VEGETATION TIME SERIES ANALYSIS OF
THE LOXAHATCHEE SLOUGH, PALM BEACH COUNTY, FL:
A GIS INCORPORATING SATELLITE IMAGERY WITH
BLACK AND WHITE AERIAL PHOTOGRAPHY

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Charles E. Roberts, Department of Geography, and has been approved by the members of her supervisory committee. It was submitted to the faculty of The College of Social Science and was accepted in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

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The Loxahatchee Slough is the largest wilderness island refuge existing in Palm Beach County, Florida. Cultural impacts have altered the hydrology of the area. This study provides a database of historical and geographical information regarding the Slough. Aerial photography and satellite imagery from pre- and post-channelization dates are classified according to vegetation ecosystems. GIS analysis is used to compare these diverse data sets. Changes in hydroperiod are examined, using vegetation as an indicator. Results show a general trend toward dryer hydroperiod vegetation land cover. Since 1979, the Army Corps of Engineers has raised water levels back toward pre-channelization levels, in a portion of the study area known as the Historic Region. Results indicate a positive response, with a net increase of longer hydroperiod vegetation in this region since 1979.

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OVERVIEW

Introduction

Human activity has detrimentally affected the environment, creating such problems as water and air pollution, toxic waste, desertification, global climate change, destruction of habitat and decline in biodiversity. "Whole landscapes are now occupied by man-dominated (and in part by man-created) faunas and floras" (Anderson, et al., 1956). The impact of these changes threatens not only the societies dependent on depleted resources, but the very survival of all forms of life. Ehrlich asserts that humanity is dependent on the "free ecosystem services" provided by microorganisms, plants, and animals, yet the expansion of human populations and activities is destroying the habitats that support these diverse lifeforms on which human survival depends. Ehrlich goes on to warn that merely setting aside a few preserves is not enough, but rather, that viable gene pools must be maintained in order for species to survive, while seeking methods for humans to utilize resources in ways that will no longer destroy the environment (Ehrlich, 1988). "Human occupance of area, like other biotic phenomena, carries within itself the seed of its own transformation" (Whittlesey, 1929). Perhaps, through responsible study and use of our resources, future transformation does not have to be destructive. "One of the prime prerequisites for better use of land is information on existing land use patterns and changes in land use through time" (Anderson, et al., 1976).

A Geographic Approach to Space and Time

Geography studies the spatial arrangement of phenomena, and the processes through time that affect those spatial patterns. Cultural impacts on the landscape leave imprints which can be examined and interpreted. A geographic approach can provide an assessment of current natural resources, contribute towards understanding how those resources have been impacted in the past, and help determine how to responsibly use and protect them in the future.

Prior to the availability of remotely sensed data, cultural geographic studies were based on data collected from the ground. The synoptic views now provided by remote sensing furnish unbiased data to which a geographic approach also can be applied. Historical aerial photography gives a view of the spatial arrangement at a moment in the past. As technology has advanced, the type of data available has expanded to include satellite imagery. Through digital image analysis of raster satellite data, and transformation of aerial photographs into vector Geographic Information System (GIS) data, these glimpses into various periods of time can be analyzed together to study the changes that have occurred over time.

Thesis Proposal

The 1990 report on the International Union of Biological Sciences (IUBS) Workshop on Ecosystem Function of Biological Diversity calls attention to the need for expanding the very limited data base on ecosystems at local and global levels, and includes in its list of main objectives the use of remote sensing to inventory ecosystem distribution and change (di Castri and Younes, 1990). Likewise, the Ecological Society of America's Sustainable Biosphere Initiative (SBI) includes remote sensing as a valuable method of building and analyzing a biological inventory across different spatial and temporal scales (Lubchenco, et al. 1991). The research priorities of SBI parallel those of UNESCO's Man and the Biosphere Programme, namely Global Change, Biological Diversity, and Sustainable Ecological Systems. Unfortunately, remote sensing, which can provide globally consistent data sets for the derivation of spatial and temporal ecological information, has been under-utilized (National Research Council, 1986).

The lack of data currently available on the changes taking place in the Loxahatchee Slough, in Palm Beach County, Florida, is an example of the "paucity of time series data both on landscape patterns, and on the species composition of forest tracts during the course of forest fragmentation, and reforestation in some regions, so that the response of the biota is difficult to assess" (Burgess and Sharpe, 1981). This project attempts to make a contribution toward remedying the situation by taking a geographic approach in studying the vegetation change in the Loxahatchee Slough. Vegetation is used here as an indicator of hydroperiod, in attempting to detect cultural impacts on the hydrology of the Slough. The physiographic, cultural and environmental history of the area is reviewed. This examination of the processes that have occurred over time suggests some of the pivotal dates for examining the spatial patterns existing at those times. Remotely sensed data provides a view for each date. Extraction of spatial patterns, through data capture and analysis, reveals the physical impacts resulting from the cultural processes at work. Results are tabulated, described and graphically displayed.

CHAPTER 2

ENVIRONMENTAL HISTORY OF THE LOXAHATCHEE SLOUGH

Environmental Theory and Policy

ISLAND BIOGEOGRAPHY THEORY

Current ideas on how to design habitat preserves to maximize species survival have primarily grown out of MacArthur and Wilson's The Theory of Island Biogeography (MacArthur and Wilson, 1967). This was an attempt at applying ecological theory for islands, and it became known as the Equilibrium Theory. The theory combines three well-known concepts. First, the Species-Area relationship predicts that a ten-fold increase in area will result in a doubling of the number of species. Second, as distance from the mainland source of colonizers increases, colonization decreases. Third, the rates of colonization and extinction will reach an equilibrium number of species, with a constant turnover rate.

Recognizing that their model was a crude first attempt, MacArthur and Wilson encouraged research and refinement of the theory. Colonization and extinction rates have since been viewed as much more complex than each having a single determining factor. For instance, Diamond's Differential Extinction indicates that some species, such as large carnivores, can only survive on larger islands, leaving smaller islands with a subset of the species available from the continental source (Diamond and May, 1976). The very idea of reaching an equilibrium has also been questioned, as expressed by Simberloff's Quasi-equilibrium, with on-going local modifications such as geologic change and rising sea-levels preventing the attainment of equilibrium (Simberloff, 1974).

The Equilibrium Theory deals with two types of islands. Oceanic islands, such as volcanic islands, start with zero species. Colonization is expected to outpace extinction until equilibrium is reached. Continental islands, originally part of the mainland, have a mainland number of species at the time of separation, such as due to rising sea-levels. The reduction in available area lowers the equilibrium number of species, resulting in an increased rate of extinction until the new equilibrium is reached.

Researchers have applied the Equilibrium Theory to fragments of forest, known as habitat islands. Fragment habitat islands, often formed when a region is converted for human use, are similar to continental islands, in that they began as part of a larger ecosystem and were later separated from it as the surrounding land area underwent change. The reduced habitat area results in a reduction in the number of species that can be supported, and therefore an increased rate of extinction. The Loxahatchee Slough is an example of a habitat island surrounded by a matrix of urban landuse.

There are, however, problems in applying the Equilibrium Theory to habitat islands. First, there may be no "continental mainland" source for colonists, especially in the case of old growth forests. Next, the ever-changing land uses of the surrounding culturally dominated matrix may prevent the system from reaching an equilibrium. Finally, the theory does not help to answer one of the primary questions regarding the preservation of habitat islands, namely Single Large or Several Small (SLOSS).

SLOSS is the debate over whether it is better to have a single large habitat island or several small ones, given the same total area. There are good arguments on both sides. For instance, a single large area minimizes the barriers that must be crossed, increasing the gene-flow of even the most barrier-intolerant species. Also, the large population size of each species that the large area supports helps keep natural oscillations in number well above the extinction threshold. However, several small areas, in close enough proximity and/or linked by habitat corridors which allow for individuals to move from one habitat island to another, may offer a greater variety of unique habitats and can protect against chance events destroying entire populations, such as disease or fire.

While the debates continue over fine-tuning MacArthur and Wilson's theory and applications such as SLOSS, there is some consensus in designing preserves. The incorporation of multi-use principles can maximize the effectiveness of the habitat island (Burgess and Sharpe, 1981; Harris, 1984). A core of old growth, surrounded by a low-impact use ecosystem not too dissimilar from the old growth, which in turn is surrounded by higher-impact use, and finally surrounded by the human-dominated landscape, will provide the greatest possible buffer to protect the old growth core (Figure 1). In the real world, however, there are only a limited number of sites available, and limited funds with which to purchase these lands. Each site must be selected based on its contribution to the overall preserve system, such as providing unique habitat or acting as a corridor between other areas (Harris, 1984). "The continuing study of natural area isolates is our present most pressing need, and ... must be considerably developed before long-range conservation strategies can be well defined," (Shafer, 1990).

UNESCO'S MAN AND THE BIOSPHERE PROGRAMME

In 1983, international cooperation in addressing the research needs for protecting and managing the biosphere resulted in the First International Biosphere Reserve Congress. Participants included the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the Food and Agriculture Organization, the United Nations Environment Programme, and the International Union for Conservation of Nature and Natural Resources. Recommendations of the Congress were incorporated into an Action Plan for Biosphere Reserves, which was adopted in 1984 by UNESCO's International Coordinating Council of the Programme on Man and the Biosphere (UNESCO, 1984).

The Man and the Biosphere Programme (MAB) was begun in 1971 by UNESCO to address the problems resulting from changes in the environment

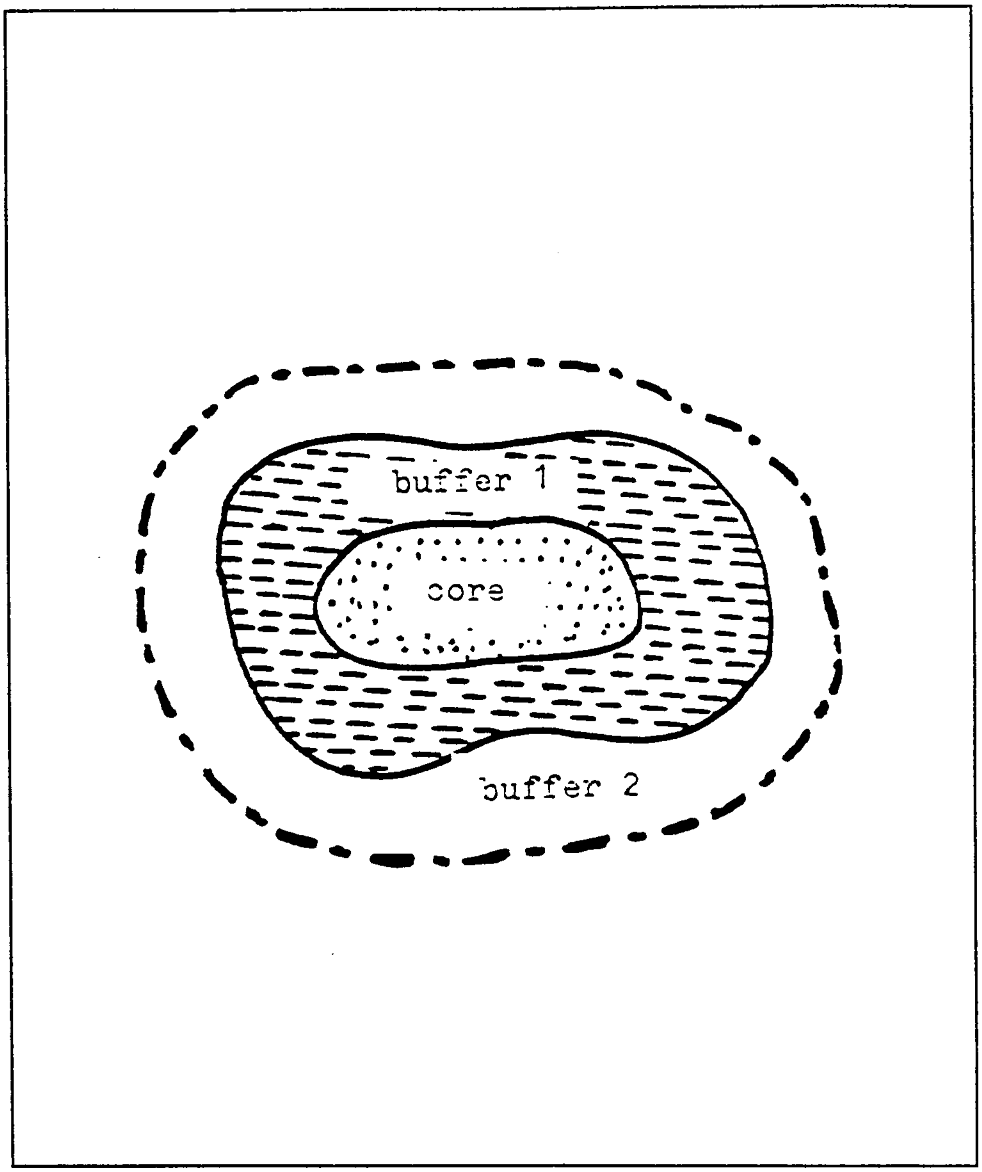

Figure 1: Multi-purpose Buffer Design for Preserves
From Shafer, 1990

caused by human impacts. The Action Plan for Biosphere Reserves addresses the need for conservation of natural areas in order to preserve ecological diversity through maintaining viable gene pools, by selecting research sites for the study of global problems such as desertification, pollution, and the dramatic decline in biodiversity, while seeking practical ways for people to live through sustainable use of their local environment.

Biosphere Reserves incorporate the concept of multi-use. A strictly protected Core Area is limited to monitoring use only. The surrounding Buffer Zone, typically a national park, allows for research stations, education, training, tourism, and limited human settlements, on a controlled basis. The outer Transition area allows for more intense use (Vernhes, 1987).

The Everglades National Park of South Florida is one of 266 sites selected worldwide as a Biosphere Reserve. With 65 percent of the original Everglades drained (Kushlan, 1990), optimizing the chances for continued viability hinges on preserving as much as possible of what still remains of this complex ecological system. This goes beyond the boundaries of the Everglades National Park Biosphere Reserve.

NATURAL AREAS PROGRAM

Preservation efforts are also being made at the state and local level. The State of Florida's Warren S. Henderson Wetlands Protection Act of 1984 recognizes that "the continued elimination or disturbance of wetlands in an uncontrolled manner will cause extensive damage to the economic and recreational values which Florida's remaining wetlands provide" (Florida Statute 403.91-403.929, 1984). In 1984, the Palm Beach County Commission adopted the Natural Areas Park Preserve Program, aimed at protecting the last remaining wilderness island refuges in Palm Beach County, including the Northern Everglades. Identification and evaluation of potential sites was completed in 1988 by Dr. Grace Iverson and Dr. Daniel Austin of Florida Atlantic University, in a report entitled <u>Inventory of Native Ecosystems in Palm Beach County, Phase III Report, Location and Evaluation of Sites for Possible Preservation as Wilderness Island Park Preserves</u>.

<u>Physical Geography of South Florida</u>

GEOMORPHOLOGY AND HYDROLOGY

Peninsular Florida is the narrow, emerged portion of a broad, stable, geologically young platform, known as the Floridan Plateau (Hoffmeister, 1974). The oldest rock formation, the Tamiami Limestone in the Southwest, dates back 6,000,000 years to the Miocene. Further North, the Caloosahatchee Marl Formation is of Pliocene origin, over 2,000,000 years old. Most of South Florida's bedrock is 100,000 year old limestone of Pleistocene origin, including the Anastasia Formation, consisting of coquina, sand, calcareous sandstone, and shell marl (Hoffmeister, 1974) which underlies the Atlantic Coastal Zone, and is the source of the highly porous Anastasia sands, forming the ground cover of much of Southeast Florida (Craig, 1991). The Atlantic Coastal Ridge is made up of less porous Pamlico quartz sand dunes and beach ridges overlaying the Anastasia formation along the ancient coastlines which existed at the onset of the Wisconsin Ice Age, (Hoffmeister, 1974).

South Florida's drainage basin is unique. The Kissimmee River and its tributaries discharge into Lake Okeechobee which, prior to damming, spilled over in a sheetflow to the Everglades (Craig, 1991). This "River of Grass", popularized by Marjorie Stoneman Douglas's famous work by that name (1947), does not follow a well-defined watercourse, but rather, seeps in a complex and shifting flow due to the low gradient and thick vegetation (Parker, 1974). "Topography is the principal factor controlling the distribution of marshes over the Florida peninsula" (Kushlan, 1990). Natural runoff from the Everglades into the ocean is impeded by the Atlantic Coastal Ridge. "Marshes occur anywhere local topography and impermeable soils prevent rapid runoff or infiltration -- either near rivers and lakes or in small basins and other depressions" (Kushlan, 1990).

According to Parker (1974), the first comprehensive studies of South Florida's pre-drainage hydrology were made in the 1940's, and he notes that during that decade, the conditions still resembled those of pre-drainage times. In 1943, the Florida Geological Survey published a 300 page study, The Natural Features of Southern Florida (Davis, 1943), which focuses on vegetation and the Everglades.

BIOGEOGRAPHY OF SOUTH FLORIDA

The predominant vegetation in South Florida 5,000 years ago was sclerophyllous oak forests. Warming climate and rising sealevels eliminated many species and caused a succession to diverse broadleaf trees. Upland herb communities were replaced by longleaf pine forests. Cypress swamps developed as water tables rose (Long, 1974).

> "The climate of the ... area is subtropical with the average daily temperature ranging from 68°F in the winter to 82°F in the summer. Rainfall occurs in fairly distinct cycles, with the wet season extending from May to October" (Lin, 1988).

The present flora was derived from four different sources: (1) tropical species arriving by long-distance dispersal over water, (2) non-tropical species from continental North America, (3) endemics surviving high sea levels in refuges on the emergent plateau, and (4) exotics and introduced species (Webb, 1990; Long, 1974). The high number of endemics can be attributed to the "unusual characteristics of the origin of South Florida vegetation" (Long, 1974). Of primary consideration in the selection of Biosphere Reserve areas in UNESCO's Man and the Biosphere Programme is whether an area is a center of endemism (UNESCO, 1984).

History of the Loxahatchee Slough

DESCRIPTION

The largest site identified in the Iverson and Austin report (1988) on Palm Beach County wilderness island sites is Ecosite 109, the Loxahatchee

Slough, spanning approximately 7,720 acres, including 7,593 acres of undisturbed ecosystem (Figure 2). The Slough is located in the City of Palm Beach Gardens within Public Land Survey System (PLSS) Townships 41S and 42S, and Ranges 41E and 42E (Figure 3). This is within the 105.8 square mile C-18 drainage basin (Cooper, 1988).

Various meanings have been associated with the term "slough." Douglas (1988) defines "slough" as "any open swampy place which may once have been a tongue of the sea or a river of fresh water, green, watery, flowery country, a place of herons and small fish." According to the Army Corp of Engineers, a "slough" is,

> "(1) A small muddy marshland or tidal waterway which usually connects other tidal areas: (2) a tideland or bottomland creek. A side channel or inlet, such as from a river or bayou, that may be connected at both ends to a parent body of water," (United States Army Corps of Engineers, 1985).

Zelinsky notes that the term is used in the U.S. Midwest to be equivalent either to "swamp", indicating "a tract of rich soil having a growth of trees or other vegetation, but too moist for cultivation", or to "marsh", which is "like swamp ... but almost always as a designation for an unforested, water-logged tract, either fresh or salt," (Zelinsky, 1962). The Oxford English Dictionary gives a cultural definition to "slough" related to transportation. "A piece of soft, miry, or muddy ground; esp. a place or hole in the road or way filled with wet mud or mire and impassable by heavy vehicles, horses, etc," (OED, 1971). This is especially

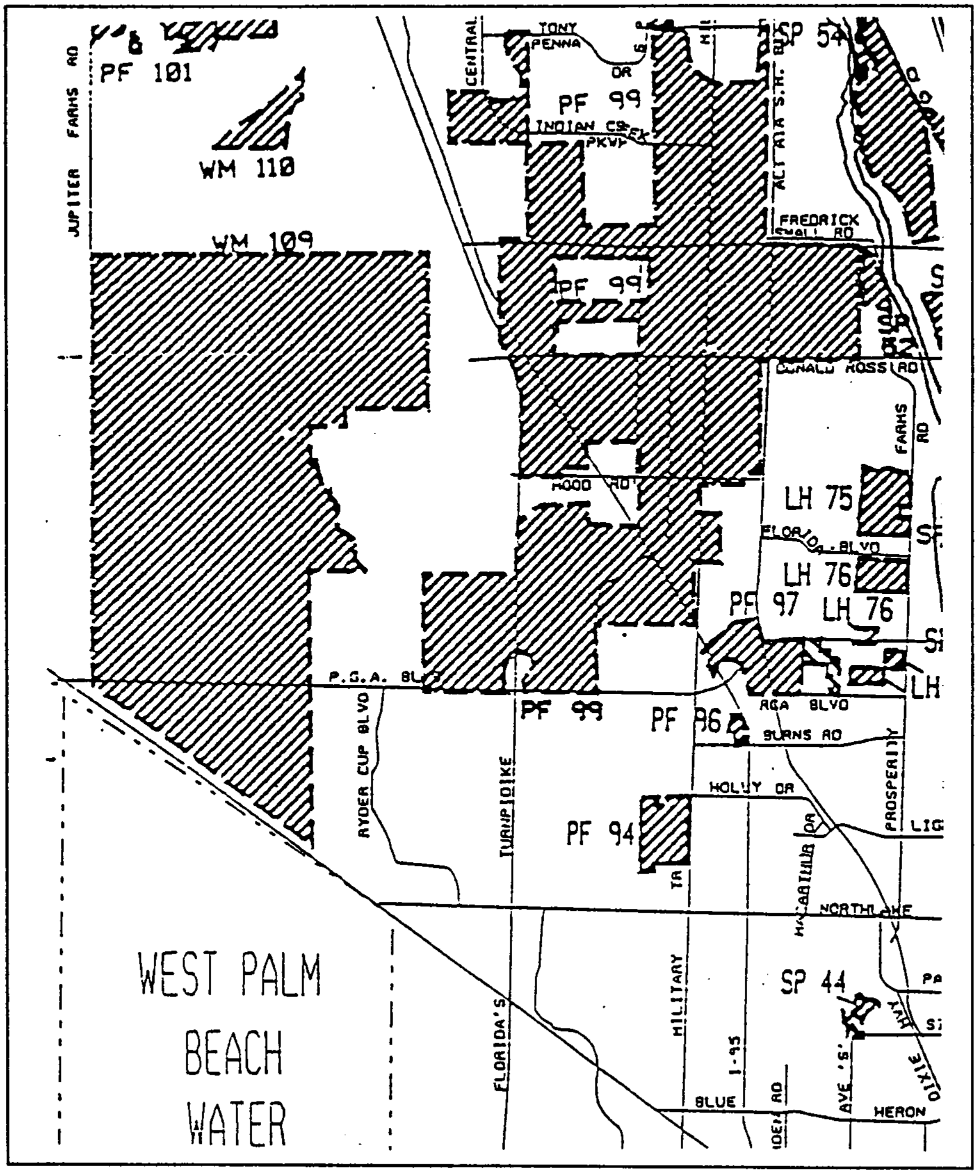

Figure 2: Ecosite 109 Location Map
From: Iverson and Austin, 1988

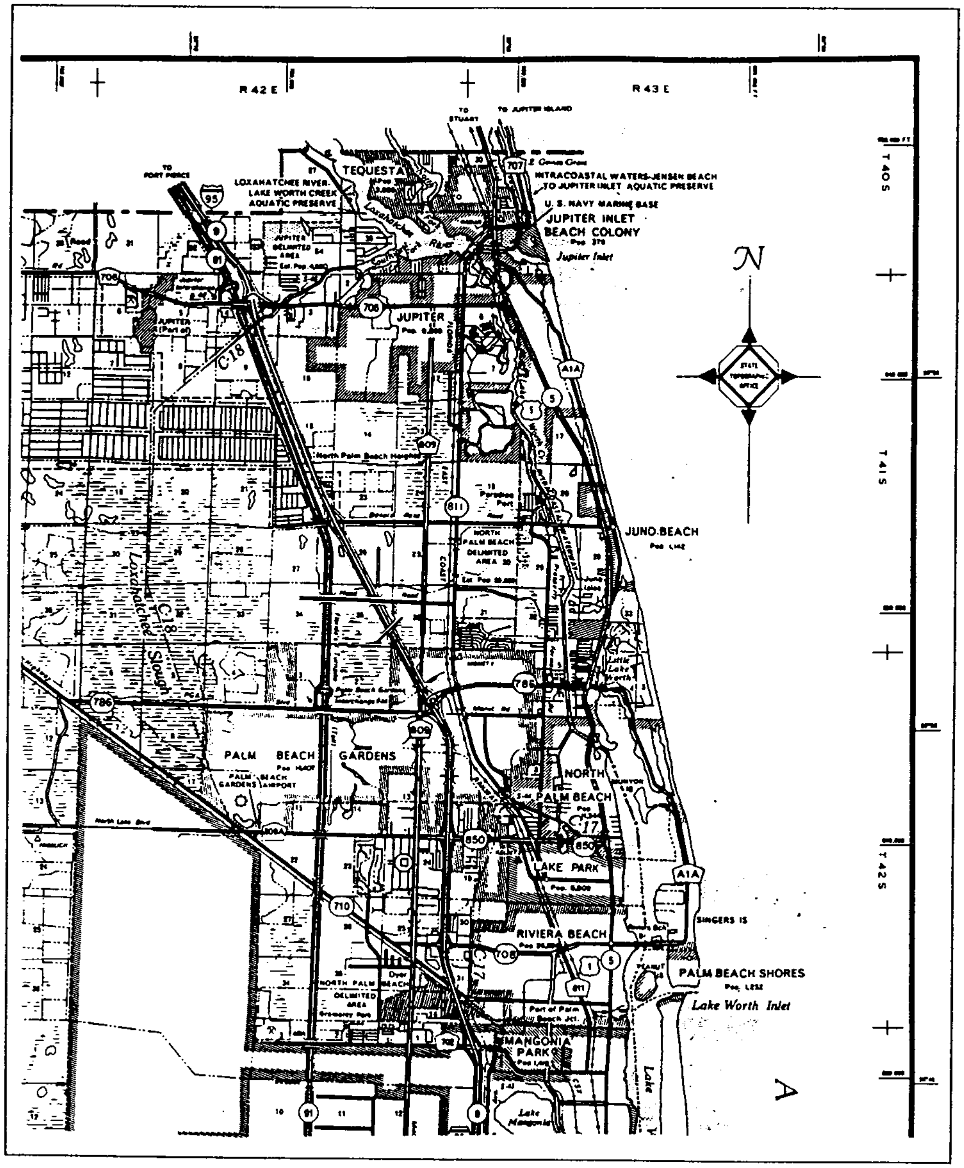

Figure 3: Palm Beach County Highway Map
From: Florida Department of Transportation, 1990

applicable to the Loxahatchee Slough, which impeded travel between Fort Jupiter and the North, along the only route available in the early 1800's.

> "The first road on the lower east coast of Florida created by white men was the old Military Trail that started at St. Augustine and ended at Fort Dallas on Biscayne Bay. It was made by United States soldiers during the Seminole wars to connect the various military posts along the coast," (Pierce, 1970)

In contrast to this focus on transportation issues in defining "slough", geomorphologic definitions are applied to "swamp" and "marsh." "Swamp" is defined as,

> "a tract of low-lying ground in which water collects; a piece of wet spongy ground; a marsh or bog. Orig. and in early use only in the N. American colonies, where it denoted a tract of rich soil having a growth of trees and other vegetation, but too moist for cultivation" (OED, 1971).

"Marsh" is defined as, "A tract of low lying land, flooded in the winter and usually more or less watery throughout the year" (OED,1971).

Kushlan (1990) offers an ecological description;

> "Marshes are wetlands dominated by herbaceous plants rooted in and generally emergent from shallow water that stands at or above the ground surface for much of the year. In general, less than one-third of the cover of a marsh consists of trees and shrubs. Marsh ecosystems include bogs, fens, mires, prairies, wet prairies, savannas, wet savannas, reed swamps, and swamps. The term *swamp*, however, is more appropriately restricted to forested or wooded wetlands. ... Florida's marshes are characterized by their subtropical location, fluctuating water levels, recurring fires, and hard water."

According to Ewel (1990), the main factors that result in varying types of swamps are hydroperiod, which affects soil aeration; fire frequency, which inhibits succession to mesic ecosystems; and source of water, which influences nutrient supply, salinity, flow rate, and hydroperiod.

The Army Corps of Engineers distinguishes between marsh and wet prairie by vegetation and soil type.

> "Marsh communities, typically dominated by aquatic vegetation and usually devoid of trees, are seasonally wet or inundated most of the year. Marsh substrates have a thick accumulation of organic material or peat. ... Wet prairie communities merge with the marsh systems. They typically contain tree islands of pines or hammock vegetation. Unlike marsh communities, wet prairies usually develop on sandy soils with thin organic accumulations" (United States Army Corps of Engineers, 1982).

Under the National Wetlands Inventory Classification System, these various emergent communities are classified together in the category of Palustrine System Wetlands. Palustrine System is at the dry end of the Wetlands continuum, with transition into drier Uplands habitat determined primarily by water regime (Cowardin, 1979).

Historically, the Loxahatchee Slough was the Northernmost part of the Everglades, as discussed later in this sub-chapter, in the section on the Hydrology and Vegetation of the Loxahatchee Slough. Despite the wealth of research and literature on the Everglades, little has been published regarding the Loxahatchee Slough. A database search through the Research Libraries Information Network (RLIN), found 20 instances for the keyword "Loxahatchee", all of which referred to either the Loxahatchee River or the Arthur R. Marshall Loxahatchee National Wildlife Refuge, but none for the Loxahatchee Slough. In <u>The Everglades: River of Grass</u>, Douglas (1988) gives a single, brief description of the Slough's origin.

> "But even from earliest times, when in the creeping spread of water the grass turned up its swords and made the Everglades, there was too much water in the great lake to carry itself off through the Glades southward. There was nothing but the east and west sandy ridges to hold back the water. To the east from Okeechobee it seeped and was not carried off and stood along an old wandering watercourse soon filled not only with saw grass but reeds and sedges and purple arrowy lilies and floating masses of grass and small trees. That is still called the Loxahatchee Slough."

Dasmann never mentions the Slough in his well known book on Florida, No Further Retreat (Dasmann, 1971). Likewise, the accounts of early explorers and pioneers such as Jonathan Dickinson, William Bartram, and Charles Pierce, lack information on the Loxahatchee Slough (Figure 4). Notice that Dickinson's map indicates that the Jupiter Inlet was the Southernmost point to which they travelled during and subsequent to their shipwreck and capture. His account never mentions travelling inland to the Loxahatchee Slough.

CULTURAL HISTORY OF THE LOXAHATCHEE SLOUGH

Early Mapping of the Southeast is the theme of Volume VI of the journal "Southern Geographer." Four articles (based on the Symposium on The Early Mapping of the Southeast, annual meeting of the Southeastern Division of the Association of American Geographers, 1965) describe the discovery, exploration and mapping of the Southeastern region of North America, including many map reprints (Cumming, 1966; de Vorsey, 1966; Ristow, 1966; Friis,

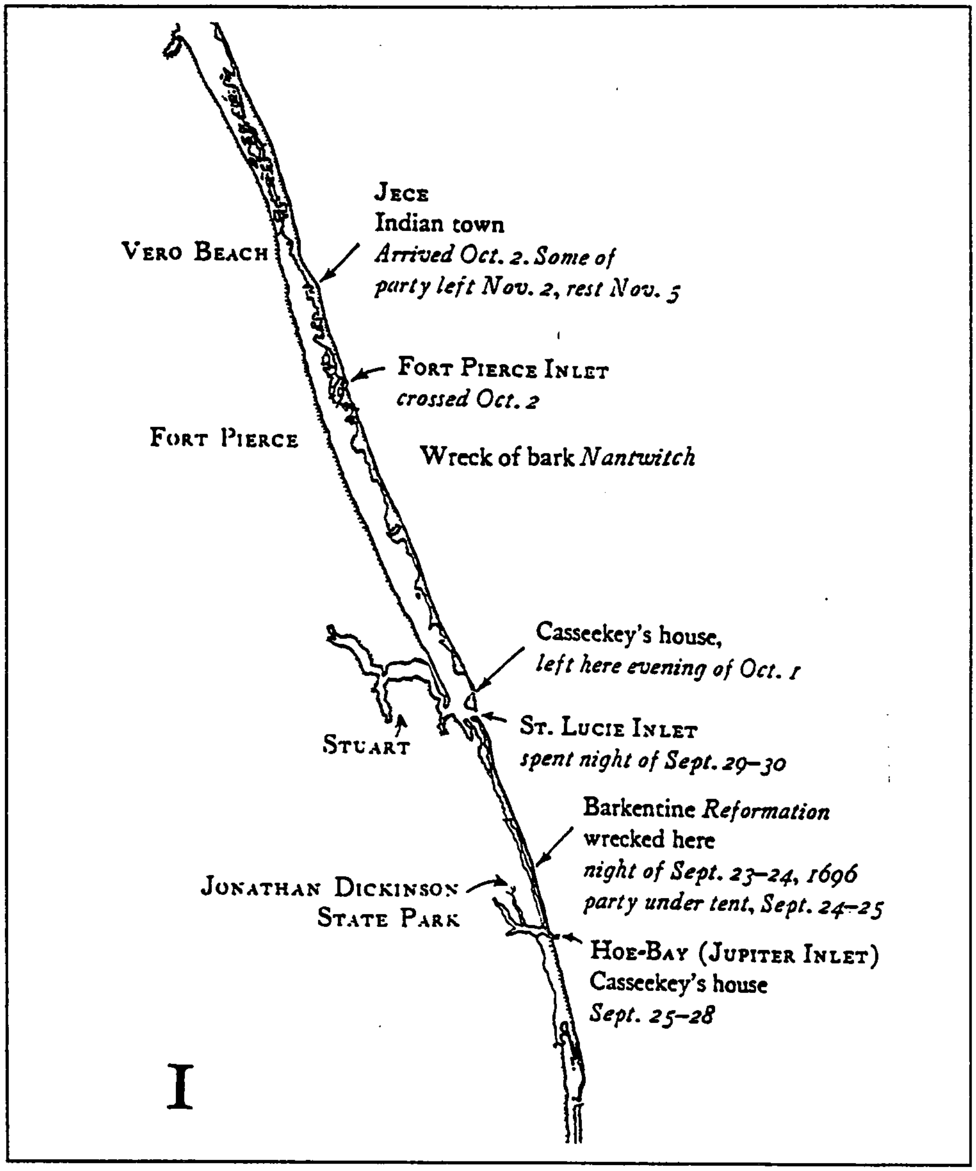

Figure 4: Location of Jonathan Dickenson's Shipwreck
From: Dickenson, 1975

1966). Harris (1972) provides a bibliography of books and articles on Florida maps. Baxter (1941) provides an annotated list of Florida maps.

Apart from observations along the coastline and some sporadic expeditions, mapping of the interior, prior to the nineteen century, was sketchy and inaccurate. The account of Jonathan Dickinson's famous 1696 shipwreck and capture in Jupiter, "the first published account of the land and inhabitants of the Palm Beach County area" (Curl, 1986), makes no mention of the Loxahatchee Slough, despite the fact that it is a major land feature only nine kilometers from Jupiter Inlet. The journal gives no indication that any of the members of Dickinson's group every ventured to the location of the Slough (Dickinson, 1975).

The travels of the noted naturalist, William Bartram, during the 1770's, likewise did not extend as far South as the Loxahatchee Slough (Bartram, 1943).

Charles Pierce is often quoted as a source for early history of Palm Beach County. He lived in Jupiter after 1872. Pierce is known for having become one of the Barefoot Mailmen, after James Hamilton disappeared on route in 1887, apparently eaten by alligators. However, the popular Barefoot Mailman's route was by boat and along the beach to the East, bypassing the Loxahatchee Slough, and Pierce left no description of the Slough (Pierce, 1970; A.C. Williams, 1962).

James A. Henshall, self-described as "an angler, a sportsman, a yachtsman, a naturalist, and a physician" who traveled extensively through Florida, notes that "a detailed description of the country below Jupiter has never before been published, so far as I know" (Henshall, 1884). However, Henshall chose to sail along the coast from Jupiter to Lake Worth, avoiding the difficult interior route, and his own description of the River and Slough is limited to a brief mention.

> "Then the Locohatchee, winding along through the savannas with many a devious turn, like a huge serpent gliding from the setting sun toward the sea. Toward the south lies a panorama of pines, cypresses, and saw-grass, with their varying tints of green, amidst which is a network of small streams, glinting in the sunlight like a filigree of silver" (Henshall, 1884).

Henshall's watery description of pre-drainage conditions confirms later assertions, such as by Parker or Douglas, that the Loxahatchee Slough is the northernmost part of the Everglades.

The first attempt at methodical mapping of the area began in 1764, when William de Brahm was commissioned by the King of England to survey the Southern district of North America. His report includes a map showing the Grenville Inlet fed by five river branches, in clockwise order named Grenville South Branch, Grenville South-West Branch, Grenville North-West great Branch, Grenville Northwest Little Branch, and the Grenville Stream. The report mentions that the Inlet also goes by the name Jupiter (de Vorsey, 1971). The map shows the North-West great Branch, which bends around to the South, and the South-West Branch, as being fed from the Slough, which is depicted as a swamp area but is not labelled (Figure 5).

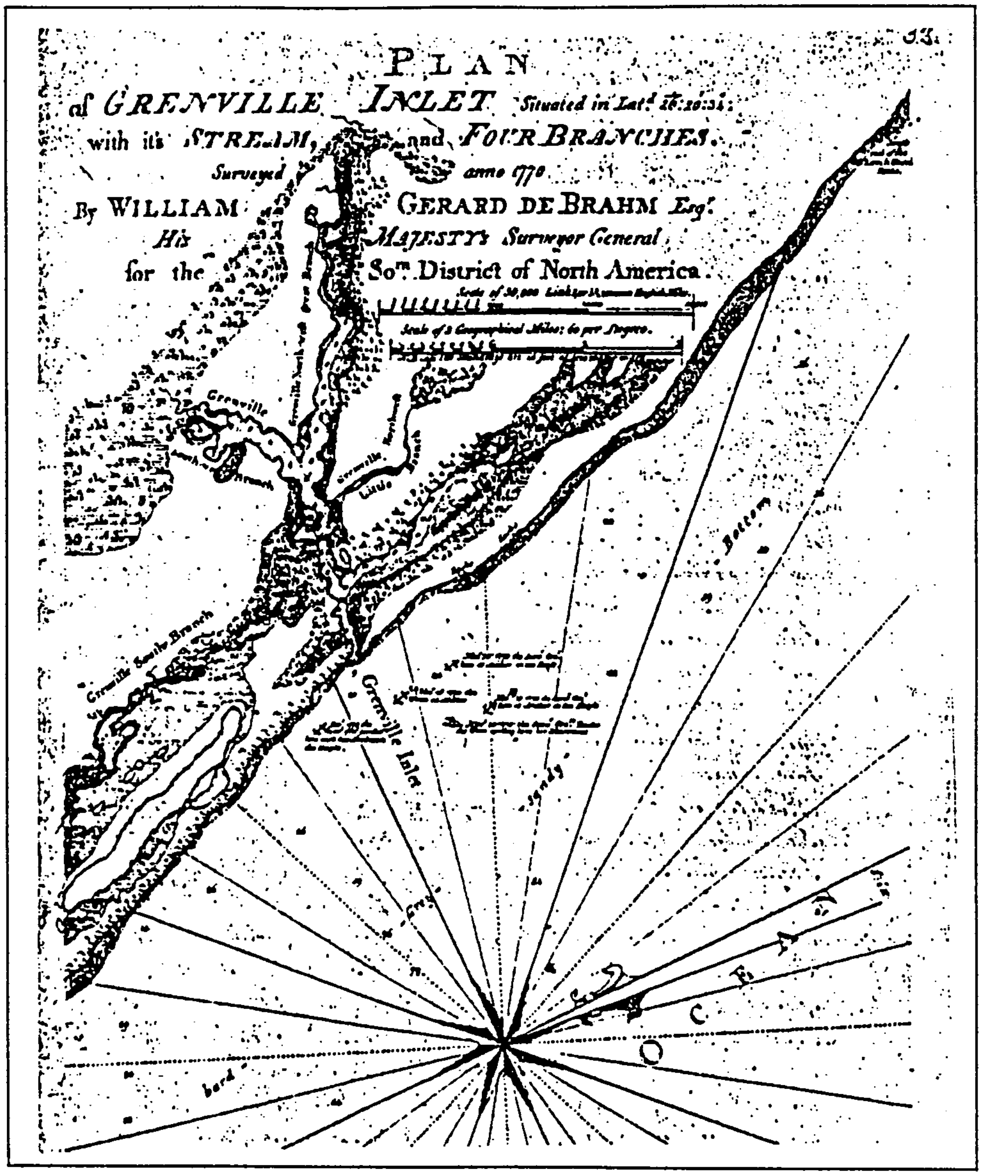

Figure 5: de Brahm's Map of the Grenville Inlet
From: de Vorsey, 1971

Romans indicates that de Brahm was the first to apply the name Grenville to the location, attributing it to a gentleman owning a tract of land in the vicinity, which is described as,

> "one of the most unaccountable pieces of white sand i ever saw; which by reason of its being covered with a large growth of all sorts of trees, indicating a fine soil, i have always looked upon in the light of a natural curiosity" (Romans, 1962).

Forbes notes that the inlet is "called Hobe, by the Spaniards; and the English, Jupiter, or Grenville" (Forbes, 1964). A.C. Williams attributes the origin of the various names to when,

> "Menendez visited the inlet in December or January, 1555 and 1556. Here he found a tribe of the Jeaga Indians who called themselves the Jobes, living on the high shell mound near the Inlet. It was the custom to name the rivers for the nearest Indians so the river flowing into the Inlet became the Jobe River, pronounce by the Spaniards as Hoebay. ... When the English arrived in 1763, the word Hoe-bay seemed the Spanish version of Jove, which they in turn changed to Jupiter" (A.C. Williams, 1962).

Vignoles applies the names Jupiter creek to de Brahm's Grenville South Branch, the term Middle River to de Brahm's Grenville South-West Branch, Grenville River to de Brahm's Grenville North-West great Branch, and Fresh-water Creek for de Brahm's Grenville Northwest Little Branch (Vignoles, 1977). J.L. Williams uses similar names, spelling Grenville as Greenville (J.L. Williams, 1962).

Systematic description and mapping of the region was established with the Ordinance of 1785 of the United States government, which instituted a system of surveying township and section boundaries of public domain lands, with field notes on vegetation, soil, ownership, roads, and hydrography. A Topographical Bureau of Army officers in the Engineer Department was created in 1818 for surveying and mapping for the purposes of internal improvements such as canals, roads, railroads and maritime activities (Friis, 1966).

The 1845 U.S. Survey of Township and Range Boundaries by A.H. Jones (1845) describes the section boundaries within the Loxahatchee Slough as "inundated swamp mostly scrubby cypress mixed with saw grass ponds impassable." Field notes were not made for the Southern boundary of T41, R42, Sec 32, perhaps verifying the use of the term "impassable" used in describing the surrounding locations.

The Seminole Wars of the Nineteenth Century spurred interest in mapping the area for military intelligence. The 1856 military map by Lieut. J.C. Ives, Topological Engineer, is similar to de Brahm's map, with the five branches in clockwise order named Lake Worth Creek, Jones Creek, Jupiter River, unnamed, and Hobe Sound (Figure 6). The Jupiter River, de Brahm's North-West great Branch, bends Southward to its headwaters, a swamp labelled "Lochahatchee", which is shown to also flow Southward into the Everglades. Jones Creek, de Brahm's Grenville South-West branch, is indicated as also fed by the Slough.

The map by Ives also shows the route of General Jesup's march to the battle of the Loxahatchee (Ives, 1856). A small naval force, under the command of Lieutenant Powell, had been attacked and overpowered by

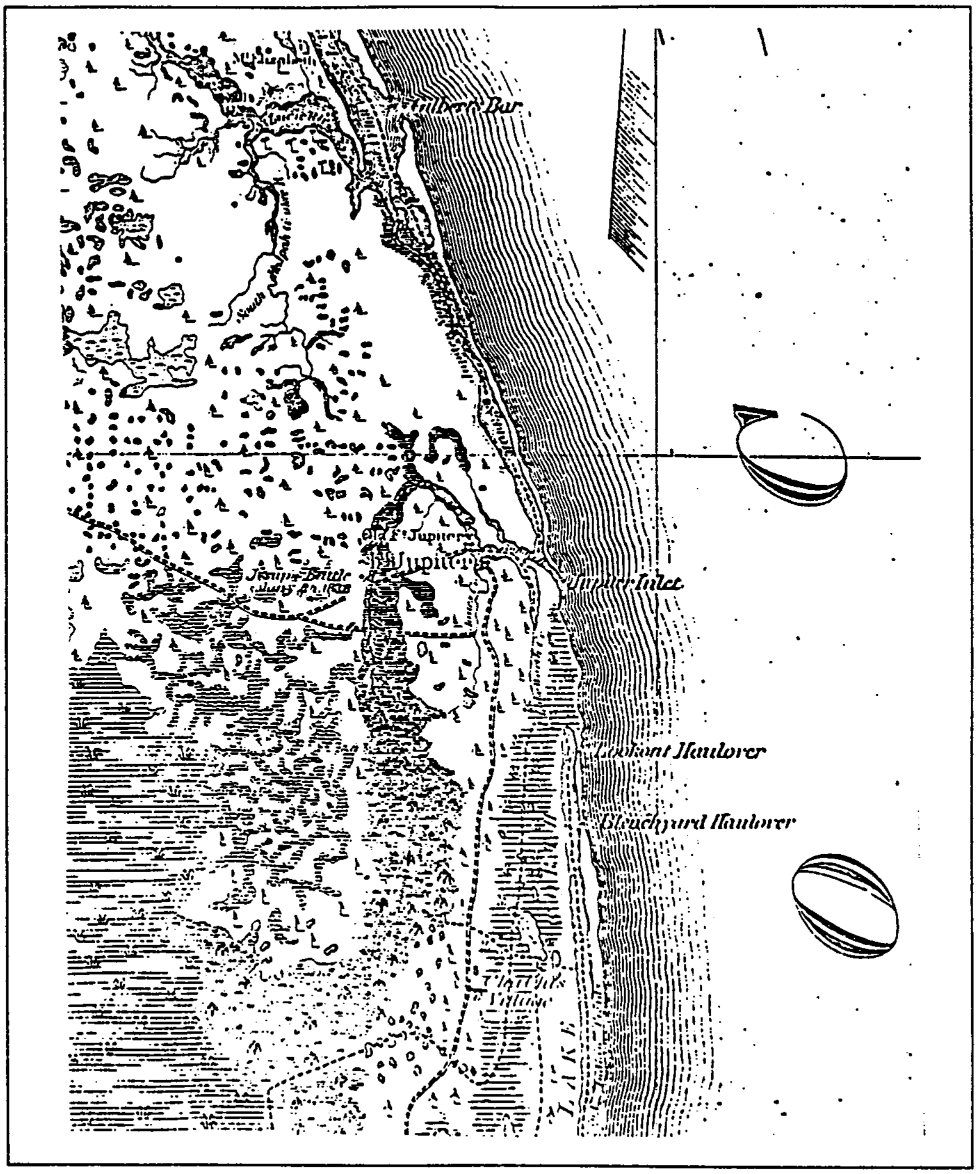

Figure 6: Ives's Military Map
From: Ives, 1856

Seminoles while exploring in the area of the Loxahatchee River in January of 1838 (Wolf, 1989; Sprague, 1964). In response, on January 24, 1838, General Thomas S. Jesup led his troops into battle,

> "in the Loxahatchee swamp at the eastern edge of the Everglades. Dr. Motte, who served the command as a surgeon remembered: 'After all, Florida is certainly the poorest country that ever two people quarreled for. The climate in the first place is objectionable; for even in Winter, while persons further north were freezing, we were melting with heat. In the next place, the larger portion ... is a poor, sandy country in the north; and in the southern portions nearly all wet prairies and swamp; healthy in winter but sickly in summer'" (Dovell, 1962).

The exact location of the battle is not known. Ives's map places the battle to the West of the Slough. Cowperthwait, a Philadelphia mapmaker who never visited the area, produced a map indicating that the battle occurred Northeast of the Slough, between the two forks of the River that are fed by the Slough (Cowperthwait, 1850). Mackay and Blake, of the Topographic Bureau, produced a map in 1839 showing the battle to have occurred North of the River (United States Army Corps of Engineers, 1839) (Figure 7). This map also shows the Loxahatchee River and Slough as a Northern branch of the Everglades. According to Wolf, the battle most likely occurred within the boundaries of what is now known as Jonathan Dickinson State Park, North of the River (Wolf, 1989).

Standardized mapping of the United States was undertaken by the United States Geological Survey (USGS), in the Department of the Interior. The USGS 7.5 minute series maps of the Loxahatchee Slough area (Delta and

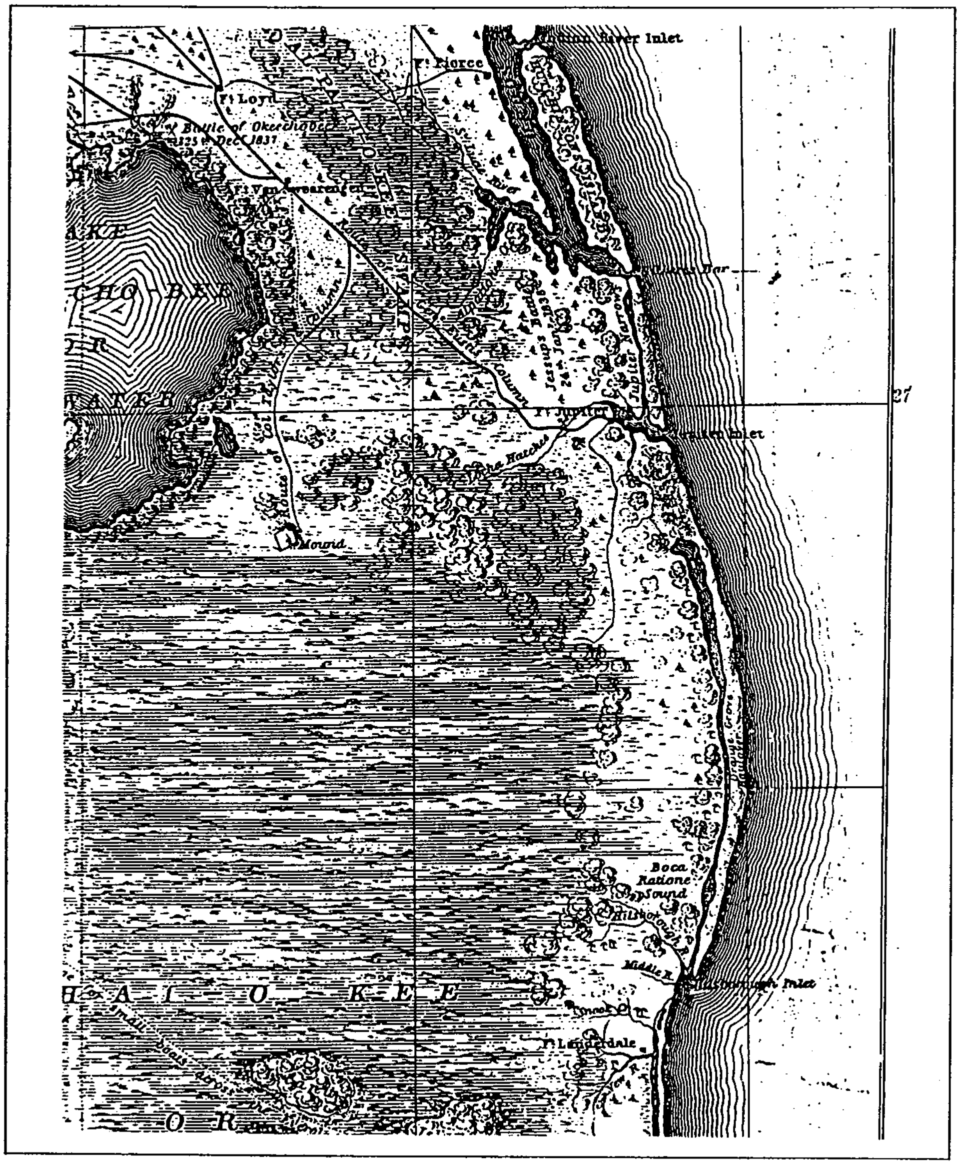

Figure 7: Mackay and Blake's Military Map
From: United States Army Corps of Engineers, 1839

Rood Quadrangles) published in the 1940's, are based on mapping by the US Coast and Geodetic Survey from aerial photographs taken in 1942 and 1945, and ground surveys in 1945 and 1948. Aerial photographs from 1980 were used to publish edited revisions in 1983 (United States Geological Survey, 1983).

The Seaboard Coast Line railroad tracks were constructed across the Loxahatchee Slough in the late 1920's. This forms the Southern boundary of the study site, dividing it from that portion of the historic Slough which would later come to be known as the West Palm Beach Water Catchment Area. Tomato farming, cattle ranching and road building of the land adjacent to the study site began in the 1930's. Pine Flatwoods in the area were logged during the 1930's and 1940's. The Beeline Highway was built alongside the railroad tracks in 1958-59, and PGA Boulevard was built across the study site in 1963. Road construction was accompanied by shellrock mining to provide roadbed fill. Off-road vehicles were driven within the boundaries of the study site during the 1970's, scarring the site with trails. With the development of golf course communities to the East, came restoration of the PGA National Marsh, a 140 acre wetlands replacing the Palm Beach Gardens Airport to the Southeast of the site (Farnsworth, PC).

Despite the multitude of European names given to the area, it is the aboriginal name which is now used for both River and Slough. According to Morris (1974), "Loxahatchee" is a mispronunciation by the U.S. soldiers of the guttural Seminole name "Lochahatchee", meaning "Turtle Creek." Forbes mentions that in "season, the loggerhead turtles land here in vast multitudes, to lay their eggs" (Forbes, 1964). Pierce also describes the turtles at this location.

> "Turtle season was another very important time of the year for the first settlers of the lake as turtle eggs were an important item of the food supply. May, June, and part of July was nesting time for such sea turtles as loggerhead, green turtle, hawksbill, ... and the giant of them all, the trunkback, or leatherback as they are sometimes called."

Yet Pierce's account for the name "Loxahatchee" goes back to a misspelling painted on a new steam barge docked on the Southern bank of the river.

> "I should have told the painter the correct spelling of the name, which was a combination of Spanish and Seminole; 'loco,' as most everyone knows, is Spanish for crazy, and 'hatchee' is Seminole for river, thus the name means 'crazy river.' Loxahatchee has no meaning whatever; it is just a name invented by a carpenter on the old steam barge" (Pierce, 1970).

Names currently appearing on the USGS 7.5 minute series (Jupiter Quadrangle) for the river branches are the Loxahatchee River Southwest Fork (de Brahm's Grenville South-West Branch), Loxahatchee River Northwest Fork (North-West Great Branch), and Loxahatchee River North Fork (Grenville Northwest Little). Lake Worth Creek (Grenville South Branch) and Jupiter Sound (Grenville Stream) are part of the Intracoastal Waterway. Names used for branches of the River on the Florida Department of Transportation map for Palm Beach County (1990) differ from the USGS map only in the name Hobe Sound used instead of Jupiter Sound (Figure 3).

HYDROLOGY AND VEGETATION OF THE LOXAHATCHEE SLOUGH

Waters from the Loxahatchee Slough at one time diverged to drain into both the Northern Everglades and the Loxahatchee River.

> "Drainage from the ... Loxahatchee Marshes is retarded by a rank growth of vegetation and by an accumulation of organic peat and muck that clogs the channels; therefore, at times the movement of water is difficult to discern. Moreover, the direction of flow in the channels may be changed by local rains. ... The Loxahatchee Marsh and Hungryland Slough together form a wishbone-shaped marshy area with the apex pointed toward Jupiter Inlet and with prongs leading to the Everglades. Drainage is in both directions from a low divide in the middle of Hungryland Slough, and from a divide in Loxahatchee Marsh west of Kelsey City. Part of Loxahatchee Marsh drains directly into the Hillsboro Lakes Marsh at a point a few miles southeast of Loxahatchee" (Parker, 1955).

Parker (1974), whose studies established a comprehensive baseline understanding of the pre-drainage hydrology of the Everglades, provides maps indicating the direction of historic surficial drainage (Figure 8) and historic ecology of the region (Figure 9).

Davis (1943) mentions the Loxahatchee Slough as lying along the Northeastern boundary of the Everglades-Lake Okeechobee Basin, where the Eastern Flatlands meet the Atlantic Coast Strip. The present Slough is a small remnant of the original marsh, destroyed in the process of "reclamation" which began in 1913 (Kushlan, 1990). Iverson and Austin attribute its formation to "a dune-back lagoon in late Pleistocene time" (Iverson and Austin, 1989). Included in Davis's report (1943) is a small scale Vegetation Map of Southern Florida based on Soil Conservation Service aerial photography, which shows the Loxahatchee Slough as Fresh-water Marshes with Hammock Forests, and

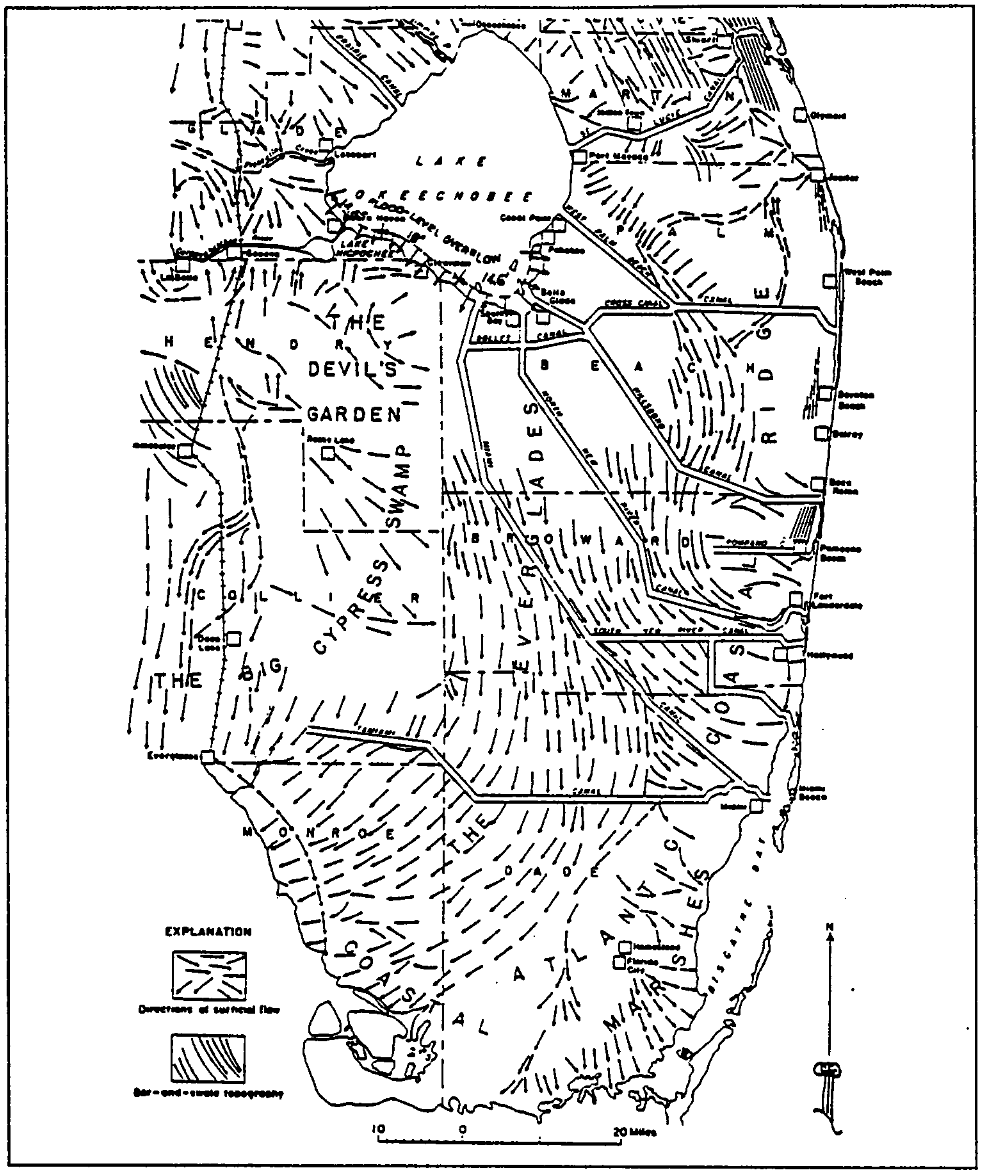

Figure 8: Map of Historic South Florida Surficial Drainage
From: Parker, 1974

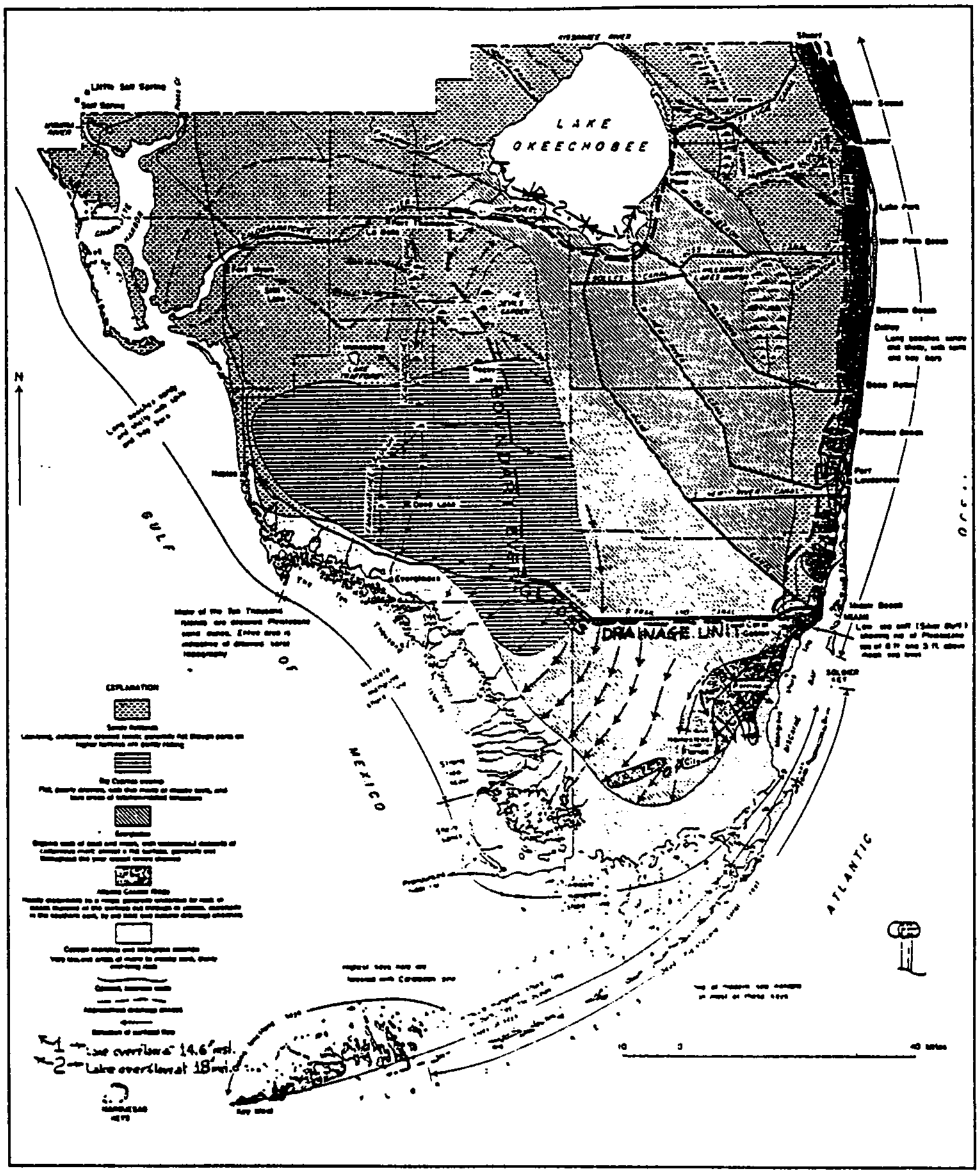

Figure 9: Map of Historic South Florida Ecology
From: Parker, 1974

indicates drainage to the West and South into Cypress Forests at the Eastern boundary of the Everglades (Figure 10). The 1983 USGS Quad sheets show more detailed distinction between open wetland and tree canopy in the Loxahatchee Slough.

Richardson (1977) describes several early vegetation community classification schemes, but maps produced for those early classifications are too small scale to differentiate between various habitats within the Loxahatchee Slough.

The 1990 annexation, by the City of Palm Beach Gardens, of the Loxahatchee Slough and surrounding lands, and consideration of changing the land-use designation of the area, prompted an assessment of the area. A report by Erwin (1992), commissioned by the landowner, the MacArthur Foundation, includes a vegetation map utilizing Levels III and IV of the Florida Land Use Cover, Forms and Classification System (FLUCFCS) of the Florida Department of Transportation (Figure 11). Categories shown for the Loxahatchee Slough include Pine Flatwoods, Wax Myrtle and Willow, Mixed Hardwood and Low Hammock, Cypress, Freshwater Marsh, Wet Prairie, Berm or Road, and Wetland Forested Mixed.

All locations within the Slough which were inspected by Iverson and Austin (1988) were given an "A" rating, signifying a "good representative of native Florida ecosystems." However, site visits for 3200 acres of the total area were limited or prevented by difficulty in access. Inaccessible portions of the

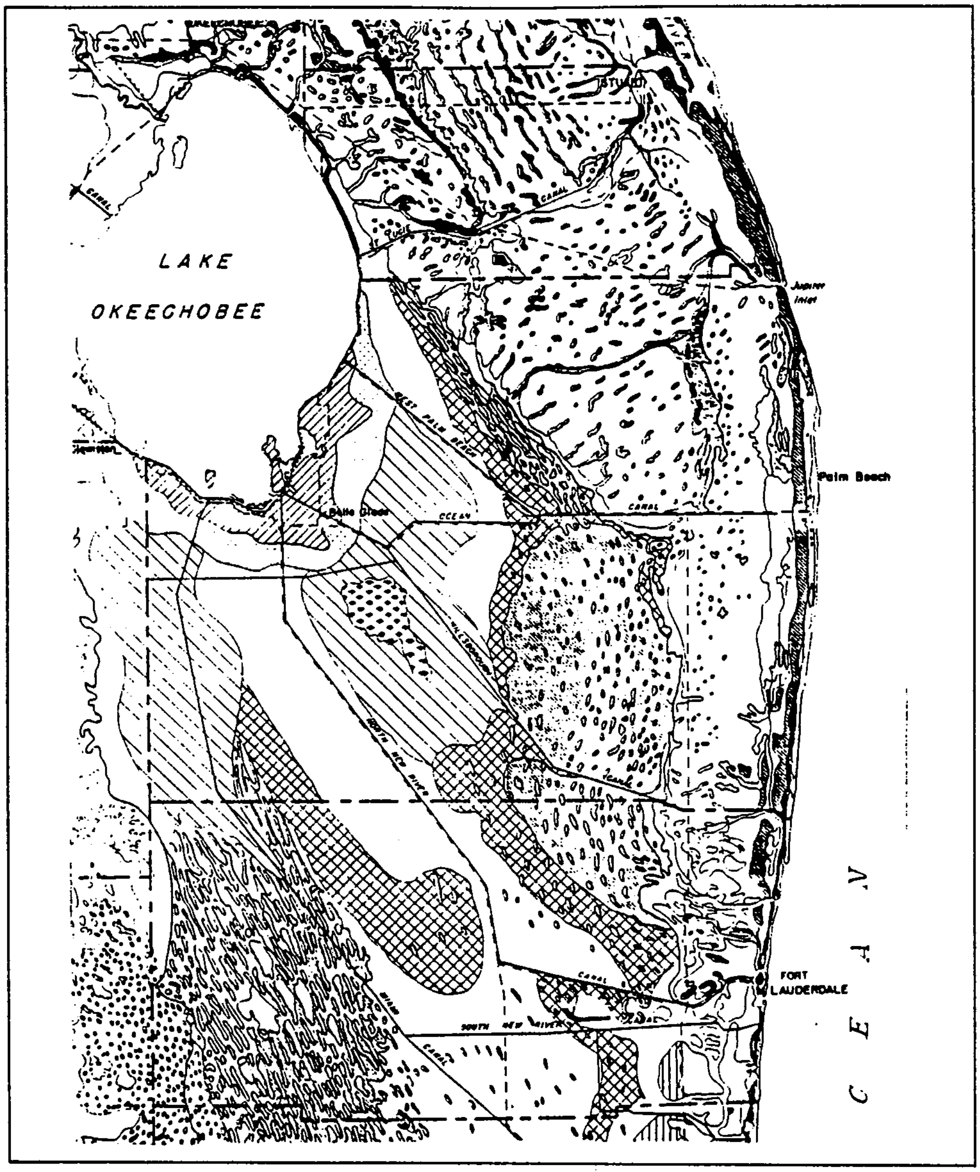

Figure 10: Map of Historic Vegetation of South Florida
From: Davis, 1943

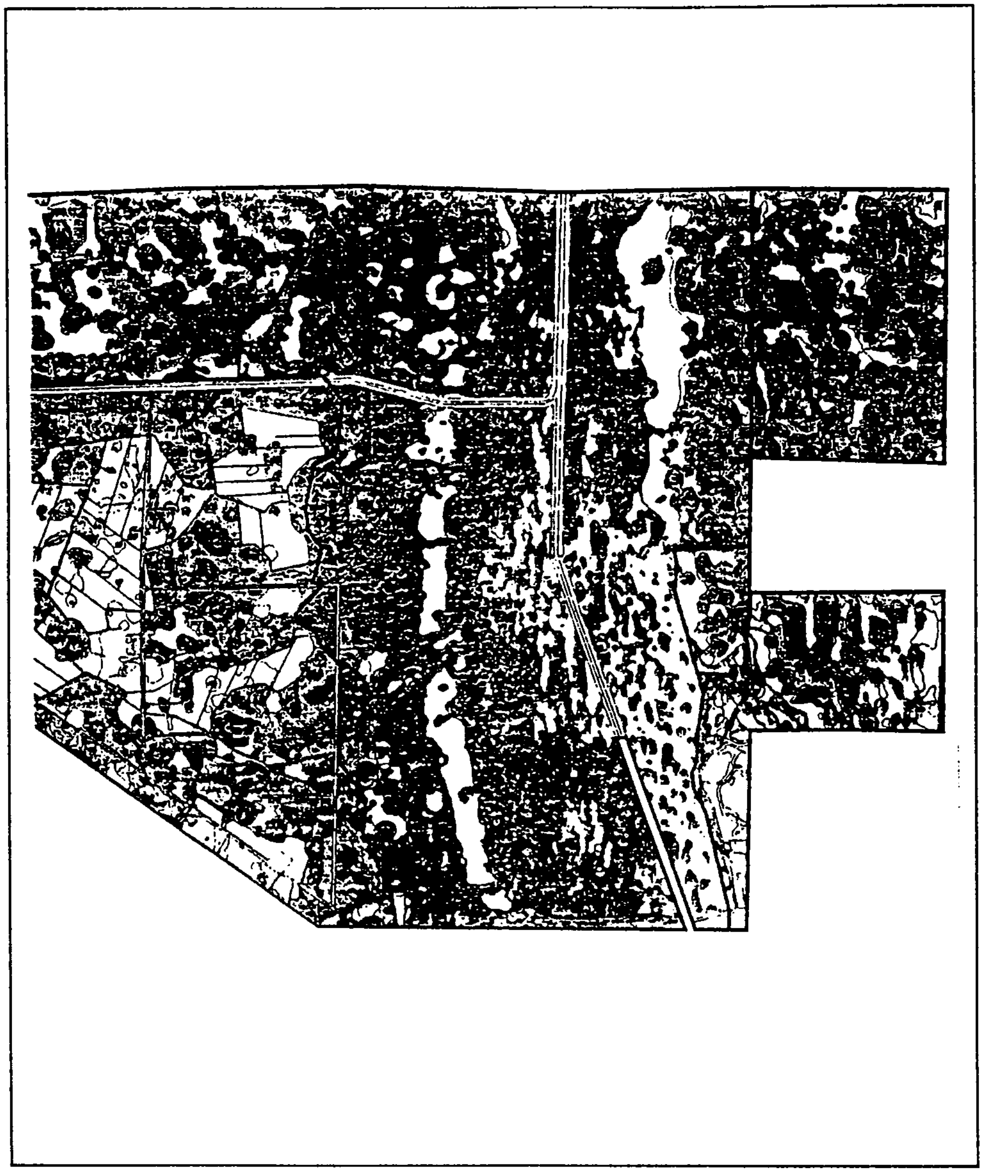

Figure 11: FLUCFCS Map of the Loxahatchee Slough
From: Erwin, 1992

Slough were rated "A?", denoting "probably a good representative, but limited or no site visit." That report indicates that the Loxahatchee Slough is comprised of an amalgam of Wetland Mosaic (6301 acres), Wet Prairie and Marsh (974 acres), Freshwater Cypress Swamp (163 acres), Disturbed Land (127 acres), Pine Flatwoods (93 acres) and Low Oak Hammock (62 acres). An amendment to the report details aerial observations. Twelve listed endangered plant species observed are: butterfly orchid, wild coco, royal fern, golden polypody, marsh fern, wild pine balbisiana, cardinal wild pine, banded wild pine, wild pine paucifolia, giant wild pine, shoestring fern and chain fern. Five listed endangered animal species observed are: American alligator, little blue heron, snowy egret, Florida sandhill crane, and bald eagle (Iverson and Austin, 1989). Ecosystem observations were also included;

> "The site is composed of wet prairie, marsh, and ponds in shallow sloughs: cypress heads: and Low Hammock. The latter has areas of dense Cabbage palm (Sabal palmetto) with Oak (Quercus sp.), and forms parallel bands that border the central path of the slough. The Wetland Mosaic of the slough ecosystems extends east and west of these somewhat higher bands of Low Hammock" (Iverson and Austin, 1989).

Vegetation-type is often used as a surrogate for soil-type in remote sensing analysis, indicating the close link between the two (Campbell, 1987). Soil in the area is of the,

> "Winder-Tequesta Association: This association is a nearly level, poorly drained sandy soil that has a loamy subsoil, and possibly a thin layer of muck at the surface. This association is in the Loxahatchee slough area along both sides of the east branch of the C-18 and in a portion of the main canal. Winder soils have a thin surface layer of black fine sand and a subsurface layer of light

> gray and brownish gray fine sand. Below this is a thin layer of loamy fine sand that rests on gray fine sand mixed with white shell fragments. Tequesta soils have approximately a 12-inch layer of black muck at the surface. The subsoil is grayish brown fine sandy loam. The minor soils in this associate are Riviera and Pahokee soils. Pahokee soils have a surface layer of black muck. Below this is black and dark reddish brown muck that rests on hard limestone at a depth of approximately 42 inches. This formed the predevelopment, natural drainage way, and the soils are subject to flooding for long periods" (Lin, 1988).

According to Storch and Taylor (1968), the process of environmental change due to drainage within the Slough itself "started less than ten years ago", (as of 1968), and that recent "environmental changes in this region are taking place at a much more rapid pace, largely because of the greater availability of public and private investment capital, and the development of more sophisticated engineering techniques applicable to agricultural drainage" (Storch, 1968).

The C-18 canal, previously known as the Limestone Creek, plus the C-18 West branch, was completed in 1958 (Lin, 1988).

> "The Loxahatchee River originally received flow into its northwest fork from the Loxahatchee Marsh and the Hungryland Slough. ... Canal-18 was constructed in these natural drainage features and diverted their flow to the southwest fork of the estuary. Because this diversion would probably be detrimental to the freshwater vegetation in the northwest fork, a culvert was placed in Canal-18 in the early 1970's, so that up to 50 cubic feet per second (cfs) could be redirected to this fork" (United States Geological Survey, 1979).

See Cooper (1988) and Lin (1988) for descriptions of the C-18 canal system, control structures, runoff rates, and flooding problems. The purpose of constructing the C-18 was three-fold;

> "(1) to provide flood protection and drainage for the basin, (2) to

> augment flows in the Northwest Fork of the Loxahatchee River, and (3) to maintain a groundwater table elevation southwest of S-46 adequate to prevent intrusion of saltwater into local groundwater. Excess water in the basin is discharged to tidewater in the Southwest Fork of the Loxahatchee River by way of S-46" (Cooper, 1988).

The C-18 basin is subdivided into 21 subbasins, with subbasins 12A, 14, 15, 16, 18 and 19 roughly corresponding to the study area. Elevation in these locations range from 12 to 21 ft National Geodetic Vertical Datum (NGVD) (Lin, 1988).

> "The most abundant wetland habitat type in the study area, emergent or wet prairie, naturally occurs within the 50 to 80 percent inundation zone. The 70 to 80 percent portion of this zone is a transition to the aquatic slough community while the 50 to 60 percent portion is the optimum inundation for wet prairie vegetation. The majority of the existing emergent community is inundated less than 50 percent of the time; therefore, it is converting to the mesic shrub/scrub community" (U.S. Army Corps of Engineers, 1983).

That portion of the Slough located to the South and West of the intersection of the West branch of the canal and the main C-18, referred to as the "Historic Region" by the U.S. Fish and Wildlife Service (Figure 12), "was subjected to an increased hydroperiod in April 1979" (U.S. Army Corps of Engineers, 1983). This change produced water levels "resembling pre-drainage period" and the area has shown "a positive response of fauna to raising water levels" (U.S. Army Corps of Engineers, 1982). Since 1982, water levels in the Historic Region, located within subbasins 12A, 14 and 16, have been "maintained above the normal water level of 14.80 ft NGVD" through the installation of boards in the culverts, to block overdrainage (Lin, 1988). However, for the majority of the

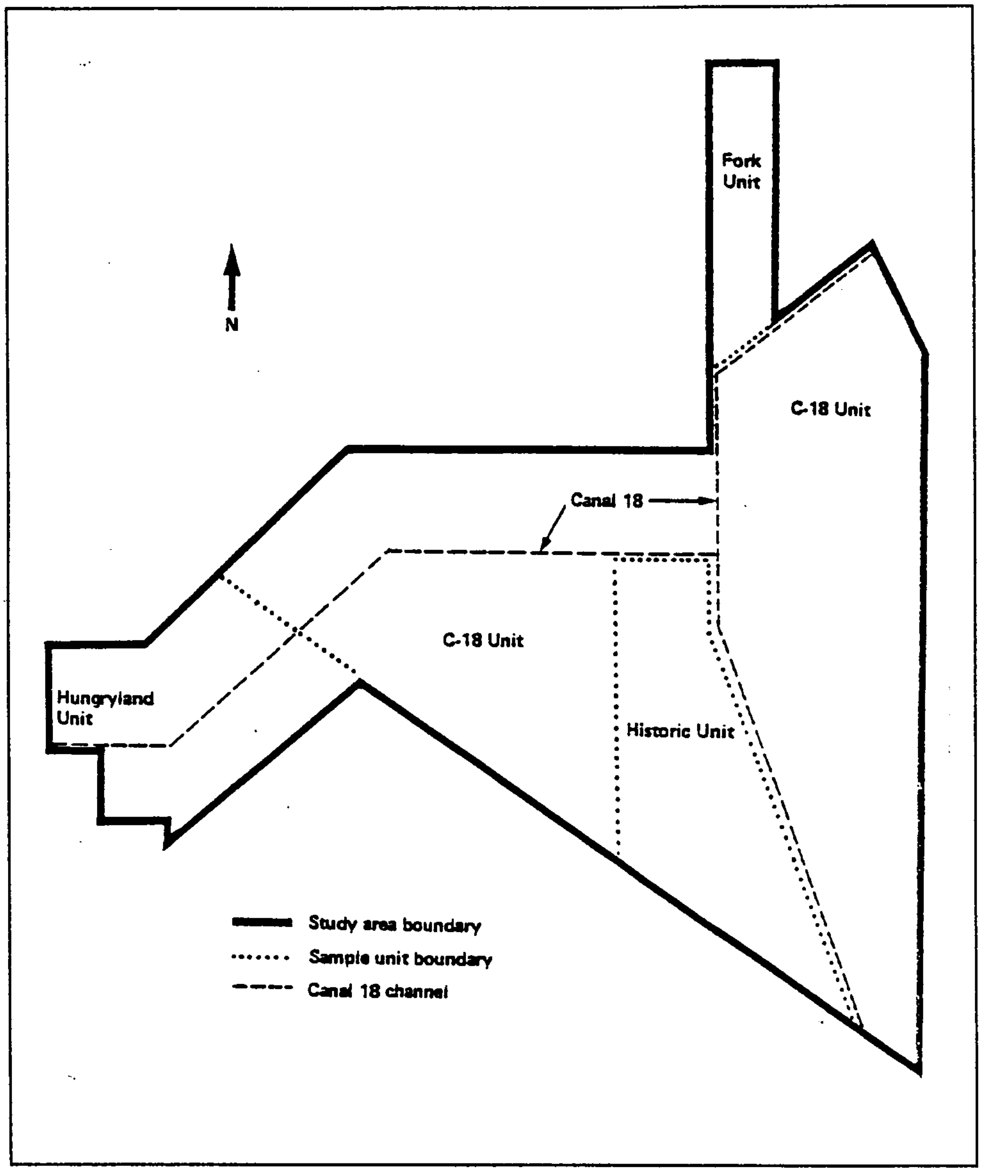

Figure 12: Map of the Historic Region of the Loxahatchee Slough
From: United States Army Corps of Engineers, 1983

study area, water levels have been reduced and,

> "as a result of drainage, marshes in the Loxahatchee Slough area are being invaded by waxmyrtle (Myrica cerifera), saltbush (Baccharis halimifolia), and the exotic species Brazilian pepper (Schinus terebinthifolius). Wet prairies also have been stressed by drier conditions and are being invaded by slash pine (Pinus elliottii var. densa) and Melaleuca quinquenervia. Additionally, the exotic fern Lygopodium microphyllum has invaded disturbed wet sites, primarily in the Loxahatchee River and slough area" (U.S. Army Corps of Engineers, 1982).

The Fish and Wildlife Service's 1980 Habitat Evaluation Procedures (HEP) classified the habitat types present as "Open Water, Emergent, Shrub-Scrub, and Forested" and determined that "habitat units of the natural wetlands of the study area were reduced by approximately 50 percent as a result of channelization of the wetlands" (U.S. Army Corps of Engineers, 1983).

IMPORTANCE OF THE SLOUGH AS A WILDERNESS ISLAND

The Environmentally Sensitive Lands Acquisition Selection Committee, appointed by the Palm Beach County Board of County Commissioners, designated the Loxahatchee Slough,

> "in County Ordinance 91-13 as one of the 14 high-priority sites for acquisition. ... Of special importance is the fact that the Loxahatchee Slough site lies within the heart of two unprotected wildlife corridors, one connecting the West Palm Beach Water Catchment Area and Jonathan Dickinson State Park and a second connecting the Water Catchment Area and the J.W. Corbett Wildlife Management Area. These two corridors are integral parts of a system of wildlife corridors which will connect every major conservation area in Palm Beach County and southern Martin County with the Everglades" (July 18, 1991 Correspondence from Joanne Davis, Chair, Environmentally Sensitive Lands Acquisition Selection Committee to Karen Marcus, Chair, Palm Beach County

Board of County Commissioners, included in the appendix of the Treasure Coast Regional Planning Council August 16, 1991 Council Meeting Memorandum).

The Foundation Land Company of the John D. And Catherine T. MacArthur Foundation, which owns much of the Loxahatchee Slough, has agreed to donate a substantial area. The Palm Beach County Department of Environmental Resources Management has applied for state funding to be combined with a portion of the County's 1991 $100 million bond issue (for the acquisition of environmentally sensitive lands), in order to purchase additional lands.

The South Florida Water Management District (SFWMD) is developing plans to restructure the C-18 canal levee and pump system in order to preserve the Loxahatchee Slough and return it to its historical function as headwaters of the Loxahatchee River, in order to relieve the current saltwater intrusion which is destroying "the only surviving example of a subtropical cypress forest river system in South Florida" (South Florida Water Management District, 1988).

CHAPTER 3

A GEOGRAPHICAL APPROACH

Time and Space in Historical Geography

Carl Sauer (1941) once criticized American geographical tradition for it's "lack of interest in historical processes and sequences." Pattern, the traditional focus of geography, is the manifestation of phenomena in space, and is shaped by the processes that occur in time. Preston James (1954) emphasizes that "the interpretation of the arrangement and character of the phenomena of terrestrial space requires an understanding of the processes which have produced them," while pointing out that "in ancient times, when the nature of all these processes was only dimly understood, geographers were mainly concerned with the identification of the phenomena that gave distinctive character to different areas." In describing the changes within the discipline of geography, Baker (1972) states that "since 1960 ... there has been a change of paradigm taking place within geography, a model-based paradigm replacing the old, predominantly classificatory, geographical tradition," and finds that the application of a mathematical approach is especially relevant for temporal process studies. Mikesell (1981) characterizes the "new geography" as "an era of deductive thinking, model building, and quantification."

Estaville (1991) describes four strategies for incorporating time in a geographic model (Figure 13). The temporal cross section is a single time

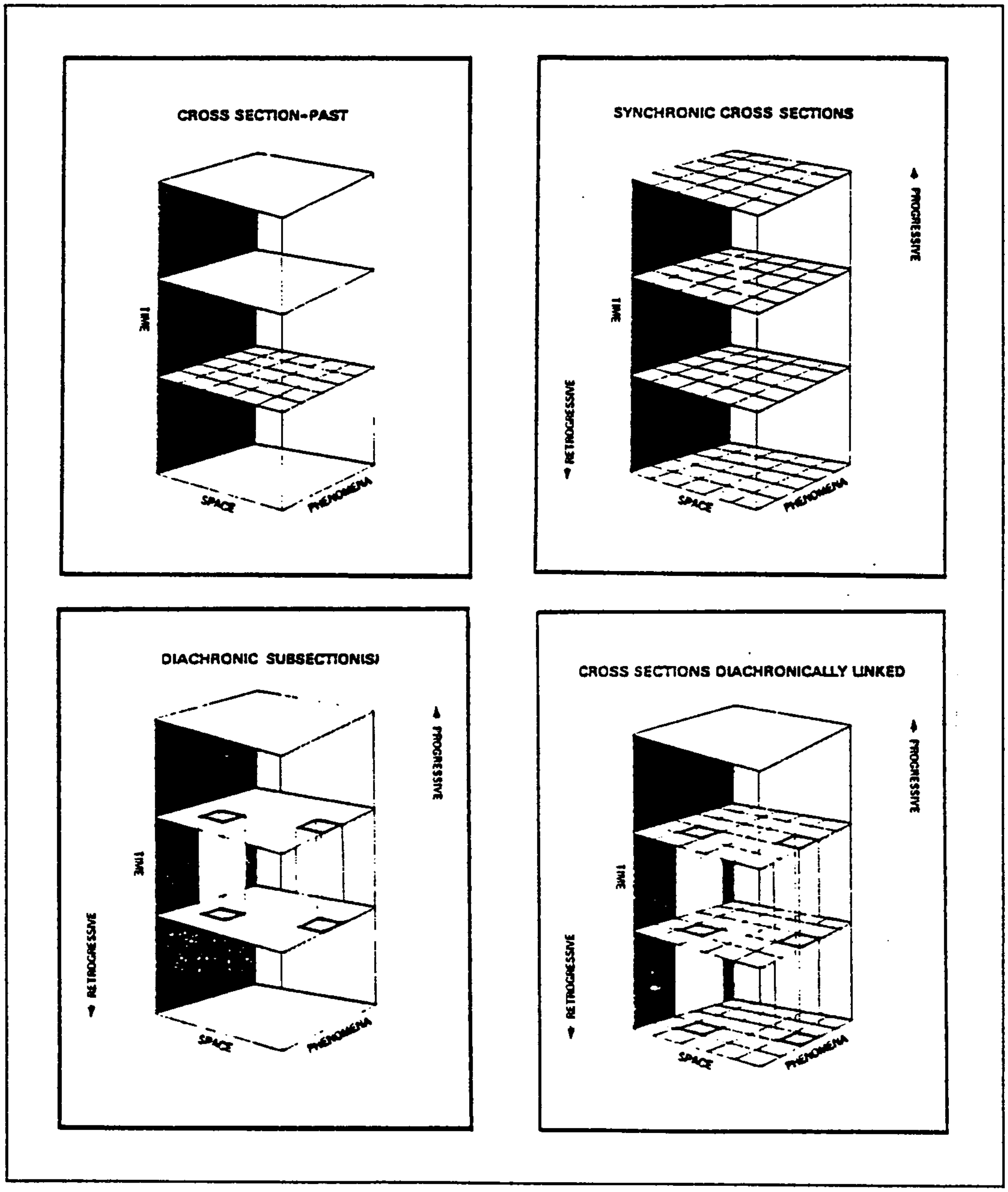

Figure: 13: Strategies for Incorporating Time into a Geographic Model
From: Estaville, 1991

slice, a simple approach for studying a pivotal time period. However, this does not allow for the examination of change. Synchronic cross sections are multiple time slices. Here, change can be quantified, but fluctuations in rates of change, and the causes of change are ignored. Diachronic subsections, also known as vertical themes, focus on the spatial relationships through time. In applying vertical themes to the study of Europe, Darby (1956) describes landscape as "evolving." A successful vertical theme study can demonstrate the contributing processes, but a lack of consistently available data across time, or the overwhelming task of sorting through details, makes this a difficult method to apply unless narrowly focused. The fourth strategy is temporal integrations. This is a combination of synchronic cross sections with vertical themes. Often it is applied by using one method to introduce the other. A vertical themes study of the processes which shaped the patterns, can help in narrowing down the pivotal dates to be selected as cross sections for examining those patterns.

Estaville's strategies elaborate on four of the twelve approaches to historical geography outlined by Newcomb (1969). Most of Newcomb's additional methods are more narrowly defined in terms of the subject of study, such as culture, environmentalism, or historic preservation. The "Dagwood sandwich" is Newcomb's equivalent of Estaville's temporal integration. This is the approach that is taken here. Vertical themes of physiographic, cultural and environmental history, discussed in the chapter on Environmental History of the Loxahatchee Slough, introduce the analysis and comparison of temporal cross sections. By examining the vertical themes, pivotal dates have been selected. Black and white aerial photographs from 1940 and 1979, plus a SPOT satellite image from 1989, provide three temporal cross sections. The earliest remotely sensed data available for the study area is from 1940, and hydrologic conditions at the time are considered to be similar to historic hydrology. Between 1940 and 1979, the C-18 canal was built, along with other cultural impacts which reduced the hydroperiod. In 1979, the Army Corps of Engineers raised the water levels in the Historic Region. The 1989 Spot image was the most recent data available when this project began. Prior studies of this type have not attempted to compare aerial photography with satellite imagery. However, through digital analysis of the satellite image, and vectorization of the aerial photographs, using consistent classification categories, the land cover classifications derived for each of these disparate data sources can be brought into a GIS, where the time slices can be compared, and land cover changes can be analyzed.

New Geographic Technologies

REMOTE SENSING AND GIS

Definitions of geography often focus on the term "landscape." For instance,

> "The objects which exist together in the landscape exist in interrelationship. We assert that they constitute a reality as a whole which is not expressed by a consideration of the constituent parts separately, that area has form, structure, and function, and

hence position in a system and that it is subject to development, change, and completion. ... The term 'landscape' is proposed to denote the unit concept of geography, to characterize the peculiarly geographic association of facts. ... Landscape ... may be defined, therefore, as an area made up of a distinct association of forms, both physical and cultural. The facts of geography are place facts; their association gives rise to the concept of landscape. Similarly, the facts of history are time facts; their association gives rise to the concept of period" (Sauer, 1925).

Dobson (1993) emphasizes the conceptual framework which links GIS and remote sensing with the geographic concept of landscape. "By 1930 landscape was comprehended and appreciated as an intellectual and philosophical concept ... but implementation was impractical, often infeasible, with the information technologies of the day." Technology has "now developed to a state in which implementation of many landscape concepts is feasible" (Dobson, 1993).

Many definitions have been offered for GIS, "but the common thread through all definitions, is the notion of spatial data processing, in addition to the more familiar textural or numeric data processing" (Parker, 1987). Spatial data is represented as points, lines and polygons, and each of these features is described by location, attributes and topology. Marble (1984) describes the four major components of all GIS as,

"a data input subsystem which collects and/or processes spatial data ... a data storage and retrieval subsystem which organizes the spatial data ... a data manipulation and analysis subsystem ... [and] ... a data reporting subsystem which is capable of displaying ... in tabular or map form."

Digital image analysis of remotely sensed data utilizes many of the same techniques as a GIS and is an important data source for building a GIS.

Remote sensing collects data through the measurement of reflected and emitted electromagnetic radiation of surface features. Digital image analysis derives information from the raw data. Jensen (1983) describes nine fundamental biophysical variables directly derived from the data. These are: planimetric location, topographic elevation, color and spectral signature, vegetation chlorophyll absorption characteristics, vegetation biomass, vegetation moisture content, soil moisture content, temperature, and texture/surface roughness. Hybrid variables can be derived through various combinations of biophysical variables. For instance, vegetation chlorophyll absorption characteristics combined with moisture content can detect vegetation stress.

The resulting database of land cover cross sections, or time slices, of biophysical and/or hybrid variables can be analyzed through GIS techniques to investigate changes over time. Available methods, according to Singh (1989), fall into two basic approaches, namely, "(1) comparative analysis of independently produced classifications for different dates and (2) simultaneous analysis of multitemporal data." Simultaneous analysis allows for a broad range of techniques, including image differencing/ratioing, vegetation index differencing, principal components analysis and change vector analysis. Comparative analysis techniques, however, are limited to post-classification comparison, with an overall accuracy equal to the product of the accuracies of each individual classification. Results of a qualitative, post-classification comparison can be summarized in a crosstabulation matrix table. This follows the same format as an error matrix, described later in the section on Ground Truthing and Accuracy Assessment.

In developing a summary of digital analysis techniques for the United Nations Institute for Training and Research, Eastman and McKendry (1991) distinguish a simple change detection for two dates, and a time series analysis of the changes across a sequence of three or more images, including the extraction of patterns found. Strahler, et al. (1986) categorize remote sensing models as either invertible (primarily empirical, where unknown scene properties can be inferred from the data) or noninvertible (primarily deterministic, with no inference). Invertible models can be further subdivided into direct inference (with a quantitative relationship between measurements and actual scene properties) or indirect inference (a qualitative relationship). This distinction between quantitative and qualitative inferences echoes Baker's assertion, that,

> "when inadequacies of the historical data entirely preclude their mathematical analysis, the alternative of a mathematical approach should prove of value. This involves determining the relationships and sets of relationships among phenomena rather than being concerned with the particular characteristics of the phenomena themselves" (Baker, 1972).

Regardless of the method selected, success depends upon accurate geometric registration of the images (Singh, 1989).

IMAGE ENHANCEMENT

Passive satellite sensors, such as the SPOT High-Resolution Visible (HRV) and the Landsat Thematic Mapper (TM), use charged coupled devices to detect the radiant flux reflected off land cover features. The SPOT satellite's HRV sensors, in multispectral configuration, sense in three spectral regions (Band 1, green, 0.50-0.59 um; Band 2, red, 0.61-0.68 um; Band 3, near infrared, 0.79-0.89 um) (Campbell, 1987). The Instantaneous Field of View for SPOT's multispectral sensors is 20 meters by 20 meters. In other words, like a picture being taken when a camera's shutter is momentarily open, each sensor detects, for its particular range of wavelengths, the total amount of light reflecting from a 20 meter square resolution cell. The measurement is recorded as the brightness value of the corresponding pixel location on the raster grid of the digital image which represents the remotely sensed scene in that wavelength band.

Each resolution cell therefore has a distinct brightness value for each of the bands sensed. Various land cover features each have their own unique set of brightness values, known as a spectral signature. Spectral signatures are the basis for spectral classification.

The multiple bands of a digital image can be combined to form a composite image, similar to color print film in a camera, which captures a picture in the three separate primary colors that are later combined to create a color photograph. Where visible spectral colors are used to display non-visible data, as in the case of the SPOT HRV, the composite is referred to as "false-color." Before compositing the bands together, however, various enhancement techniques are available to improve the visual display. Contrast Stretches utilize the full range of grey tones available for display on the monitor. Filtering can enhance edges and lines, smooth-out "noise" in the image, or prepare an image for textural analysis. Ratioing of two bands can remove shadowing. Ratioing or Image Differencing of images of the same location from two different times can be used for change detection. Principal Components Analysis can compress information in many bands down to two or three.

After the appropriate enhancements have been made, the enhanced bands can be composited into a false-color image for use in training field selection for image classification.

IMAGE CLASSIFICATION

The first priority in classifying an image into a choropleth map of land cover categories, is to determine what classification categories, or classes, will be used. The purpose for which a study is made impacts strongly on the categories selected. For instance, Erwin's 1992 report to the City of Palm Beach Gardens, written for a city government's consideration in determining land use policy, uses jurisdictional categories of Uplands, Transitional, and Wetlands. These categories are more closely aligned to elevation, soil type and drainage conditions rather than canopy cover or spectral signatures, and therefore do not correlate strongly with the classifications possible with remotely sensed data. Ecological reports by biologists typically are from on-site observation of groups of species in functioning ecosystems. In that type of classification strategy, a single ecosystem group may include a jumble of varying spectral signatures. Although their reports may give very fine detail about the sites actually visited, constraints often prevent visiting every possible location. Lack of time, insufficient budget and personnel, and inaccessible terrain may force a "best-guess" for some locations, such as the "A?" rating in Iverson and Austin (1988).

Each pixel in a remotely sensed image is equally well "visited." However, the radiant flux recorded for each resolution cell is an averaging together of the radiant flux of all the features within that cell. Therefore, features smaller than the resolution cell size will not be detected as individual features. The success or failure of this trade-off must be evaluated through ground truthing in the field, as discussed in the next section.

After deciding on the classes to be used in the classification, the enhanced image is used for identifying a sample of pixels for each class, through the creation of a vector file of training fields. The actual spectral signatures are determined from the raw data for these sampled pixels. The classification algorithm then compares the spectral signature of each pixel in the raw image with the mean spectral signature of the training field samples for each category, assigning each pixel to the category to which it is most similar.

GROUND TRUTHING AND ACCURACY ASSESSMENT

Verification of the validity of a land cover classification is done by comparison with a selected sample of observation points, either in the field or, if not possible, then with another map considered to be "true." Ground truthing observation of the entire site would determine the exact accuracy of the classification, but generally is not feasible, due to either difficult terrain or lack of time and funding. Typically, therefore, a subset of the points is ground truthed.

The land cover classification is most commonly compared with the ground truthed sample set through construction of an error matrix, also referred to as a confusion matrix or contingency table (Story and Congalton, 1986). The matrix displays the number of points sampled in each category of the land cover classification. The number of points correctly classified, according to the ground truthing sample set, is shown, along with the number of incorrectly classified points. Incorrect classifications are broken out according to their true classes.

The matrix reveals two basic types of errors. An Error of Commission occurs when a pixel is included in the wrong category. An Error of Omission denotes that a pixel was omitted from its true category. The percent of errors of omission, subtracted from 100%, yields the "user's accuracy", also called "reliability" (Janssen and van der Wel, 1994). USGS accuracy criteria for land cover classification from remotely sensed data sets the minimum standards.

> "The minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data should be at least 85 percent. ... The accuracy of interpretation for the several categories should be about equal" (Anderson, et al., 1976).

Methods of selecting the sample set vary according to the type of data and the accessibility of sampling points. A simple random sample, using a random number table or generator to select coordinates, is useful for inferential statistics, but does not apply to geographic data which is spatially correlated. A stratified random sample assigns a minimum number of observations to each class of data, but within each class the sampling is done randomly. This is the preferred method (Janssen and van der Wel, 1994), yielding excellent results both statistically and geographically, but requires extensive access to sampling data. Systematic sampling selects points at equally spaced intervals. This not only precludes the use of inferential statistics, but can result in skewed results if the landscape displays linear patterns, such as a grid of evenly spaced city blocks. A systematic random pattern, also known as a stratified systematic nonaligned pattern, divides the area into a grid and randomly selects one point in each grid cell. Like the stratified random sample, this method yields results which can be analyzed statistically, and is also easily applied to raster data, but again requires extensive access to sampling data. Where access is limited, observations may be done through cluster sampling. At each available sampling location, observations are made of a cluster of surrounding points

(Campbell, 1987). This can cause skewed results and is not subject to statistical analysis, but for some sites it is the only available sampling method.

CHAPTER 4

METHODOLOGY

Thesis Objectives

The objective of this study is to detect culturally induced changes in the hydroperiod of the Loxahatchee Slough. Vegetation types are used as an indicator of hydroperiod. A vegetation time series analysis of 1940, 1979 and 1989 land cover has been accomplished by separately classifying remotely sensed data for each year, and analyzing the results in a GIS through qualitative, post-classification comparison. Any attempt to compare the raw data, consisting of aerial photographs and satellite imagery, would "be like mixing apples and oranges." But by transforming the data into classified choropleth maps, through digital image analysis and photointerpretation techniques, using consistent classification categories, these three data sets can be compared and spatially analyzed in a GIS (Figure 14).

Data Sources

Primary data for the three time slices consist of the following. (1) Two overlapping 1940 United States Department of Agriculture (USDA) 1:40,000 scale black and white aerial photographs (CJF 4 86, CJF 6 81) taken on February 28 and March 9 (Figure 15). This is the earliest remotely sensed data available of the study site (Richardson, 1977). (2) Two overlapping 1979 USDA

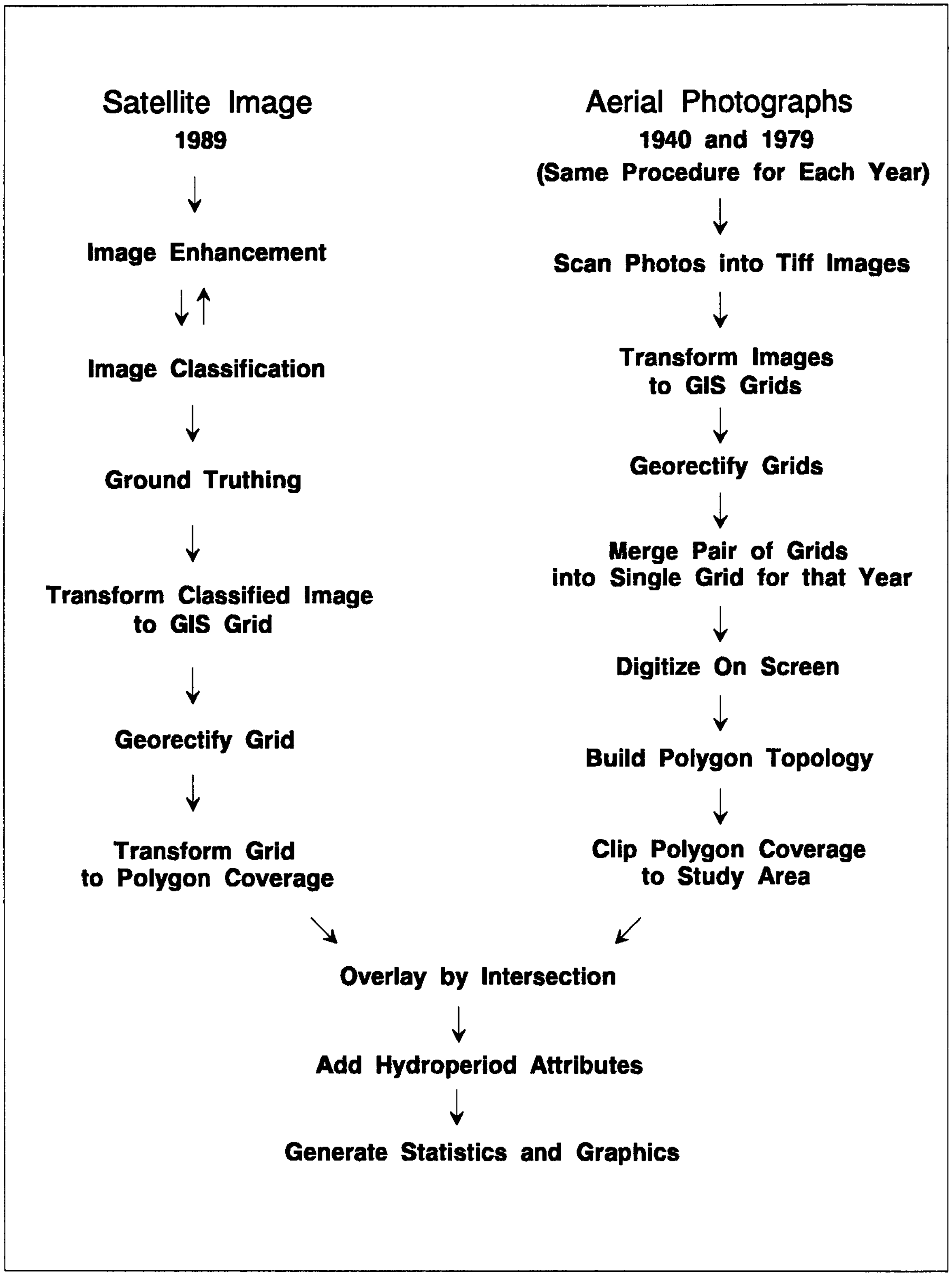

Figure 14: Methodology Flow Chart

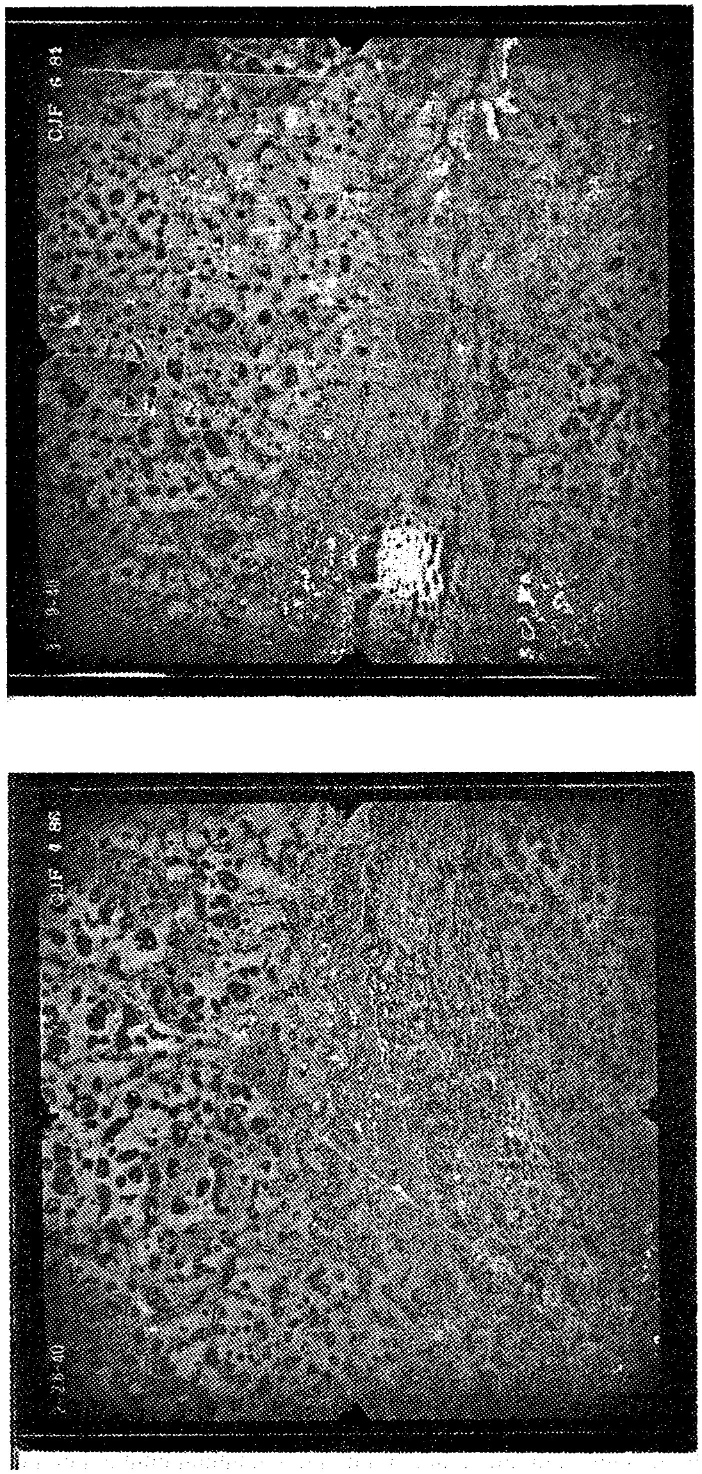

Figure 15: Scanned 1940 USDA Aerial Photographs

1:40,000 scale black and white aerial photographs (12099 178-63, 12099 178-65) taken on December 26 (Figure 16). (3) A 1989 SPOT HRV multispectral (green, red and near infrared) 20 meter resolution satellite image scanned on May 13.

Ancillary data include Richardson's 1977 study of the pre-drainage Atlantic Coastal Ridge, 1984 NHAP color infrared aerial photos, Iverson and Austin's 1988 report to the Palm Beach County Commission, 1989 Palm Beach County Property Appraiser's aerial sections, and the 1992 Vegetation Map included as Appendix A to Erwin's 1992 report to the City of Palm Beach Gardens.

Boundaries of the study area are those defined for Ecosite 109 in the Iverson and Austin report (1988) (Figure 2).

Introduction to the Methodology

This project began with clipping the 1989 SPOT raw image to the study area boundaries, applying image enhancement techniques to improve visual distinction of land cover, and creating a supervised classification from training fields selected from the enhanced image. An important component of the project was the development of a workable classification scheme for digital satellite data for this complex site. This required determining which land cover classes could be differentiated through spectral signatures, given the spectral

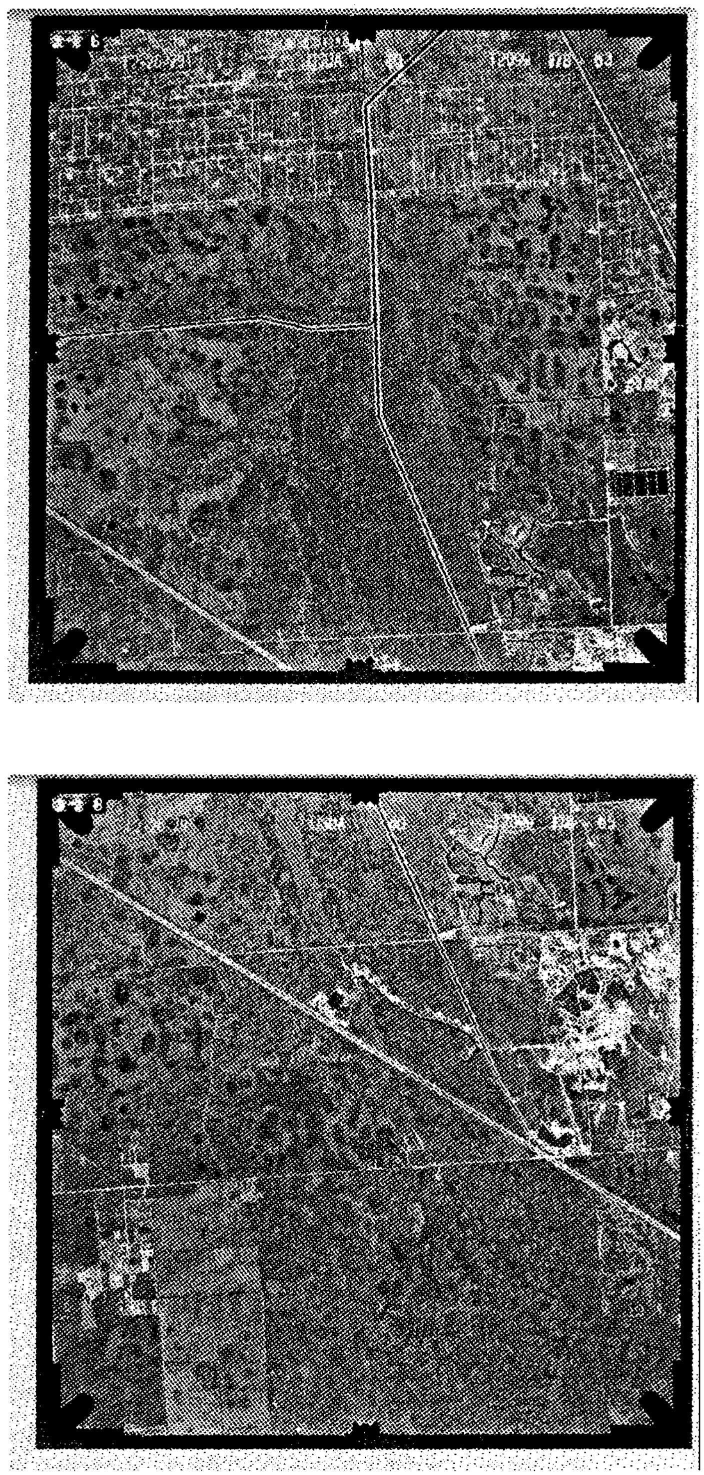

Figure 16: Scanned 1979 USDA Aerial Photographs

bands and resolution available. Ground truthing was done by the cluster sampling technique. The supervised classification image was then imported as a grid into a GIS, geo-rectified, and converted to a polygon coverage.

During the process of image classification of the 1989 satellite image, the classification system developed for spectral signatures was reclassed down to categories which also can be distinguished on the USDA aerial photographs for 1940 and 1979. Data for 1940 and 1979 each consist of a pair of overlapping photographs. In both cases, the pair of photographs were scanned and imported into GIS as grids. The grids were geo-rectified and each pair merged into a single grid for that year.

These single grids were displayed and digitized on screen. Location of the boundaries to be digitized between land cover types was determined through photointerpretation. Characteristics observed in making the decision of where to place boundaries include image tone, image texture, shadow, pattern, association, shape, size and topographic position (Campbell, 1987). Polygon topology was built and each coverage was clipped to the study area. Land cover type was attributed to each polygon. No ground truthing material was available for circa 1940 or 1979, so no accuracy assessment was made.

A GIS analysis of the three cross sections reveals the vegetation land cover changes for the study area. Using vegetation as an indicator for hydroperiod, hydrologic changes in the area were examined.

Steps in the Classification of the 1989 SPOT Image

IMAGE ENHANCEMENT

Selection of techniques for image enhancement of the 1989 SPOT image was determined by the software and data available. IDRISI 4.0 grid-based geographic information and image processing software was utilized on IBM-compatible PC's. Change detection through ratioing and image differencing of multiple images was not possible, because satellite raster data was available from only a single date. The flat terrain makes shadow removal unnecessary. The canals and roads already stand out well and do not require an edge detector filter. With virtually no noise in the image, a smoothing filter was not needed. Examination of the histograms for each band revealed low frequency tails. Therefore, enhancement was done using contrast stretching techniques.

A linear "min-max" stretch was done, in which the very low frequency tail at the high brightness-value end of each band's histogram was combined, or "saturated", into a single frequency in order to improve the contrast for visual display. This is similar to turning the contrast knob on a television set, to adjust a picture that is too dark or light, resulting in an image that has a more even distribution of light and dark tones on the screen. The min-max stretched bands were then composited to create a false-color image. Upon visual inspection, this seemed to have good results, and image classification was attempted. However, poor classification results prompted further enhancements.

The raw bands were piecewise stretched and composited into a new false-color enhanced image (Figure 17). The piecewise stretches on each band primarily saturated the high brightness-value pixels, similar to the min-max stretches. In addition, a few neighboring brightness values, of extremely close frequency, were combined in order to bring the total number of classes for the three bands to below 256. This insured that there would be no reclassing done automatically during the compositing process, which could have combined heterogeneous land cover types into a single, indistinguishable class.

IMAGE CLASSIFICATION

At the onset of the image classification process, in order to determine which land cover features could be successfully detected by spectral signatures at 20 meter resolution, an unsupervised classification was made on the min-max linear stretched composite, using the CLUSTER module (with Fine-Keep class assignment option). The output clusters were reclassed down to the classes used in the Iverson and Austin report (1988), namely, Wetland Mosaic, Wet Prairie and Marsh, Cypress Swamp, Pine Flatwoods, Low Oak Hammock and Disturbed Land. In the present study, the Disturbed class is interpreted to include roads, paths, canal levees and canal water. Although canals are considered by the National Wetlands Inventory to have riverine values (Cowardin, et al, 1979), in this case, the vegetation existing before channelization, has been destroyed and the canal is now described as having

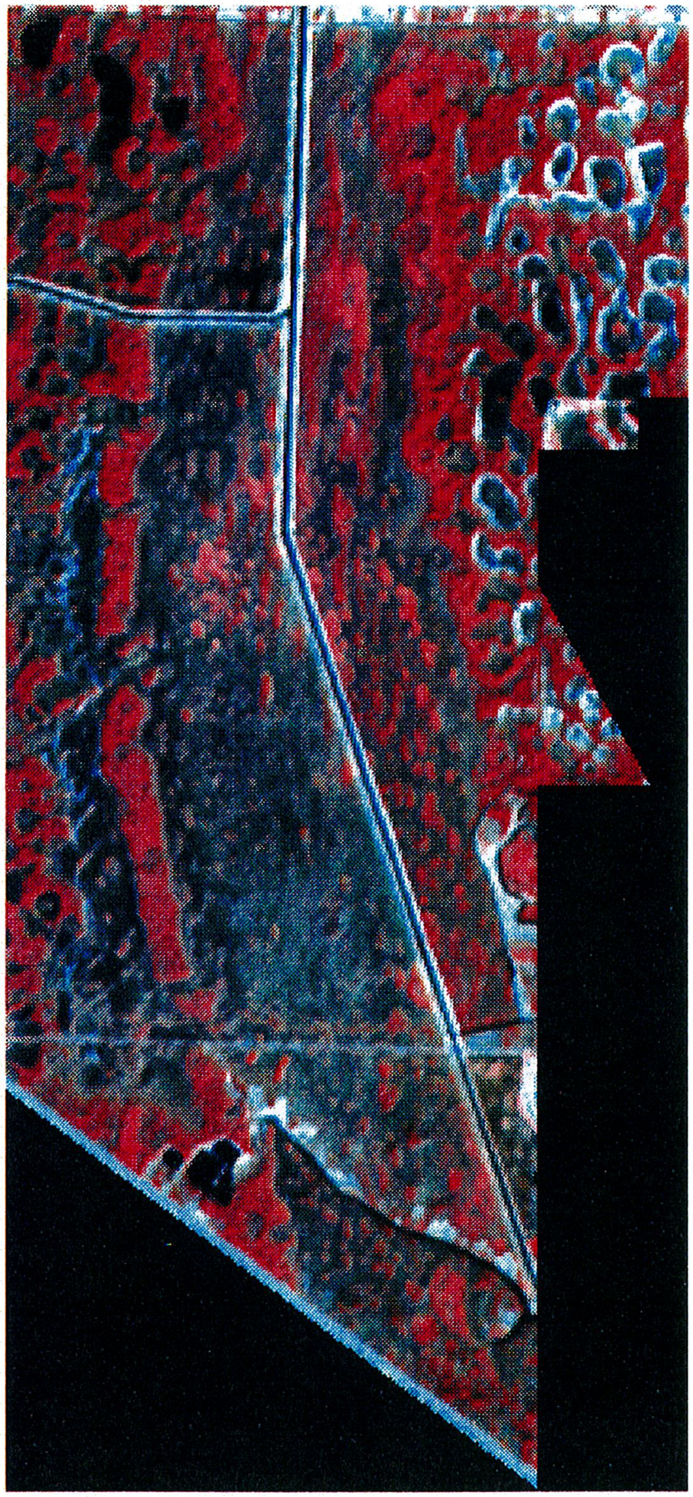

Figure 17: 1989 SPOT Image False Color Composite

"unvegetated steep banks and little or no emergent or submerged vegetation" (United States Army Corps of Engineers, 1983). The resulting unsupervised classification appeared to roughly conform with the ancillary data. Therefore, these classes were used when proceeding with the Supervised Classification.

A vector file of training fields was made on the min-max linear stretched composite, with signatures generated on the raw data using the MAKESIG module. A minimum distance supervised classification was run, with poor results. Several attempts to retake the training fields continued to give poor results. Use of the EDITSIG module, to reduce overlaps in the spectral signatures, did little to improve the classification. An improvement in image enhancement was sought through piecewise stretching.

Upon completion of the piecewise stretch composite, a reevaluation was also made of the categories chosen for the classification. The Disturbed training field signature was very broad, and many pixels were being misclassed into this category. This was caused by the inclusion of several dissimilar land cover types in this single category. Canal water tends to absorb light, reflecting very little back, and appearing dark on an image or photograph. In contrast, roads and sandy paths reflect most of the light, looking bright on an image or photograph. Therefore, the Disturbed category was split into two categories: Disturbed Road and Disturbed Canal. This resulted in two narrower signatures.

Wetland Mosaic was likewise a broad signature, causing misclassification of other pixels into this category. Wetland Mosaic is not a single ecosystem, as the others are. Rather, it signifies that the various ecosystems at that location are so small in scale, that they can not be distinguished at the resolution of observation. Therefore, lacking the homogeneity needed for creating a spectral signature from training fields, this category was dropped from the classification strategy.

Wet Prairie and Marsh together make up one of the categories in the Iverson and Austin classification strategy. However, these are spectrally distinguishable. Therefore, they were split into two categories. In addition, some marsh areas are flooded on the SPOT image. Therefore, Water was added as a new category.

Homogeneous training fields were taken on the piecewise stretch composite image for Water, Marsh, Wet Prairie, Cypress Swamp, Low Hammock, Pine Flatwoods, Disturbed Road and Disturbed Canal. The resulting Minimum Distance Classification appeared to be more accurate than prior results, when compared with ancillary data. However, canal water pixels were spectrally indistinguishable from flooded marsh water, and therefore were manually selected out and reclassed as Disturbed Canal. The resulting eight classes was the maximum number of classes that could be distinguished through digital image analysis of the SPOT NIR satellite data.

In order to use these classes for comparison with the 1940 and 1979 aerial photographs, a preliminary photointerpretation of the aerials was made. The eight classes were not distinguishable, but grouping together several of the classes resulted in four categories that could be distinguished on the aerials. Therefore, the eight categories were reclassed down to four, and renamed in conformity with USGS land cover classes (Anderson, et al., 1976). Forest Land consists of Low Hammock and Pine Flatwoods. Forest Land is a Level I class under the USGS system, and typically is applied to biomes. Therefore, it is a broad class, and includes both Low Hammock, which is at the driest end of the range of Palustrine System vegetation, and Pine Flatwoods, which falls in the drier class of Upland System vegetation. Cypress Swamp was retained as a distinct category, relabelled as Forested Wetland. Nonforested Wetland combines Water, Marsh and Wet Prairie. Both Forested Wetland and Nonforested Wetland are Level II classes, indicating that they are somewhat narrower in what they include, and can also be combined together under the Level I class of Wetland. Under the USGS system, pixels of disturbed land cover would be classed with the surrounding ecosystem types, but for this study, which is at a more local scale, a distinction was required. Therefore, a fourth category of Disturbed includes both Disturbed Road and Disturbed Canal.

Determination of a classification system applicable to both photographic and spectral data allows for the creation of a GIS for time series analysis, incorporating both aerials photographs and satellite imagery.

GROUND TRUTHING

Ground truthing in the field utilized the cluster sampling technique due to limitations in access because of difficult terrain and lack of time to thoroughly sample the area. The difficulties in traveling through the area, as indicated by Iverson and Austin's (1988) use of the "A?" rating for nearly half of the site, precluded a more systematic statistical approach to sampling. Ground observations made in the interior of the site during field visits on March 23, March 28, and May 8, 1993, plus low altitude aerial observations made during a flight onboard a CESNA 172 over the site on August 20, 1993, provided familiarity with the area. Locations selected for ground truth sampling include points along the perimeter and along the easement of the C-18 canal where position could be approximated. However, exact correlation of sampled locations to satellite image pixels was not verifiable, because GPS and survey equipment were not available for use during the site visits. Therefore, the ground truth sampling data could not be used for developing an error matrix. Nevertheless, photographs taken at the sampling locations were visually compared with the supervised classification, and appear to generally confirm its validity.

CONVERSION TO GIS AND GEO-RECTIFICATION

The IDRISI format supervised classification image was exported to ERDAS 7.4 format. The ERDAS image was then imported as a grid into

Arc/Info 6.1.1 running on a Sun SPARCstation LX (UNIX, SunOS 4.1.3c) with the IMAGEGRID command, using nearest neighbor resampling. The grid was geo-rectified with CONTROLPOINTS and GRIDWARP using a first-order polynomial transformation. This method references coordinates on an existing, georeferenced coverage, called ground control points (GCP) with the corresponding points on the grid to be geo-rectified. In this case, a soils coverage in State Plane Coordinate System Projection, consisting of 1985-1986 USDA Soil Conservation Service (SCS) linework based on soil surveys taken in 1970-1975, was used for selecting GCP. Vegetation land cover is often used as a surrogate for mapping soil types (Campbell, 1987). The close association between vegetation and soil type results in similar polygon boundaries which maintain their shape over time. The geo-rectified grid was transformed to a polygon coverage with GRIDPOLY (Figure 18).

Steps in the Classification of the Aerial Photographs

SCANNING INTO GIS

The USDA black and white aerial photographs for 1940 and 1979, two for each year, were scanned with a Howtek Scanmaster 3+ scanner at 400 dots per inch (dpi) greyscale, resulting in tiff images with a pixel resolution of 100 inches square, or roughly two and a half meters square. The tiff images were brought into Arc/Info 6.1.1 with nearest neighbor resampling in IMAGEGRID.

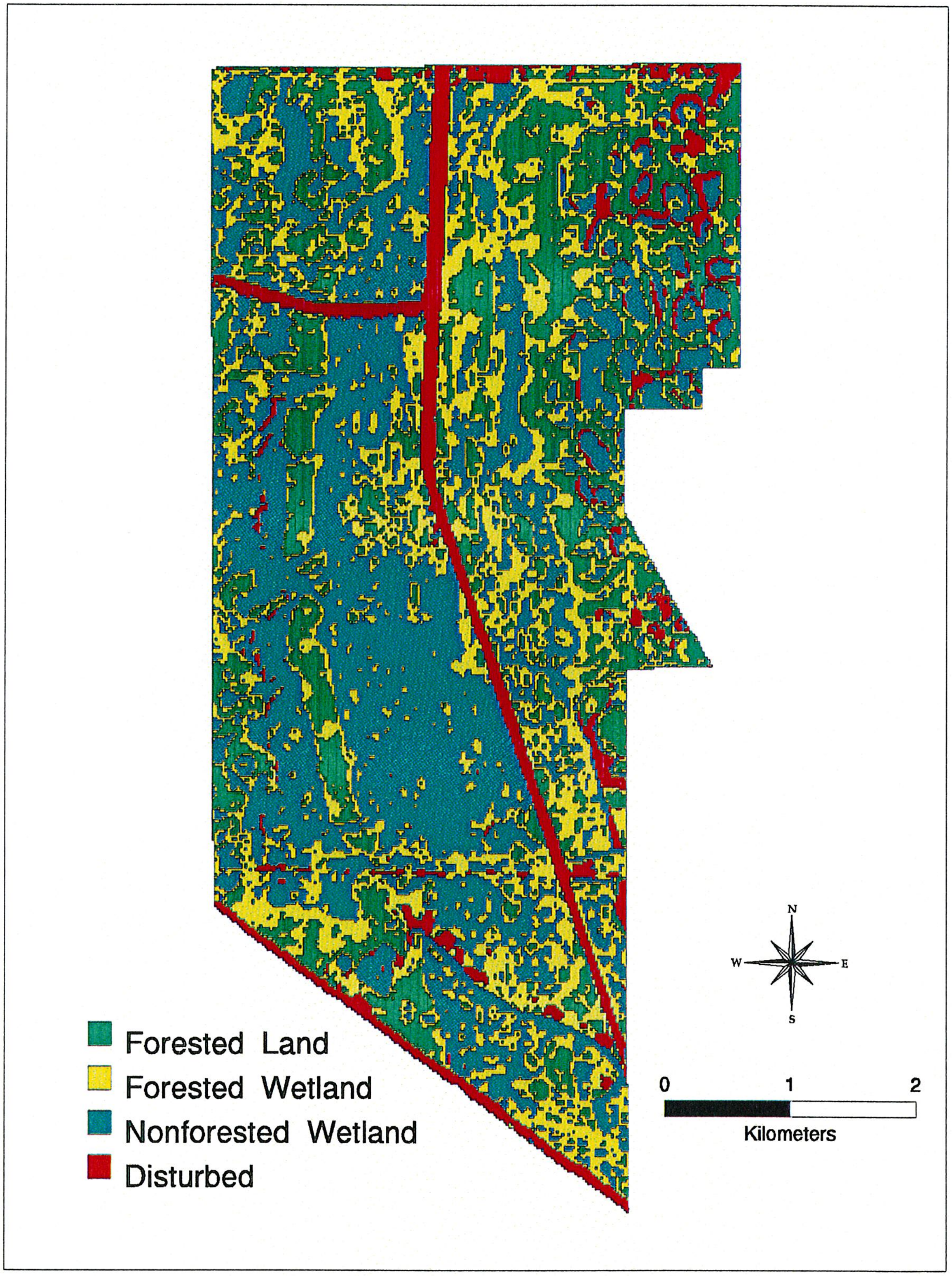

Figure 18: 1989 Land Cover Polygon Coverage

GRID GEO-RECTIFICATION AND MERGING

The grids were geo-rectified with CONTROLPOINTS and GRIDWARP using a first-order polynomial transformation. The same soils coverage used in geo-rectifying the 1989 image was also used here. Due to the underlying soil types and topology, many of the tree islands in the Loxahatchee Slough have maintained their shape over time, even where the vegetation type has changed over time due to changes in hydrology. These persistent shapes made it possible to identify GCP on the soils coverage to match with points on the scanned aerials.

For each year, the pair of overlapping grids was combined into a single grid. First, one of the two grids was clipped to remove some, but not all of the overlapping area. The two grids were then combined with MERGE, using the clipped grid as the primary input. In other words, if the paper photographs were being physically joined together, the clipped one would be on top. By following this procedure, there is no photograph "edge" running across the middle of the combined grids. In addition, with aerial photographs, planimetric distortion is greatest along the edges. Clipping allows more of the less-distorted central portions to be displayed (Figures 19 and 20).

ON SCREEN DIGITIZING AND PHOTOINTERPRETATION

Utilizing the Arc/Plot grid display capabilities, the merged grid was displayed and a new coverage was digitized on screen in Arc/Edit. On screen

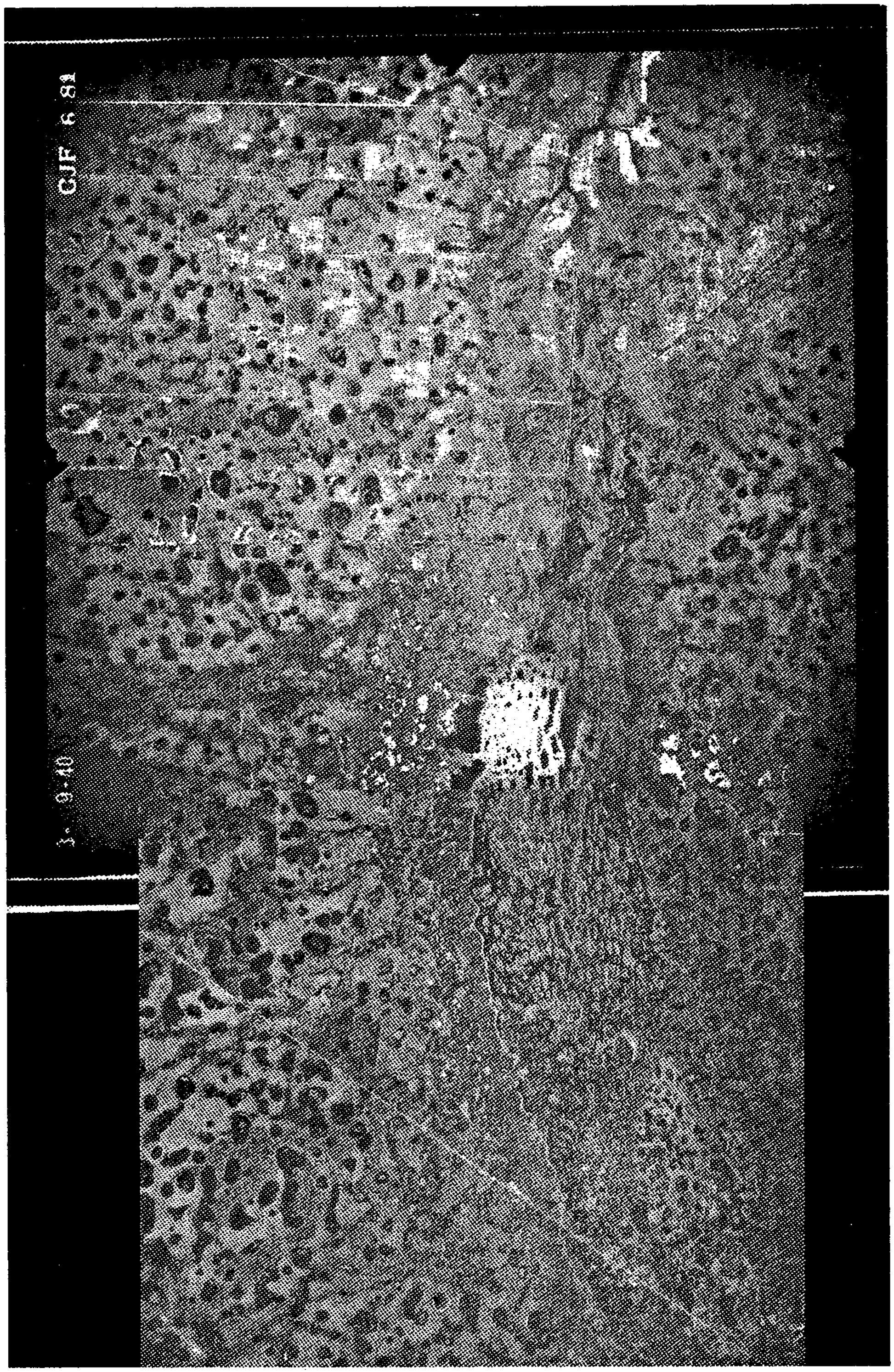

Figure 19: Merged 1940 Grids

Figure 20: Merged 1979 Grids

digitizing allows for zooming in on the displayed grid as needed, to optimize the accuracy of the photointerpretation. This procedure was applied to both the 1940 and the 1979 merged grids. The same four final categories used for classifying the 1989 SPOT image, namely, Forest Land, Forested Wetland, Nonforested Wetland and Disturbed, were also used for classifying the 1940 and 1979 grids during photointerpretation. The digitized coverages were cleaned, built with polygon topology and clipped to the study area boundary (Figures 21 and 22).

ACCURACY ASSESSMENT

There are no ground truthing data available for use with the 1940 or 1979 coverages. Richardson (1977) provides vegetation maps based on aerial photographs from 1940, 1945 and 1973, which distinguish between low hammock, swamp, marsh and wet prairie within the Loxahatchee Slough. However, no geo-rectification or GIS analysis was made in that study, and no numerical results were given. Therefore, the maps could not be used for spatial overlay and an error matrix could not be constructed.

Maffini, et al (1989) found that error propagation during digitizing is caused primarily by two factors, namely, scale of the material being digitized, and the speed of digitization. The effect of these two factors was minimized by using the zoom in capability while displaying the scanned aerials, and by putting no time constraint on completing the process. Any digitized lines that were not

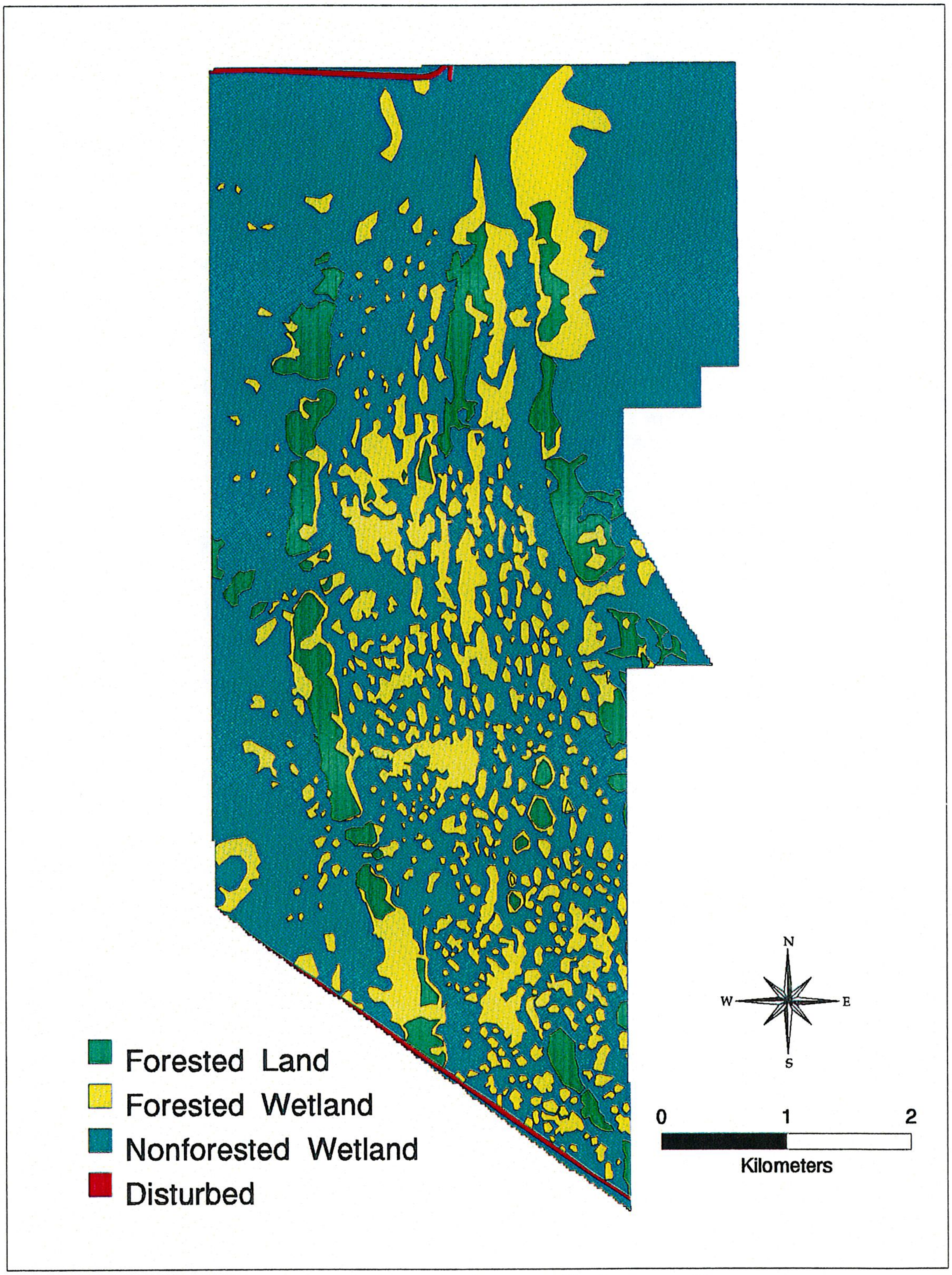

Figure 21: 1940 Land Cover Polygon Coverage

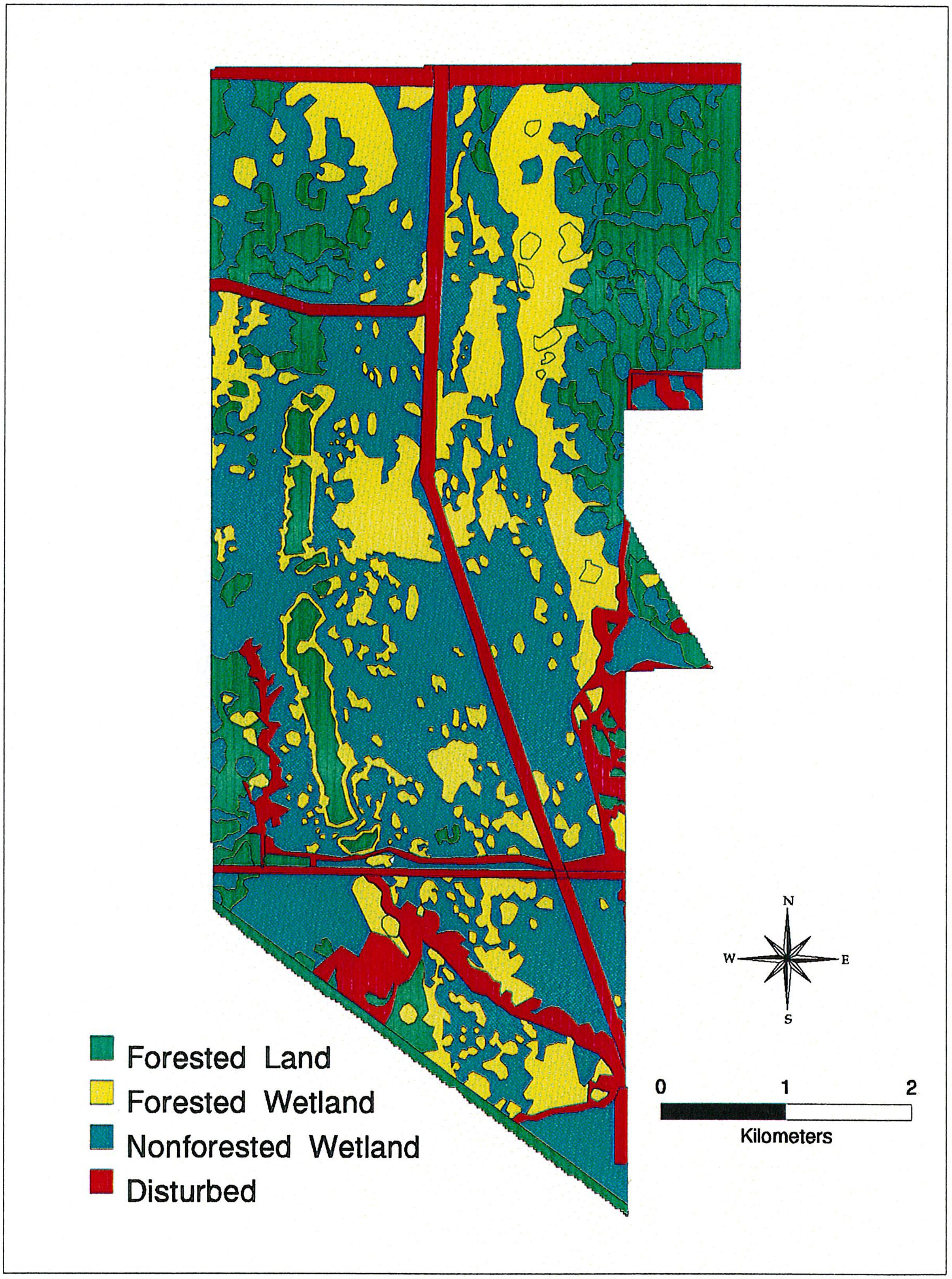

Figure 22: 1979 Land Cover Polygon Coverage

completely satisfactory were deleted and redigitized. In analyzing digitizing trials, Sadowski, et al. (1987) found that "overestimated proportions for some polygons were in effect compensated by underestimated proportions in others." Therefore, while the location of the boundaries of a land cover polygon may not be digitized exactly, the total percentage of land cover reported for each category can be considered to be minimally affected by digitizing error.

Time Series Analysis: 1940 to 1989

The three temporal cross sections, or time slices, each having been transformed into an identical format within a GIS, could next be analyzed in a post-classification comparison. Total areal extent for each land cover type was obtained with STATISTICS, and percentages calculated (Figures 23 and 24, and Table 1).

In order to use vegetation types as an indicator of hydroperiod, a hydroperiod value must be associated with each vegetation class. The hydroperiod values used here are based on Brown (1989) (Table 2).

In the present study, the Nonforested Wetlands class includes both of Brown's Wet Prairie and Marsh classes. This gives a hydroperiod range of 150-365 days. forested Wetland, or Cypress, falls within this range, and therefore an ordinal ranking cannot be made which distinguishes between these classes. In order to analyze land cover change by hydroperiod, the Forested Wetland and Nonforested Wetland classes must be combined. Adhering to the

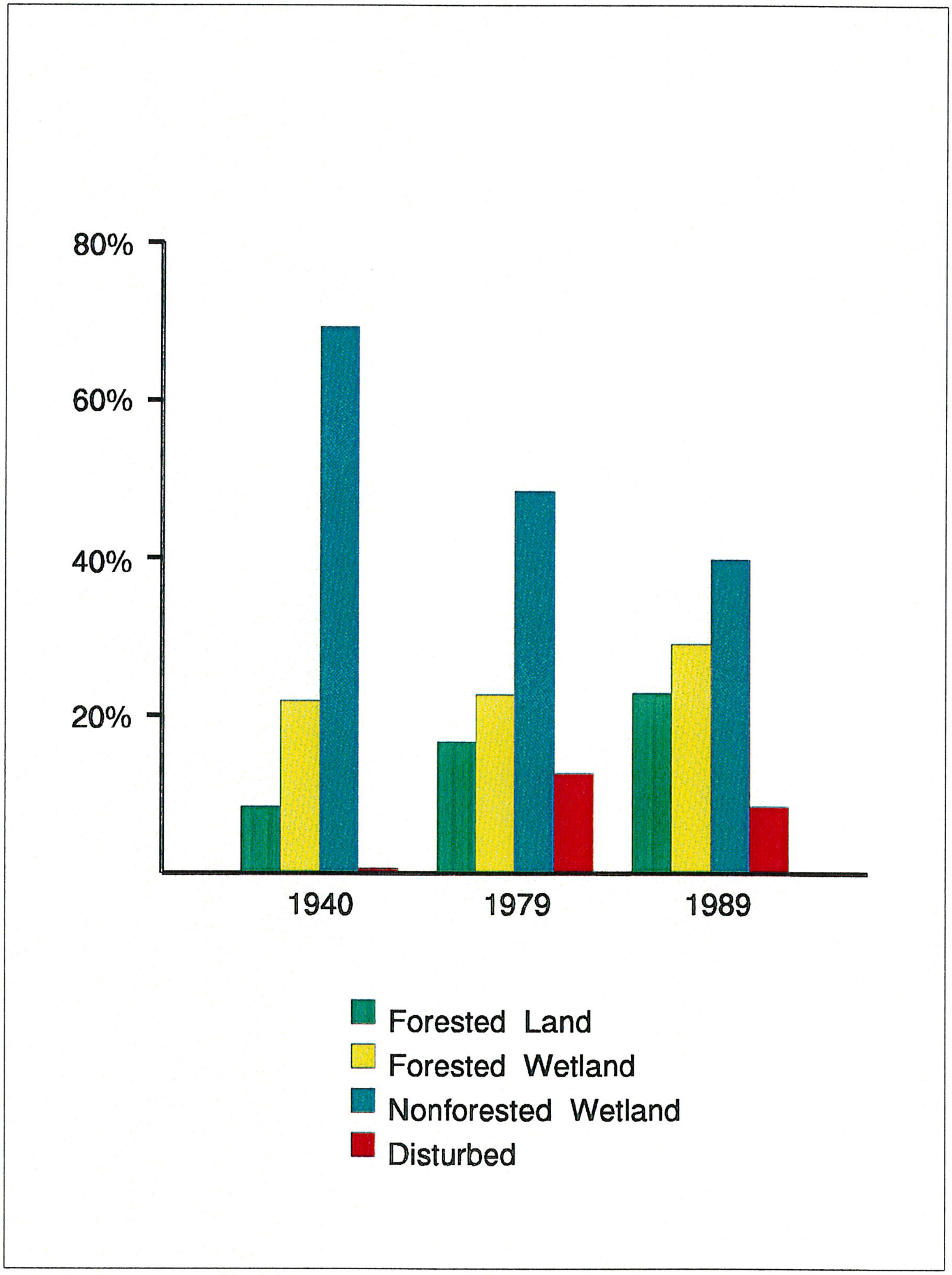

Figure 23: Land Cover Percent by Year

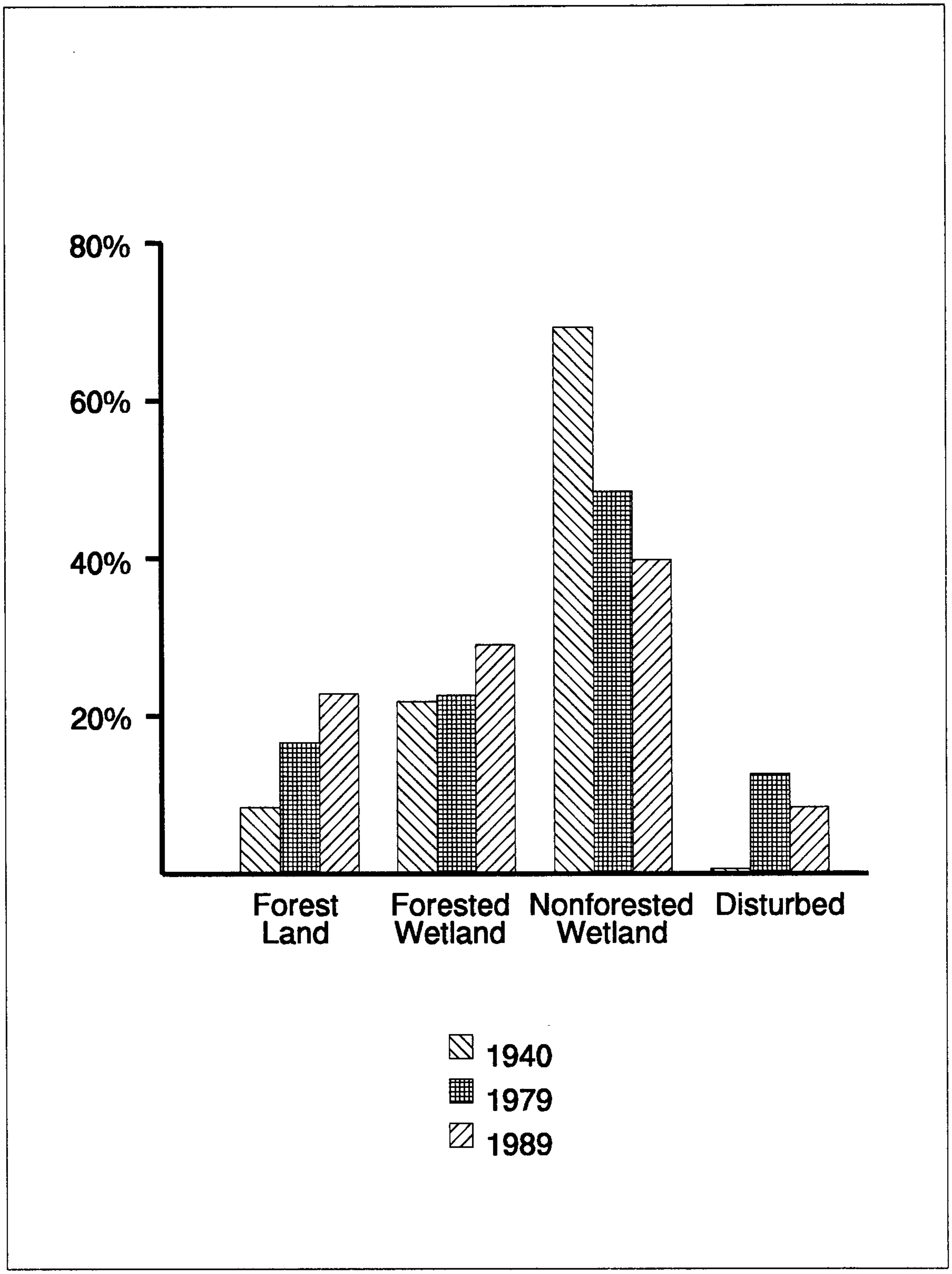

Figure 24: Land Cover Percent by Class

CLASS	1940	1979	1989
FOREST LAND	8.33	16.57	22.82
FORESTED WETLAND	21.88	22.51	29.05
NONFORESTED WETLAND	69.15	48.31	39.74
DISTURBED	0.65	12.60	8.39

Table 1: Land Cover Percent by Year and Class

CLASSES USED HERE	BROWN'S CLASSES	HYDROPERIOD
FOREST LAND	HAMMOCK	100-150 DAYS
NONFORESTED WETLAND	WET PRAIRIE	150-200 DAYS
FORESTED WETLAND	CYPRESS	250-300 DAYS
NONFORESTED WETLAND	MARSH	365 DAYS

Table 2: Vegetation Type and Related Hydroperiod

nomenclature of the USGS land cover system (Anderson, et al., 1976) this combination class is Wetland, with a hydroperiod of 150 days or more.

Brown's Hammock class indicates the hydroperiod for the Palustrine System portion of the Forest Land class of the present study is 100-150 days. Forest Land also includes Pine Flatwoods, an Upland System type, which has a shorter hydroperiod than Palustrine System. Therefore Forest Land has a hydroperiod of less than or equal to 150 days. In the present study, the Disturbed category is rated as functioning at the lowest level for supporting a wetlands ecosystem, and therefore equivalent to the shortest hydroperiod. The ordinal ranking of these three classes, then, from longest to shortest hydroperiod, is: Wetland, Forest Land and Disturbed.

Hydroperiod ranking was added as a new attribute to each polygon coverage. Areal percentages for each of these classes were calculated from STATISTICS output (Figures 25 and 26, and Table 3). The polygon coverages, for 1940, 1979 and 1989, were overlaid, using the INTERSECT command. This intersected coverage was then divided into the Historic Region, where water levels were increased as of 1979, and the remainder of the study area, labelled the Non-Historic Region. This allows for a spatial analysis of where hydroperiod has increased, decreased or remained the same for 1940 to 1979, 1979 to 1989, and 1940 to 1989 (Figures 27, 28 and 29).

Examination of these change maps indicates that along some of the tree islands and portions of the canal, hydroperiod has increased along one edge

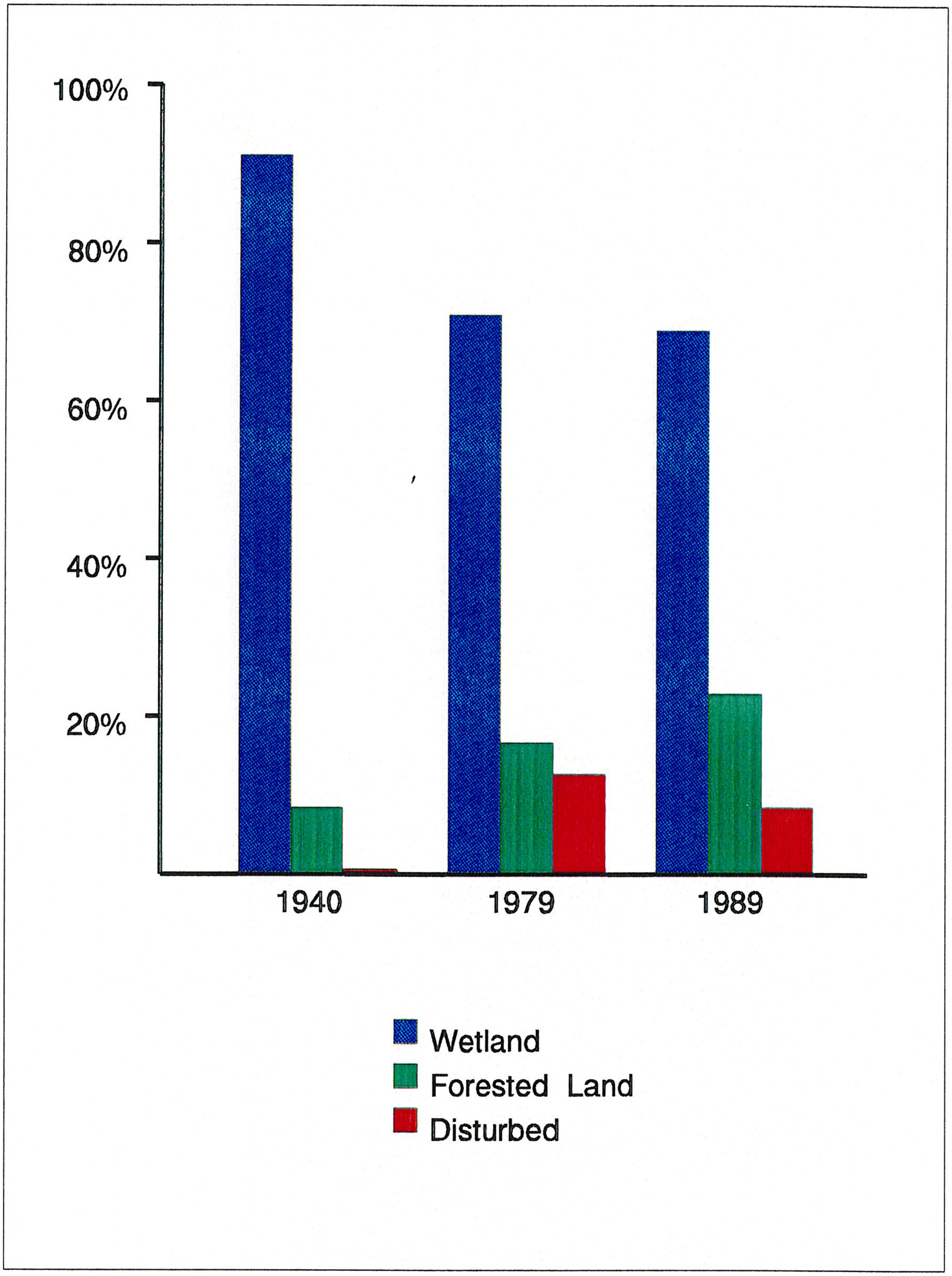

Figure 25: Hydroperiod-ranked Vegetation Percent by Year

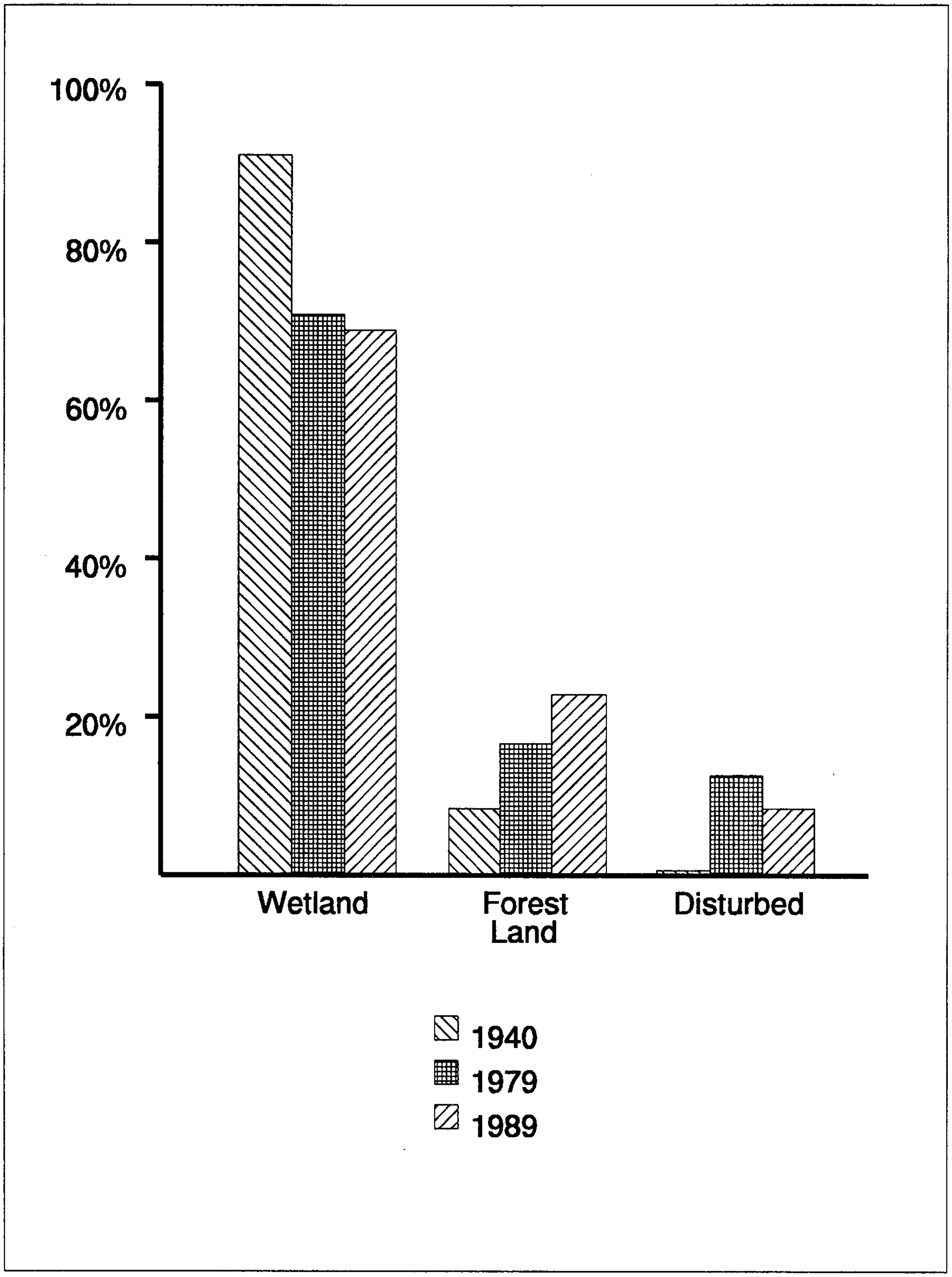

Figure 26: Hydroperiod-ranked Vegetation Percent by Class

CLASS	1940	1979	1989
WETLAND	91.03	70.82	68.79
FOREST LAND	8.33	16.57	22.82
DISTURBED	0.65	12.60	8.39

Table 3: Hydroperiod-ranked Vegetation Percent by Year and Class

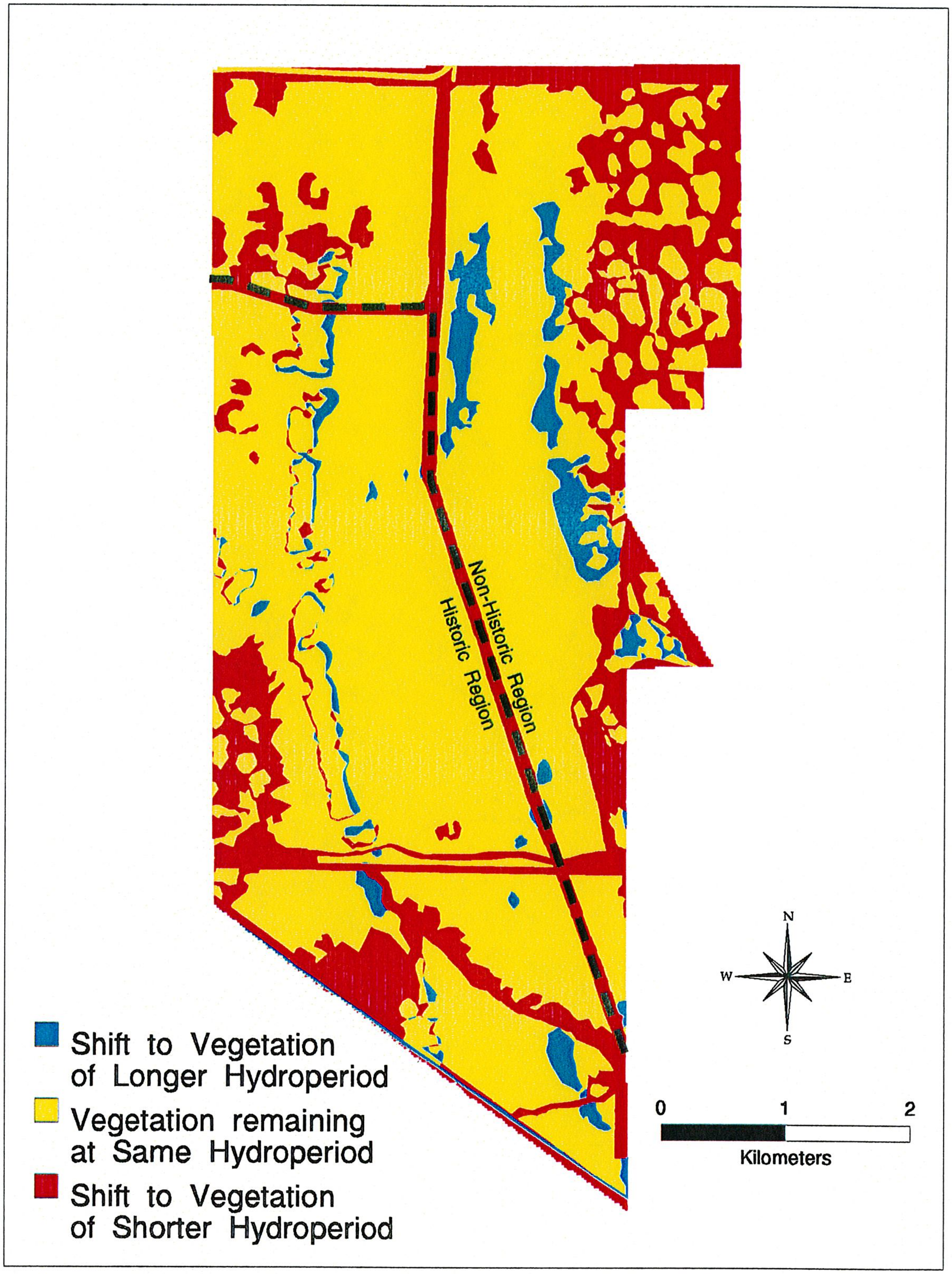

Figure 27: 1940 - 1979 Hydroperiod Change

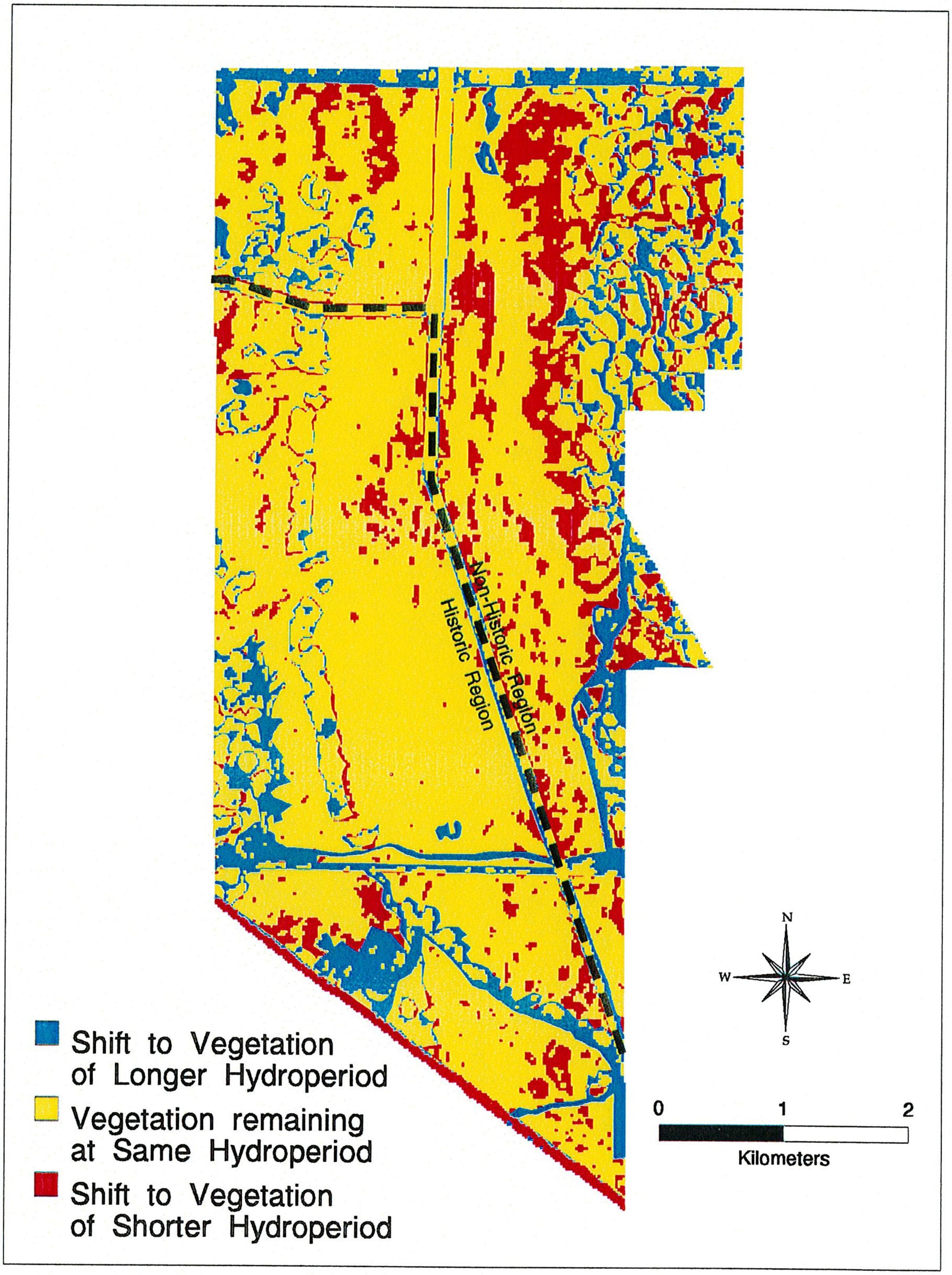

Figure 28: 1979 - 1989 Hydroperiod Change

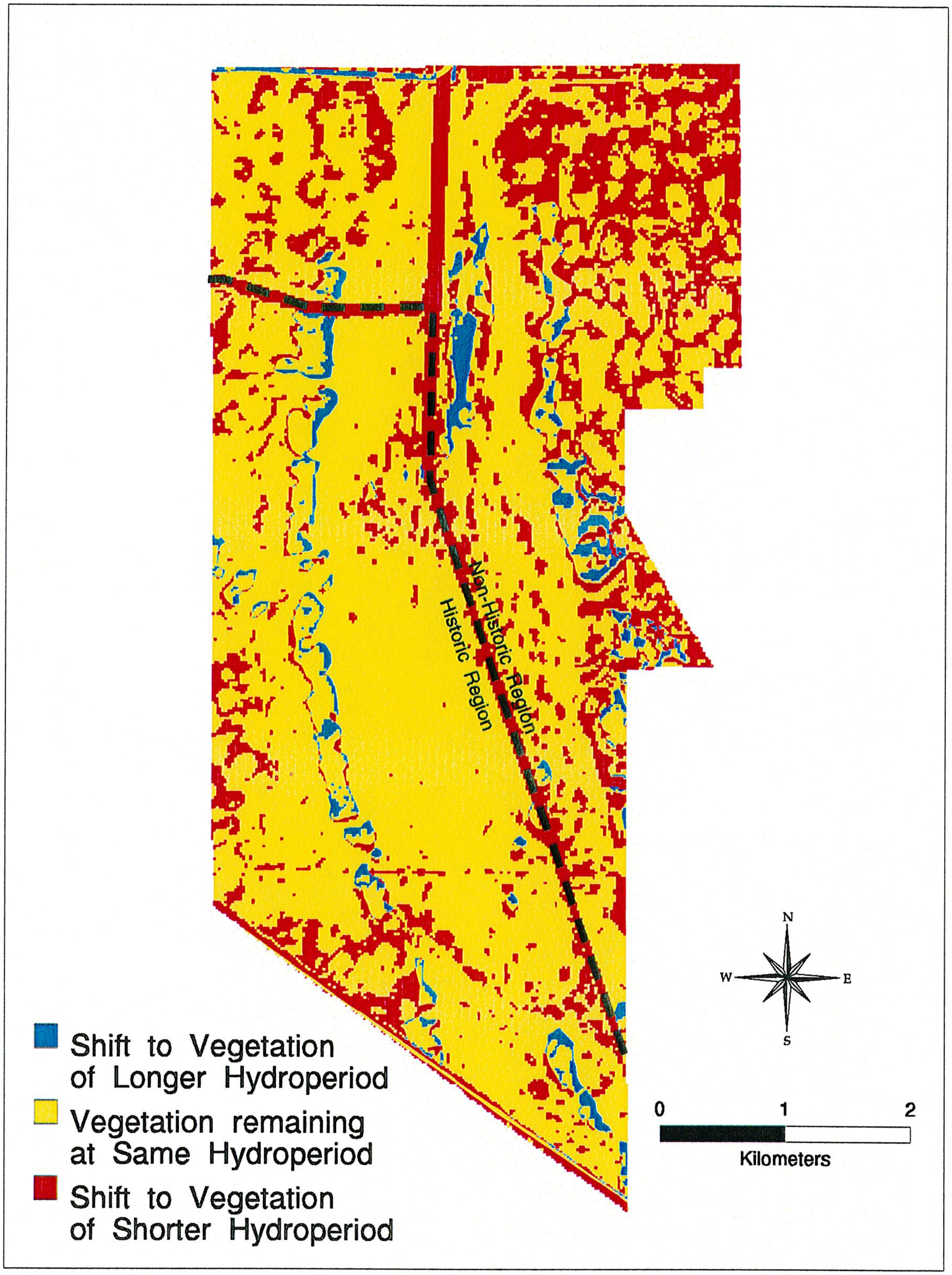

Figure 29: 1940 - 1989 Hydroperiod Change

while decreasing along the opposite edge. The individual time slices do not confirm this trend. This appears to be an artifact of mis-registration during the geo-rectification process, causing the overlays to be slightly offset. This can most likely be attributed to three factors. First, the study area has very few stable manmade land cover features to utilize as registration points to match with GCP. The boundaries between ecotones were used, and are subject to interpretation. Richardson (1977) reports that with manual aerial photointerpretation,

> "the transition from Swamp to Low Hammock is difficult to identify. ... In the Loxahatchee Slough, for example, 'tree islands' may be Swamps, Low Hammocks or Tropical Hammocks. Their exact classification as to community type is sometimes difficult to assess without extensive field analysis."

Second, the registration points from each time slice were matched to a soils coverage, based on the assumption that the shapes of vegetation features had not changed over time. This assumption may have been too broad. While vegetation can be used as a surrogate for soil type in image classification, it is only one contributing factor. The shapes of these features may, in fact, have changed. Exotic species have increasingly invaded the area. Fires, which evidently occurred sometime during the 1940's and 1950's (Erwin, 1992), and suppressed succession to mesic species, may also have changed the shape of vegetation boundaries. Changes in hydrology may have affected water flow, and caused new soil deposits, which could then result in new vegetation patterns. Even a simple rise or fall in water level could result in a changed boundary between submergent and emergent vegetation. Third, Arc/Info 6.1 has a bug in the CONTROLPOINTS command which causes the GCP reference coverage (in this case the soils coverage) to black-out before a window can be selected for overlay. Often, the resulting overlay was not closely aligned, making selection of registration points and matching GCP difficult.

This mis-registration error has resulted in artificially inflating the percents for both Increased Hydroperiod Vegetation Land Cover Change and Decreased Hydroperiod Vegetation Land Cover Change, by equal amounts. In order to compensate for this error, the difference is taken between these percents. While some of the discounted percents may reflect actual change, rather than being an artifact of mis-registration, how much is not ascertainable here. This calculation of the difference also serves to summarize the results of this study. These results indicate that for the study area as a whole, hydroperiod has dropped since channelization, but it appears that the rate at which hydroperiod is dropping has slowed since water levels were increased for the Historic Region in 1979 (Figure 30 and Table 4). An increase of hydroperiod has been detected for the Historic Region since water levels were increased in 1979 (Figure 31 and Table 5).

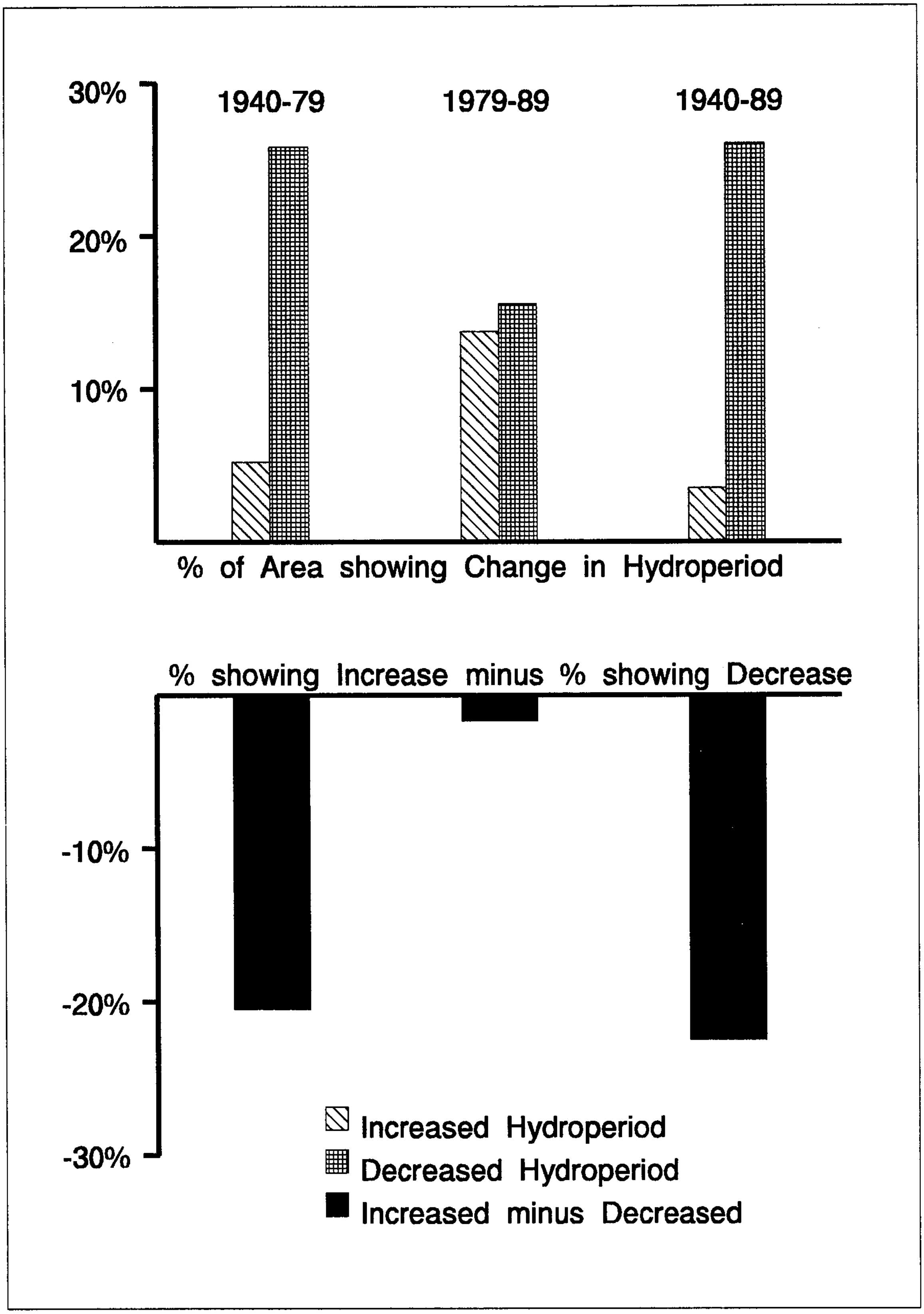

Figure 30: Final Results of Time Series Analysis using Vegetation Types as Indicators of Hydroperiod, for Study Area

	1940 - 1979	1979 - 1989	1940 - 1989
INCR HYDRO	5.22	13.73	3.49
SAME HYDRO	69.03	70.79	70.53
DECR HYDRO	25.75	15.48	25.98
INCR MINUS DECR	-20.53	-1.75	-22.49

TABLE 4: Percent of Change in Hydroperiod using Vegetation Types as Indicators, for Study Area

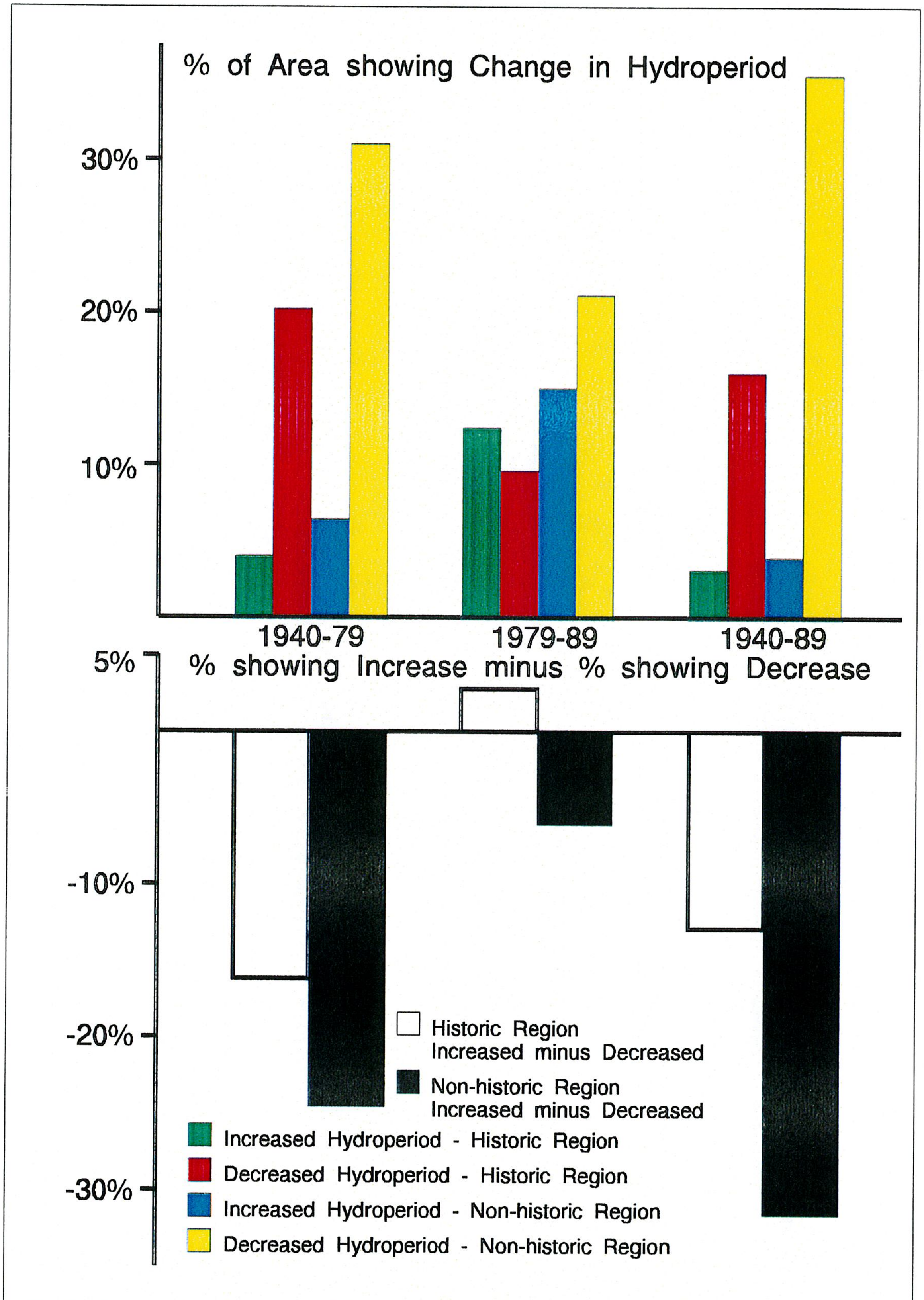

Figure 31: Final Results of Time Series Analysis using Vegetation Types as Indicators of Hydroperiod, by Region

	1940 - 1979		1979 - 1989		1940 - 1989	
	HIST	NON-H	HIST	NON-H	HIST	NON-H
INCR HYDRO	4.02	6.35	12.39	15.00	3.05	3.90
SAME HYDRO	75.33	62.67	78.06	63.91	80.98	60.62
DECR HYDRO	20.24	30.98	9.55	21.09	15.97	35.47
INCR MINUS DECR	-16.22	-24.63	+2.84	-6.09	-12.92	-31.57

Table 5: Percent of Change in Hydroperiod using Vegetation Types as Indicators, by Region

CHAPTER 5

CONCLUSION

The objective of this study was to examine the culturally induced changes in hydroperiod of the Loxahatchee Slough. Vegetation land cover classifications for three pivotal dates were done using aerial photographs and satellite imagery, and results were integrated in a GIS. Vegetation was used as an indicator of hydroperiod. A time series analysis of the land cover classifications indicates a shorter hydroperiod since channelization. In addition, the impact of increased water levels since 1979 in the Historic Region was examined. Results indicate that this increase caused a reversal back towards supporting longer hydroperiod species within the Historic Region. However, these gains were not sufficient to offset the drying trend for the entire study area. The Northernmost portion of the study area has not only shifted from Wetland to Forest Land, but is now Upland Pine Flatwoods. This observation underscores the profound degree of hydrologic change experienced in the Loxahatchee Slough.

During the course of this study, it was found that the steps of image enhancement and image classification can be an iterative process. Evaluation of the enhanced image is made during image classification, and may need to be revisited. The classes utilized in the image classification may be determined, in part, by the results of the image enhancement. As the enhancement is revised, the classification scheme may also need to be revised. Therefore, the optimal classes may not be predictable at the onset of digital image analysis. However, knowledge gained during the process, such as of the peculiarities of the spectral signatures for a specific site, may also contribute to improving the image enhancement and the image classification. An iterative process, therefore, can produce better results than simply following a standard procedure.

Tables 1 and 3 indicate that the percent of Disturbed Land Cover decreased from 1979 to 1989. Despite the increased hydroperiod for the Historic Region since 1979, and restoration of the PGA National Marsh in 1981, an actual decrease in Disturbed Land Cover is highly unlikely. Examination of Figures 18 and 22 shows that much of the contiguous Disturbed class for 1979 was classified as broken fragments of Disturbed mixed with other classes for 1989. This might indicate a limitation to the consistency of classifications done for the satellite image and for the aerial photographs. Or it may reflect seasonal differences or varying weather conditions at the time of data collection. The satellite image is from May, while the 1979 aerial photographs are from December.

To test the consistency of classifications for the satellite image and for the aerial photographs, images and photographs of the same location and the same date could be independently classified. A comparison of the results would show the degree of compatibility between the classifications of these two types of data. Studies of this sort would enable researchers to integrate satellite imagery, which is becoming increasingly available, with aerial photography, which is the best source of unbiased historical data.

Comparability may also have been affected by the resolutions involved. The aerials were scanned at 400 dpi, resulting in two and a half meter resolution. Future studies could test the differences in digitizing and classifying the same photograph scanned at various resolutions. At what resolution would a single band black and white aerial photograph best provide comparable results with a three band 20 m resolution image?

Methods of incorporating data into a GIS also need investigation. Scanning and on screen digitizing could be compared with digitizing from the hard-copy photograph. Also, geo-rectification after the photograph has been brought into the GIS could be compared with using an ortho-transfer scope to geo-rectify before scanning or digitizing.

Time series studies would likely be improved if the data were selected for consistent seasonal conditions. A study of rainfall data would provide assurance of consistent weather and flooding conditions. Also, trends would more likely be apparent where a greater number of pivotal dates were examined. For the present study, the addition of data from the period 1956-58, when the C-18 canal was built, would be a good candidate. Accuracy assessment would certainly be improved if ground truthing sample points could be geo-registered closely enough to be useful in constructing an error matrix.

Global Positioning Systems (GPS) could prove useful for a site such as the Loxahatchee Slough, where manmade features, which are helpful in pin-pointing location, are lacking. A quantitative accuracy assessment would provide statistical confidence in the results of the analysis.

While statistical confidence in the quantitative results derived in the present study is unavailable, this study has produced qualitative results which are indicative of the changing conditions of the Loxahatchee Slough. Visual inspection, alone, of the individual aerial photographs and satellite image, do not reveal the trend toward increased hydroperiod in the Historic Region since 1979. However, this has been detected through time series analysis. Change in hydroperiod is a primary cultural impact on natural areas in South Florida. Natural areas in human-dominated landscapes require management in order to remain natural. Geographic studies incorporating remote sensing and GIS can provide the information needed for effective management of natural areas.

LITERATURE CITED

Adicks, R., 1978. Le Conte's Report on East Florida. Orlando, FL: University Presses of Florida.

Anderson, E., 1956. Man as a maker of new plants and new plant communities. In Man's Role in Changing the Face of the Earth, ed. Thomas, W.L. Chicago: University of Chicago Press. pp. 763-77.

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer, 1976. A Land Use and Land Cover Classification System for use with Remote Sensor Data. Geological Survey Professional Paper 964. Washington, DC: U.S. Government Printing Office.

Baker, A.R.H., 1972. Rethinking Historical Geography. In Progress in Historical Geography, ed. Baker, A.R.H. New York: John Wiley & Sons.

Bartram, W., 1943. Travels in Georgia and Florida, 1773-74, A Report to Dr. John Fothergill. Transactions of the American Philosophical Society, New Series, Vol. 23, Part 2, November 1943.

--------, 1980. Travels Through North and South Carolina, Georgia, East and West Florida, a facsimile of the 1792 London edition. Charlottesville, VA: University Press of Virginia.

Baxter, J.M., 1941. An annotated checklist of Florida maps. Tequesta No. 1, 107-115.

Blake, N.M., 1980. Land into Water -- Water into Land, A History of Water Management in Florida. Tallahassee, FL: United Presses of Florida.

Brown, M.T., 1989. Forested wetlands in urbanizing landscapes. In Proceedings of the Symposium: The Forested Wetlands of the Southern United States. Gen. Tech. Rep. SE-50, eds. D.D. Hook and R. Lea. Asheville, NC: USDA, Forest Service, SE Forest Experiment Station.

Burgess, R.L., and D.M. Sharpe, 1981. Forest Island Dynamics in Man-Dominated Landscapes. New York: Springer-Verlag.

Campbell, J., 1987. Introduction to Remote Sensing. New York: Guilford Press.

Cooper, R.M., and J. Lane, 1988. An Atlas of Eastern Palm Beach County Surface Water Management Basins. Technical Memorandum DRE-244. West Palm Beach, FL: Water Resources Division, Resource Planning Department, South Florida Water Management District.

Cowardin, L.M., V. Carter, F.C. Golet, E.T. LaRoe, 1979. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. Washington, DC: Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior.

Craig, A.K., 1991. The physical environment of South Florida. In South Florida: The Winds of Change, ed. T.D. Boswell. Miami: Association of American Geographers. pp. 1-16

Cumming, W.P. 1966. Mapping of the southeast: the first two centuries. The Southeastern Geographer 6:3-19.

Curl, D.W., 1986. Palm Beach County, an Illustrated History. Northridge, CA: Windsor Publications.

Darby, H.C., 1956. The Clearing of the Woodland in Europe. In Man's Role in Changing the Face of the Earth, ed. Thomas, W.L. Chicago: University of Chicago Press.

Dasmann, R.F., 1971. No Further Retreat, the Fight to Save Florida. New York, NY: The Macmillan Company.

Davis, J.H., 1943. The Natural Features of Southern Florida, Especially the Vegetation, and the Everglades. Geological Bulletin No. 25. Tallahassee: The Florida Geological Survey.

de Vorsey, L.D., 1966. The colonial southeast on "an accurate general map." The Southeastern Geographer 6:20-32.

--------, 1971. DeBrahm's Report of the General Survey in the Southern District of North America. Columbia, SC: University of South Carolina Press.

di Castri, F., and T. Younes, 1990. Ecosystem function of biological diversity. Summary report of an IUBS/SCOPE workshop held on 29-30 June, 1989, in Washington D.C., U.S.A. Biology International Special Issue 22:1-20.

Diamond, J.M., 1978. Critical areas for maintaining viable populations of species. In The Breakdown and Restoration of Ecosystems, eds. Holdgate, M.W. and M.J. Woodman. New York: Plenum Press. pp. 27-37.

Diamond, J.M. and R.M. May, 1976. Island biogeography and the design of natural reserves. In Theoretical Ecology: Principles and Applications. ed. R.M. May. Oxford: Blackwell Scientific Publ. pp. 163-186.

Dickinson, J., 1975. Jonathan Dickinson's Journal, or, God's Protecting Providence: Being the Narrative of a Journey from Port Royal in Jamaica to Philadelphia between August 23, 1696 and April 1, 1697. Stuart, FL: Valentine Books.

Dobson, J.E, 1993. Commentary: a conceptual framework for integrating remote sensing, GIS, and geography. Photogrammetric Engineering & Remote Sensing 59(10):1491-1496.

Douglas, M.S., 1988. The Everglades: River of Grass. Revised edition. Sarasota, FL: Pineapple Press.

Dovell, J.E., 1962. Indian War on the East Coast. In The East Coast of Florida, A History, 1500-1961. eds. Nance, E.C, and H. Nance. Delray Beach, FL: The Southern Publishing Company. pp. 65-79.

Eastman, J.R., and J.E. McKendry, 1991. Explorations in Geographic Information Systems Technology, Vol. 1, Change and Time Series Analysis. Geneva, Switzerland: The United Nations Institute for Training and Research.

Ehrlich, P.R., 1988. The loss of diversity: causes and consequences. In Biodiversity. ed. E.O. Wilson. Washington, DC: National Academy Press. pp. 21-27.

Erwin, K.L., 1992. Preliminary Ecological Inventory and Assessment of 11,164 Acres in Palm Beach Gardens. July 1992 Draft. Unpublished report to the City of Palm Beach Gardens. pp. 122.

Estaville, L.E., 1991. Organizing Time in Geography: Explanations and Activities for Teachers. Journal of Geography. 90(6):267-270.

Ewel, K.C., 1990. Swamps. In Ecosystems of Florida. eds. R.L. Myers and J.J. Ewel. Orland: University of Central Florida Press. pp. 70-100.

Farnsworth, Steve. Environmental Analyst, Environmental Review and Natural Areas Division, Palm Beach County Department of Environmental Resources Management. Personal communication. February 2 and 10, 1994.

Florida Department of Transportation, 1985. Florida Land Use, Cover, and Forms Classification System. Second Edition. Procedure No. 550-010-001-a. Tallahassee: Florida Department of Transportation.

--------, 1990. Palm Beach County, FL, General Highway Map, August 1975, revised and reprinted July 1990. Tallahasse, FL: Florida Department of Transportation.

Florida Statutes, 1984. 1984 Supplement to Florida Statutes 1983. Title 29, Chapter 403, ss.403.91-403.929.

Forbes, J.G., 1964. Sketches, Historical and Topographical, of The Floridas; More particularly of East Florida, facsimile reproduction of the 1821 edition. Gainesville, FL: University of Florida Press.

Friis, H.R., 1966. Highlights of the geographical and cartographical activities of the federal government in the southeastern United States: 1776-1865. The Southeastern Geographer 6:41-57.

Harris, L.D., 1984. The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. Chicago: University of Chicago Press.

Harris, M.H., 1972. Florida History: A Bibliography. Metuchen, NJ: Scarecrow Press.

Henshall, J.A., 1884. Camping and Cruising in Florida. Cincinnati: Robert Clarke and Co.

Hoffmeister, J.E., 1974. Land from the Sea, the Geologic Story of South Florida. Coral Gables: University of Miami Press.

Iverson, G.B., and D.F. Austin, 1988. Inventory of Native Ecosystems in Palm Beach County, Phase III Report; Location and Evaluation of Sites for Possible Preservation as Wilderness Island Park Preserves. Unpublished report to the Palm Beach County Commission.

--------, 1989. Inventory of Native Ecosystems in Palm Beach County, Amendment Covering Evaluation of Sites in Range 41, Townships 41, 42, and 43. Unpublished report to the Palm Beach County Commission.

Ives, J.C., 1856. Memoir to accompany a Military Map of the Peninsula of Florida South of Tampa Bay. New York: M.B. Wynkoop, Book & Job Printer.

James, P.E., 1954. Introduction: the field of geography. In American Geography: Inventory and Prospect, eds. James, P.E. and C.F. Jones. Syracuse: Syracuse University Press. pp. 2-17.

Janssen, L.L.F., and F.J.M. van der Wel, 1994. Accuracy assessment of satellite derived land-cover data: a review. Photogrammetric Engineering and Remote Sensing 60(4):419-426.

Jensen, J.R., 1983. Biophysical remote sensing. Annals of the Association of American Geographers. 73(1):111-132.

Jones, A.H., 1845. General Land Office Survey Notes, Palm Beach County, FL. Township 42, Range 42, South and East; and Township 41, Range 42, South and East. Tallahasse, FL: General Land Office.

Kushlan, J.A., 1990. Freshwater Marshes. In Ecosystems of Florida. eds. R.L. Myers and J.J. Ewel. Orlando: University of Central Florida Press. pp. 324-363.

Lin, S.S.T., 1988. Flood Management Study of the C-18 Basin. Technical Publication 88-11. West Palm Beach, FL: South Florida Water Management District.

Long, R.W., 1974. Origin of the vascular flora of southern Florida. In Environments of South Florida: Present and Past. ed. P.J. Gleason. Miami, FL: Miami Geological Society. pp. 28-36.

Lubchenco, J., et. al., 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72(2):371-412.

MacArthur, R.H., and E.O. Wilson, 1967. The Theory of Island Biogeography. Princeton, Princeton University Press.

Maffini, G., M.Arno, and W. Bitterlich, 1989. Observations and comments on the generation and treatment of error in digital GIS data. In Accuracy of Spatial Databases. eds. M. Goodchild and S. Gopal. London, Taylor and Francis. pp. 55-67.

Marble, D.F., 1990. Geographic information systems: an overview. In Introductory Readings in Geographic Information Systems. eds. D.J. Peuquet and D.F. Marble. London: Taylor and Francis. pp. 8-17

Mikesell, M.W., 1981. Continuity and Change. In The Origins of Academic Geography in the United States. ed. Blouet, B.W. Hamden, CN: Archon Books. pp. 1-15.

Morris, A., 1974. Florida Place Names. Coral Gables, FL: University of Miami Press.

National Research Council, Committee on Planetary Biology, 1986. Remote Sensing of the Biosphere. Washington, DC: National Academy Press.

Newcomb, R.M., 1969. Twelve Working Approaches to Historical Geography. Yearbook of the Association of Pacific Coast Geographers. 31:27-50.

Parker, G.G., 1974. Hydrology of the pre-drainage system of the everglades in southern Florida. In Environments of South Florida: Present and Past. ed. P.J. Gleason. Miami, FL: Miami Geological Society. pp. 18-27.

Parker, G.G., G.E. Gerguson, S.K. Love, et.al., 1955. Water Resources of Southeastern Florida. Geological Survey Water-Supply Paper 1255. Washington, DC: United States Government Printing Office.

Parker, H.D, 1987. What is a geographic information system? In Proceedings of the Second Annual International Conference, Exhibits and Workshops on Geographic Information Systems (GIS '87) October 26-30, 1987. San Francisco, CA: GIS '87. pp. 72-80.

Pierce, C.W., 1970. Pioneer Life in Southeast Florida ed. D.W. Curl. Coral Gables, FL: University of Miami Press.

Richardson, D.R., 1977. Vegetation of the Atlantic coastal ridge of Palm Beach County, Florida. Florida Scientist 40(4):281-330.

Ristow, W.W., 1966. State maps of the southeast to 1833. The Southeastern Geographer 6:33-40.

Romans, B., 1962. A Concise Natural History of East and West Florida, a facsimile reproduction of the 1775 edition. Gainesville, FL: University of Florida Press.

Sadowski, F.G., J.A. Sturdevant, and R.A. Rowntree, 1987. Testing the consistency for mapping urban vegetation with high-altitude aerial photographs and landsat MSS data. Remote Sensing of Environment 21:129-141.

Sauer, C.O., 1925. The morphology of landscape. University of California Publications in Geography 2(2):19-53.

--------, 1941. Foreward to Historical Geography. Annals of the Association of American Geographers. 31(1):1-24.

Shafer, C.L., 1990. Nature Reserves: Island Theory and Conservation Practice. Washington, DC: Smithsonian Institution Press.

Simberloff, D.S., 1974. Equilibrium Theory of Island Biogeography and Ecology. Ann. Rev. Ecol. Syst. 5:161-182.

Simberloff, D.S, and L.F. Abele, 1982. Refuge design and island Biogeographic theory: effects of fragmentation. The American Naturalist 120(1):41-50.

Singh, A., 1989. Digital change detection techniques using remotely-sensed data. Int. J. Remote Sensing 10(6):989-1003.

South Florida Water Management District, 1988. A Closer Look, Loxahatchee River and Slough Restoration Program, Phase II: Loxahatchee Slough. PIO 262 Rev. 588 5M. West Palm Beach, FL: South Florida Water Management District.

Storch, W.V. and R.L. Taylor, 1968. Some Environmental Effects of Drainage in Florida. Presented at the May 13-17, 1968, ASCE Environmental Engineering Conference at Chattanooga, Tennessee.

Story, M. and R.G. Congalton, 1986. Accuracy assessment: a user's perspective. Photogrammetric Engineering and Remote Sensing 52(3):397-399.

Strahler, A.H., C.E. Woodcock and J.A. Smith, 1986. On the nature of models in remote sensing. Remote Sensing of Environment 20:121-139.

Tebeau, C.W., 1971. A History of Florida. Coral Gables, FL: University of Miami Press.

Treasure Coast Regional Planning Council, 1991. Memorandum of August 16, 1991 Council Meeting, Local Government Comprehensive Plan Review, Agenda Item 6B4.

UNESCO, 1984. Action Plan for Biosphere Reserves. Nature and Resources 20(4):11-22.

United States Army Corps of Engineers, Jacksonville District, 1956. Central and Southern Florida Project For Flood Control and Other Purposes, Part V, Supplement 20, General and Detail Design Memorandum, Canal 18 and Control Structure 46. Jacksonville, FL: Department of the Army, Corps of Engineers.

--------, 1980. Reconnaissance Report [Stage 1], Central & Southern Florida, Canal 18, Jupiter Inlet and Loxahatchee River. Jacksonville, FL: Department of the Army, Corps of Engineers.

--------, 1982. Final Report, Environmental Investigation of the Canal 18 Basin and Loxahatchee Slough, Florida. Jacksonville, FL: Department of the Army, Corps of Engineers.

--------, 1983. Draft Feasibility Report and Environmental Assessment for Canal 18 Basin Loxahatchee Slough, Central & Southern Florida. Jacksonville, FL: Department of the Army, Corps of Engineers.

--------, 1985. Water Resources Development in Florida 1985. Jacksonville, FL: Department of the Army, Corps of Engineers.

--------, 1991. Central and Southern Florida Project, Environmental Restoration of the Kissimmee River, Florida, Draft Integrated Feasibility Report and Environmental Impact Statement. Jacksonville, FL: Department of the Army, Corps of Engineers.

United States Army Corps of Engineers, Topographic Bureau, 1839. Detailed map of Florida, based on reconnaissances of Captain John Mackay and Lieutenant Jacob Blake. Jacksonville, FL: Department of the Army, Corps of Engineers.

United States Geological Survey, 1979. Planning Document, Loxahatchee River Estuary Assessment. Revised November 1979. Washington, DC: United States Government Printing Office.

--------, 1983. 7.5 minute map series. Reston, VA: United States Geological Survey.

Vernhes, J.R., 1987. Biosphere reserves: the beginnings, the present, and the future challenges. In Proceedings of the Symposium on Biosphere Reserves, 4th World Wilderness Congress Worldwide Conservation. eds. Gregg, W.P., S.L. Drugman, and J.D. Wood. Atlanta, U.S. Dept. of the Interior. pp. 7-20.

Vignoles, C., 1977. Observations upon the Floridas, a facsimile reproduction of the 1823 edition. Gainesville, FL: University Presses of Florida.

von Droste, B., 1987. The role of biosphere reserves at a time of increasing globalization. In Proceedings of the Symposium on Biosphere Reserves, 4th World Wilderness Congress Worldwide Conservation. eds. Gregg, W.P., S.L. Drugman, and J.D. Wood. Atlanta: U.S. Dept. of the Interior. pp. 1-6.

Webb, S.D., 1990. Historical Biogeography. In Ecosystems of Florida. eds. R.L. Myers and J.J. Ewel. Orland: University of Central Florida Press. pp. 70-100.

Williams, A.C., 1962. Palm Beach County. In The East Coast of Florida, A History, 1500-1961. eds. Nance, E.C, and H. Nance. Delray Beach, FL: The Southern Publishing Company. pp. 313-332.

Williams, J.L., 1962. The Territory of Florida: or Sketches of the Topography, Civil and Natural History, of the Country, the Climate, and the India Tribes, a facsimile reproduction of the 1837 edition. Gainesville, FL: University of Florida Press.

Whittlesey, D., 1929. Sequent occupance. Annals of the Association of American Geographers 19(3):162-165.

Wolf, J.B., 1989. The Battle at the Loxahatchee River: The Seminole War. Jupiter, FL: Loxahatchee Historical Society.

Zelinsky, W., 1962. Generic terms in the place names of the northeastern United States. In Readings in Cultural Geography. eds. Wagner, P.L., and M.W. Mikesell. Chicago: The University of Chicago Press. pp. 129-156.