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Use of remotely sensed data to detect recent changes in both areal boundary and species composition of mangrove communities along the Guyana coast.

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Use of Remotely Sensed Data to Detect Recent Changes in Both Areal Boundary and Species Composition of Mangrove Communities Along the Guyana Coast

by

John Michael Kovacs

A Thesis
Submitted to the Faculty of Graduate Studies
through the Department of Geography
in partial fulfilment of the requirements
for the degree of Master of Arts at the
University of Windsor

Windsor, Ontario, Canada
1994

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Ancient	0579
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Canadian	0334
European	0335
Latin American	0336
Middle Eastern	0333
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Plant Culture	0479
Plant Pathology	0480
Plant Physiology	0817
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Biology	
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Biostatistics	0308
Botany	0309
Cell	0379
Ecology	0329
Entomology	0353
Genetics	0369
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Microbiology	0410
Molecular	0307
Neuroscience	0317
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Zoology	0472
Biophysics	
General	0786
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Paleontology	0418
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Physical Geography	0368
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Pathology	0571
Pharmacology	0419
Pharmacy	0572
Physical Therapy	0382
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Elementary Particles and High Energy	0798
Fluid and Plasma	0759
Molecular	0609
Nuclear	0610
Optics	0752
Radiation	0756
Solid State	0611
Statistics	0463

Applied Sciences

Applied Mechanics	0346
Computer Science	0984
Engineering	
General	0537
Aerospace	0538
Agricultural	0539
Automotive	0540
Biomedical	0541
Chemical	0542
Civil	0543
Electronics and Electrical	0544
Heat and Thermodynamics	0348
Hydraulic	0545
Industrial	0546
Marine	0547
Materials Science	0794
Mechanical	0548
Metallurgy	0743
Mining	0551
Nuclear	0552
Packaging	0549
Petroleum	0765
Sanitary and Municipal	0554
System Science	0790
Geotechnology	0428
Operations Research	0796
Plastics Technology	0795
Textile Technology	0994

PSYCHOLOGY

General	0621
Behavioral	0384
Clinical	0622
Developmental	0620
Experimental	0623
Industrial	0624
Personality	0625
Physiological	0989
Psychobiology	0349
Psychometrics	0632
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ABSTRACT

Two approaches were taken to investigate mangrove forests located along the coast of Guyana. The first involved assessing the extent of recent changes for both species composition and areal boundary, as well as identifying the major factors associated with these changes. The second approach involved evaluating satellite imagery as a means for monitoring these communities.

For the first study, a Geographic Information System (GIS) was utilized to track the changes over time. It was determined that mangrove communities located between the Pomeroon and Corentyne Rivers have experienced an overall decrease by 5.57% or a loss of 24.93 km^2 between the periods 1960-64 and 1986-88. Forests dominated by *Rhizophora mangle* and by mangrove associates were reduced by 94.23% (7.35 km^2) and by 10.27% (35.81 km^2) respectively. *Avicennia germinans* dominated communities experienced an increase by 3.75% (2.84 km^2) and mixed stands of *Avicennia* and *Rhizophora* an increase by 106.05% (15.39 km^2). Mangrove communities located west of the Pomeroon River towards the Moruka River experienced an overall increase by 19.09% or a gain of 121.45 km^2. Mangrove associate and *Avicennia germinans* dominated forests contribute to roughly 57% and 43% of this expansion respectively. Furthermore, data extracted from the GIS provided a means for identifying causal agents. The leading cause of mangrove forest loss between the Pomeroon and Corentyne Rivers was determined to be urban/agricultural expansion. The majority of the gains has resulted from accretion in the coastal environment. The fluctuations and the gains of mangrove communities west of the Pomeroon River could not be linked to any particular agent of change.

From the satellite image analysis study it was determined that an unsupervised classification with LANDSAT MSS cannot, under the conditions presented, be used to monitor mangrove forests along the coast of Guyana. It may, however, be used to monitor agricultural expansion and/or wetlands (mangrove communities/swamp savanna).

DEDICATION

To my parents, Frank and June Kovacs.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Mangrove forests form a highly dynamic environmental interface between land and sea (Azariah et al., 1988). These forests are composed of a single storeyed layer of facultatively halophytic tree species that flourish between the subtidal and supratidal areas on tropical and subtropical coasts (Adegbenin and Nwaigbo, 1990; Flores-Verdugo et al., 1992).

Mangrove forests are beneficial for local inhabitants. For example, they aid in nutrient and waste absorption (Barbier, 1993); support diverse populations of mammals, reptiles, birds and insects (Carter, 1988; Pritchard, 1988); supply both shelter and organic matter necessary for nearshore fisheries (Odum, 1978); and provide coastal protection by aiding the accretion and stabilization of shorelines (Semeniuk, 1980). In addition, under proper management, mangrove forests provide a renewable source of firewood, construction materials, peat, honey, dyes, drugs and even tannins which are utilized in the leather treatment industry (Odum, 1978; McVey, 1988; Adegbenin and Nwaigbo, 1990).

Unfortunately mangrove forests have recently been subject to a variety of human and natural disturbances that have caused both a rapid degeneration of forest boundaries and sudden changes in tree species composition (Ball, 1980). In fact, agricultural practices and urban expansion (infrastructure) are deemed to be the primary catalysts for the changes in these forests. Recently there has been a worldwide trend to focus on these problems (Azariah et al., 1988; McVey, 1988; Barbier, 1993). In South America, a lack of information on historical changes in both mangrove forest boundaries and species composition is impeding proper management of this valuable resource.

In order to measure the historical changes in areal boundaries as well as the species composition of mangrove forests, both aerial photographs and remotely sensed imagery from satellites will be utilized. The country of Guyana, South America, has been chosen for the study because of the extensive mangrove forests located along its coastline. Both pure and mixed stands of *Rhizophora mangle* (Figure 1), *Avicennia germinans* (Figure 2), as well as less distinct mangal communities (Figure 3) will be measured.

There are three objectives to this study: (1) to provide a LANDSAT MSS remote sensing interpretation key for the mangrove forest types of Guyana; (2) to quantify historical changes in both areal boundaries and species composition for each mangrove forest; and, (3) to determine statistically if the anthropogenic factor strongly correlates with mangrove forest change along the coast. Such knowledge would be useful for both policy makers and resource managers concerned with mangrove forests.

1.1 Study Area

Coastal Plain

The mangrove forests under investigation are located along the coastal plain of Guyana between the Pomeroon and Corentyne rivers (Figure 4). Guyana is located along the northern coastline of South America and is bounded to the north by the Atlantic Ocean, to the south by Brazil, to the west by Venezuela and

FIGURE 1: Rhizophora mangle community located on Leguan Island, Essequibo River, Guyana (Source: Author, 1993).

FIGURE 2: Avicennia germinans community located at Hope, Mahaica River, Guyana (Source: Author, 1993).

FIGURE 3: Mangal community composed of both mangrove and mangrove associates located on Wakenaam Island, Essequibo River, Guyana (Source: Author, 1993).

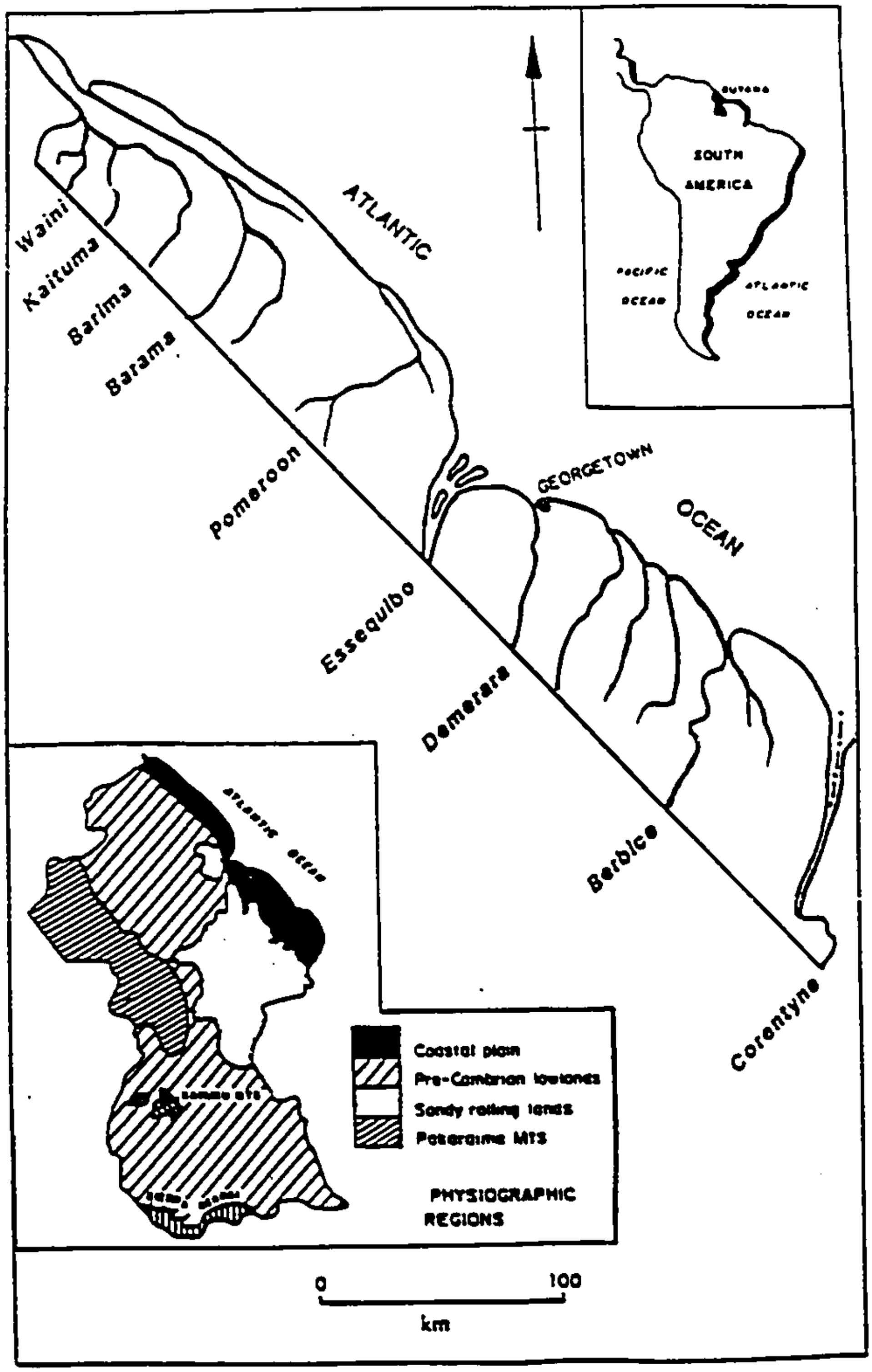


FIGURE 4: Guyana's Coastal Plain.

Source: V. C. Lakhan, 1993.

to the east by Suriname. The country is situated between 0° 41'N and 8° 33'N and between 56° 32'W and 61° 22'W.

The coastal plain represents one of the country's major physiographic regions. The coastal plain is bordered to the south by the Pre-Cambrian lowlands in the west and by the sandy rolling lands in the east. The plain extends 432 km along the coast and its width varies between 77 km in the west to 26 km in the east. This low lying region of marshes and ridges consists of an alluvial plain developed over time by the deposition of sea borne clays. As the result of an elaborate system of sea defences, several areas within this region fall well below sea level. Consequently, the coastal plain is estimated to lie, on average, between 0.5 to 0.1 meters below high spring tide level. The region's climate is tropical. The year round temperature rarely rises above 30° C or falls below 24° C. The majority of the rainfall, 2000-2500mm/year, occurs during two peak periods, May-June and December-January. Winds are consistently between northeast and north-northeast, and storms and cyclones are extremely rare. Occupying only 8% of Guyana's total land area, the coastal plain is especially important since an estimated 90% of the country's population lives within its boundaries.

Study Regions

Since available data were limited, only a specific area of Guyana's coastal plain will be investigated for mangrove forest change (Figure 5). The area selected for this investigation extends from a site located approximately 43km northwest of the mouth of the Pomeroon River to a site located approximately

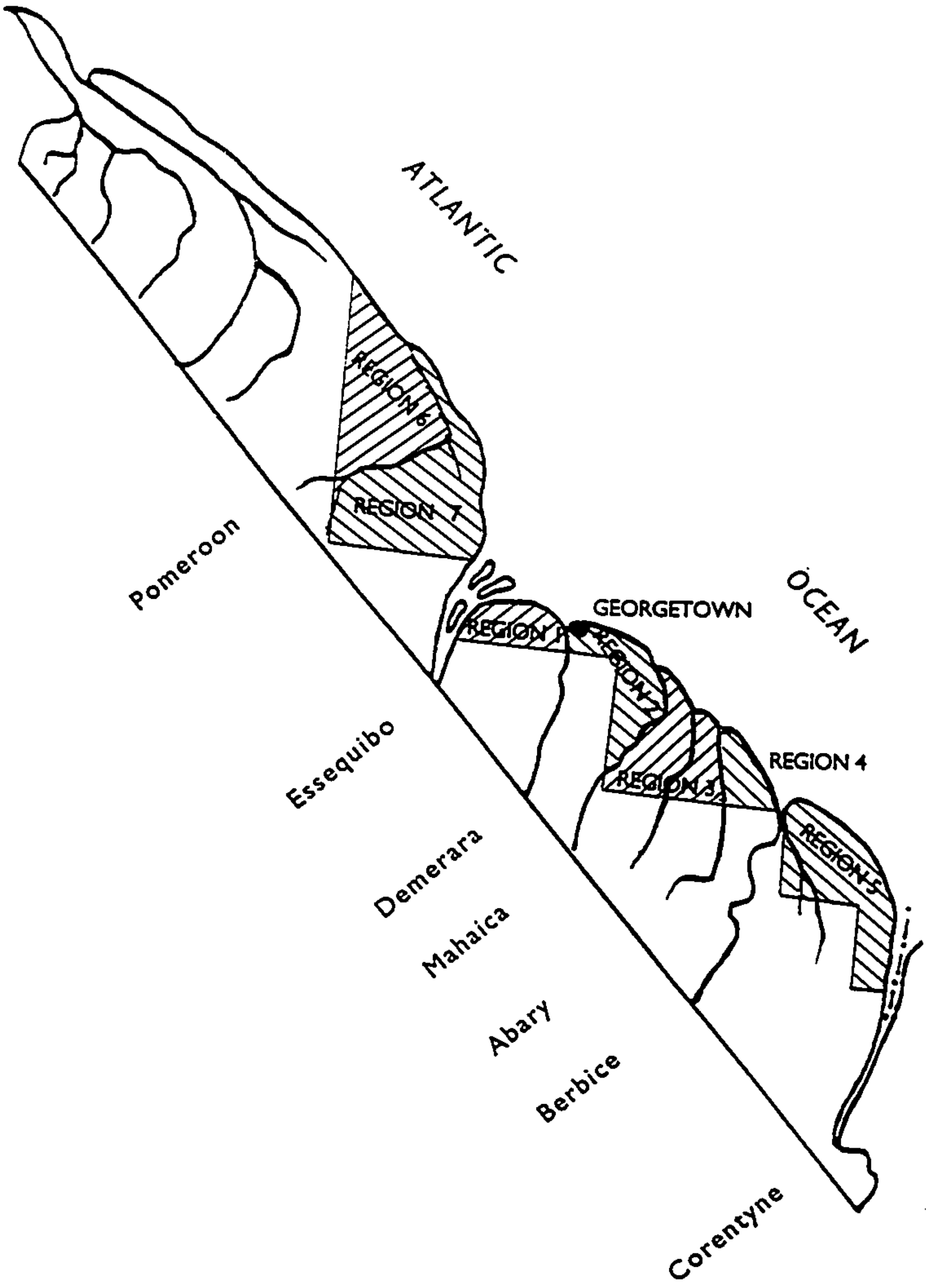


FIGURE 5: Study Regions

Source: Author, 1993.

30km southeast of the the mouth of the Corentyne River. This area was then further subdivided into seven regions according to both pre-existing political and natural boundaries to aid in both the monitoring and management of mangrove forests. These regions are as follows;

Region 1: Essequibo River to Demerara River

From Huist Bock Maria located along the Ship Channel of the Essequibo River to Nismes, located on the west shore of the Demerara River.

Region 2: Demerara River to Mahaica River

From Diamond located on the east shore of the Demerara River and south of Georgetown to the west shore of the Mahaica River.

Region 3: Mahaica River to Abary River

From the east shore of the Mahaica River to the west shore of the Abary River.

Region 4: Abary River to Berbice River

From the east shore of the Abary River to Blairmont, located on the west side of the mouth of the Berbice River.

Region 5: Berbice River to Corentyne River

From New Amsterdam to a location 2.5 km south of Moleson Creek located on the west shore of the Corentyne River.

Region 6: Moruka River to Pomeroon River

From a site located 27 km northwest of the Moruka River to the west shore of the Pomeroon River.

Region 7: Pomeroon River to Essequibo River

From the east side of the Pomeroon River to Aurora, located on the West Channel of the Essequibo River.

The extent of area covered for each region was also dependent upon the amount of available data. The total land area covered for each region is listed in Table 1. The Essequibo islands could not be studied for change due to insufficient data. However, this region was included for the investigation into the possible use of LANDSAT MSS imagery for monitoring mangrove forests.

TABLE 1: Total Area Occupied by Region 1986-88

Study Region	Km2
Region 1	406.40
Region 2	422.60
Region 3	399.81
Region 4	392.13
Region 5	1371.49
Region 6	1224.80
Region 7	1256.03

CHAPTER 2

LITERATURE REVIEW

This review focuses on the relevant studies which have used aerial photographs and/or remotely sensed imagery from satellites to classify coastal wetland boundaries and vegetational composition. In addition, this review will present several key problems associated with the literature. The use of aerial photographs and remotely sensed imagery from satellites provides a wealth of information for mapping and understanding changes in coastal wetlands (Mausal, 1989). Several authors (Semeniuk, 1980; Dorp et al., 1985; Rehder and Patterson, 1986; Lyon and Greene, 1992) have utilized aerial photographs to show spatial changes in wetlands and in some cases, inferred probable causes for this change.

One study of forest dynamics and distribution in mangrove communities utilized a time sequence of aerial photographs to show that since 1949, wetlands along the coastal region of King Sound, Western Australia, progressively adapted to rapid erosion (Semeniuk, 1980). Coastal erosion rates, mangrove species composition and population densities were determined and mapped from aerial photographs. !t was concluded from these maps that zonation of mangrove species was truncated where erosion was greatest, and that new mangrove communities replaced old ones within only a few years following coastal retreat.

Van Dorp et al. (1985) utilized a time sequence of aerial photographs to produce vegetation maps of coastal dunes near Oostvoorne in the Netherlands. Through interpretation of the aerial photographs, species composition, distribution and vegetation density were estimated. The vegetation maps produced for each time period were then compared to determine pathways of vegetation succession as well as the rates of successional change. This study determined that the rates of successional changes in vegetation for the outer dunes was very high at the beginning, but has slowly been decreasing over time, whereas the reverse situation occurred within the inner dunes. In addition, this study determined distinct pathways for species succession between both the inner and outer dune study areas.

Aerial photographs are not the only means of remote sensing that can be used for mapping coastal wetlands. Pu and Miller (1991) utilized LANDSAT Thematic Mapper data in addition to topographic and stock maps to classify and evaluate a protected forest area on a mud flat in Dongtai, China. Vegetational classification, evaluation and mapping of the area were based on the relationships amongst site type, landscapes, and their corresponding satellite image characteristics. This form of site classification and evaluation, based on the interpretation of remotely sensed imagery from satellites, is an effective way to make an inventory that consumes less time and is more cheaper than the traditional methods. Traditional methods would include the use of an airplane and several surveyers. Not only are the costs high, but such a task could take several weeks to several months to complete.

In addition to utilizing remotely sensed imagery to assess coastal wetland changes, probable causes have been postulated. Ball (1980) utilized sequential aerial photographs as well as a false colour infrared image of a mangrove forest at

Biscayne Bay, Florida. These images were used to measure both successional vegetation changes as well as changes in shoreline position. Wetland boundary, species density, distribution and canopy height were estimated from the remotely sensed images. From these measurements, it was determined that within the area of the forests closest to the sea, vegetation was maturing towards a pure *Rhizophora* forest, whereas *Laguncularia* was slowly out-competing other species in the higher, drier regions of the mangrove forest. In addition, a historical increase in salinity levels associated with fresh water diversion projects was inferred as the probable cause of these changes.

Coastal wetland changes can also be assessed utilizing both aerial photographs and satellite images. Rehder and Patterson (1986) utilized both sequential aerial photographs and a LANDSAT MSS image to map mangrove forest acreage and species composition of the Marco Island area of Florida. Maps produced for each time period were inputted into an ERDAS geographic information system. A matrix overlay analysis, a component of the ERDAS system, was utilized to produce statistical comparisons between the different maps. It was determined that between 1952 and 1984, the total area of mangrove forest within the region had been reduced from 45.67 km^2 to 34.7 km^2. Black mangrove (*Avicennia*) species had experienced the greatest loss. In addition, it was postulated that increases in the areal extent of residential and commercial land development had depleted the mangrove forests.

Statistical analysis can also be utilized to test the probable causes of historical changes in coastal wetlands. Lyon and Greene (1992) utilized eleven series of aerial photographs to estimate losses of wetlands area at Pointe Mouilee in Monroe County, Michigan. Wetland boundaries were defined on each aerial photograph, as well as their areas. It was determined that an 80% reduction of total wetland area had occurred between 1935 and 1980. In addition, the rates of wetlands lost between sequential photographs were compared to the water levels for each year. A strong inverse relationship ($R^2=0.8722$) between wetlands area and water levels between 1950 and 1980 was determined.

Only two studies have mapped the coastal landforms and vegetation of Guyana using remotely sensed imagery. One study by Singhroy (1983) utilized October 1977 LANDSAT imagery to map coastal landforms to help the government of Guyana to develop drainage and irrigation systems. The results of the remotely sensed study were subsequently used to develop new drainage systems along the coastal zone (Lakhan, 1993).

Another study, by Pastakia (1990), utilized one set of aerial photographs and personal observation from a flight over the coast to map changes from the mid-1970s to 1990 in the extreme seaward edge of mangrove forests located along the coast. Although this was the first attempt to map changes in Guyana's mangrove forests, this study has not been utilized by the government due to its limited study area and the subjective nature of the analysis.

There are several problems associated with the aforementioned literature. A lack of literature on mangrove forests has resulted in this author utilizing relevant studies incorporated within the more general topic of coastal wetlands. Although all literature reviewed utilized remotely sensed imagery to determine vegetational composition and areal boundaries, no accurate interpretation key was ever offered. Furthermore, with the exception of Lyon and Greene's article, there was a lack of descriptive methodology. With this exception in mind, the literature inferring probable causes (Ball, 1980; Rehder and Patterson, 1986) did not utilize any statistical testing. However, based on the previous studies, it has been shown that both aerial photographs and satellite imagery can be successfully utilized to provide information on changes in wetland boundaries and composition. In addition, the reviewed studies clearly indicate the necessity for continuing research on the spatial changes in wetlands. It is well known that whenever there are losses in coastal wetlands, there are decreases in coastal biodiversity (Lachica, 1978), increased flooding (Odum, 1978; Leitch and Shabman, 1988), coastal erosion (McVey, 1988), and loss of fishing grounds (Poli and Snizek, 1978; Gundermann and Popper, 1984).

CHAPTER 3

A PRIORI MODEL AND HYPCTHESES

There is a wealth of information available regarding the various factors associated with rapid changes in both composition and boundary area of mangrove forests. At the more general level, mangrove forest changes are associated with biological, anthropogenic and physical/climatic agents (Ball, 1980; Adegbenin and Nwaigbo, 1990). Specific agents of change are integrated within and between these three more general components. The presence of such agents, as well as their degree of impact on mangrove forest change, is dependent upon location. An a priori model (Figure 6) was constructed to demonstrate that biological, physical/climatic and anthropogenic factors contribute to changes in mangrove forests. In addition, the model demonstrates that both agricultural practice and urban expansion also have a strong influence on mangrove forest change.

From the literature, it is apparent that both physical and climatic elements of an environment contribute to the composition and areal distribution of mangrove forests (Thom, 1967; Semeniuk, 1985). Certain key climatic factors such as prolonged periods of drought or excessive precipitation can alter the normal flow of fresh water into a mangrove forest. Drought may create excessive salinization within the forest whereas excessive precipitation may create abnormal dilution of the surrounding saline water. Consequently, these conditions stress the osmotic regulation of the trees resulting in a rapid decrease in forest boundary and/or a rapid change in species composition (West, 1977; Cintron and Novelli, 1992). In

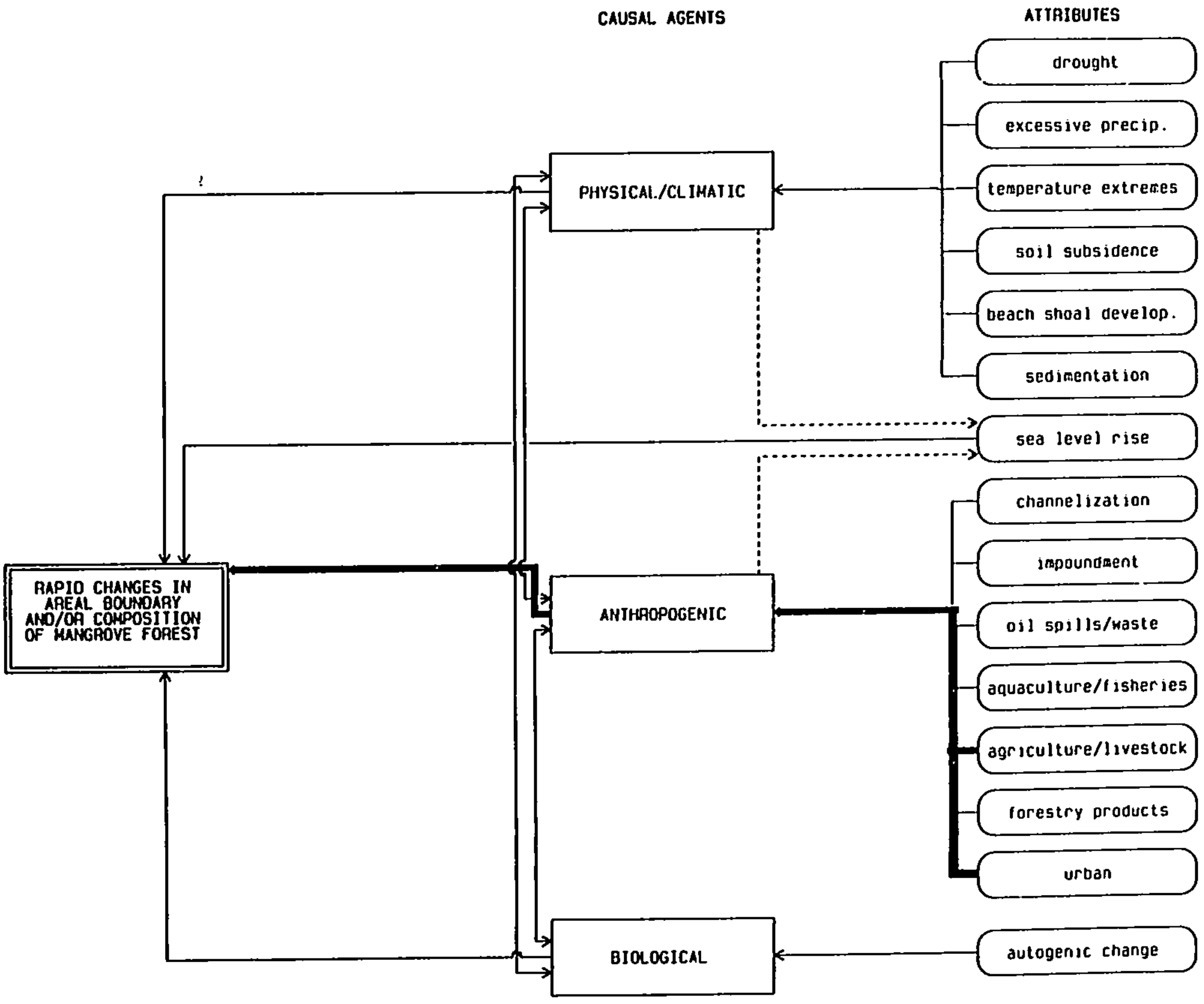


FIGURE 6: A Priori Model

Source: Author, 1993.

addition, complete destruction of mangrove forests often occurs as a result of periods of abnormally high or low temperatures (West, 1977). Such temperatures physiologically stress the trees resulting in a rapid die-off.

Physical factors of an environment contribute to mangrove forest change. Soil subsidence, for example, can rapidly alter both the composition and areal boundary (Semeniuk, 1980). In such conditions, the rate of shoreline (substrate platform) loss may exceed the rate of re-establishment by retreating mangroves. On the other hand, beach shoal development contributes to mangrove development (Vann, 1980). Such shoals provide an ideal substrate platform for establishment of mangrove seedlings and consequently alter the boundary of mangrove forests.

Anthropogenic factors contributing to rapid change in mangrove area boundary and composition are numerous (Bacon, 1978; Cintron, 1978; Ball, 1980; McVey, 1988; Adegbenin and Nuraigbo, 1990). Impoundment/empolderment from dike construction can cut off nutrients to mangrove forests as well as preventing the flushing of harmful compounds. In addition, empolderment may elevate water levels which interfere with the trees' gas exchange capabilities or in drier areas increase salinization. Under such conditions, mangrove trees are physiologically stressed, which causes a decrease in forest boundaries and/or changes in species composition (West, 1977; Ball 1980). Channelization or diversion of freshwater may also alter mangrove forest composition or areal boundaries by both limiting normal nutrient inputs and elevating salinities beyond the tolerance level of the mangroves (Cintron and Novelli, 1992). Oil spillage from offshore oil-drilling or sea-going vessels destroys mangrove forests (Bacon, 1978; Adegbenin and Nuraigbo, 1990). Oil can directly destroy mangrove forests through toxic contamination or via blockage of the gas exchange structures of the trees. Oil can also indirectly induce changes by elevating substrate temperature, increasing evaporation and salinities or even by killing off substrate microbes that are essential for nutrient cycling. Activities associated with resource exploitation of mangrove forests also contribute directly to rapid changes in both mangrove composition and boundary area (Cintron, 1978; McVey, 1988; Adegbenin and Nwaigbo, 1990; Cintron and Novelli, 1992). Aquaculture, for example, can kill off mangrove forests by preventing both the flushing of excessive contaminant build-up and inflows of nutrients from the sea. Agricultural practice, such as land clearing or excessive pesticide or fertilizer use can destroy adjacent mangrove forests (Martyn, 1933; Odum, 1978; Azariah et al., 1988; McVey, 1988; Barbier, 1993). In Guyana, agricultural and urban expansion have been suggested as the leading cause of mangrove forest degradation (Martyn 1933; Singhroy and Bruce 1983; Pastakia 1990).

Biological factors can also alter the composition and areal boundaries of mangrove forests. These factors include all plants and animals that are the agencies of change associated with autogenic change (Colinvaux, 1986). For example, a sudden increase in the population of a herbivore, selective for a particular mangrove species (Farnsworth and Ellison, 1991), could result in rapid changes in both the areal boundary and species composition of a mangrove forest.

The three general components mentioned are not independent of one another and complex interaction between them can induce mangrove forest change. For example, a brief period of excessive rainfall (climatic/physical), not large enough to create drastic flooding, could indirectly alter the biological component by providing an ideal environment for breeding mosquitoes. Although this brief fluctuation in the mosquito population may not induce rapid autogenic change, it may indirectly alter the anthropogenic component. Fluctuations in mosquito populations have resulted in clear cutting of mangrove forests by adjacent inhabitants who fear the possible spread of many disease vectors such as malaria (Martyn, 1933).

Rapid sea level rise, a possible composite of both anthropogenic and physical/climatic components, may also influence mangrove forest change. Rapid sea level rise may alter mangrove forests in a variety of ways. For example, changes in mangrove forest composition and boundary area result from increased flooding and intrusion of salt water (Titus, 1986; Cintron and Novelli, 1992).

Given the fact that the aforementioned literature emphasizes that mangrove forest changes occur because of the influence of physical/climatic, anthropogenic and biological factors, the A Priori Model incorporates these factors. Due to its very basic nature, this A Priori model is limited in that it does not depict all specific agents of change and all specific relationships. For example, non-visible, smaller components, such as changes in pH or nutrient content, have been incorporated but not displayed within the model diagram. The reasoning behind this is because they are considered to be a smaller component within the much larger system.

Several hypotheses can be formulated from the a priori model. However, since the study is specifically concerned with understanding mangrove forest changes in coastal Guyana, the hypotheses will be restricted to this location. Utilizing both satellite imagery and a Geographic Information System database, this invesigation wiil attempt to verify the following hypotheses:

1.) Physical/climatic and biological components have little or no impact on recent mangrove forest loss in Guyana;

2.) a strong relationship exists between mangrove forest loss and anthropogenic agents;

3.) LANDSAT MSS imagery can be used as an effective alternative to conventional methods for monitoring mangrove forests along the coast of Guyana.

CHAPTER 4

METHODOLOGY AND RESULTS

4.0 Introduction

The procedures carried out during this invesigation have been separated into two parts. The Geographic Information System (GIS) section describes the investigation into recent changes in both areal boundary and species composition of mangrove forests located along the coast of Guyana. The satellite imagery section investigates the possible use of Landsat MSS imagery to monitor mangrove forests in Guyana. Although the sections complement one another, it is believed that this separation will allow for a more thorough understanding of each methodological approach.

Part 1-Geographic Information System Investigation

4.1 Introduction to the use of a GIS Database

A time series analysis was conducted to monitor changes in both species composition and areal boundaries of mangrove forests. A variety of different data types were utilized. These included aerial photographs, topographic sheets and field observations. In order to integrate, manipulate and process these data, a specialized database, a geographic information system was chosen. Unlike other database systems, GIS preserves the locational identities of all information recorded. All imported information is assigned to one common geographic coordinate system. As a result, a GIS can match different images from different data sources. Conversion of both projection and scale, an asset of this type of database, can also be utilized to match images.

Other important functions of a GIS, which were essential to this investigation, include visualization and overlaying of data. Visualization of data in maplike format allows for the extraction (identification) of geographic patterns and interrelationships. Overlays, on the other hand, allow many data sets to be superimposed for display and analysis purposes. One type of overlay, a logical overlay, is often utilized for data inference. This procedure creates new variables by combining different data sets from an overlay.

The choice of a GIS database was also based upon its use as an efficient management system. Past records, as well as future data, can easily be integrated and manipulated, allowing for an effective means of monitoring changes in mangrove resources.

4.1.1 Initial Data

Data were collected and initially analyzed during a field trip to Guyana in the summer of 1993. These data included field surveys, aerial photographs, topographic sheets and ancillary data. Ancillary data included government documents, technical papers and hydrological charts. In addition, personal interviews were conducted with environmental officers as well as with lecturers, cartographers and Amerindian students from the University of Guyana.

Both topographic sheets and aerial photographs were acquired from the University of Guyana cartographic laboratory as well as from The Lands and Surveys division of the Ministry of Agriculture. The topographic sheets, scale 1:50000, were derived from either a 1960-64 or 1986-1988 series. The earlier set of topographic sheets was produced in the United Kingdom by both the Ministry of Defence and the Directorate of Overseas Surveys. The more recent set was produced by the British Survey. Ideally, more information would have been acquired but there were regions not yet mapped or else the original mylar maps were missing.

Aerial photographs were not purchased because of their poor quality. As a result, those acquired were analyzed at the cartographic laboratory of either the University of Guyana or Lands and Surveys. Most were dated 1953, 1954, 1962, 1980, 1981 at a scale of 1:30000 and 1:20000. Due to the limitations in both time and available resources, aerial photographs were primarily utilized to aid in both reclassification and verification of the maps.

Ground truthing required approximately three weeks to accomplish with the aid of two field assistants. A small number of study sites along the coast were surveyed and photographed. Limitations to the number of sites included inaccessibility due to lack of roads and mode of transportation, as well as high costs associated with the use of private boats or planes to otherwise remote regions. Locations covered included: region one- Parika, Fellowship, Rotterdam; region two- Good Hope, Bachelors Adventure, Hope; region three- Woodlands; region four- Rosignol; region five- New Amsterdam; region seven- Good Hope, Riverstown, Suddie, Maria's Lodge. With the use of a local speed boat the following locations within the Essequibo River delta were covered: southern tips of Tiger, Wakenaam and Leguan Islands; northern tips of Hog and Great Trulie Islands; eastern shore of Leguan Island (Vrouw Anna) and the western shore of Wakenaam Island (New Friendship).

4.1.2 Geographic Information System Operational Database

In order to determine both the potential and limitations of this investigation, it was essential that the GIS database be thoroughly understood. The Spatial Analysis System (SPANS) 5.22 GIS package, together with several auxiliary software packages, constituted the functional GIS operating system employed for the analysis of the collected data. All software packages were run on a 486-PC, operating within a DOS environment.

Before being imported into SPANS, it was necessary for all data to be transformed into digital format. The TYDIG 5.0 software package was chosen for the conversion of all conventional non-digital data (i.e. topographic sheet maps) into digital form. TYDIG 5.0, created by INTERA TYDAC Technologies Inc., is a digitizing and editing software package that produces cartographic data files. These files complement several geo-based systems such as SPANS 5.22. In addition to the TYDIG 5.0 software package, a digitizing table and a hand held 16-button cursor with serial interface were employed for data geocoding.

The SPANS 5.22 GIS chosen for this study was also created by INTERA TYDAC Technologies Inc. This system can integrate, analyze and model a variety of geographically referenced data. Three data structures can be processed within SPANS, including raster, vector, and quadtree types. SPANS, which operates within a menu driven environment, contains seven main operational directories or files. These main directories, all necessary for this investigation, include the EDIT, VISUALIZE, FILE, TRANSFORM, QUERY, ANALYZE, and MODEL files.

JOINVECS, a software package created at the University of Windsor by David Webster and Gordon Wilcox, was employed to join adjacent maps before analysis. This program was selected because it does not create slivers when joining areas of similar attribute across map boundaries.

In addition to the aforementioned programs, a SPSS PC+ (version 5.0) statistical package was chosen to analyze data outputted from the SPANS database. Hard copy output from the GIS operational database was created with the aid of HP Laserjet 4 and a Minolta 35mm camera with tripod.

4.1.3 Data Transfer/Manipulation and Preliminary Statistics

(A) Geocoding

All conversion from non-digital data to digital format was carried out within the TYDIG 5.0 digitizing system. Before digitization, polygons, representing the many land categories (see classification scheme), were traced onto each map. This task was accomplished with the aid of aerial photographs, field observation data and ancillary data. In addition, specific reference points were plotted and their location recorded. With the assistance of the departmental cartographer (Mr. Ron Welch), several maps, damaged from exposure to prolonged humidity, were also repaired before proceeding with the geocoding.

Maps were securely fixed to the digitizing table and each assigned a unique filename within TYDIG. Two types of reference points were then generated for each map. Calibration points were digitized for three corners of each map. These points are used by the TYDIG system for reference when assigning coordinate values to all following digitized data. Following calibration points, ground control points were entered for each map. These points, a minimum of 15 per map, are used by both TYDIG and SPANS systems as a means of georeferencing the digitized maps. The UTM coordinates, assigned to each ground control point were converted to longitude and latitude before final conversion to decimal degrees.

Once the reference points were digitally inputted, the boundaries of each land category were digitized for each map. This task was accomplished utilizing the new data function of the TYDIG system. As the hand held digitizer crosshairs traced the boundaries of the map, the collect point function recorded the corresponding digital arcs. The initial point (node) of the serial arcs of each boundary was created utilizing the start snap function. In order to end a boundary or close the series of arcs to form a polygon, the end snap function was employed. To eliminate errors created during digitizing, the search and delete functions of the edit mode were used. With the exception of those polygon boundaries which were created by joining adjacent maps, all arcs were closed as polygons.

The export data mode of TYDIG was employed once a map was completely digitized. Without topology or least squares transformation, the digitized data was exported with SPANS option. This procedure created two files, a vector and header, for each digitized map. Following this methodology a total of twenty four maps of 1:50000 scale were digitized.

(B) Join and Import of Vector Files

The majority of the regions under investigation were created by combining several of the original digitized maps. To avoid polygon slivers created from joining adjacent arcs of different maps, the JOINVECS software package was employed. The format of all exported TYDIG files is based upon digitized coordinates. The JOINVECS program, on the other hand, reads only lat/long or UTM coordinates. In order to avoid difficulties associated with this problem, a series of complex steps were taken. These steps, as well as those taken in the creation of the original SPANS maps, are as follows:

(1) With the use of the FILE main function of SPANS, the first step was to create a directory for each region/study area. Once created, each new directory was retrieved for user interface. Each study area was then assigned a projection selected interactively from the SPANS master projection list. For every case, the Universal Transverse Mercator Zone 21 of the Northern Hemisphere was selected. From within the Q editor/DOS environment, vector (vec) and header (veh) files of digitized maps corresponding to each select study area, were copied over from the DIGDAT directory of TYDIG 5.0 into the GIS study area directory. The boundary extents were then set individually for every vector/header file.

(2) With the use of the TRANSFORM main function, each vector file was then imported into the spatial universe of the SPANS study area. All vector/header files were assigned corresponding TOP and VTX files. Quad level for thinning tolerance was set for a value of 15 and intent for polygon creation rejected. A quad level of 15 represents the maximum resolution that can be attained within SPANS. Following the import procedure, the new TOP/VTX files were exported as new header/vector files with the coordinate format set for longitude and latitude. This procedure, executed for each digitized map, converted the original digitizer coordinates to actual long/lat coordinates acceptable by the JOINVECS program.

(3) Within the Q edit/DOS environment, the JOINVECS program was then run (Figure 7). The new veh/vec files were combined to create new vector maps. Each new vector map was saved as vec /veh file.

(4) Under the FILE function, the boundary extents were then set for the newly combined map vector files. Under the TRANSFORM function the map files were imported, assigned a quad tolerance level of 15.0 and selected for the polygon creation option. The imported vector maps were then transformed to polygons and the resulting polygons were transformed into actual maps. Each map was set for a quad level value of 15.

A total of seven regions/study areas were created. For each of these regions, a 1960-64 and a 1986-89 map was produced.

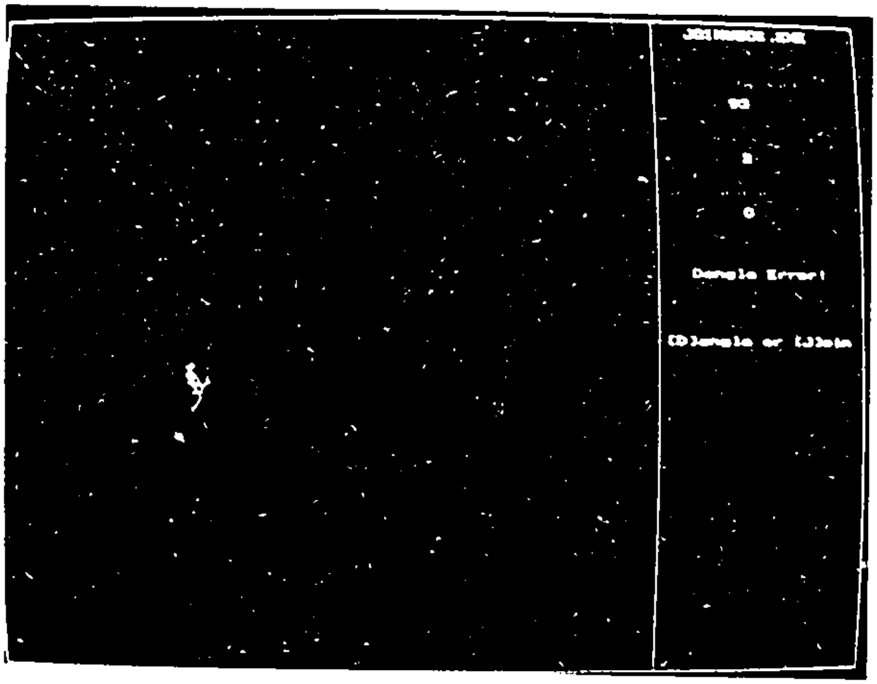
(C) Classification Scheme

The following wetland classes were created for this investigation. The selection of these classes, as well as their assignment to land areas was based upon information derived from field surveys and ancillary data.

(1) Rhizophora - a halophytic plant community dominated by *Rhizophora mangle.*

(2) Avicennia - A halophytic plant community dominated by *Avicennia germinans.* Large numbers of fern species such as *Batis maritima* may be present within the understory.

(3) Avicennia/Rhizophora - a halophytic plant community dominated by a fairly equal number of *Rhizophora mangle* and *Avicennia germinans.*



Dangle Error!

(D)angle or (J)oin

FIGURE 7: Joinvecs Program Created at the University of Windsor.

(4) Mangai-A - a halophytic plant community where *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa* are present but not dominant. Mangrove associates include ferns (*Batis maritima*, *Acrostichium danaeifolium*), vines (*Rhabdadenia biflora*, *Brachypteris ovata*), palms (*Mauritia flexuosa*) and shrubs (*Machaerium lunatum*).

(5) Swamp Savanna - a halophytic plant community absent of true mangrove species. Composed mainly of sedges, reeds, grasses, ferns, small copses of palms and other aquatic plants. Important species include the ferns *Mauritia flexuosa*, *Manicaria saccifera* and *Euterpe edulis* and the aquatic grasses *Sporobolus virgincus*, *Spartina brasiliens* and *Scleria* species.

(6) Marsh Swamp - a plant community dominated by fresh water wetland species. Several species associated with swamp savannas (i.e., palms) may be present. Within riverine areas, species such as *Thespesia populnea* and *Montrichardia aborescens*, replace mangrove species.

(D) Preliminary Statistics

Once transferred into the GIS, the maps were manipulated in order to determine the exact measure of mangrove forest change. Again, a series of steps were followed to extract the measurements.

The first step involved the reclassification of polygons for each map. It had been determined ahead of time that this procedure of assigning topology could be accomplished much faster within SPANS than within TYDIG. Utilizing the SPANS MODEL function, each map was assigned an associated reclassification template. With the use of the Q edit/DOS environment, each polygon of the template was, in turn, assigned a unique number from 1 to 14. Only fourteen distinct colours can be displayed at one time. A map was then produced from the altered template. With the use of the VISUALIZE function the new map and its legend were displayed. The legend colours could then be employed to assign the location of each polygon on the map to its numerical location in the template. Since only fourteen distinct colours could be used at one time, each map was reclassified several times in order to assign all polygons of a map to its template. A map was drawn to keep track of the polygon template number for each polygon on the original map. After determining exactly where each polygon was located on the reclassification template a final reclassified map was produced. As a result, all polygons were given an attribute(class). A legend, unique to each map, was also produced from within the library sub-function of the EDIT function (Figures 8 through 21).

Following reclassification, analysis of the areal extent of all land categories for each map was carried out. A basemap was necessary for each map. As a result, the first step involved utilizing the build map classification sub-function of the MODEL function to create, interactively, a basemap from each reclassified map. Within the FILE function, the basemap was then assigned to the study area. Once assigned, an area analysis of its associated reclassified map was conducted from within the ANALYZE function of SPANS.

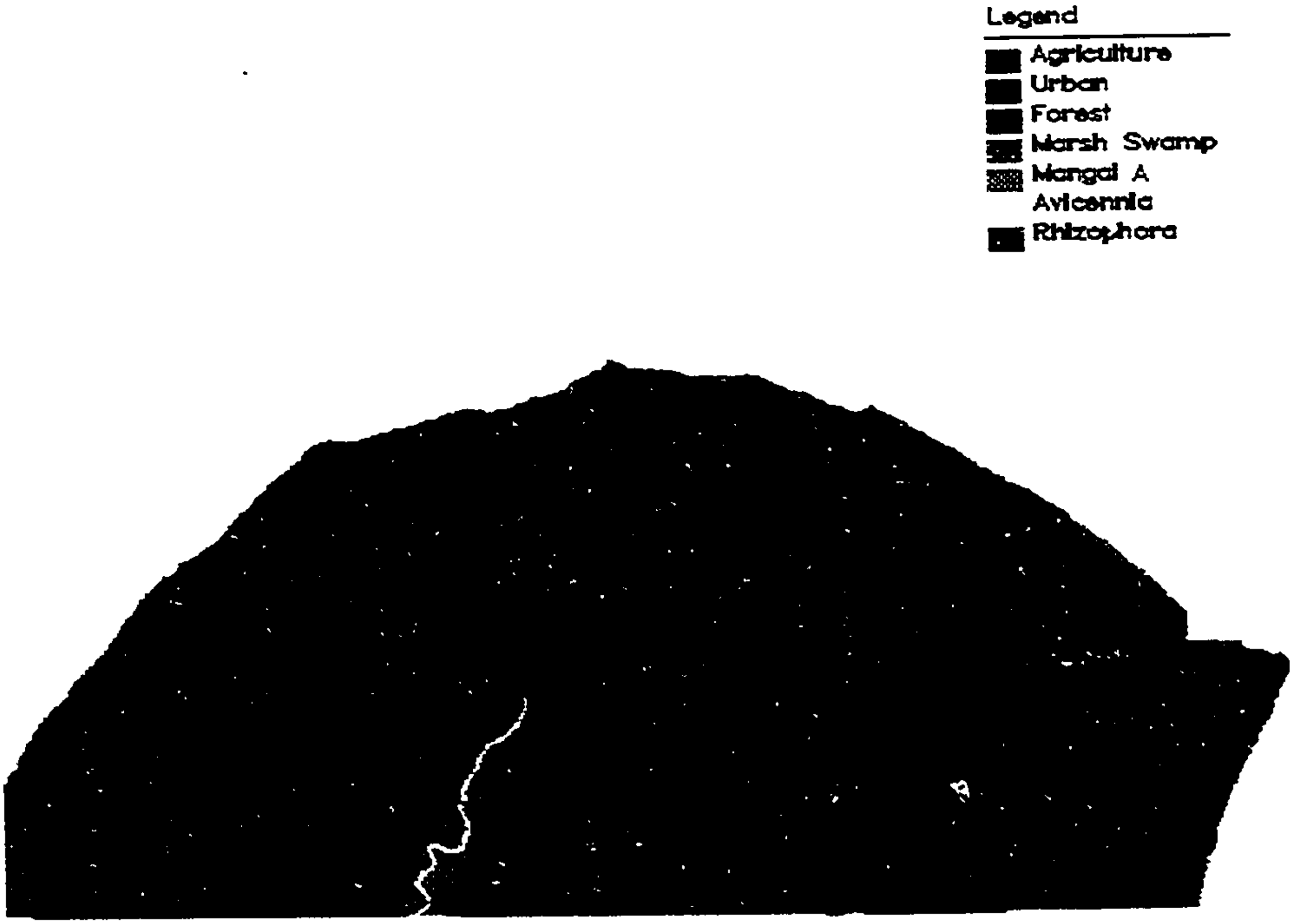


FIGURE 8: Area Occupied by Each Class for Region One (1960-1964).

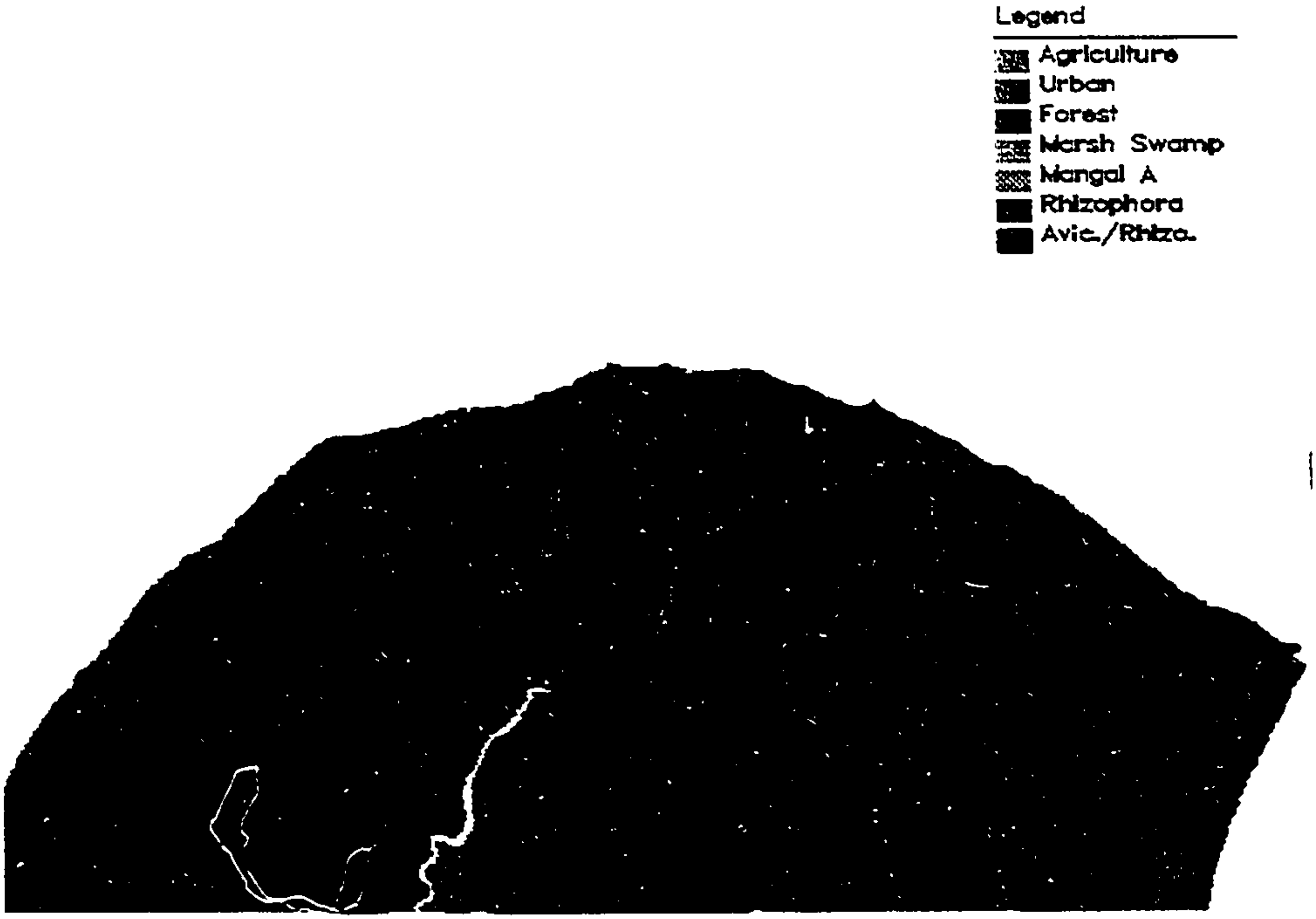


FIGURE 9: Area Occupied by Each Class for Region One (1986-1988).

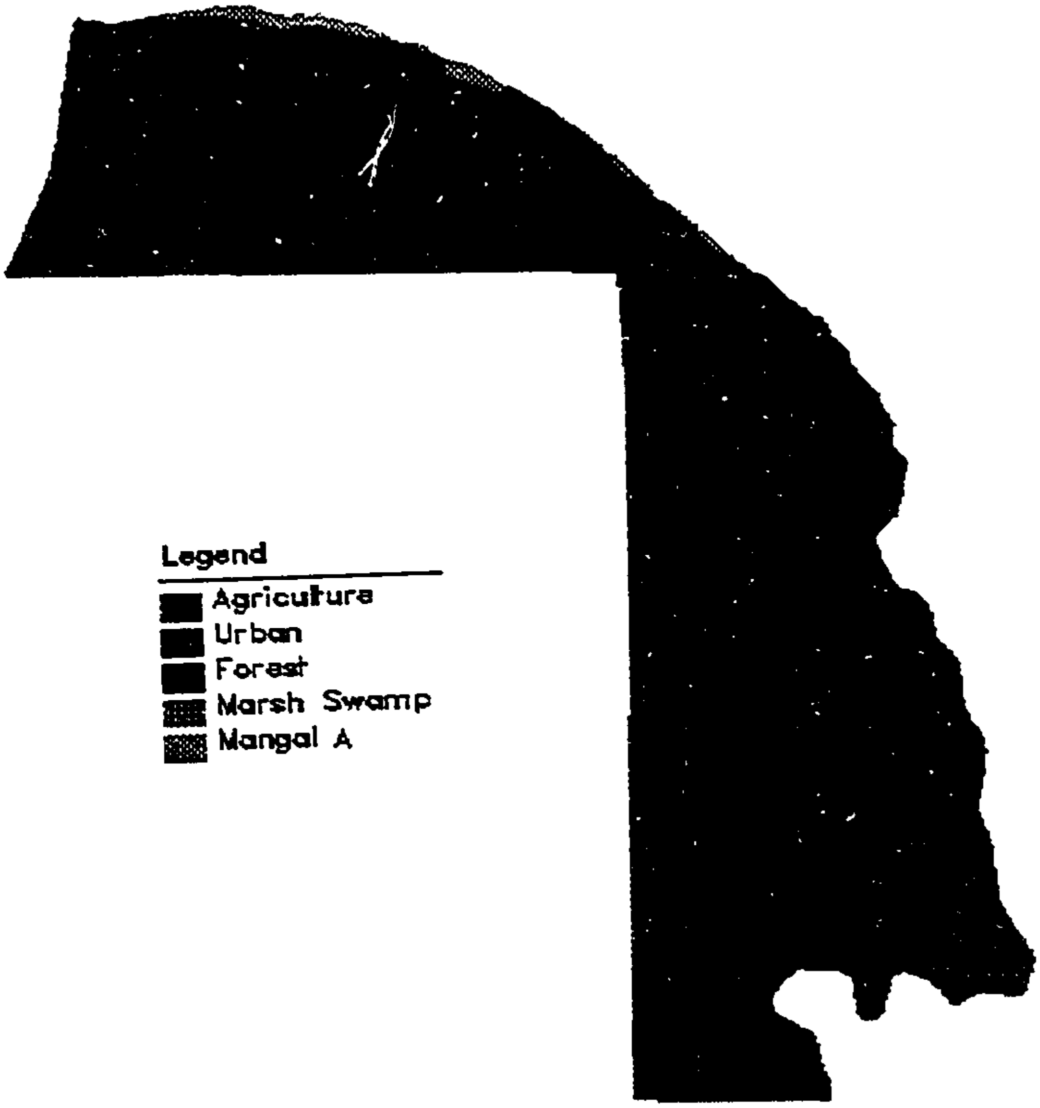


FIGURE 10: Area Occupied by Each Class for Region Two (1960-1964).

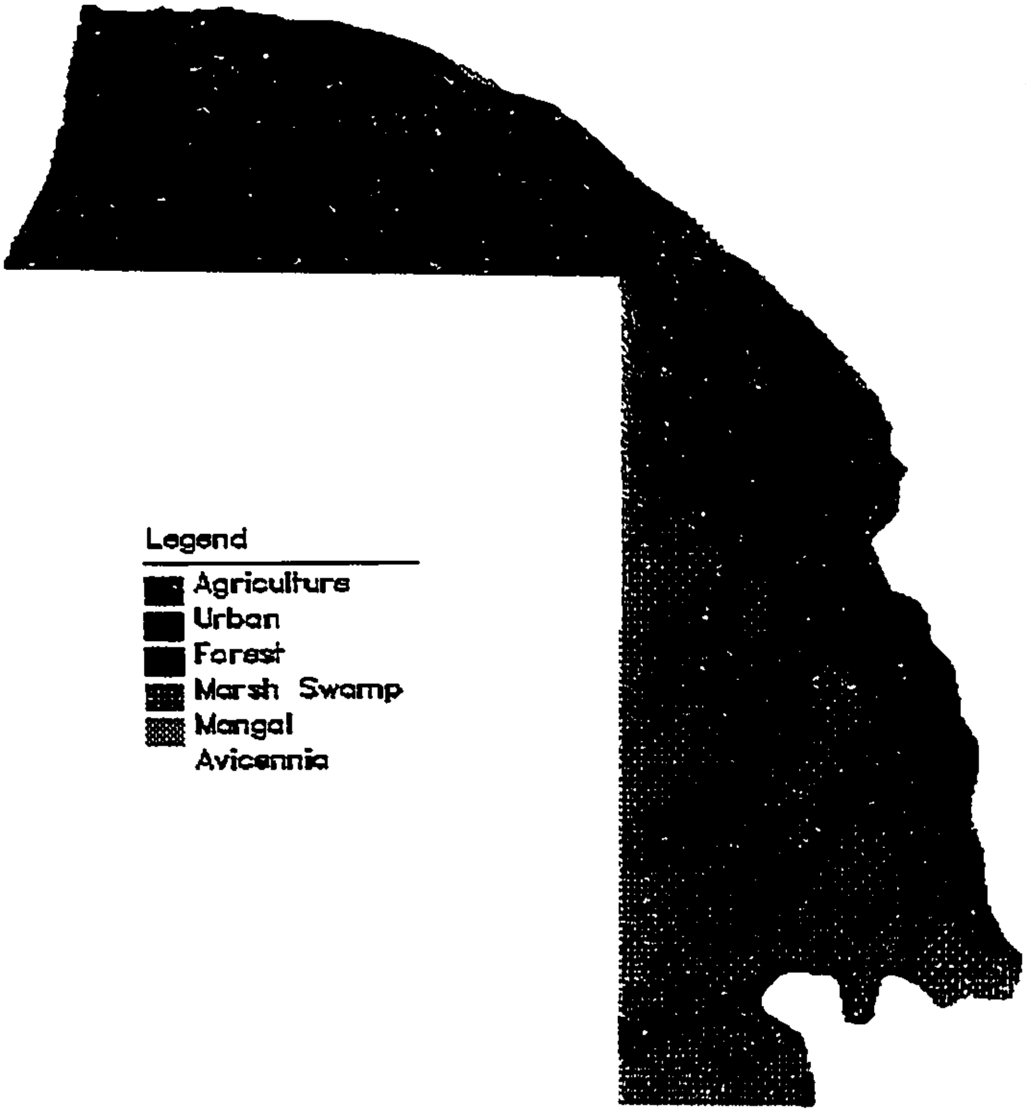


FIGURE 11: Area Occupied by Each Class for Region Two (1986-1988).

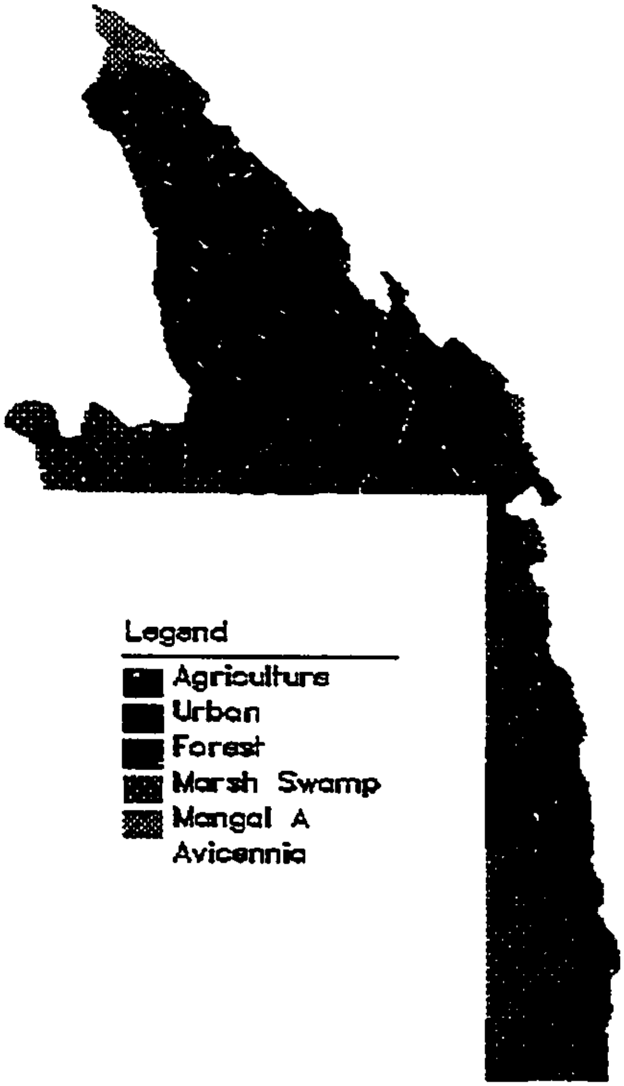


FIGURE 12: Area Occupied by Each Class for Region Three (1960-1964).

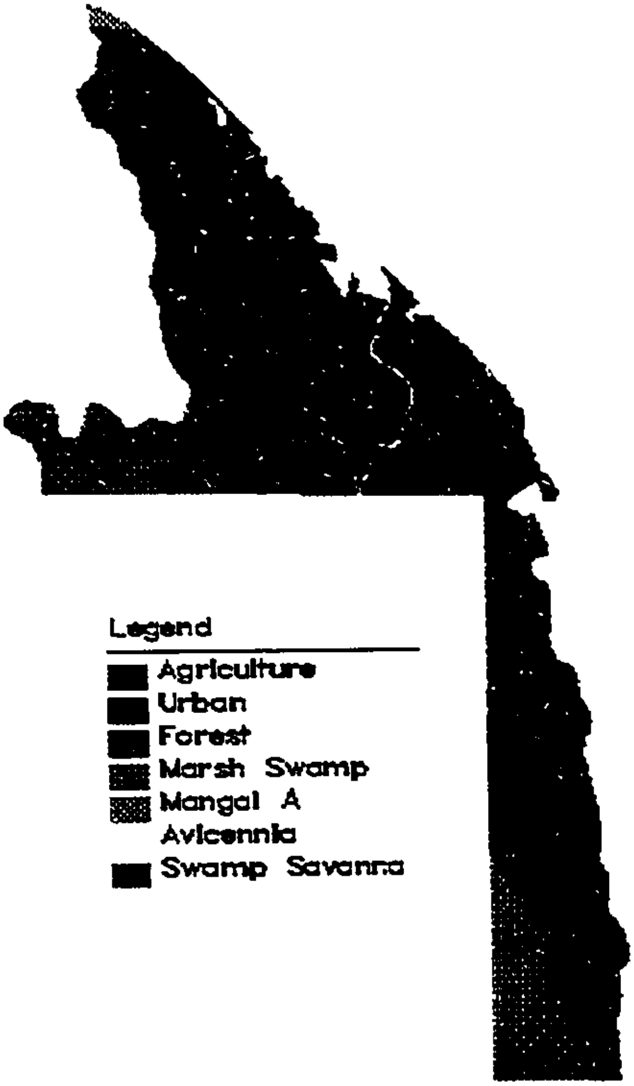


FIGURE 13: Area Occupied by Each Class for Region Three (1986-1988).

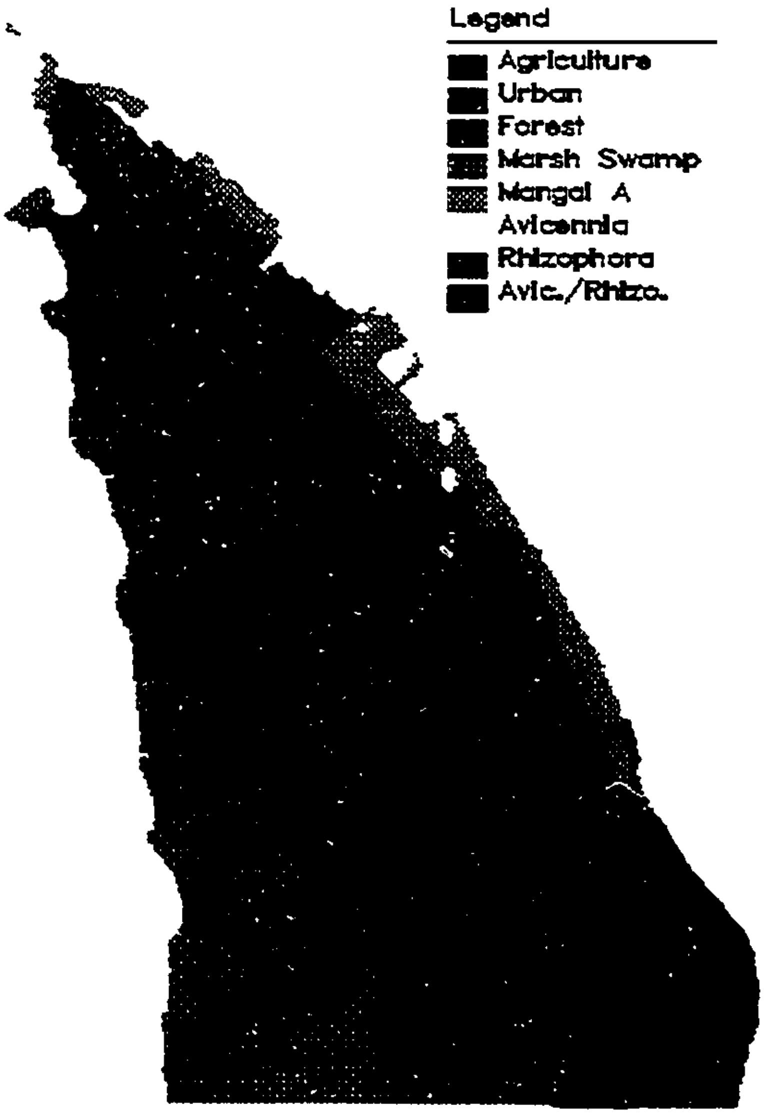


FIGURE 14: Area Occupied by Each Class for Region Four (1960-1964).

FIGURE 15: Area Occupied by Each Class for Region Four (1986-1988).

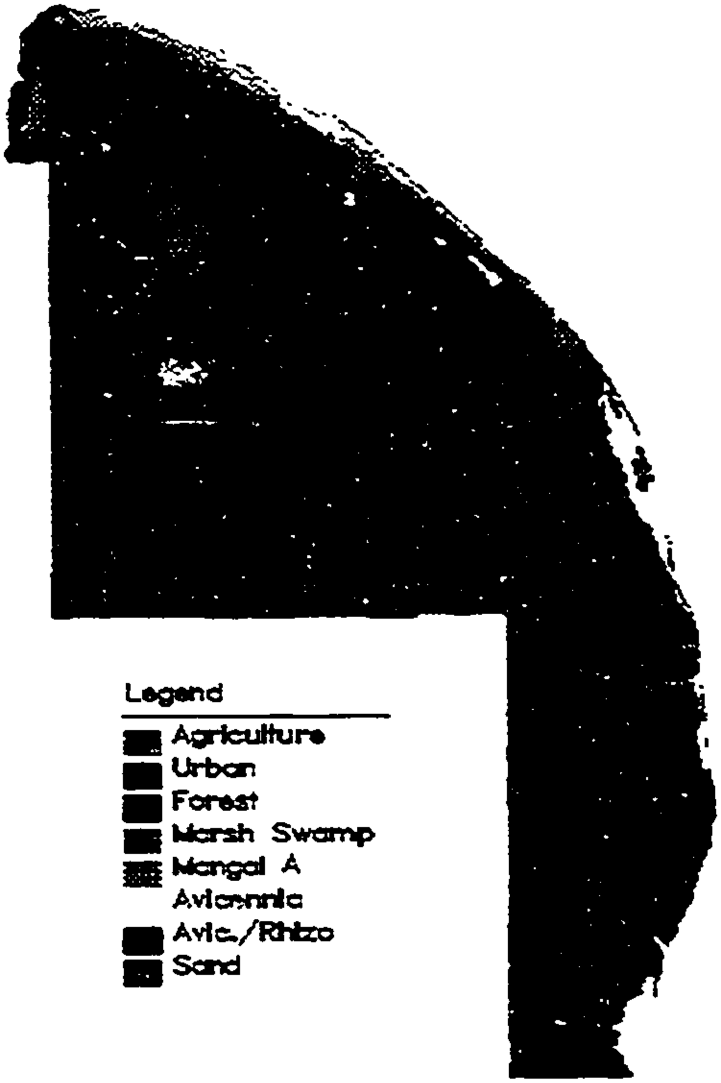
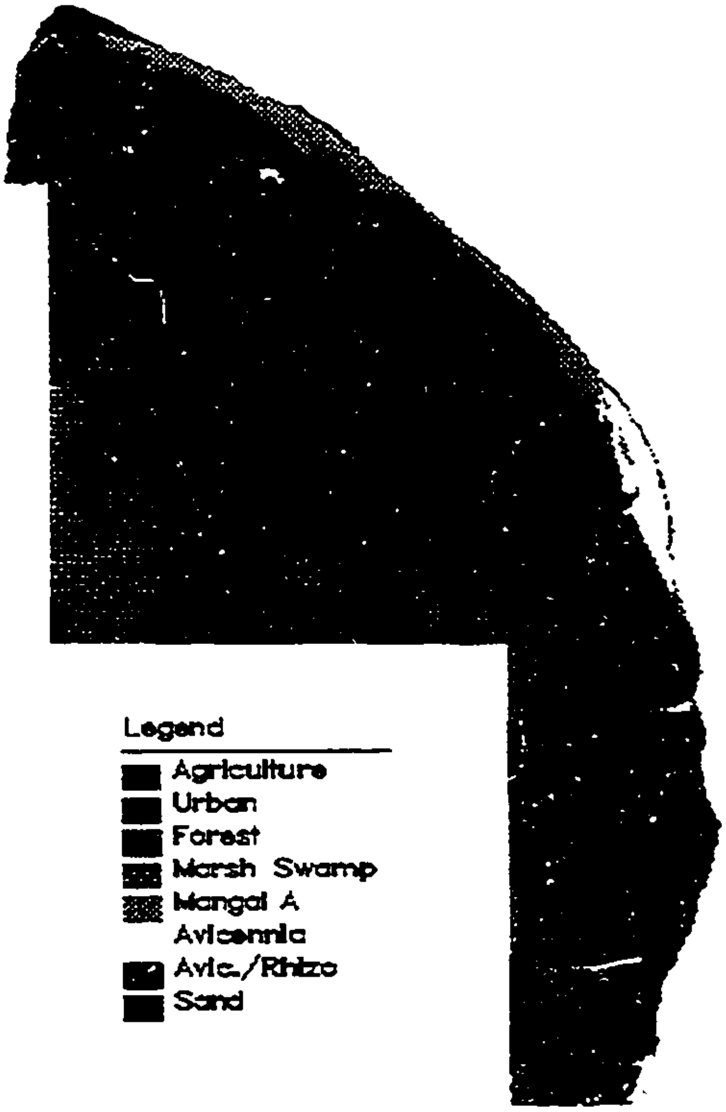


FIGURE 16: Area Occupied by Each Class for Region Five (1960-1964).



<u>FIGURE 17</u>: Area Occupied by Each Class for Region Five (1986-1988).

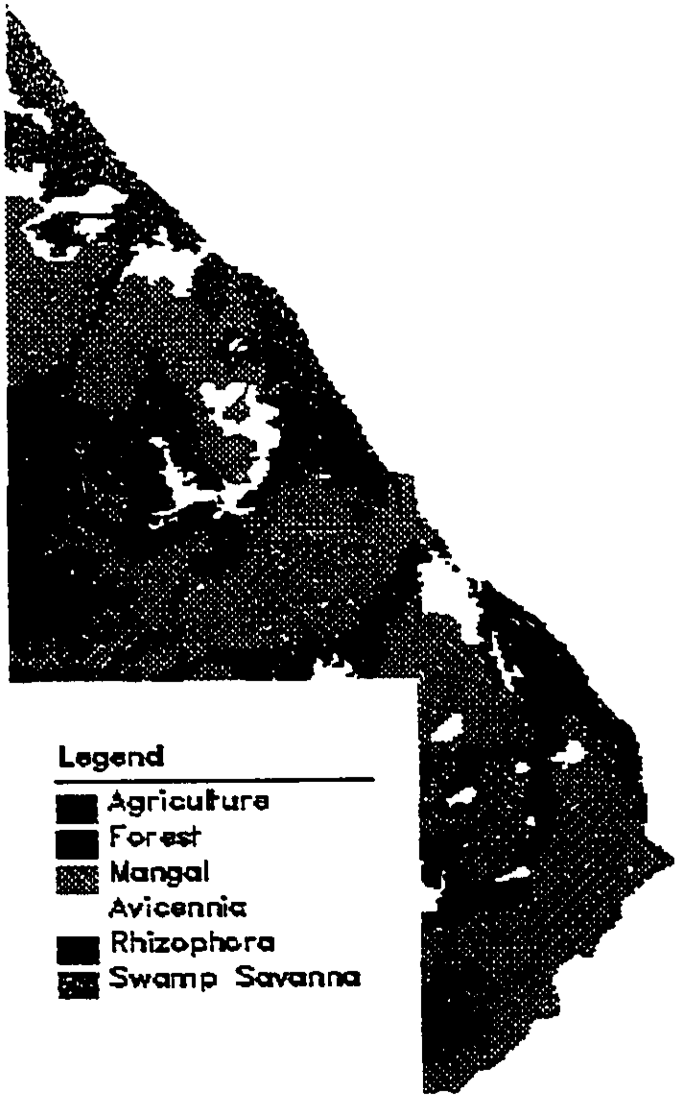


FIGURE 18: Area Occupied by Each Class for Region Six (1960-1964).

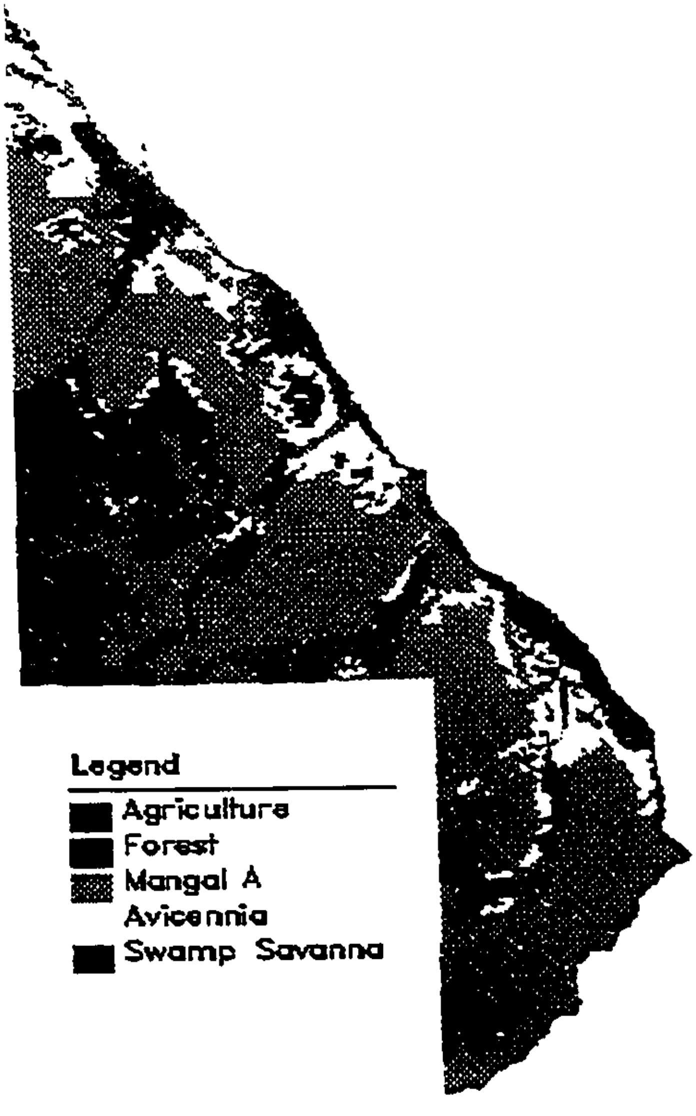


FIGURE 19: Area Occupied by Each Class for Region Six (1986-1988).

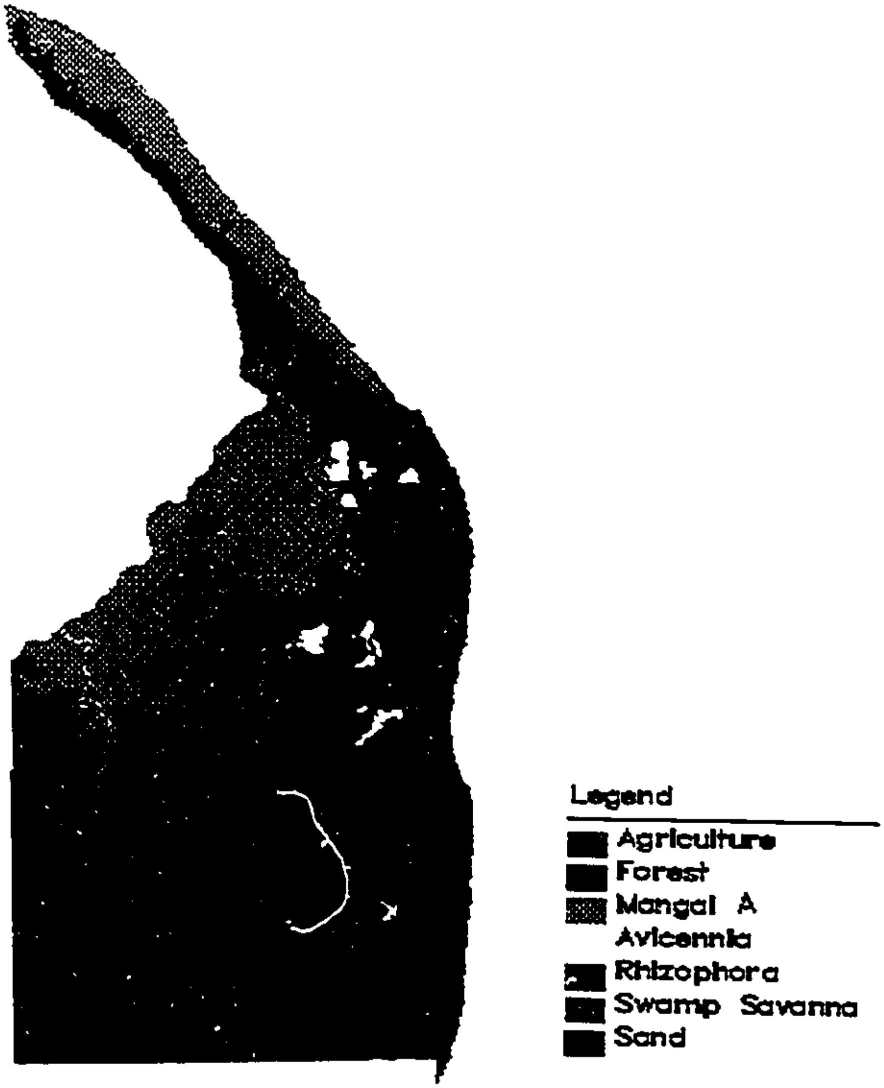


FIGURE 20: Area Occupied by Each Class for Region Seven (1960-1964).

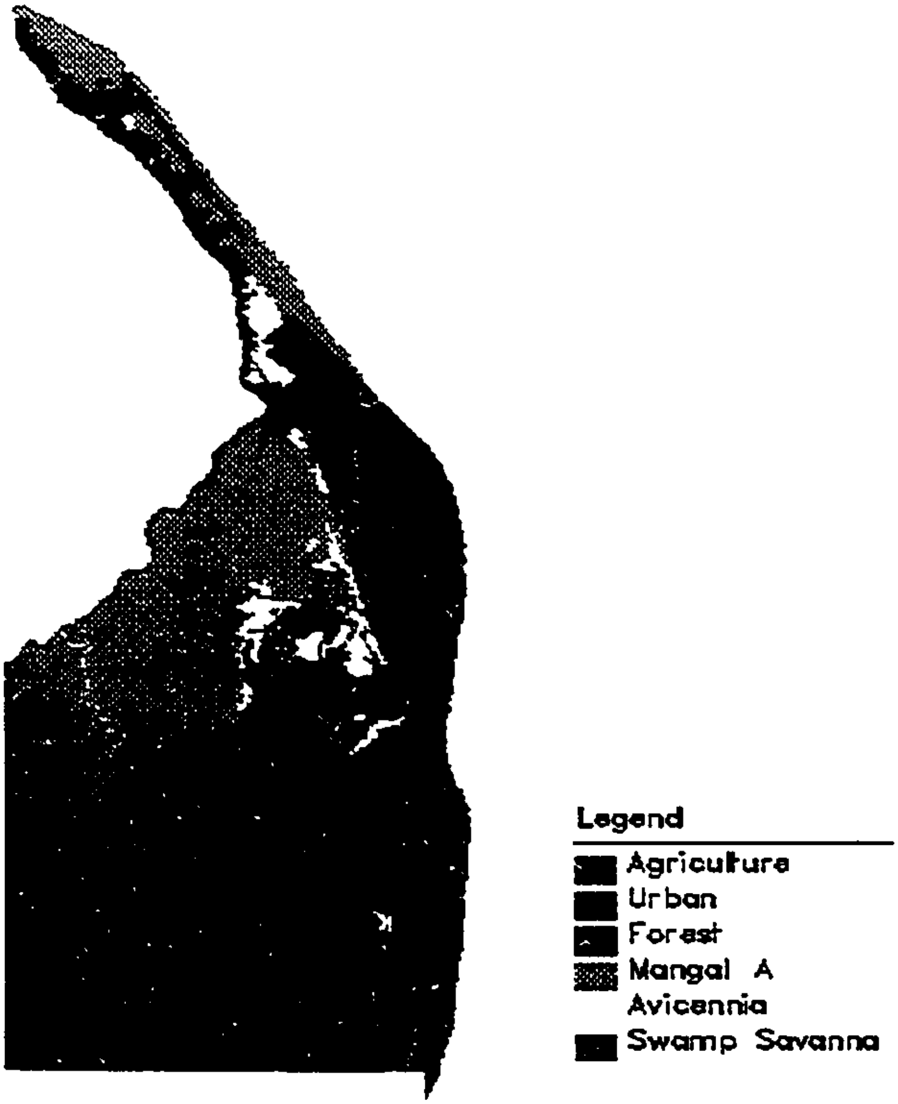


FIGURE 21: Area Occupied by Each Class for Region Seven (1986-1988).

A report of these measurements are found in Table 2 and Table 3.

For each region, the first statistical measure of change employed was Cramer's V. This involved an area analysis between the 1960-64 and the 1986-88 maps associated with each study area. A high Cramer's V value represents a strong similarity (relationship) between the class boundaries of both time periods. Consequently, the higher the 1-Cramer's V value the greater the dissimilarity between the class boundaries of the 1960-64 and 1986-88 maps. However, before the two map area analysis of the ANALYZE function could be executed a new basemap was necessary. The new basemap, assigned within the FILE function, was created by conducting an overlay join of the two basemaps already created for each map of the study area. The join procedure is found within the MODEL function of SPANS. The results of the analysis are found in Table 4.

The final step involved mapping the exact location of the species change in order to extract the exact measurement of change and to discover which land categories were lost to another. To carry out this procedure, the matrix overlay sub-function of the MODEL function was employed. The first step involved assigning a matrix template to the two maps of each region. The 1960-64 and 1986-88 maps assigned to the column and row position respectively within the matrix template. Within the Q edit/DOS environment, selected values were assigned to the matrix based upon the purpose of the map to be created. Once edited a map was created from the template utilizing

TABLE 2: AREA AND PERCENT OF TOTAL REGION OCCUPIED BY EACH CLASS (1960-64)

REGION 1: Essequibo River To Demerara River

CLASS	AREA(%)	AREA(Km2)
Agriculture	46.25	186.941
Urban	1.64	6.629
Forest	47.85	193.421
Marsh Swamp	3.83	15.470
Mangal-A	0.10	0.404
Avicennia	0.25	1.013
Rhizophora	0.09	0.349
TOTAL	100	404.227

REGION 2: Demerara River To Mahaica River

CLASS	AREA(%)	AREA(Km2)
Agriculture	49.98	209.677
Urban	7.96	33.395
Forest	1.14	4.795
Marsh Swamp	39.39	165.250
Mangal-A	1.53	6.427
TOTAL	100	419.543

REGION 3: Mahaica River To Abary River

CLASS	AREA(%)	AREA(Km2)
Agriculture	58.24	227.398
Urban	0.12	0.486
Forest	5.37	20.959
Marsh Swamp	29.58	115.506
Mangal-A	2.10	8.192
Avicennia	4.58	17.898
TOTAL	100	390.440

REGION 4: Abary River To Berbice River

CLASS	AREA(%)	AREA(Km2)
Agriculture	48.22	191.954
Urban	0.44	1.764
Forest	5.58	22.230
Marsh Swamp	36.74	146.264
Mangal-A	5.31	21.138
Avicennia	2.60	10.342
Rhizophora	0.08	0.314
Avic./Rhizo.	1.03	4.107
TOTAL	100	398.111

REGION 5: Berbice River To Corentyne River

CLASS	AREA(%)	AREA(Km2)
Agriculture	36.18	483.72
Urban	0.32	4.33
Forest	17.11	228.75
Marsh Swamp	38.74	517.91
Mangal-A	3.12	41.68
Avicennia	2.89	38.60
Avic./Rhizo.	0.77	10.32
Sand	0.87	11.58
TOTAL	100	1336.90

REGION 6: Moruka River To Pomeroon River

CLASS	AREA(%)	AREA(Km2)
Agriculture	1.94	23.41
Forest	13.80	166.16
Mangal-A	45.05	542.55
Avicennia	7.70	92.77
Rhizophora	0.08	1.00
Swamp Savanna	31.42	378.47
TOTAL	100	1204.35

REGION 7: Pomeroon River To Essequibo River

CLASS	AREA(%)	AREA(Km2)
Agriculture	13.51	169.46
Forest	54.14	678.94
Mangal-A	21.61	270.98
Avicennia	0.66	8.32
Rhizophora	0.57	7.14
Swamp Savanna	9.49	119.03
Sand	0.01	0.09
TOTAL	100	1253.95

TABLE 3: AREA AND PERCENT OF TOTAL REGION OCCUPIED BY EACH CLASS (1986-88)

REGION 1: Essequibo River To Demerara River

CLASS	AREA(%)	AREA(Km2)
Agriculture	75.55	307.025
Urban	3.60	14.637
Forest	6.70	27.243
Marsh Swamp	13.60	55.260
Mangal-A	0.12	0.495
Rhizophora	0.03	0.114
Avic./Rhizo.	0.40	1.623
TOTAL	100	406.397

REGION 2: Demerara River To Mahaica River

CLASS	AREA(%)	AREA(Km2)
Agriculture	47.38	200.223
Urban	12.68	53.586
Forest	1.03	4.351
Marsh Swamp	38.55	162.909
Mangal-A	0.32	1.354
Avicennia	0.04	0.181
TOTAL	100	422.603

REGION 3: Mahaica River To Abary River

CLASS	AREA(%)	AREA(Km2)
Agriculture	70.89	283.426
Urban	0.14	0.571
Forest	4.40	17.600
Marsh Swamp	18.76	75.005
Mangal-A	0.37	1.497
Avicennia	4.32	17.255
Swamp Savanna	1.11	4.450
TOTAL	100	399.805

REGION 4: Abary River To Berbice River

CLASS	AREA(%)	AREA(Km2)
Agriculture	73.78	289.313
Urban	0.82	3.219
Forest	2.70	10.603
Marsh Swamp	13.08	51.292
Mangal-A	6.58	25.792
Avicennia	1.80	7.066
Rhizophora	0.09	0.339
Avic./Rhizo.	1.15	4.501
TOTAL	100	392.125

REGION 5: Berbice River To Corentyne River

CLASS	AREA(%)	AREA(Km2)
Agriculture	58.53	802.73
Urban	0.88	12.06
Forest	13.50	185.13
Marsh Swamp	20.40	279.73
Mangal-A	2.97	40.69
Avicennia	1.72	23.55
Avic./Rhizo.	1.73	23.70
Sand	0.28	3.90
TOTAL	100	1371.49

REGION 6: Moruka River To Pomeroon River

CLASS	AREA(%)	AREA(Km2)
Agriculture	4.21	51.52
Forest	13.74	168.28
Mangal-A	49.99	612.31
Avicennia	11.88	145.46
Swamp Savanna	20.19	247.24
TOTAL	100	1224.80

REGION 7: Pomeroon River To Essequibo River

CLASS	AREA(%)	AREA(Km2)
Agriculture	21.95	275.71
Urban	0.28	3.47
Forest	51.90	651.92
Mangal-A	19.36	243.18
Avicennia	2.47	30.96
Swamp Savanna	4.04	50.79
TOTAL	100	1256.03

TABLE 4: Statistical Analysis of Change between 1960-64 and 1986-88

Study Region	Cramer's V	1-Cramer's V
Region 1	0.4038	0.5962
Region 2	0.6289	0.3711
Region 3	0.4817	0.5183
Region 4	0.4962	0.5038
Region 5	0.4301	0.5699
Region 6	0.4443	0.5557
Region 7	0.4389	0.5611

TABLE 5: Regional Loss or Gain in Mangrove Communities between 1960-64 and 1986-88

Study Region	Loss or Gain (Km2)	Total Area in 1987-89 (Km2)
Region 1	+0.47	406.40
Region 2	-4.89	422.60
Region 3	-7.34	399.81
Region 4	+1.80	392.13
Region 5	-2.66	1371.49
Region 6	+121.45	1224.80
Region 7	-12.29	1256.03

the MODEL function. A legend was also created for each new matrix map. Two maps were produced for each region. One map depicting total loss or gain in mangrove communities over time and the other depicting all changes in mangrove communities over time. The results, derived from the map ANALYZE function, are recorded in Table 5 and Table 6 respectively.

4.1.4 Advanced Statistics

A Kendall's Tau-b value was used to determine if a relationship, as depicted in the a priori model, does exit between the anthropogenic factor and mangrove forest change. This statistical technique, which measures the association between two ordinal scale variables, is ninety one percent power efficient (La Valle, 1990). The two ordinal variables, which were selected by the author and ranked according to the study regions, included the human disturbance factor (HD) and agricultural and urban combined factor (AUC).

The HD factor was computed by dividing the amount of mangrove forest lost to urban and agricultural development over time by the total amount of mangrove forest change over time. For this variable regions 1, 2, 3, 4, 5, 6, and 7 were ranked 4, 1, 2, 6, 3, 7 and 5 respectively. The AUC factor was determined from the proportion of land allocated to urban and agriculture for the period 1960-64. For this variable regions 1,2,3,4,5,6, and 7 were ranked 4,2,1,3,5,7 and 6 respectively.

At ninety five percent confidence and degrees of freedom equal to five,

TABLE 6: Regional Changes in Mangrove Communities from 1960-64 to 1986-88

REGION 1: Essequibo River To Demerara River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	13.68	0.49485
Sea	Rhizophora	2.26	0.08168
Urban	Rhizophora	0.28	0.00998
Sea	Avic./Rhiz.	35.59	1.28792
Urban	Avic./Rhiz.	0.01	0.00038
Mangal-A	Agriculture	9.45	0.34193
Mangal-A	Urban	1.71	0.06175
Avicennia	Agriculture	4.59	0.16622
Avicennia	Urban	14.16	0.51234
Rhizophora	Urban	9.03	0.3266
Avicennia	Avic./Rhiz.	9.26	0.3349
TOTAL		100	3.61854

REGION 2: Demerara River To Mahaica River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	12.61	0.88656
Agriculture	Mangal-A	0.01	0.00061
Sea	Avicennia	2.58	0.18099
Mangal-A	Sea	24.98	1.75553
Mangal-A	Agriculture	7.43	0.52195
Mangal-A	Urban	52.4	3.6827
TOTAL		100	7.02834

REGION 3: Mahaica River To Abary River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	2.18	0.5055
Sea	Avicennia	16.59	3.8515
Agriculture	Avicennia	14.06	3.2642
Forest	Avicennia	0.34	0.0779
Mangal-A	Sea	1.83	0.4239
Mangal-A	Agriculture	25.7	5.9661
Mangal-A	Marsh Swamp	1.45	0.3362
Avicennia	Sea	0.92	0.2137
Avicennia	Agriculture	29.07	6.7464
Avicennia	Marsh Swamp	5.82	1.3512
Mangal-A	Avicennia	2.04	0.4744
TOTAL		100	23.2109

REGION 4: Abary River Tc Berbice River

FROM.	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	3.81	1.465
Agriculture	Mangal-A	17.6	6.7623
Sea	Avicennia	3.49	1.3399
Agriculture	Avicennia	9.87	3.7911
Sea	Rhizophora	0.03	0.0109
Agriculture	Rhizophora	0.27	0.103
Urban	Rhizophora	0.08	0.0296
Sea	Avic./Rhiz.	9.6	3.6879
Mangal-A	Sea	5.01	1.9253
Mangal-A	Agriculture	13.28	5.1012
Mangal-A	Urban	1.07	0.4112
Avicennia	Sea	9.03	3.4713
Avicennia	Urban	3.3	1.2697
Rhizophora	Sea	0.15	0.0575
Rhizophora	Agriculture	0.1	0.0374
Rhizophora	Urban	0.06	0.024
Avic./Rhiz.	Sea	0.03	0.0116
Avic./Rhiz.	Agriculture	7.2	2.7663
Avic./Rhiz.	Urban	0.82	0.3169
Mangal-A	Avicennia	2.43	0.9348
Mangal-A	Avic./Rhiz.	0.14	0.0545
Avicennia	Mangal-A	11.97	4.6004
Avic./Rhiz.	Mangal-A	0.66	0.2534
TOTAL		100	38.4251

REGION 5: Berbice River To Corentyne River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	13.17	13.1479
Agriculture	Mangal-A	1.77	1.7639
Forest	Mangal-A	1.39	1.3917
Sand/Beach	Mangal-A	1.26	1.2572
Sea	Avicennia	9.49	9.4739
Agriculture	Avicennia	0.4	0.3978
Forest	Avicennia	1.4	1.3928
Marsh Swamp	Avicennia	0.09	0.0867
Sand/Beach	Avicennia	1.42	1.4214
Sea	Avic./Rhiz.	7.02	7.0098
Agriculture	Avic./Rhiz.	1.41	1.4078
Urban	Avic./Rhiz.	0.04	0.0437
Sand/Beach	Avic./Rhiz.	0.46	0.4625
Mangal-A	Sea	0.08	0.0751
Mangal-A	Agriculture	21.64	21.5991
Mangal-A	Urban	1.41	1.4076
Mangal-A	Forest	0.08	0.0791
Mangal-A	Marsh Swamp	0.04	0.036
Avicennia	Sea	0.05	0.0482
Avicennia	Agriculture	15.97	15.9387
Avicennia	Urban	0.44	0.436
Avicennia	Forest	0.94	0.9375
Avicennia	Marsh Swamp	0.54	0.535
Avic./Rhiz.	Sea	0.39	0.3866
Avic./Rhiz.	Agriculture	0.06	0.0628
Avic./Rhiz.	Urban	0.38	0.3772
Mangal-A	Avicennia	0.74	0.7368
Mangal-A	Avic./Rhiz.	6.23	6.2205
Avicennia	Mangal-A	10.61	10.592
Avicennia	Avic./Rhiz.	0.07	0.0737
Avic./Rhiz.	Mangal-A	1.01	1.0108
TOTAL		100	99.81

REGION 6: Moruka River To Pomeroon River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	2.45	7.894
Agriculture	Mangal-A	1.01	3.248
Forest	Mangal-A	2.19	7.051
Swamp Savanna	Mangal-A	17.85	57.477
Sea	Avicennia	0.48	1.537
Agriculture	Avicennia	0.52	1.663
Forest	Avicennia	0.11	0.369
Swamp Savanna	Avicennia	32.73	105.409
Mangal-A	Sea	0.79	2.548
Mangal-A	Agriculture	2.53	8.146
Mangal-A	Forest	2.58	8.321
Mangal-A	Swamp Savanna	8.43	27.157
Avicennia	Sea	0.17	0.544
Avicennia	Agriculture	0.85	2.74
Avicennia	Forest	0.51	1.651
Avicennia	Swamp Savanna	3.56	11.45
Rhizophora	Agriculture	0.05	0.16
Rhizophora	Forest	0.15	0.477
Mangal-A	Avicennia	5.23	16.853
Avicennia	Mangal-A	17.69	56.983
Rhizophora	Mangal-A	0.04	0.132
Rhizophora	Avicennia	0.07	0.231
TOTAL		100	322.043

REGION 7: Pomeroon River To Essequibo River

FROM	TO	AREA (%)	AREA (Km2)
Sea	Mangal-A	4.94	6.977
Agriculture	Mangal-A	1.74	2.456
Forest	Mangal-A	15.99	22.596
Swamp Savanna	Mangal-A	3.93	5.55
Sea	Avicennia	0.01	0.014
Agriculture	Avicennia	0.27	0.386
Forest	Avicennia	4.34	6.132
Swamp Savanna	Avicennia	11.75	16.605
Mangal-A	Sea	2.97	4.203

Mangal-A	Agriculture	27.13	38.348
Mangal-A	Forest	8.38	11.852
Mangal-A	Swamp Savanna	4.07	5.758
Avicennia	Sea	0.03	0.039
Avicennia	Agriculture	4.19	5.925
Avicennia	Swamp Savanna	0.58	0.813
Rhizophora	Sea	2.19	3.098
Rhizophora	Agriculture	1.97	2.783
Rhizophora	Urban	0.13	0.187
Mangal-A	Avicennia	4.54	6.421
Avicennia	Mangal-A	0.09	0.133
Rhizophora	Mangal-A	0.76	1.069
TOTAL		100	141.346

a t-critical value of 2.02 was determined from a student's t table. The paired variables (two for each region) were assessed in SPSS PC+ (Version 5.0) for a Kendall Tau-b value of the crosstabulation function. A t observed value of 2.3 was calculated for the Kendall Tau-b analysis. Consequently, the alternative hypothesis of the statistical testing, that a direct relationship does exist between the two variables, was accepted at ninety five percent confidence. In addition, a Kendall Tau-b value of 0.52381 was calculated. Therefore, the relationship between the amount of land allocated to urban and agricultural practice in 1960-64 and the amount of mangrove forest lost to urban/infrastructure and agriculture is moderately strong.

Part II-Satellite Image Investigation

4.2 Introduction to the use of Satellite Imagery

To determine if satellite imagery can be utilized to monitor changes in both mangrove areal boundary and species composition, a single LANDSAT MSS image was analyzed using an EASI/PACE image analysis processor. The choice of both data and processor type were based upon the initial assessment of the time constraints and type of analysis to be carried out in this investigation. A series of complex procedures was employed to transform the raw digital data into classified data useful for image interpretation. At the most basic level, this included the extraction of the study area followed by preprocessing and finally classification. Due to the importance of these steps, a detailed account of each separate procedure follows.

4.2.1 The Satellite Data

The LANDSAT 5 MSS tape acquired from the Earth Observation Satellite Company (EOSAT) Data Centre contains data for a particular scene of the coastal plain region of Guyana. The centre of the image scene is located at 7°0'13" N by 58°0'22"W and is dated May 3, 1985 at 1340 hours. The entire scene, for which 4 separate reflectance bands can be represented, covers a surface area measuring approximately 185Km^2. It is comprised of 2983 scan lines (or rows), each composed of 3596 pixels.

A cell or pixel represents a ground surface resolution of 59 by 79 meters. Each pixel is assigned a numerical value. This value, which ranges from 0 to 127, depicts the intensity of reflectance exhibited by the particular surface feature. On this scale, a value of 127 represents the highest reflectance and a value 0 the lowest reflectance possible. A pixel's reflectance value may vary considerably between bands. Each of the four bands represents a different region of the electromagnetic spectrum (Table 7).

TABLE 7: Multispectral Response for Scanners of LANDSAT 4 and 5 Remote Platforms

Band	Spectral Reflectance	Colour
1	0.5-0.6 micrometers	green
2	0.6-0.7 micrometers	red
3	0.7-0.8 micrometers	near infra-red
4	0.8-1.1 micrometers	near infra-red

(Source: Richason, 1983)

The format for the image data tape is band sequential. This format is considered the most practical for display and analysis purposes. All data for band 1 is written in sequence, followed by all data for band 2, band 3 and finally for band 4.

Although the LANDSAT MSS pixel resolution is much coarser than that of LANDSAT TM (30m x 30m) or SPOT (20m x 20m) data, there are two advantages to its choice for this investigation. The MSS digital image (185 km^2) is much larger than that of SPOT (60 km^2) and costs much less than TM and SPOT digital images. In addition, data coverage for LANDSAT MSS is more extensive making time series investigations more pertinent. LANDSAT MSS data collection began in 1972 whereas LANDSAT TM and SPOT began in 1982 and 1986 respectively.

4.2.2 Image Analysis Software Package

An understanding of the fundamental characteristics of the digital image processing system is essential for the extraction of meaningful information from satellite imagery. An EASI/PACE image analysis software package, installed on a 486 PC running with the DOS operating system, was utilized during this investigation. The EASI/PACE system is composed of three main components: EASI, PACE and the parameter file. The advantage of this form of organization was considered when choosing between this image processing system and the IDRISI system also available within the Department of Geography.

The function of EASI (Engineering Analysis and Scientific Interface) is to govern all interactions between the user and the digital image processing system. As a result, all input instructions are carried out within EASI. The advantage of this application-independent component system is that it eliminates all differences between host operating systems, file structures and editors. Different systems (eg. PC SUN work station) can be networked and databases transferred, shared or accessed directly without the need to reformat.

PACE (Picture Analysis Correction and Enhancement) consists of programs which carry out actual image analysis. There are approximately 200 programs available for PACE, but this number is dependent upon the number of software packages purchased by the user. This investigation used only those programs already installed in the EASI/PACE system, thus precluding any costs associated with the purchase of extra programs. Examples of these programs/modules used in this investigation include the MAGSTRU (Tape Record and File Structure), CIM (Create Image Database File), and IVI (Database to Display Image Transfer) programs.

The parameter file is a single disk file that contains all parameters necessary for the execution of PACE programs. These parameters include such variables as filenames, program options and numerical values. Rather than being requested from the user, all information is taken from this file when a procedure (program) is executed. There are two main advantages to this format. Any single parameter can be changed at any time using the single EASI interface system, thus reducing the confusion created by multiple files. In addition, parameters remain set until changed by the user. As a result, user interaction time is reduced when several procedures, which share a large number of parameters, are to be sequentially executed.

Additional hardware, used in conjunction with the EASI/PACE operational system, included an extra Mitsubishi Diamond Scan Colour Monitor for video image output and a Cypher M995 0.5"9 track tape drive for data input. Hard copy output devices included a HP Laser Jet 4 and Tectronix 4697 (Colorquick) 216 dpi colour inkjet printer. Due to a poor quality in colour resolution from the colour inkjet, a Minolta 35mm camera with tripod was also used for hardcopy output.

4.2.3 Extraction of the Study Area

As a result of a limited capacity for micro-computer storage, only a small portion of the entire satellite image could be assessed. The selection of a smaller study area along the coast was based upon the following procedure: land over water followed by cloud free over cloud covered followed by ground truthed mangrove forest over non-ground truthed mangrove forests. The initial step in the extraction process began with the creation of a DOS directory from which the EASI/PACE program was executed. Because of the complex nature of the remaining extraction procedures, the following steps, in order of execution, are described independently and with greater detail:

(1) Before the data could be downloaded from Cypher M995 0.5"9 track tape to the EASI/PACE operating system, the MAGSTRU (Tape Record and File Structure) program was employed to retrieve the tape format. From the report, it was determined that each band had a corresponding header and trailer file. In addition, it was determined that both header and trailer files were not required for data transfer.

(2) A view of the entire image was necessary before a smaller region

could be selected and downloaded for analysis. The MVB (tape to display, band sequential format) program was executed four separate times to display each of the four bands of the whole image onto the video display. The parameters kept during all four operations included the length of the data records in bytes set at 3596, the number of lines per record and records to skip before data read both set at 1, and finally the magnetic tape input window set to 0,0,3596,2983. As with all windows in EASI/PACE, the magnetic tape input window values represent, in order, the x offset, the y offset, the x size (in pixels) and the y size (in lines). The origin (0,0) is located in the upper left corner of the original image. The two parameters that did change with each execution included the video output channel and the startfile. For the video output channel parameters 1,2,3,4 the startfile was set for 2,5,8 and 11 respectively. As a result, the video channel display number corresponded with the actual number of the LANDSAT MSS band extracted (i.e. channel 1 for band 1). After viewing the entire image on display, it was decided that a window set at 1200, 1400, 1200, 1200, represented the best preliminary study area. This decision was based primarily on the fact that this area contained the least cloud cover.

(3) The CIM (Create Image Database File) program was used to create a PCIDSK database for the storage of the raw image data. The database, called "guyana", was created to hold images of 1200 pixels by 1200 lines. This size was based upon the earlier selected region. The number of image

channels chosen was four 8-bit unsigned integer type. Each channel was created to store one band of MSS imagery. The only restriction to the created database was that the number of pixels per line be a multiple of eight.

(4) The raw digital data were then transferred from the tape to the newly created database. The MIB (Magnetic Tape to Image database - Band Sequential Data) program served this function. Much like the MVB program, the MIB program was executed four times for each separate band of image data. With the exception of the tape input window set at 1200, 1400, 1200, 1200, the parameters utilized were the same as those employed for the MVB procedure (step 2). Once transferred, the database channels were displayed to the video output utilizing the IVI (Database to Display Image Transfer) program. It was then determined that an even smaller region within the Essequibo Delta showed the greatest potential for mangrove classification.

(5) The WINFILE (Window Selection from File) program was then utilized to define the extent of the final sub-scene needed for the mangrove classification. A small window of the sub-scene was created with the cursor draw function of the WINFILE program. The set values for the window were determined to be 166, 473, 696, 696.

(6) A new database file, "guyana 2", was then created to receive the new sub-scene data. The image data capacity was set for 696 pixels by 696 lines. The number of image channels chosen was sixteen 8-bit unsigned integer channels. The first four channels were created to receive the four

bands of the MSS image. The following twelve channels were created to receive additional data resulting from the manipulation of the original bands.

(7) The final procedure involved the transfer of the data from the original database file to the new database file. The III (From Image Database to Image Database, Image Data Transfer) program was employed to accomplish this task. The parameters included the large input file "guyana", the small input of file "guyana2", input channels 1, 2, 3, 4 and the corresponding database output channels 1,2,3,4. The amount of data transferred was restricted to the database input window 166, 473, 696, 696.

4.2.4 Preliminary Statistics and Radiometric Enhancement

To improve image quality before main analysis, there are several algorithms which can be applied to satellite digital data. Geometric preprocessing techniques, for example, can register the image to another reference map. Radiometric preprocessing techniques, on the other hand, can also be applied to remove the sensor errors associated with the effects of a hazy atmosphere. In addition, image enhancement techniques can be employed to improve image quality. However, these techniques are more subjective in nature since the improvement to image equality is based upon user discretion. A particular form of image enhancement, contrast enhancement, allows the user to exploit the full range of brightness values associated with a particular digital data type. This procedure is accomplished by stretching all or a particular range of brightness values across the whole spectrum. During this investigation, a combination of radiometric preprocessing and enhancement techniques were utilized to extract both the cloud cover and water from the study area before classification.

Before algorithms could be applied, it was essential that initial statistics, in terms of histograms, be studied. From the study of these histograms, certain brightness values could be associated with particular surface features. As a result, land surface areas could be extracted, contrast stretched and finally classified. These procedures are quite complex and each step is explained separately in order as follows:

(1) Following the transfer of the sub-scene bands to the second database, all four bands were displayed utilizing the IVI (Database to Display Image Transfer) program (Figure 22). Each band was displayed individually and in combination with another. Consequently, specific regions of concern (i.e. extensive cloud cover or land cover) were detected.

(2) The HIS (Histogram Image Data) program was employed to determine the characteristic shape of the frequency curve for the brightness values of each spectral band. A graphic display was created depicting the actual number of pixels per brightness value class. The class interval was set for 2 and the range set for 0 to 127 (Figures 23 through 26).

(3) The analysis of histograms was carried out utilizing the DCP (Display Control Package) program. This program enables the manipulation of image

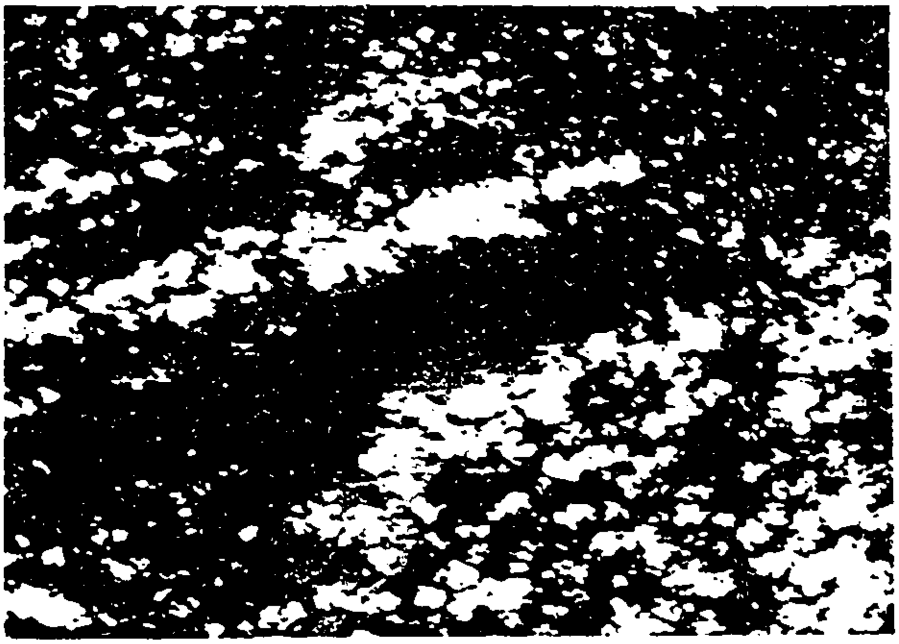
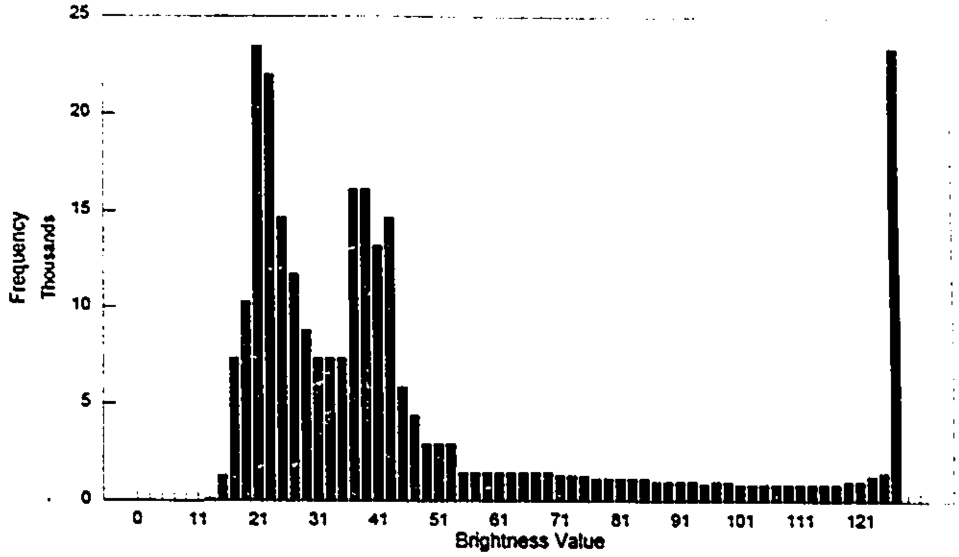


FIGURE 22: LANDSAT MSS Sub-Scene Extracted for the Investigation (Bands 1, 2, 4 displayed).

Figure 23-Band 1(MSS) Pixel Distribution

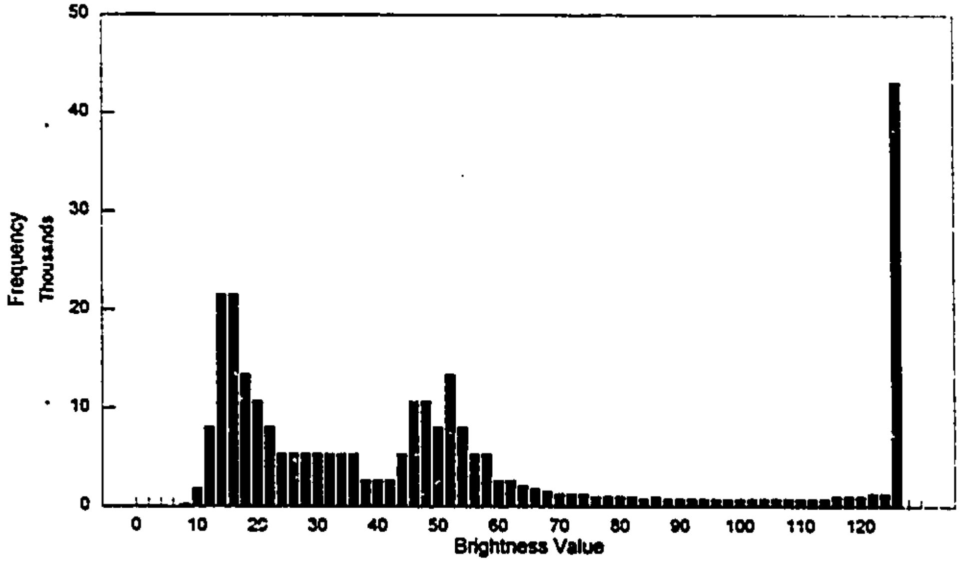
Guyana Sub-Scene



# of Pixels Plotted: 484416
Mean: 48.433
Median: 38
Standard Deviation: 32.233

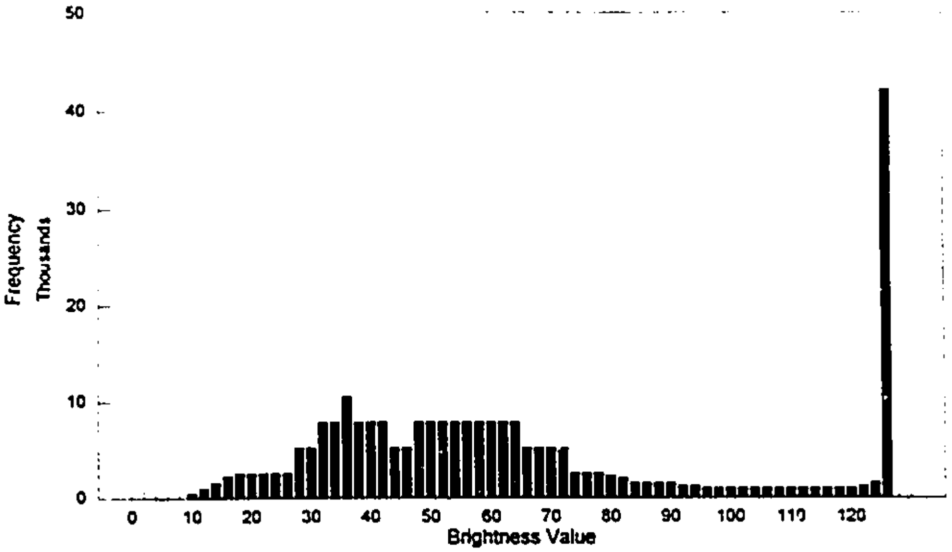
Figure 24-Band 2(MSS) Pixel Distribution

Guyana Sub-Scene



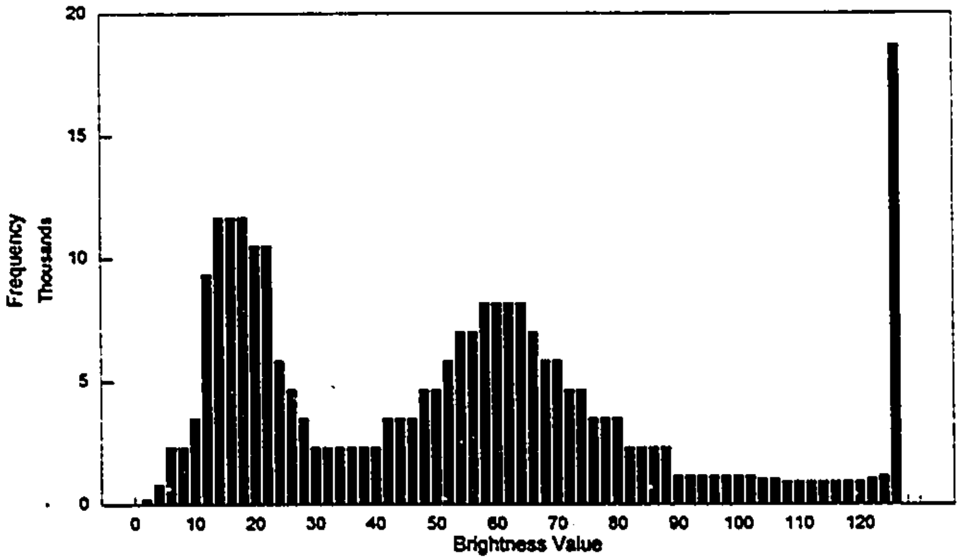
# of Pixels Plotted: 484416
Mean: 51.133
Median: 45
Standard Deviation: 35.697

Figure 25-Band 3(MSS) Pixel Distribution
Guyana Sub-Scene



# of Pixels Plotted: 484416
Mean: 62.378
Median: 56
Standard Deviation: 31.181

Figure 26-Band 4(MSS) Pixel Distribution
Guyana Sub-Scene



# of Pixels Plotted: 484416
Mean: 53.264
Median: 54
Standard Deviation: 32.093

data in the video display without altering the actual database. One specific task of the DCP, the Pseudo-Colour Table commands mode, assessed the characteristic features associated with each peak and low within the individual histograms. Each channel (band) was displayed separately. An associated pseudo-colour table was turned on using the display function and initialized to the smooth grey option. The modify function of the pseudo-colour table was then employed to assign particular colours to particular ranges of grey (brightness) levels within each band. After considerable manipulation, specific regions of the bands could be assigned to specific surface features (Figures 27 through 30). As a result, the grey-levels (brightness values) associated with land surface could be distinguished from cloud and water surfaces.

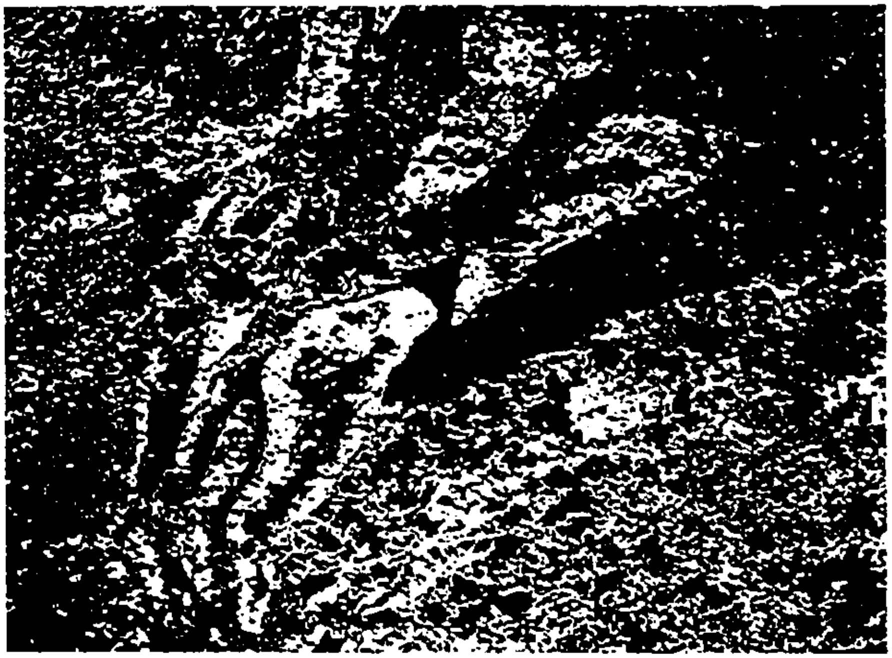
(4) Following the DCP procedure, the STR (Contrast Stretch File) program was employed to carry out radiometric enhancement. The grey levels, which were determined in the preceding procedure to represent land surface, were stretched across the whole brightness (grey-level) spectrum. The program was executed four times for the four separate bands. Parameters kept during all four runs included a stretch option set for linear, an output grey level range set for 0 to 127, and a database look-up table auxiliary segment set to computer default. In addition, all pixels that fell above or below the grey-level range to be stretched were assigned to the maximum output grey level of 127. Consequently, pixels associated with cloud and water features were assigned to a grey level of 127. The only parameters to change

Pixel Range	Colour Assigned
13-19	pink
21-29	red
31-35	yellow
37-41	green
43-53	light blue
55-127	blue

FIGURE 27: Band 1 Pseudo Colour Assignment, Guyana Sub-Scene.

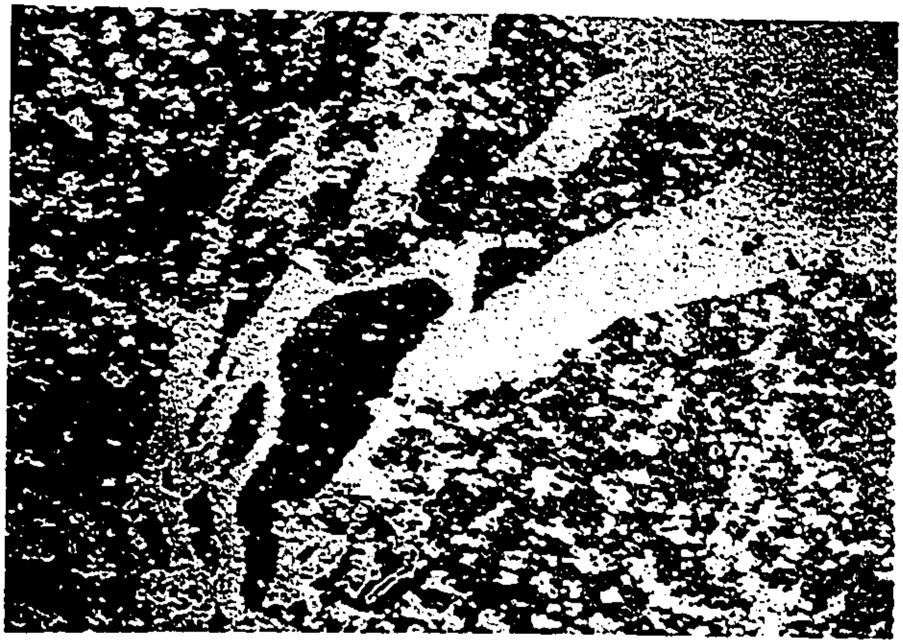
Pixel Range	Colour Assigned
8-12	pink
14-22	red
24-36	yellow
38-42	blue
44-50	green
52-58	turquoise
60-126	light blue
127-127	grey

FIGURE 28: Band 2 Pseudo Colour Assignment, Guyana Sub-Scene.



Pixel Range	Colour Assigned
10-26	pink
28-48	green
50-64	red
66-84	yellow
86-126	blue
127-127	grey

FIGURE 29: Band 3 Pseudo Colour Assignment, Guyana Sub-Scene.



Pixel Range	Colour Assigned
2-28	pink
30-42	green
44-88	red
90-126	blue
127-127	grey

FIGURE 30: Band 4 Pseudo Colour Assignment, Guyana Sub-Scene.

were the database input channel number and the specific input grey level range to be stretched. Once executed, the file created a particular auxiliary segment for each stretched band.

(5) The LUT (Look-Up Table Transformation) program allowed the stretched images, in a form of auxiliary segments, to be permanently transformed into new images occupying specific database channels. The parameters assigned included the original database channel numbers, the associated database look-up table segments numbers and the numbers for the new database channels to receive the permanently stretched image.

(6) Each new channel was then displayed with the IVI program and its associated histogram created by the HIS program.

4.2.5 Multispectral Classification

Image classification is often the final step in most digital image processing investigations. During this process, pixels of similar brightness values within their spectral channels are assigned to a particular group or class. These groupings of pixels form the categories of interest to the investigator of the data. There are two approaches to image classification. One approach, the supervised classification, employs samples of pixels of known identity to classify pixels of unknown identity. These samples or training areas are chosen by the analyst and provide the statistics necessary for the image processor to classify the entire digital image. Unsupervised classification, on the other hand, utilizes specific algorithms to divide a large number of unknown pixels into a particular number of classes. This approach is more objective in that the classes created are based upon the natural groupings or structures within the multispectral data.

The unsupervised approach to classification was employed for this investigation. There are several reasons for this choice. Due to the extensive cloud cover within the image scene, the suggested minimum number of 5 to 10 training areas per class could not be found. In addition, the recommended size of 40 pixels per training area was also restricted. The majority of the training areas of appropriate size did not exhibit a strong spectral homogeneity or uniformity. Moreover, the cloud cover limited the study to a region with very little ground truthing. Consequently, ideal sample regions could not be used as training areas since they could not be classified with sufficient accuracy.

In order to conduct a full unsupervised classification of the study area, it was necessary to carry out a series of steps within the EASI/PACE image analysis system. The initial step involved the creation of a four dimensional histogram utilizing the HGN (Histogram Generation) program. The histogram was based upon the brightness values associated with those four image channels created from the application of a piecewise stretch to the original four band channels. Parameters specified included the database input channels 5 through 8; the number of high-order bits used per 8-bit data value set at 6, the grid sampling set for every fourth pixel on every fourth line, and an output file name "histo1".

The four dimensional histogram was then clustered utilizing the HMM (Histogram Migrating Means Clustering) program. The algorithm applied assesses the squared distance between all histogram data values and the mean value of all clusters. The histogram data values are then assigned to the cluster whose squared distance it is closest to. Once assimilated into the appropriate cluster, the mean cluster value is then reassessed and the calculations repeated. This process continues until all cluster means have moved less than the specified distance threshold or until a specified maximum number of recalculations have been performed to the migrating means. The parameters specified included the input histogram file "histo1", the default cluster number set at 8, the maximum migrating means recalculation number set at 20, and the minimum means migrating threshold set at 2 pixels. In order to keep the classification unbiased, the original parameter cluster mean values were set for computer default.

Following the clustering step, the HSG (Histogram Signature Generation) program was employed to create signature segments of the histogram clusters/classes. Parameters specified included the histogram input file "histo1", the database input file "guyana2", the cluster input numbers 1 through 8, a gaussian feature-space threshold of 3.0 standard observations, and a bias value of 1.0. Once executed, the HSG created eight auxiliary segments representing eight classes for the final classification.

The final procedure performed was a maximum likelihood classification. This procedure was executed utilizing the MLC (Maximum Likelihood Classification) program. The parameters utilized included the eight auxiliary segments previously mentioned, a database output channel of 9, the database input file "guyana2", and the type of classification full maximum likelihood. The output classified image channel 9 was then displayed utilizing IVI and each class assigned a specific colour by the pseudo-colour function of the DCP program (Figure 31).

4.2.5.1 Maximum Likelihood Classification

Unlike most other classification strategies, the maximum likelihood classification approach considers both the mean and the variation of each class. More specifically, the algorithm uses the mean vector, the variance and

Class	Colour Assigned
forest	green
agriculture	yellow
wetlands	red
cloud,water,shadow	black

FIGURE 31: Unsupervised Classification of Guyana Sub-Scene.

the correlation of the spectral response patterns of its different classes. As a result, unknown pixels that are located in the zone of overlap between different classes can be classified. The main assumption of this approach is that all classes are considered to possess a multivariate normal (gaussian) frequency distribution. The basic concept behind this classification approach can be depicted by the ellipsoidal equiprobability contours found in Figure 32. The shape of the contour characterize the sensitivity of the classifier to correlation. Within the program, the radius of the ellipse which surrounds the class mean is determined by threshold value set in standard deviations. If a pixel falls within this threshold (ellipse) it is assigned to that given class. If a pixel does not fall inside any ellipse (class) it is assigned to a null class. For those pixels which fall within the overlap of two classes, the bias value of the program is often utilized to resolve which class it is assigned to by weighing one class in favour of another.

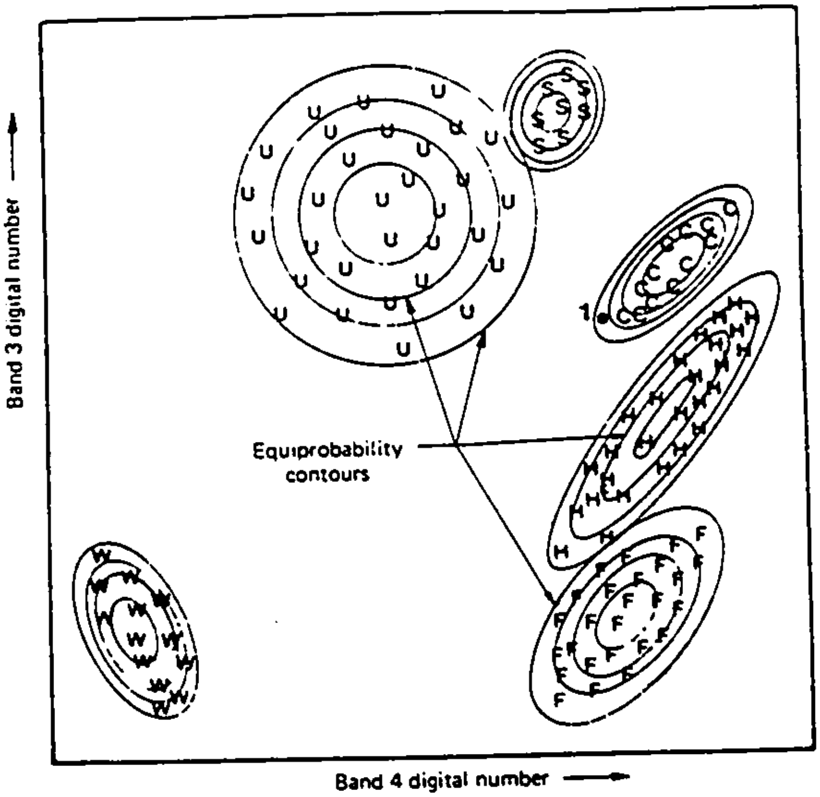


FIGURE 32: Equiprobability Contours Defined by a Maximum-Likelihood classifier (Source: Lillesand and Kiefer, 1979).

The Mahalanobis minimum distance classifier, incorporated into the EASI/PACE system, was the algorithm utilized in this investigation. The equation of the algorithm is as follows:

$$Gi(X)= -1/2(X-Ui)^{t}\, Ci^{-1}\, (X-Ui) - d/2\log(2\pi) - 1/2\log(|Ci|) + \log(Pi)$$

Where;

Gi(X)= the result for class i on pixel X

d = the number of channels in the classification

X=(x1,...,xd) = the (d by 1) pixel vector of grey-levels

Ui = the (d by 1) mean vector for class i

Ci = the (d by d) covarience matrix for class i

π = pi = 3.141...

Ci = the determinant of the covarience matrix

Pi=Bi/SUM(Bi) = the a priori probability for class i

Bi = the Bias for class i

SUM(Bi) = the sum of the Biases for all classes used

t = denotes transpose

-1 = denotes inverse

Ti = the threshold value for class i

With respect to a given classes (i) depiction in feature space, Ci^{-1} defines the characteristic shape and orientation of the hyperellipsoid i. Whereas Ti and Ui determine the size and position respectively. The process of the classification is as follow:

a) If a pixel x is found inside only one hyperellipsoid it is assigned to that class. Hence the following must be true $(X-Ui)^{t} Ci^{-1} (X-Ui)<=Ti^{2}$;

b) if a pixel x does not fall into any hyperellipsoid it is assigned to the null class; and

c) if pixel x is found within several ellipsoids the Gi(x) equation is calculated. The pixel x is then assigned to the class with highest Gi(x) value.

CHAPTER 5

CONCLUSION

5.0 Discussion of Results for GIS Database

Region one, Essequibo River to Demerara River, experienced the largest amount of change in land use boundaries (1-Cramer's V=0.5962). Agriculture, forest and marsh swamp account for the largest changes in class over time (Table 2 and 3). The area of both agriculture and marsh swamp classes increased, from 46.25% to 75.55% and 3.83% to 13.6% respectively. The forest class suffered the greatest loss. During the 1960-64 period, 47.85% of the total area of region 1 was occupied by forest. By 1986-88, this figure had decreased to 6.7%. Mangrove communities, although occupying only a small portion of the land, also recorded changes in areal boundary. The amount of area occupied by both the *Avicennia* and *Rhizophora* dominated communities decreased. Overall, a gain of 0.47 km^2 in total mangrove community was observed (Table 5). The largest proportional area change within the mangrove community was that of a growth of forests dominated by a mix of *Avicennia* and *Rhizophora* seaward (Table 6). This was followed by a loss of *Avicennia* to urban expansion and a gain in mangai-A (dominated by mangrove associates) seaward.

Region two, Demerara River to Mahaica River, recorded the lowest amount of change in land use boundaries (1-Cramer's V=0.3711). The urban class experienced the largest amount of change. The proportional area occupied by the urban environment increased from 7.96% during 1960-64 to 12.68% during 1986-88 (Table 2 and 3). During this period, the mangal-A community decreased and the *Avicennia* dominated community experienced growth. In total, the mangrove community lost approximately 4.89 km^2 of its surface area (Table 5). The largest proportional area change in the mangrove community was mangal-A loss to both the sea and urban expansion (Table 6).

With respect to the other study regions, region three, Mahaica River to Abary River, experienced a moderate amount of change in land use boundaries (1-Cramer's V=0.5183). The largest changes recorded included agriculture, an increase from 58.74% to 70.89% of the total land area, and marsh swamp, a decrease from 29.58% to 18.76% of the total land area (Table 2 and Table 3). Within the mangrove community, the area occupied by mangal-A decreased and that of the avicennia class remained approximately the same. Overall, this region suffered one of the greatest losses in total amount of mangrove community. Between the periods 1960-64 to 1986-88, 7.34 km^2 of mangrove forest was lost (Table 5). The largest proportional area change in the mangrove community was the loss of both mangal-A and avicennia class to agricultural expansion (Table 6). Following these losses were gains in the avicennia class seaward and into abandoned agricultural land.

Region four, Abary River to Berbice River, recorded a similar amount of change to that of region three (1-Cramer's V=0.5038). Over the time period, agricultural land occupation increased from 48.22% of total land area to 73.3% of total land area (Table 2 and Table 3). Marsh swamp occupation decreased from 36.74% to 13.08%. Within the mangrove community, only *Avicennia* dominated communities lost a significant amount of land area. Overall, region four experienced a slight gain of 1.8 km^2 in total mangrove community occupation (Table 5). The largest changes in the mangrove community, which counteracted one another, was a change from agriculture to mangal-A and from mangal-A to agriculture (Table 6). These rates of change were closely followed by a loss of the avicennia class to mangal-A.

Region five, Berbice River to Corentyne River, recorded the second highest amount of change in land use boundaries (1-Cramer's V=0.5899). Agricultural land occupation increased significantly, from 36.18% to 58.53% of total land area (Table 2 and Table 3). Conversely, marsh swamp occupation decreased, from 38.74 to 20.40% of total land area. Within the mangrove community, both *Avicennia* and mangrove associate dominated (mangal-A) communities decreased in proportional land occupation whereas the mixed *Avicennia/Rhizophara* dominated community increased. In total, 2.66 km^2 of region five's mangrove community was lost during the two time periods (Table 5). The greatest amount of change in the mangrove community was a loss of mangal-A to agricultural expansion (Table 6). This rate of change was closely followed by a loss of the avicennia class to agriculture.

With respect to region five, region six, Moruka River to Pomeroon River, recorded a very similar amount of change (1-Cramer's V=0.5557). Between the two time periods, swamp savanna occupation decreased significantly. During 1960-64, swamp savanna occupied 31.42% of total land area and in 1986-88 it occupied only 20.19% (Table 2 and Table 3). Region six contains the largest community of mangal-A. This class occupied 45.05% of the total land area in 1960-64 and this figure increased to 49.99% by 1986-88. The largest increase in total mangrove forest is found in this region, a gain of 121.45 km^2 (Table 5). The majority of this gain can be attributed to a large loss of swamp savanna to *Avicennia* dominated forests (Table 6). The next highest rates of change experienced by the region's mangrove community was the gain of mangal-A from both swamp savanna and avicennia clases.

Region seven, Pomeroon River to Essequibo River, experienced a rate of change in class boundaries similar to the two previously mentioned regions (1-Cramer's V=0.5611). The agricultural class recorded the largest change in amount of area occupied. The proportion of agricultural land occupied increased from 13.51 to 21.95% (Table 2 and Table 3). The largest loss experienced was that of swamp savanna, from 9.49% of total land area in 1960-64 to 4.04% in 1986-88. Within the mangrove community, *Avicennia* occupation increased whereas mangrove associates (mangal-A) and *Rhizophora* decreased. Approximately 12.26 km^2 of total mangrove community was lost between the two periods (Table 5). The largest change in the mangrove community was the loss of mangal-A to agricultural expansion (Table 6).

With respect to the study area, all study regions combined, mangrove forests experienced an overall increase by 8.91% or a gain of roughly 96.52 km^2. However, region six contributes to the majority of this gain. Between the two periods, mangrove forests in this region increased by 19.09% or a gain of approximately 121.45 km^2. Mangrove associate and *Avicennia* dominated forests contribute to roughly 57% and 43% of this increase respectively. Excluding region six, there was an overall decrease by 5.57% or a loss of 24.93 km^2 of mangrove forests. Stands dominated by mangrove associate and *Rhizophora* were reduced by 10.27% (35.81 km^2) and by 94.23% (7.35 km^2) respectively. On the other hand, *Avicennia* dominated forests experienced an increase by 3.75% (2.84 km^2) and *Avicennia/Rhizophora* dominated forests an increase by 106.05% (15.39 km^2).

With regards to the a priori model discussed earlier, several key observations have been noted. With the exception of region six, the region with the lowest significant number of inhabitants, the anthropogenic factor accounts as the major cause for mangrove forest loss in every study region. Urban and agricultural expansion resulted in approximately 99, 71, 85, 65, 95, 12 and 66 percent of mangrove forest loss in regions one, two, three, four, five, six and seven respectively. Loss of mangrove forests to the physical/climatic component was observable in two regions but weakly represented overall.

Roughly 29 and 36% of mangrove forest loss in regions two and four can be attributed to this component. For region six, no particular agent of change could be linked to the expansion of swamp savanna and tropical forest into areas previously occupied by mangrove forests. The physical/climatic component, although weakly represented in mangrove loss, contributes as the major factor for mangrove forest gain. Accretion in the coastal environment could account for roughly 99, 99, 57, 38, 76, 5 and 12 percent of gains in mangrove forests for regions one, two, three, four, five, six and seven respectively.

5.1 Discussion of Results for Satellite Imagery

Of the eight classes created from the unsupervised classification three denote distinct land surface features. The colours yellow, red and green have been assigned to the pixels representing these cases. (Figure 32). The black coloured pixels represent the remaining five classes. These pixels denote either a water surface, a cloud surface or a land surface covered by a cloud shadow.

The class assigned to the color green represents regions whose surface is covered by thick forest canopy. Most notable is the region of dense tropical forest located inland from the western shore of the Essequibo River (a).

Yellow coloured pixels represent agricultural land. These pixels are more predominant and more homogenous in areas known for large scale agricultural production. Such regions include the islands of Leguan (b), Tiger (c) and Wakenaam (d) as well as the land located east of the Essequibo River delta (e). Yellow pixels are in general also quite dominant along the shorelines where agricultural practice has always been prevalent. Both Hog Island (f) and Liberty Island (g) show an agricultural land expansion inland from the water's edge.

Red coloured pixels represent a mangal or swamp savanna community. This class is least likely to be present in areas of high agricultural production. Consequently, few red pixels are found at the Islands of Wakenaam, Tiger, and Leguan. However, the class is strongly represented in islands with small populations such as Rock(h) and Akorikora(i) Islands. Red pixels are also dominant within the transition zones between tropical forest and agricultural land (j).

Although the classification created could distinguish with some accuracy certain key land features it could not distinguish between different mangrove communities.

5.2 Conclusion

The aforementioned discussion allows several conclusions to be made. From the GIS investigation it was determined that both the first and second hypotheses can be accepted. Both physical/climatic and biological components have little or no impact on recent mangrove forest loss in Guyana. The majority of loss in mangrove forests between 1960-64 and 1986-88 can be attributed to anthropogenic agents. This relationship was further investigated using advanced statistical testing. At the ninety-five percent confidence level, a direct/positive relationship does exist between the proportion of land already allocated to urban and agricultural development and the amount of mangrove forest lost to urban/agricultural expansion over total mangrove forest change. This relationship is moderately strong.

From the investigation into satellite imagery it has been determined that the third hypothesis cannot be accepted. The unsupervised classification with LANDSAT MSS cannot, under the conditions present, be used to monitor mangrove forests along the coast of Guyana. It may, however, be used to monitor agricultural expansion and/or wetlands (mangrove communities/swamp savanna).

5.3 Limitations to the Study

There are several limitations to this investigation. The most limiting factor of the GIS study was the lack of aerial photographs and topographic sheets. Poor economic conditions during the 1980s resulted in the failure of air conditioning units at the Lands and Surveys headquarters. Consequently, numerous aerial photographs were destroyed. A large number of topographic sheets also disappeared during this same period. In addition, the regions west of the Moruka River, towards Venezuela, have not been mapped recently and thus could not be included in this investigation.

Slight errors within the data are expected in this GIS investigation. For example, errors associated with the subjective nature of manual digitizing. Errors also result from misclassification during topographic map production. Although all topographic sheets utilized in this investigation were created in the United Kingdom, their production was based upon the photo interpretation skills of different cartographers from two different time periods. Consequently, error associated with the subjective nature of boundary delineation is also present. In addition, it is noted that the degree of compounded error present is subject to scale. For example, the smaller the boundary of a given class the greater the probability of error associated with it.

There are also numerous limitations to the satellite imagery investigation. The greatest limiting factor was the extensive cloud cover present in the image scene. As a result, no supervised classification could be conducted. In addition, analysis of urban regions could not be investigated.

The timing of the image scene also hindered proper classification. Certain areas known to be agricultural and not covered by clouds as shadows were depicted as water surfaces. This fact is well represented on both Wakenaam and Leguan Islands. The reasons for this misclassification lies in the fact that during the rainy season, when the image was taken, both rice and sugarcane fields are purposefully flooded. As a result, these lands exhibit a reflective behaviour of water rather than land.

The coarseness of the LANDSAT MSS resolution may have also limited this investigation. Fringe mangrove communities, if present, could not be distinguished and thus not depicted from the analysis. Misclassification can also be associated with pixel inaccuracy. For example, the presence of the yellow bands located between the red and green (a). These pixels do not represent agricultural land but are the result of a composite signature (mixed pixels). The averaged reflective value of the combined green and red classes is more similar to that of agricultural land than of the two classes they represent.

5.4 Recommendations for Further Studies

Future consideration for the GIS analysis may include another field season of ground truthing as well as a collection of data on the large expanse of mangrove forest located between the Moruka River and the Venezuelan border. This region has yet to be fully explored, and may reveal information regarding natural changes in mangrove communities. With this in mind, further research should be conducted to identify the specific agents of change associated with gains and losses of mangrove communities in region six. If a better satellite image could be acquired and integrated, the GIS database may provide a very powerful tool for monitoring mangrove communities as well as other land features located along the coastal plain.

If LANDSAT MSS imagery is to be utilized, the image scene selected should be taken during the dry season and with the least amount of cloud cover. Such an image would be ideal if one is to conduct a supervised classification. In addition, the problem associated with flooded agricultural fields would be avoided. More ground truthing, possibly another field season, would also be ideal.

Other considerations may include the use of SPOT and/or LANDSAT TM imagery. The SPOT's finer resolution would allow for a more detailed account of mangrove communities especially if thin fringe mangrove communities exist. The LANDSAT TM offers a greater number of bands with smaller reflectance intervals. Both SPOT and LANDSAT TM also provide a larger range of pixel brightnesses per band. These advantages may help to distinguish between different mangrove communities.

More practical, and the original intent of the author would be the use of an active satellite sensor rather than a passive one. For example, the use of radar satellite imagery. Unlike the previously mentioned sensors, this type of sensor can not only penetrate cloud cover to some degree but, more importantly, it can sense a region at night when cloud cover is minimal. This is an important fact when considering a tropical location like the country of Guyana.

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