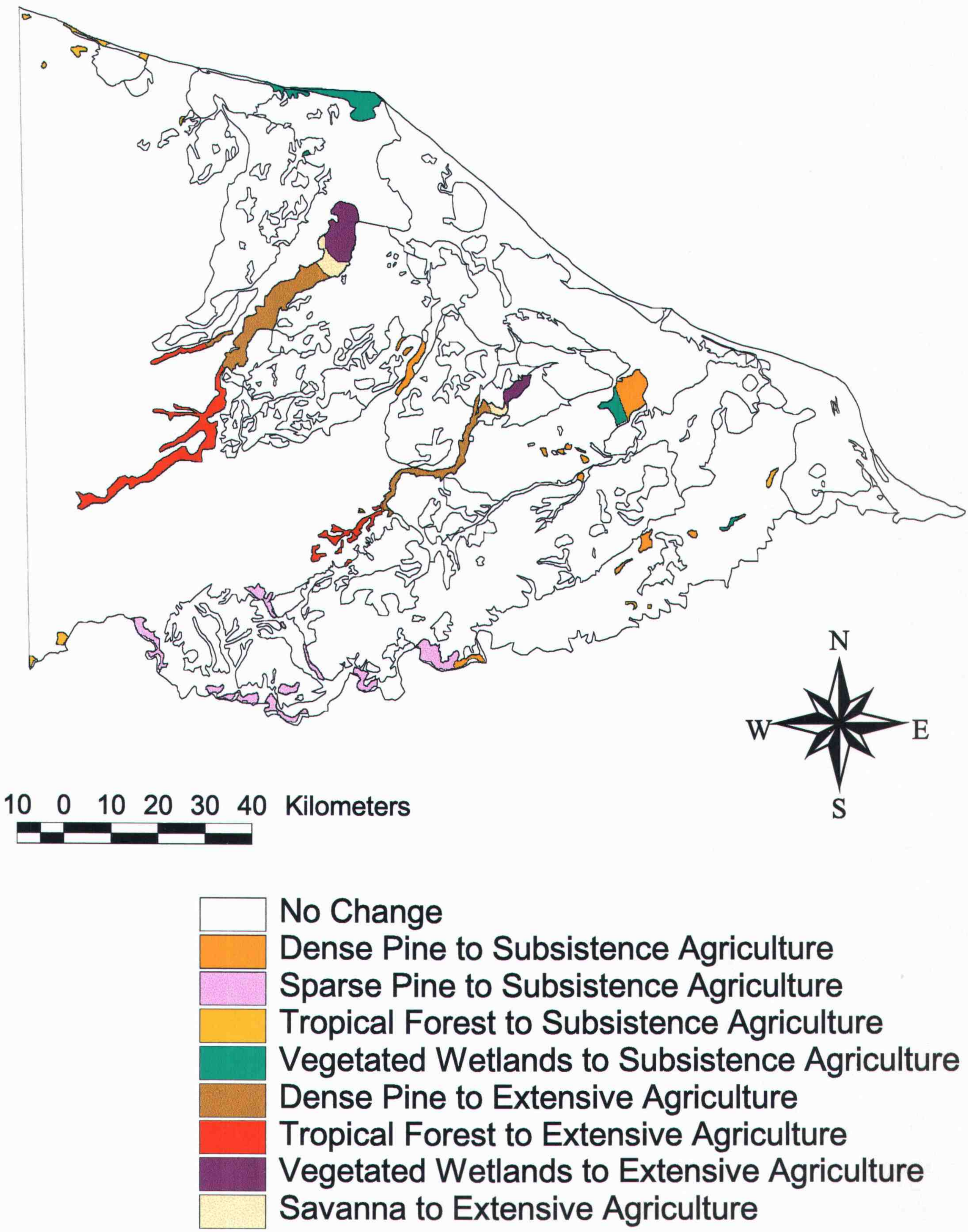
Table 2.

Land Use in 1986-89	Total Area Changed in 1995	Area Changed to Subsistence Agriculture	Area Changed to Extensive Agriculture
Sparse Pine	2,019	1,446	573
Tropical Forest	14,0552	1,03792	3,6760
Vegetated Wetland	35,690	35,630	60

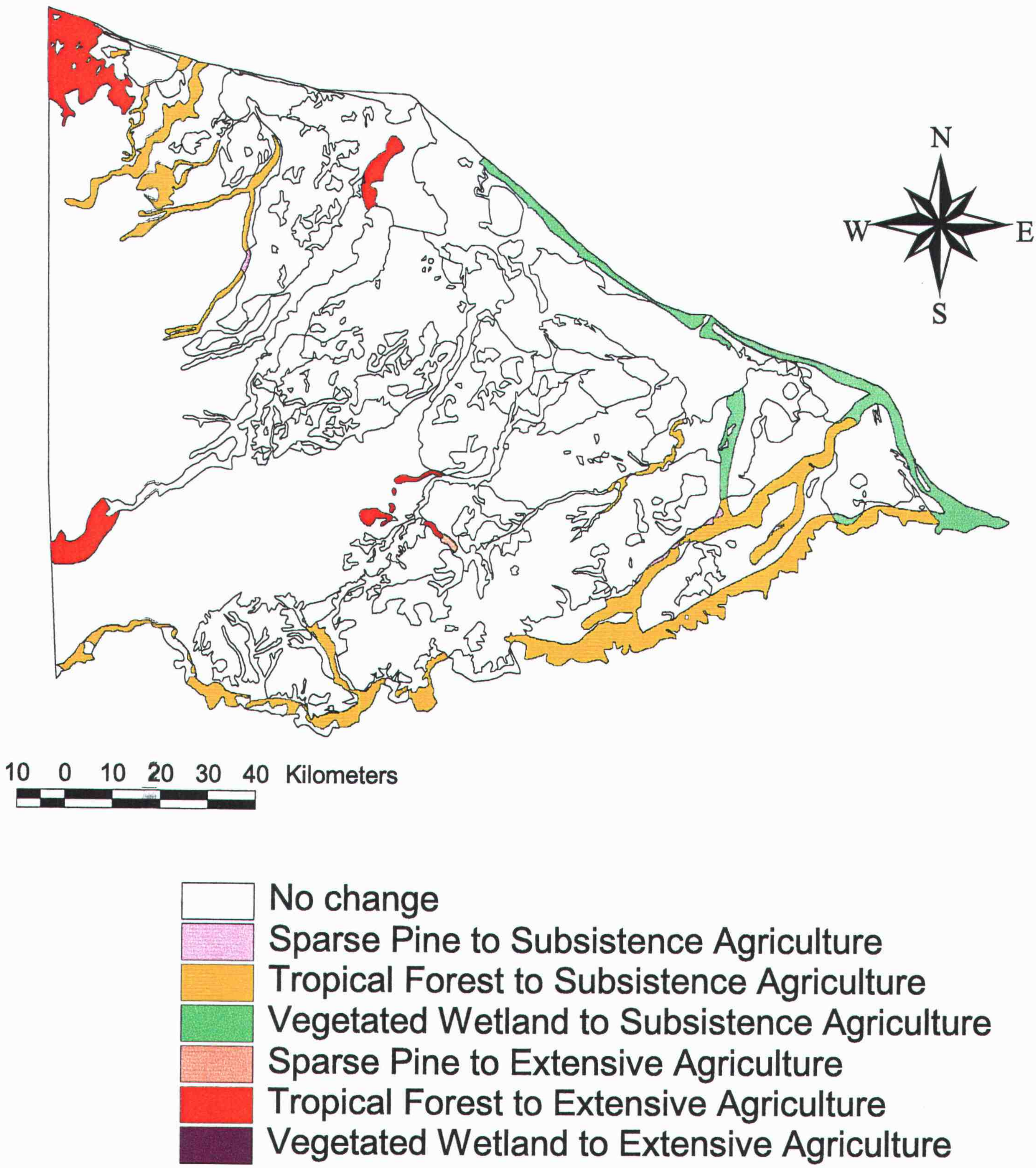
Relationship Between Rivers and Deforestation:

Figure 4 shows a regression line for proximity to rivers and deforestation due to subsistence agriculture. From the graph we can see that there is a linear relationship between proximity to rivers and deforestation (corr. coeff.= -83.3, R2 = 0.69). The

Areas of Change in La Mosquitia from 1965 to 1986



Areas of Change in La Mosquitia from 1986 to 1995



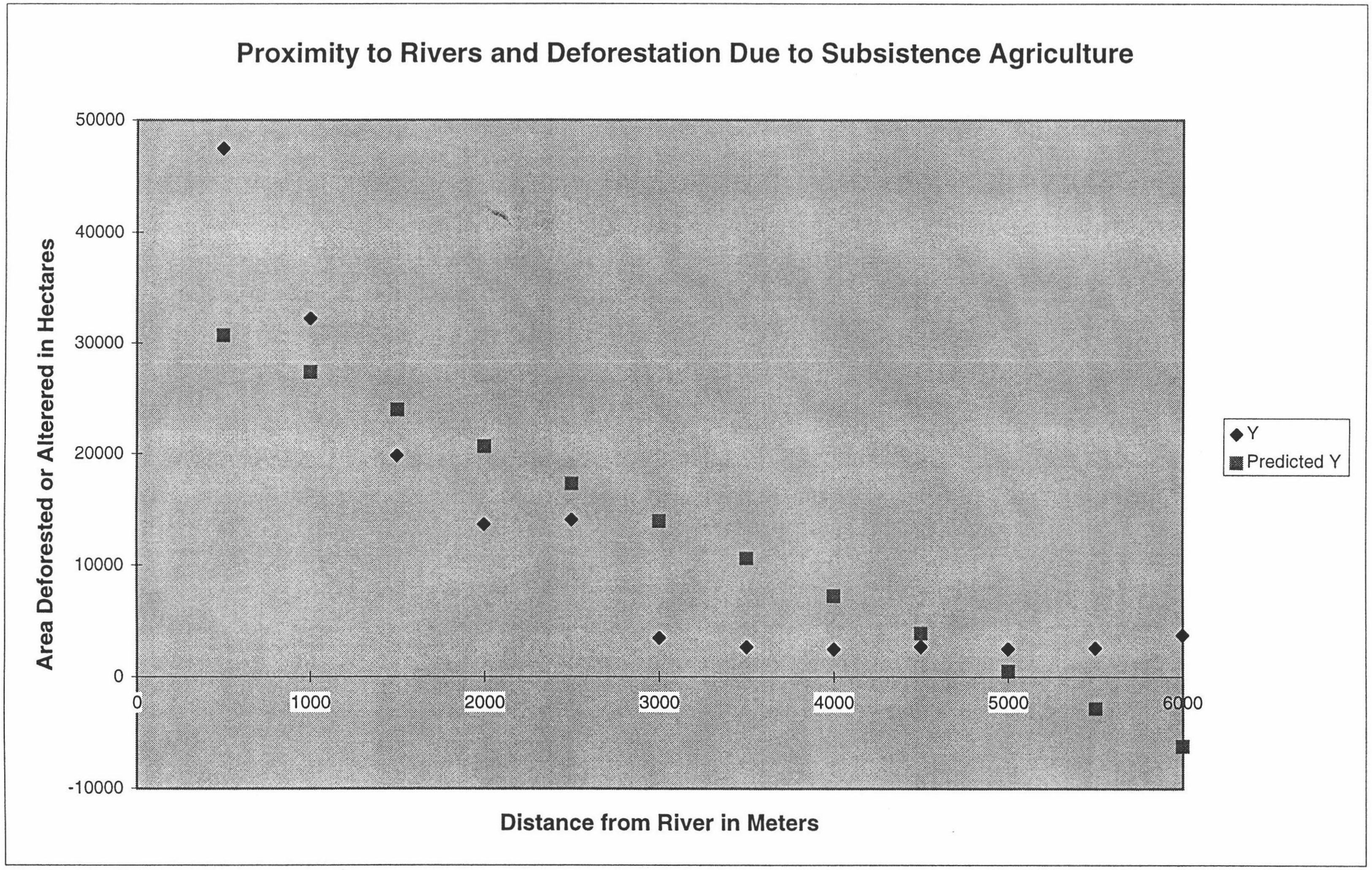

Proximity to Rivers and Deforestation Due to Subsistence Agriculture
Area Deforested or Alterered in Hectares
50000
40000
30000
20000
10000
0
-10000
0
1000
2000
3000
4000
5000
6000
Distance from River in Meters
Y
Predicted Y

Figure 4

percentage of forest loss decreases linearly with increased distance from rivers for the areas within 6 km of rivers. More than 54% of the area deforested for subsistence agriculture in the Mosquitia Region occurs within 1,000 meters from rivers; 76% of the area cleared is within 2,000 meters. The rest of the area cleared decreases as distance from rivers increases up to 6 kilometers. Figure 5 shows the regression line for proximity to rivers and deforestation due to extensive agriculture. Again, there is a strong linearity between these variables (corr. coeff. = -78, R2= 60). 38% of the deforestation due to extensive agriculture occurs within 500 meters from rivers, more than 59 percent occurs within 1000 meters, and more than 78 percent within 2,000 meters. After that the amount of deforestation decreases up to a distance of 6 km.

DISCUSSION

The Mosquitia Region experienced moderate change during the period between 1965 and 1986-89, and more intense change for the period between 1986-89 and 1995. The period between1965 and 1986-89 started the process of change in the Mosquitia Region. According to historical records prior to the 1960's there were not major impacts on the Mosquitia. Most of the activities of the prior years were low impact-subsistence activities with a low population density. The isolation of the area from the rest of Honduras contributed to the preservation of the resources of the area. The reported change in the dense pine areas for the period between 1965 and 1986-89 had to do more with the quality of the 1965 classification than with reality. The 1965 map exaggerates the area occupied by dense pine. When the 1965 map is compared to higher resolution map

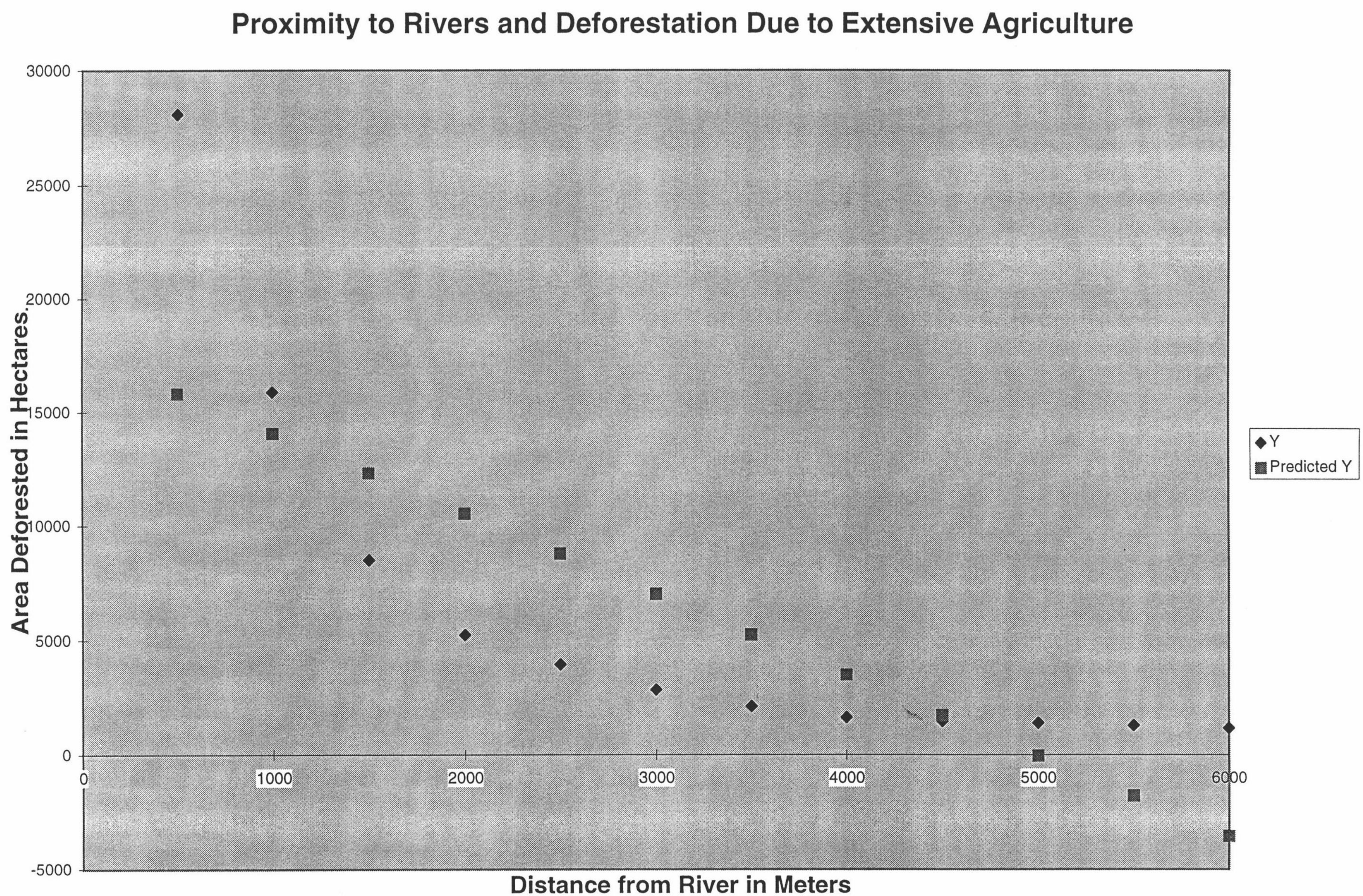

Proximity to Rivers and Deforestation Due to Extensive Agriculture
30000
25000
20000
15000
10000
5000
0
-5000
Area Deforested in Hectares
0
1000
2000
3000
4000
5000
6000
Distance from River in Meters
Y
Predicted Y

Figure 5

produced from LANDSAT TM data those areas portrayed as dense pine in 1965 become sparse pine in 1986-89.

In the period between 1986-89 and 1995 a total of 103,792 ha. of tropical forest were converted to subsistence agriculture. It shows the most dramatic increase in tropical deforestation and alteration. A total of 36,760 ha. were deforested for extensive agriculture. Most of this deforestation corresponds to areas around the Sico and Paulaya Rivers which the presidential decree of 1995 promoted as a settlement for land reform. The area of pine forest did not experience the same amount of change than the tropical forest. The reason for this is that the areas where pine grows are not perceived as areas of high soil fertility. Therefore, less area was clear cut for agricultural purposes.

During the study I detected several extensive areas that had been burned in the pine savanna area. The intensity of the fires is unknown. However, I know from experience, and by reference, that crown destructive fires are virtually unknown in the area (Parsons 1955, 57). Fire is a common factor that contributes to the perpetuity of the pine savanna. As long as the fire intensity and frequency does not reach the destructive level no major damaged is inflicted to the pine. Therefore, these burned areas were ignored for the purpose of the study. Again, proximity to rivers seems to explain, in most of the cases, the deforestation of the area. Alluvial soils along the rivers are fertile, and at the same time, rivers provide a means of transportation.

Regarding the data, the 1965 map presents some challenges. First, the scale of the study is very generalized and comparison with finer surveys can lead to exaggeration in the level of change in the area. In spite of this limitation, the 1965 map constitutes the only known reference for that period. Similar studies have been carried out in the Philippines and Costa Rica using data of around the same period of time with similar limitations. The 1986-89 and 1995 maps provide a more robust data set due to improved spatial and spectral resolution. Initial attempts to quantify the change in the area using AVHRR data were not successful. There was a strong tendency to confuse classes in the map derived from these data. Due to the one kilometer spatial resolution of the data small clusters were generalized and registration of the data to a coordinate system was very difficult. Identification of landmarks as ground control points had to be approximated. Nonetheless AVHRR data provided hints about the general trend of change in the area. The fact that AVHRR data can be obtained for free as part of a global data base project makes it worth looking at. Several studies dealing with deforestation at the regional and continental scale have used AVHRR data . That is perhaps the best utility for those data.

The satellite data analysis and processing was very successful. Detecting clear cuts in tropical forest is a relatively simple process. Band 5 was selected because it provided a good contrast between vegetated and non-vegetated areas. The visual enhancement of the data using a linear filter further improved the process of delineating the areas of change. The areas where disturbances and deforestation had taken place were characterized by greater reflection due to the increased exposed soils and thinner canopy. The areas of subsistence agriculture did not show the same reflection as the areas of extensive agriculture, since areas of extensive agriculture had more soil area exposed due to clear cuts. When these areas were magnified, it was possible to see the field boundaries. Throughout the study several transformations of the data were carried out for the purpose of visualizing the data and obtaining clues about the change. These transformations included Principal Component Analysis and the Tasseled Cap Transformation. These proved to be of only marginal utility in the analysis. In the end, they increased the volume of the data without any added benefit. As an image processing exercise they were fun to work with, but in practical terms the lesson learned is that the technique should not drive the analysis regardless of its sophistication.

CONCLUSION

Tropical deforestation is a global issue with serious implications for all life on planet earth. The Mosquitia Region deserves to be protected due to its biological, human, and aesthetic value. The lack of roads in the area has helped keep people away from the area. At the same time the lack of roads has resulted in the use of rivers as alternative means for transportation. The high fertility of the river areas along with the existence of high value tree species such as mahogany has made these places very attractive to settlers. Remote sensing and GIS are important tools to monitor, evaluate, and detect global change. In the case of Honduras these tools provide a fast, economical, and effective way to evaluate vast areas that otherwise could take many years. The government promotion of the Sico and Paulaya rivers as areas for land reform is causing accelerated damage to the area. It is urgent to stop the settlements in the buffer and in the core of the Rio Platano Biosphere. The colonization front made up of landless farmers needs to be offered alternative places in areas of lower impact. These strategies may include the return to the already deforested southern Honduras along with the application of farming techniques that are sustainable and promote soil conservation. At the present rate of change, there is almost no hope for the area.

REFERENCES

Berta, S.M., Mausel, P.W., and Harrison, J.A. 1990. Multidate Image Analysis of Forest Degradation in Equatorial Africa. Geocarto International. 4: 57-61.

Blasco, F. 1990. Analysis of Vegetation Seasonal Evolution and Mapping of Forest Cover in West Africa with NOAA AVHRR HRTP Data. Photogrammetric Engineering & Remote Sensing 1359-1365

Boyd, D.S., Foody, G.M., Curran, P.J., Lucas, R.M., and Honzak, M. 1996. An Assessment of Radiance in LANDSAT TM Middle and Thermal Wavebands for the Detection of Tropical Forest Regeneration Photogrammetric Engineering & Remote Sensing Vol. 17, No. 2, 249-261.

Brunt, M.A. 1981. La Mosquitia, Honduras: Resources and Development Potential, Volume 1 the Environment. Land Resources Development Centre, Overseas Development Administration. Surbiton England.

Chuvieco, E., and Martin, P. 1994. Global Fire Mapping and Fire Danger Estimation Using AVHRR Images. Photogrammetric Engineering & Remote Sensing Vol60, No. 5, 563-570.

Dodds, D.J. 1994. The Ecological and Social Sustainability of Miskito Subsistence in the Rio Platano Biosphere Reserve Honduras. Ph.D. thesis, Vol. I and II. University of California, Los Angeles

Gilruth, P.T., and Hutchinson, C.F. 1990. Assessing Deforestation in the Guinea Highlands of West Africa Using Remote Sensing. Photogrammetric Engineering & Remote Sensing Vol. 56, No 10, 1375- 1382.

Griffin, W. 1997. Lumberjacks Down Mahogany Timber Despite Moratorium. Honduras This Week Special Edition: The Environment. March 20. (http://www.marder.com/htw).

Johnson, K.C. 1997. Devastation in Honduras: What will Happen with the Forest?. (http://shuang.fmarion.edu/www.html/ESSAY/HONDURAS.HTM).

Liu, D.S., Iverson, L.R., and Brown, S. 1993. Rates and Patterns of Deforestation in the Philippines: Application of Geographic Information System Analysis. Forest Ecology and Management, 57: 1-16.

Moody, A. and Woodcock, C.E. 1994. Scale Dependent Errors in the Estimation of Land-Cover Proportions: Implications For Global Land-Cover Datasets. Photogrammetric Engineering & Remote Sensing, Vol. 60, No. 5, 585-594.

Parsons, J.J. 1955. The Miskito Pine Savanna of Nicaragua and Honduras. Annals of the Association of American Geographers 45 (1): 39-63

Rainforest Action Network. 1992. Honduras Rejects Stone. (rainforest@igc.org).

Rainforest Alliance. 1992. US Loggers Fail in Honduras. (canopy@igc.org)

Richards, M. 1996. Protected Areas, People and Incentives: the Search for Sustainable Forest Conservation in Honduras. Rural Development Forestry Network, Overseas Development Institute, Regents College, Regents Park, London, NW14NS.

Sader, S.A., and Joyce, A.T. 1988. Deforestation Rates and Trends in Costa Rica, 1940 to 1983. Biotropica, 20: 11-19.

Skole, D., and Tucker, C. 1993. Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988. Science, 260: 1905-1910.

Stone, T.A., Schlesinger, P. Houghton, R.A., and Woodwell, G.M. 1994. A Map of the Vegetation of South America Based on Satellite Imagery. Photogrammetric Engineering & Remote Sensing Vol. 60, No. 5, 541-551.

Tear Fund. 1997. Honduran Rain Forest in Danger. (http://www.tearfund.org.uk/honduras)