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**SPATIAL AND TEMPORAL PATTERNS OF TREE ISLANDS IN THE ARTHUR R.
MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE**

By

LAURA ANN BRANDT

**A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY**

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**Abstract of Dissertation Presented to the Graduate School
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**SPATIAL AND TEMPORAL PATTERNS OF TREE ISLANDS IN THE ARTHUR R.
MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE**

By

Laura Ann Brandt

December, 1997

**Chairman: Dr. Wiley M. Kitchens
Major Department: Wildlife Ecology and Conservation**

A landscape approach was used to examine the relations between patterns of tree islands and patterns of hydrologic variables in the Arthur R. Marshall Loxahatchee National Wildlife Refuge, a remnant of northern Everglades wetland. Landscape level patterns were examined using a classified satellite image. Results from analysis of the satellite image were used to design a sampling regime for analysis of current (1991) and historic (1950) patterns of tree islands using aerial photography. Tree island number, size, shape, and orientation were compared between years and between methods. Patterns of tree islands were related to the hydrologic variables flow magnitude, flow direction, hydroperiod, and ponding depth, obtained from two models designed to simulate hydrologic conditions on the post-managed (Managed Systems Model) and pre-managed landscape (Natural Systems Model).

Tree island size, shape, and orientation varied considerably throughout the study area and between methods. Small tree islands made up a larger percent of the total area covered by tree islands than did large tree islands. The orientation of elliptical tree islands was not different from the orientation of modeled historic water flows. Historically, range in hydroperiod and flow magnitudes were related to tree island shape, size, and number. Current relations between tree islands and hydrologic variables were very different from historic relations, with current hydroperiod and ponding depth related to tree island size. Percent cover of tree islands in plots closer to the canals decreased while percent cover of tree islands in plots in the interior part of the refuge increased. Changes in patterns of tree islands were correlated with changes in hydrologic variables, with larger changes in the hydrologic variables correlated with larger changes in tree island variables.

Results from this study illustrate the importance of flow magnitude as well as hydroperiod and depth in structuring the patterns of tree islands within this peat wetland. Restoration of historic hydroperiods and depths without historic flow patterns may not be sufficient to restore or maintain the historic pattern and function of the system.

CHAPTER 1 INTRODUCTION

Overview

Anthropogenic activities have changed landscape patterns world wide. Large scale human alterations change not only a landscape's appearance, but also it's function (Forman 1995). The Florida Everglades is an example of how large scale human alterations have led to changes in the appearance and function of a landscape. Once a dynamic flow-through system, the Everglades has been transformed into a series of impoundments and canals. The changes in hydrology are believed to have caused changes in vegetation communities, water storage capacity, and species diversity (Davis and Ogden 1994). Concern that changes in hydrology, and development of urban and agricultural areas are contributing to the "death of the Everglades" resulted in multi-agency efforts to develop Everglades restoration criteria. Successful restoration will not occur without an understanding of the relations between landscape change and changes in structuring processes. This study is a step toward understanding such relations. By identifying and quantifying patterns of tree islands in a remnant part of northern Everglades wetlands and relating these patterns to changes in hydrologic variables, this study provides a statistical description of patterns and their associations with process. The results of this study will provide a better understanding of the importance of hydrologic variables in structuring the

patterns of tree islands. In addition, it will provide documentation of changes through time that can be used to develop hypotheses on the linkages of pattern and process.

The framework followed (Figure 1-1) uses existing data sources available for all of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (a classified satellite image and hydrologic models) to answer the questions: Can tree islands be classified by size or shape? Do tree islands of different size or shape occur in different landscape positions? Are the differences in distribution related to hydrology and topography? The distribution of the variables measured using the imagery then are used to determine an appropriate plot size and shape, and to determine the location of sample plots for the analysis of changes in tree island patterns over time using aerial photography. Aerial photography is used to identify tree islands in sample plots that cover 10% of the refuge from 1950 and from 1991. These data are used to answer the questions: Are the 1950 patterns of tree islands correlated with pre-drainage hydrology? Are the 1991 patterns of tree islands correlated with post-drainage hydrology? Have the patterns of tree islands changed over the last 40 years? Are the changes in patterns of tree islands correlated with changes in hydrology? If the patterns of tree islands are correlated with hydrology, what are the most important hydrologic variables? This framework addresses the structure and change in a landscape, two of the three major focuses of landscape ecology (Forman and Godron 1986).

Landscape Ecology

Landscape ecology is the study of the reciprocal effects of spatial pattern on ecological processes and has developed as a means of understanding the development and dynamics of pattern in ecological phenomena, the role of disturbance, and the

characteristic spatial and temporal scales of ecological events (Urban et al. 1987).

Knowledge about the relations among the building blocks of the landscape (structure), and the functioning of the landscape as a system can be used as a basis for planning, managing, improving, and conserving lands (Zonneveld 1990). Before relations between landscape patterns and the processes can be made, the elements and the structure of the system must be ordered and described. Description of landscape elements includes the study of morphology (description of the structure and elements), classification (systematic ordering), chorology (spatial patterns and variations), and chronology (temporal variation- e.g. change over time; Zonneveld 1990). These interdependent areas provide the basis from which the structure, function, and change of landscapes can be studied.

Structure is the spatial relation or pattern of landscape elements including the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configuration of the elements. Much research has been conducted recently on the quantification of landscape patterns (see Turner and Gardner 1991), the identification of spatial units (e.g. what to quantify), development of measures that relate to ecological processes (Kepner et al. 1995), and the use of remote sensing in landscape studies (Quattrochii and Pelletter 1991, Roughgarden et al. 1991). Many studies have focused on the importance of scale in the identification of landscape patterns (Turner et al. 1989, Turner et al. 1991, O'Neill et al. 1992, Cullinan and Thomas 1992, O'Neill et al. 1995). Scale consists of both extent, the overall bounds of the study, and grain, the size of the smallest individual unit of observation. The extent and grain of a study must match the question being addressed and the features being studied or the landscape patterns will be meaningless. For example, Gardener et al. (1987) have shown that both changing the

grain and the extent can influence measured landscape patterns. In addition, patterns that appear to be ordered at one scale may appear random when viewed at other scales (Miller 1978). The development of remote sensing techniques makes it possible to conduct studies of larger extent. To be logistically feasible, studies of larger extent generally have larger grain. An understanding of the relation between patterns measured over larger extents and larger grain with patterns observed at smaller extents and finer grain will be important in our ability to link patterns and processes at multiple scales.

Function is the interaction among the spatial elements, the flows of energy, materials, and species among the elements. Spatial pattern has been shown to influence many ecologically important processes such as the spread of fire (Turner and Bratton 1985), the movement of organisms across the landscape (Wegner and Merriam 1979), species diversity (Milne and Forman 1986), and recolonization (Hardt and Forman 1989). In addition, driving forces such as hydroperiod, elevation, flow patterns, and disturbance are known to influence processes such as soil accumulation, erosion, colonization, and mortality, which in turn, influence spatial patterns such as patch size, shape, and distribution. The result is a landscape whose pattern reflects the complex interaction between structure and function.

Change is the alteration in the structure and function of the ecological mosaic over time (Forman and Godron 1986). Landscapes change naturally through succession, responses to global climate change, and in response to disturbance. Change in unmanaged landscapes usually reflects the natural periodicities in the structuring processes such as rainfall, hydrology, and disturbance. Likewise, changes observed in managed or developed systems are a reflection of the structuring processes operating under

management guidelines. Often systems are managed to reduce variability (Holling 1987) resulting in processes and patterns unlike those found in natural systems.

Understanding the relation between landscape structure, function, and change is not a simple matter. Unlike smaller scale studies, it is not possible to carry out traditional experiments where there are controls and replications. We can either conduct experiments on “landscape microcosms” with the assumption that these can be scaled up to the landscape or take advantage of “natural experiments.” The Everglades is an example of a large scale “experiment” that may help us to better understand landscape dynamics.

The Everglades

The Everglades, once a vast dynamic flow-through wetland extending from the Kissimmee chain of lakes (in central Florida) south to Florida Bay (Figure 1-2), has been severely altered during the last century. Known as the “River of Grass,” the Everglades is unlike any other river system in flow characteristics or vegetation. Historically, water flowed slowly along the shallow elevation gradient (a change of about 5 m over 200 km) from Lake Okeechobee to Florida Bay through a mosaic of aquatic slough and wet prairie. Flow rates reached a maximum of approximately 36 m per h (Holling et al. 1994) during the June to October rainy season when water upstream created a hydraulic head that pushed water south. The development of south Florida has led to the conversion of portions of the historic system to urban and agricultural uses and the conversion of the once sheet-flow system into a series of highly regulated impoundments and canals. The vast mosaic of marsh, slough, tree islands, and pinelands has been reduced to half of the historic 3.6 million ha (Davis and Ogden 1994). In addition, what remains is subject to

hydrologic regimes that, in places, bear little resemblance to pre-drainage patterns (Light and Dineen 1994).

The historic hydrological patterns were vital in maintaining the heterogeneity of the landscape which in turn contributed to the persistence and resilience of the system. The Everglades, like other ecosystems, is the product of forces such as climate, geology, hydrology, nutrient inputs, and disturbance (DeAngelis and White 1994). These driving forces operate over a range of spatial and temporal scales that interact to form the current landscape patterns. Changes in macroscale forces such as geology and climate occur over long time scales and are generally not noticeable within a human lifetime. At the other extreme, changes in microscale processes such as nutrient transfer can occur very rapidly and the consequences to wetland vegetation may be observable in a season. In between are mesoscale forces and processes that act on a scale of kilometers to tens of thousands of kilometers and over a time scale of 10 to 100 years. Hydrology is the dominant mesoscale force acting in the Everglades. It is also the force that has been most seriously altered and has caused the largest changes to the remaining vegetation in the system. Changes in hydrologic patterns have contributed to the reduction in plant community heterogeneity, the compositional change and decrease in wildlife populations, and changes in the historic functioning of the Everglades. Changes in vegetation structure and composition have been noted in many regions of the Everglades (Loveless 1959, Alexander and Crook 1984, Parks 1987, Worth 1988), however, the total extent of these changes is unknown, nor will the magnitude of the changes ever be completely understood. Restoration of the Everglades ecosystem requires an historic reference on what vegetation communities existed and in what spatial arrangement, how historic

processes contributed to the landscape patterns, and wherever possible, what the relation between anthropogenic changes in structuring processes and current landscape patterns are.

The Arthur R. Marshall Loxahatchee National Wildlife Refuge

The Arthur R. Marshall Loxahatchee National Wildlife Refuge, or Water Conservation Area 1, is a 57,234 ha remnant of northern Everglades wetland. The Loxahatchee NWR was established in 1951 to enhance populations of rare and endangered species, protect native flora and fauna, and maintain populations of wading birds and water fowl (Thompson 1970). The U.S. Fish and Wildlife Service has administrative responsibility for the area which also is used by the South Florida Water Management District to store water from agricultural fields in the wet season.

Loxhatchee NWR is located within a portion of what was historically known as Hillsboro Marsh or Hillosboro Lake (Figure 1-2), which is south and west of the Loxahatchee River and slough. Hillsboro Marsh corresponded roughly to a trough in the underlying limestone bedrock known as the Loxahatchee Channel and was part of an uninterrupted wetland extending from Lake Okeechobee to Florida Bay. This channel, running generally north-west to south-east from Lake Okeechobee to the southern end of what is now Loxahatchee NWR, was believed to act as an overflow valve for Lake Okeechobee (Gleason et al. 1984). Unlike many areas of the Everglades where there is little substrate overlaying the bedrock, the Hillsboro Marsh was an area with a deep peat base (Stephens and Jones 1951, Stephens 1984). Peat depths in Loxahatchee NWR range from 1.25 m to over 4.5 m (Richardson and Kitchens unpublished data). Distribution of

vegetation communities in Loxahatchee is correlated with the peat surface topography (Pope 1991) and includes a mosaic of sawgrass marsh, wet prairie, slough, and tree islands.

Historically, the hydrologic patterns in Loxahatchee were driven by rainfall (Parker et al. 1955). During most of the year, rain that fell directly on Loxahatchee was the primary hydrologic input. In wetter periods inputs from upstream, such as overflows from Lake Okeechobee, also were important. In fact, it may well be that these “pulse” events were as important in shaping the landscape as were the average conditions. Natural flows were generally south and east following the topography of the region (Figure 1-1).

Hydrologic changes to Loxahatchee and the rest of the Everglades started in the 1800s with the connection of Lake Okeechobee to the Calossahatchee River to the west. Additional canals and levees were constructed primarily for flood control and “reclamation” of the Everglades (Light and Dineen 1994). By 1917 four major canals (West Palm Beach, Hillsboro, North New River, and Miami) draining water from Lake Okeechobee to the east were in place and the dynamic sheet-flow from the Lake to Loxahatchee had been altered. Further hydrologic alterations occurred with the completion of the St. Lucie canal to the north in 1931. In the early 1950s (1952-1954) the eastern Levee of Loxahatchee (L-40) was constructed and by 1961 the entire Refuge was bounded by canals. The result was an impoundment in an area that had been a flow-through system. Water levels are regulated by the Army Corps of Engineers with water control structures in the north and south to match a prescribed schedule. Water enters the Refuge via the surrounding canals and pools behind the dike in the south until it is released

into Water Conservation Area 2A to the south. The result is longer hydroperiods of deeper depth in the south and shorter hydroperiods in the north.

Tree Islands

Tree islands are a dominant feature of the Everglades and of the Loxahatchee area. They have been called "...the most striking botanical feature in the Everglades" (Loveless 1959 pp. 4) and "one of the chief scenic features of the landscape" (Davis 1943 pp. 166). They represent areas of slightly higher elevation where non-wetland plants have been able to colonize. They are important ecologically as sites of high botanical species richness and as habitat for species such as wading birds, alligators, turtles, and deer.

Tree islands are an integration of many processes operating over a wide range of temporal and spatial scales. At the microscale, processes such as the deposition and removal of sediment around the island, establishment of seedlings, tree growth, and mortality dominate at time scales ranging from seconds to years. Microscale processes are influenced by higher level processes/driving forces such as hydroperiod, inundation depth, and water flow that act over a temporal scale of 1-100 years. These higher level processes are in turn influenced by events such as hurricanes, floods, and fire and by still higher level processes such as climate change and geomorphology operating on temporal scales of hundreds of years. Major differences in the magnitude or frequency of any of these processes will be expressed by different patterns on the landscape through changes in physical and biotic mechanisms. The vegetation of a particular tree island is determined by mechanisms operating on individual plants. For example, whether a tree island has a particular species will depend on the availability of a seed source and the availability of

appropriate dispersal mechanisms. Dispersal mechanisms include wind, water flow, and biotic dispersers such as bird, mammals, and reptiles. Once a seed reaches a tree island, physiological tolerances and life history traits will determine whether or not it germinates. If the tree island is too wet, does not have the appropriate nutrients or pH the seed may not be able to germinate before it dies or is moved to another location. If the seed germinates, competitive interactions among and between species, response to herbivory and extreme events such as fire, freezes, and floods will determine if the plant survives. The feedbacks between colonization, growth, competition, death, and decomposition determine the structure of the tree island.

Tree islands have been described by their general size, shape, and orientation as either small and circular; "Circular tree islands...are normally quite small in size, ranging from only about one-quarter acre to five or six acres in extent." (Loveless 1959 pp. 4) or large and elongated and oriented in the direction of flow (Davis 1943, Jones 1948, Gleason et al. 1984). It is generally thought that the interaction of topography and surface water flow resulted in the characteristic shape and orientation of the larger tree islands as is illustrated by this quote from Davis (1943 pp. 179):

The vegetation of the Tamiami Slough and tree-island area on the western side of the Everglades is definitely determined by topography and surface water conditions. On the higher parts, which are low ridges, are island-like groups of trees, and in the lower parts or sloughs there are aquatic plants and marsh vegetation. These sloughs and tree-islands are elongated in the direction of flow of the surface water. In fact the oval shaped tree-islands are "stream-lined" with their bluntest ends facing the direction of flow of the water, and they seem to have become this shape as a consequence of the direction of flow of the surface water.

Jones (1948 pp. 48) made a similar reference to tree islands in the Loxhatchee area as well as for areas farther south.

These islands are usually oval in shape, widest on the upstream end and tapering toward the lower end. The pattern that is developed therefore appears to indicate the direction in which water flowed in the past. In Hillsboro Marsh the islands point southeasterly. In the southwestern section, north of the trail they point southeasterly and south of the Trail southwesterly.

In these and in more recent writings there is discussion and speculation on the origin of these tree islands. The discussions focus on two general mechanisms for tree island formation. The first is that the tree islands have formed on peat ridges or bedrock outcrops between the sloughs (Loveless 1959). The second is that the tree islands have formed from mats of floating vegetation or peat "popups." The first is a more plausible explanation for tree islands in the lower Everglades where limestone outcrops are more common and a shallow peat layer makes it unlikely that floating peat islands could develop. It also may be a reasonable explanation for the formation of tree islands in the eastern portion of Loxahatchee, where there are more pronounced peat ridges.

The formation of tree islands from peat "popups" or floating vegetation is more likely in areas such as Loxahatchee where peats are relatively deep (3 to 4 m). There are three ways that peat "popups" might form: bulges, free floating batteries, or "gator holes". Bulges are formed when a surface layer of peat becomes separated from the deeper peat and rises to the water surface, but remains attached to the submerged peat on its periphery (Cypert 1972). Free-floating batteries occur where the peat breaks loose from the bottom and rises to the surface. They also may occur with the return of high water following a period of low water. There is some evidence that this occurs in Loxahatchee (Gleason et al. 1980). Disturbance by alligators also might result in floating peat mats. As an alligator creates its wallow the underlying substrate is pushed out of the way. This could result in either a floating peat mat or a local topographic high, either of which could lead to tree

island formation. In Loxahatchee, tree islands are often associated with alligator holes (Silveira 1996). Once these areas of peat reach the surface they can be colonized first by aquatic vegetation such as sawgrass (Cladium jamaicensis) and Eleocharis, as these plants die, the mass increases making it possible for larger more woody plants to become established. A similar successional pattern from floating mat to tree island probably occurs on the floating vegetation mats described by Davis (1943) and Jones (1948).

As illustrated above, hydrology is thought to play an important role in the distribution and form of tree islands. Alterations in the hydrology in Loxahatchee provide an opportunity to study the effects of changes in landscape patterns in relation to changes in structuring forces and to develop hypotheses concerning the linkage of pattern and process.

Dissertation Structure

The objective of this research is to identify and quantify the pattern of tree islands in Loxahatchee and to relate these patterns to selected driving forces that helped to form them. Chapter 2 describes the patterns of tree islands in Loxahatchee in relation to selected potential driving forces using a coarse view that encompasses the entire refuge. Chapter 3 addresses the problem of subsampling in a heterogeneous environment and compares the results of a coarse-scale and fine-scale analysis. Chapter 4 addresses the question of patterns of change over time by using photo plots from 1950 and 1991. These patterns are discussed in the context of current and historic hydropatterns. Chapter 5 summarizes the results of the previous chapters and discusses directions for future research.

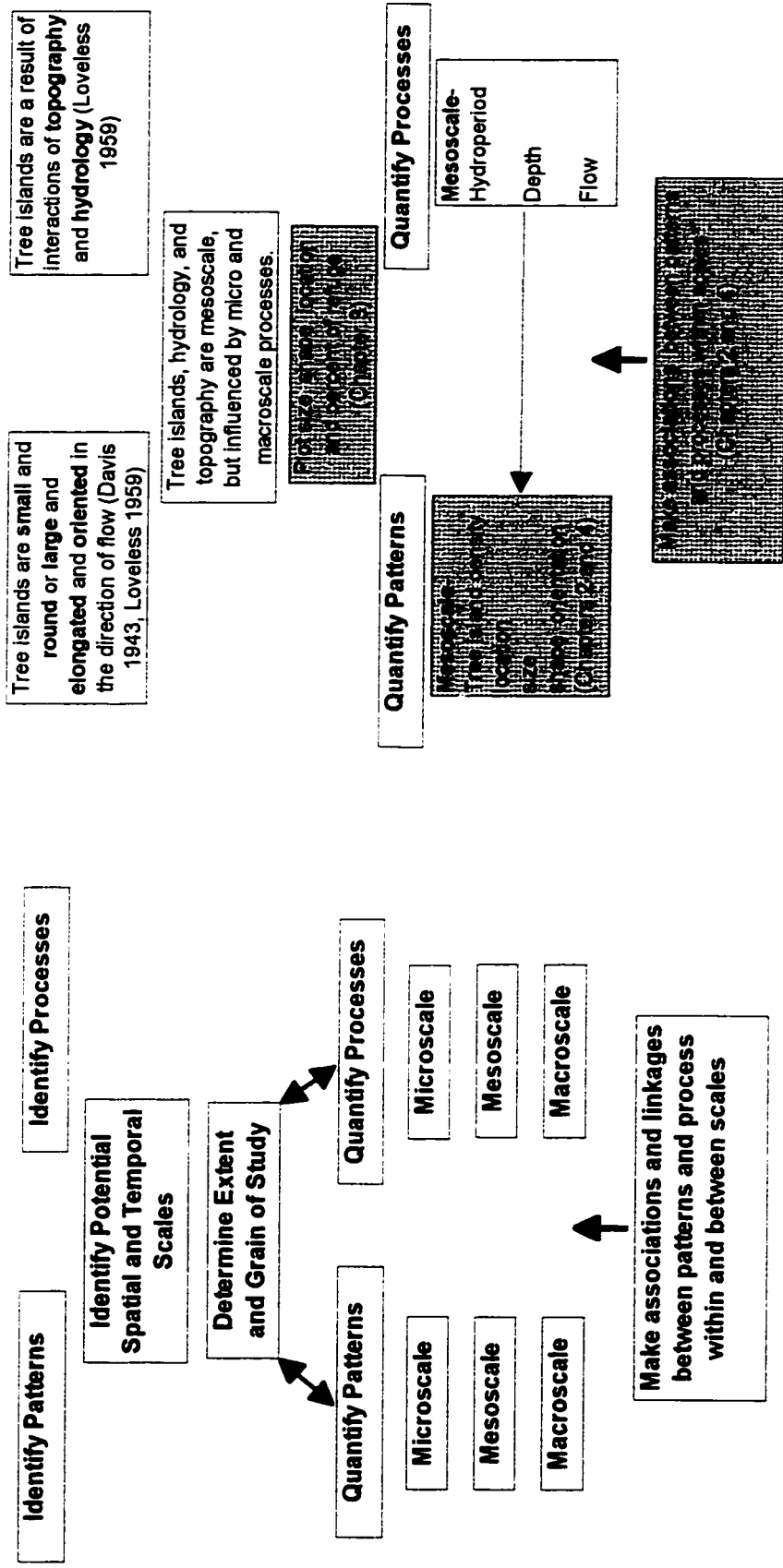


Figure 1-1. Framework for examining the relations between landscape patterns and processes (Left) and how it is applied in this study (Right). Shaded boxes indicate topics of Chapters in this work.

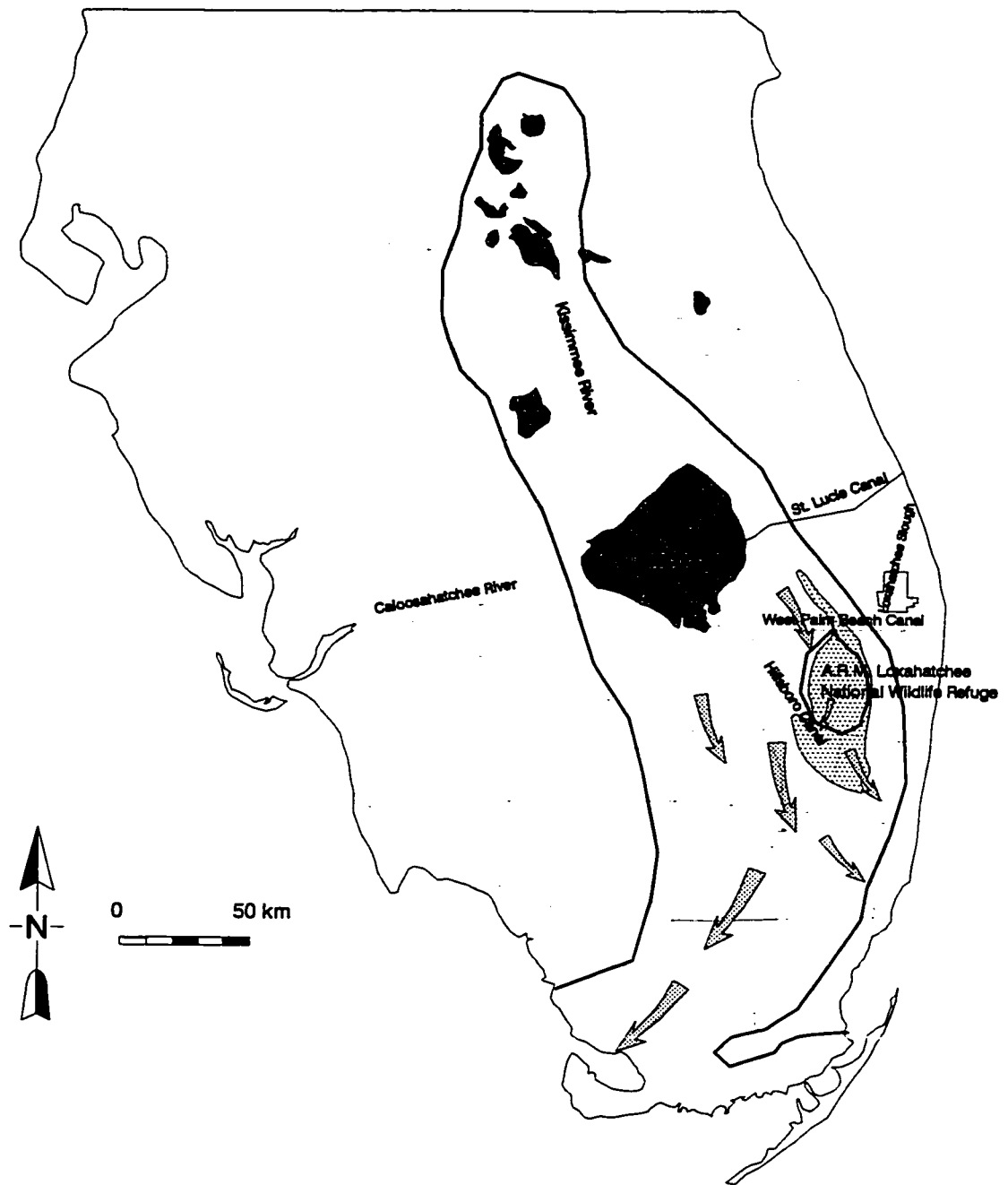


Figure 1-2. Location of Loxahatchee National Wildlife Refuge within the Everglades Ecosystem. Arrows show general direction of historic sheet flow. Shaded area indicates the extent of the historic Hillsboro Marsh. Adapted from Light and Dineen 1994 and Parker 1984.

CHAPTER 2

DISTRIBUTION OF TREE ISLANDS IN LOXAHATCHEE NATIONAL WILDLIFE REFUGE IN RELATION TO HYDROPATTERNS AND ELEVATION

Introduction

The linkage of spatial patterns and ecological processes at landscape scales has been identified as a need of both basic research and for solving applied environmental problems (Turner and Gardner 1991). Many of today's environmental issues are related to how the landscape has changed in response to changes in environmental processes, often as a result of human alteration. Evaluation of future consequences of these changes will require a landscape perspective based on identification and quantification of the linkages of pattern and process. Successful linkage of pattern and process will include: identification of the pattern, identification of the process(es), identification of appropriate temporal and spatial scales, quantification of the pattern, quantification of the process(es), identification of associations between pattern and process, and linkage of the patterns and process through causal mechanisms. Because of interactions between pattern and process, within and between scales, this is not a linear process. A framework for such investigations is presented in Figure 1-1. This framework is used in this study to investigate the potential associations between patterns of tree islands (areas of trees that occur on elevations slightly higher than the surrounding marsh) in Loxahatchee National Wildlife Refuge and hydrology.

Landscape patterns are the complex interaction of driving forces operating at different temporal and spatial scales (DeAngelis 1994, Holling 1986, 1992). Holling (1992) has proposed that the landscape forms a hierarchy that contains breaks in object sizes, object proximities, and textures at particular scales. These breaks in geometry in the landscape occur because structuring processes exert their influence over defined ranges of scale. Identification of the patterns of discontinuities in landscape structure may give us insight into the nature and scale of historic processes operating on the landscape and help us to assess the impacts of changes to these processes.

Tree islands are a predominant landscape element in the Everglades. They provide habitat for a wide range of species including alligators, wading birds, and deer and have been called “the most striking botanical feature in the Everglades” (Loveless 1959 pp. 4) and “one of the chief scenic features of the landscape” (Davis 1943 pp. 179). These and other authors have noted the general shape and orientation of these islands to be small and circular; “Circular tree islands...are normally quite small in size, ranging from only about one-quarter acre to five or six acres in extent.” (Loveless 1959 pp. 4) or large and elongated and oriented in the direction of flow (Davis 1943, Jones 1948, Gleason et al. 1984). There is geographic variation in the size and shape of tree islands throughout the Everglades. Tree islands in the central part of the lower Everglades are large and teardrop shaped (Wade et al. 1980), while small circular tree islands are prevalent in Loxahatchee and in the marl prairies of the lower eastern Everglades. Large elongated strand tree islands occur in Loxahatchee and in the other Water Conservation Areas. Though the origin of tree islands is not well understood, it is generally thought that the

interaction of topography and surface water flow resulted in the characteristic shape and orientation of the tree islands (Davis 1943; Jones 1948).

Teardrop-shaped tree islands are thought to have formed on pockets of soil that accumulates downstream of bedrock outcrops or other obstructions. Their characteristic tail is formed as a result of soil accumulation as dictated by water flow magnitude and direction. There are several hypotheses for the formation of strand tree islands including Egler's (1952) suggestion that the entire Everglades basin was a continuous swamp forest and that fire restricted tree islands to their present locations. Similar degenerative processes are believed to have structured the majority of tree islands in the boreal peatlands, where there is evidence that forested areas have been replaced with wetlands through flooding and erosion (Glaser 1987). Little evidence exists for such processes operating in the Everglades. Other hypotheses of tree island development focus on additive processes rather than degenerative processes. Elongated tree islands are believed to have developed as a result of a general trend of emergence from long-flooded marsh to occasionally-flooded bayhead (Gleason and Stone 1994), while smaller more circular tree islands may have formed in relation to solution features that produced local ponded areas that developed peat deposits as a result of hydrophytic community structure (Robertson 1953).

It also has been suggested that small round tree islands in Loxahatchee and other deeper peat areas such as the Okeefenokee Swamp in Georgia, are related to the development of floating mats (Gleason and Stone 1994). Patterns of tree islands in some of the prairie regions of Okeefenokee appear similar to those in Loxahatchee, though they do not have the characteristic alignment that is observed in the Loxahatchee islands. This

difference in patterns may be due to differences in water flow patterns. Okefenokee experiences very little flow while Loxahatchee, at least historically, experienced sheet-flow especially during the wet season.

If tree islands of different types are a consequence of different hydrologic processes, changes in hydrologic variables may affect the patterns of formation and development of tree islands of different types. Hagenbuck et al. (1974) suggested that longer hydroperiods might favor the development of tree islands formed from peat batteries by allowing detritus to build up as a loose mat. This unattached mat would be more prone to becoming free-floating and promote the formation of “popup” battery tree islands. At the same time, longer hydroperiods and deeper depth might drown lower-elevation tree islands.

To assess the potential impacts of altered hydrology (including flow magnitude and direction, inundation depth, and length of inundation) on tree islands of different types at the landscape scale we must first have some way of distinguishing different types of tree islands. Types may be distinguished by form, position, distribution, or association with other tree islands. Once types have been identified their occurrence in the landscape can be related to environmental variables to assess the relations between pattern and process.

The pattern of landscape elements is a result of driving forces operating at a wide range of temporal and spatial scales. In the case of tree islands it has been hypothesized that topography and hydrology are the primary driving forces that have shaped the distribution and form of the tree islands. Here these hypotheses are addressed by examining the distribution of tree islands in relation to environmental variables in a deep peat wetland in the Everglades. Specifically, the following questions are addressed: Can

tree islands in Loxahatchee be classified by size or shape? Are there differences in the distribution of tree islands of different types? Can differences in distribution and type of tree islands be related to hydrologic and topographic variables?

Methods

Study Site

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Loxahatchee) is a 57,324 ha area of northern Everglades wetlands. Located in Palm Beach County, Florida, south and east of Lake Okeechobee (Figure 1-1), it was once a connected part of the historic Everglades system. Loxahatchee is located over the Loxahatchee Channel, a shallow peat-filled depression extending from Lake Okeechobee south and east that may have acted as an overflow valve for Lake Okeechobee, shunting water east and south (Gleason et al. 1984). Changes to the flow patterns in and around Loxahatchee started as early as the 1800s with the construction of the Caloosahatchee canal, which moved water to the west from Lake Okeechobee and continued with the completion of the St. Lucie canal, which moved water to the east from Lake Okeechobee, in 1931. Additional changes occurred with the completion of the Hillsboro Canal in the 1920s and with the complete enclosure of the area by the L-7 canal on the west and the L-40 canal on the east during the 1950s (Light and Dineen 1994). The construction of these canals changed a once-dynamic flow-through system to an impounded marsh with the majority of non-rainfall inputs being shunted around the marsh via the exterior canals.

Loxahatchee is a peat-based marsh system consisting of a mosaic of sloughs and wet prairie to sawgrass, brush, and tree islands. Tree islands are one of the dominant

features of the landscape and provide habitat for a large number of wildlife species including deer, alligators, and wading birds.

Hydrology and Elevation

Data on hydroperiod, water depth, flow direction, and magnitude were obtained from the South Florida Water Management District. Data are from two models: the Natural Systems Model version 4.4 (NSM) which simulates the hydrologic response of pre-drainage south Florida using climatic data from 1965-1990 (Fennema et al. 1994), and the South Florida Water Management Model (WMM) which was developed to simulate the hydrology of the water management system in south Florida (MacVicar et al. 1984). Both models have a grid cell size of 3.2 km x 3.2 km (2 miles x 2 miles). Grid cells are referred to as hydrology zones throughout this text. Depth, flow direction and magnitude are the yearly average values for each hydrology zone calculated over the entire period of record (1965-1990). Direction was standardized to 0-180 degrees to match the range used for the tree island orientation and then transformed using $\tan(\theta/2)$. Two variables were used to represent hydroperiod: the first was the 90% hydroperiod or the hydroperiod that was exceeded in 90% of the 26 years. The second hydroperiod variable was range in hydroperiod. This was used to reflect the variability among the hydrology zones.

The topographic surface generated by Richardson et al. (1990) for Loxahatchee NWR was used for this analysis. The grid cell resolution of this surface was 183 m x 183m. The 3.2 x 3.2 km cell boundaries for the hydrology models were overlain on the elevation surface and average elevation and elevation gradient were calculated for each zone of the hydrology model.

Identification and Characterization of Tree Islands

Tree islands were identified from an existing land cover classification for Loxahatchee developed from merged, HIS transformed, 10 m panchromatic data and 20 m SPOT data (Richardson et al. 1990). Details of the classification methods are available in Richardson et al. 1990. Two tree island classes described as “lower stature tree island community made up of a mix of wax myrtle (Myrica cerifera), dahoon holly (Ilex cassine) and red bay (Persea borbonia)”, and “core of larger tree islands, larger stature trees made up primarily of dahoon holly and red bay...” (Richardson et al. 1990 pp. 40) were used in this analysis (Figure 2-1). Fragstats (McGarigal and Marks 1995) was used to calculate area, perimeter, nearest neighbor (edge to edge), and proximity index for each tree island. The proximity index quantifies the spatial context of a tree island in relation to its neighbors. The index equals the sum of tree island area divided by the nearest edge-to-edge distance squared between the tree island of interest and all tree islands within a 500 m radius (McGarigal and Marks 1995). All other things being equal, a tree island located in an area with more tree islands will have a larger index value than one located in an area with fewer tree islands. Tree islands > 0.04 ha were classified as circular, elliptical, or irregular using a combination of a circularity index (Miller 1953) and ellipse index. These indices are the ratio of the area of the tree island to the area of a circle or ellipse respectively given the same long axis and secondary axis. Tree islands with a circularity index of 0.5 or larger were considered circular. Tree islands with a circularity index < 0.5 were elliptical if their ellipse index was >0.6 and < 2.5. All remaining tree islands were classified as irregular. Orientation was determined for elliptical tree islands by calculating the direction of the long axis using a program developed in S-plus (Statistical Sciences,

Inc. 1995). Orientation ranges from 0 to 180 with 0 as north and 180 as south. No attempt was made to distinguish the leading edge of the tree island from the trailing. Orientations were transformed using $\tan(\theta/2)$ for analysis with the linear variables.

Analysis

Because the data did not meet the assumption of normality, the following transformations were performed prior to analysis: number of tree islands = $\sqrt{\text{number of tree islands}}$; long axis = $\ln(\text{long axis})$.

To test if significant size groups of tree islands (total area and long axis) could be identified I used methods developed to examine the discontinuities in body mass (Holling 1992). Holling (1992) has proposed that processes that operate at different scales differentially structure the landscape and that this lumpy structure is reflected throughout the ecological hierarchy from species body mass distribution to landscape physiography. To test this, several methods have been developed. The first is the Body Mass Difference Index (BMDI), the second is the Gap Rarity Index (Marples unpublished). Though these primarily have been used in the analysis of species body-mass distributions they should be able to identify clumps in any size-related variable. Tree island area was used because it is analogous to body mass, reflecting an integration of a range of processes, and long axis because it may more directly reflect the processes relating to water flow that have shaped the tree islands.

The BMDI was used on a ranked list of log tree island size (ha) and is calculated as $BMDI = (S_{n+1} - S_n) / (S_n)^x$ where S_n is the size of the nth tree island in the ordered list and x is an exponent sufficient to detrend the data. The results are plotted as a histogram showing the differences between adjacent sizes. Large differences indicate a relatively

large difference between adjacent sizes. Very large differences suggest gaps between sizes.

The Gap Rarity Index compares each data set to a random sample drawn repeatedly from a continuous null distribution (bootstrapping). The output of the Gap Detector is a discontinuity distribution value (D-value) for each size. Gaps in the size distribution are indicated by high values. The advantage of this method is that the D-distribution has known statistical properties that allow for an assignment of a significance value, in this case 0.05.

Comparisons between tree island variables of different size or shapes were made using a Wilcoxon Test. Relations among individual variables were examined using correlation analysis. Comparison of distributions were done using a Kolmogorov-Smirnov goodness of fit test. Paired-t-tests or Signed-rank tests were used to compare variables summarized by cell.

The relations between tree island variables (mean size, mean long axis, number of circular and number of elliptical tree islands per cell, or number of tree islands of different size by cell) and hydrologic variables (NSM magnitude, NSM hydroperiod, NSM depth, NSM range in hydroperiod, WMM magnitude, WMM hydroperiod, WMM depth, WMM range in hydroperiod, mean elevation, and elevation gradient) were examined using canonical correlation analysis. Canonical correlation analysis is used to investigate the relationship between two sets of variables by deriving a linear combination of the X variables ($U = aX_1 + aX_2 + \dots + aX_i$) and a linear combination of the Y variables ($V = aY_1 + aY_2 + \dots + aY_i$) such that the correlation between U and V is as large as possible (Manly 1986). A non-significant result indicates that the largest canonical correlation can be

accounted for by sampling variation alone. Canonical correlation combines the multiple variables into a single index variable (U or V). Examination of the coefficients of the individual variables that make up U or V indicates the contribution of that variable to the overall index. Variables with higher coefficients are more important. In these analyses the hydrologic variables are the X variables and the tree island variables are the Y variables.

Statistical analysis was done using S-plus (Statistical Sciences, Inc. 1995), SAS (SAS Institute Inc. 1989), or SigmaStat (Fox 1994).

Results

Hydrology and Elevation

Hydrologic variables were significantly different between the NSM and WMM. Flow direction by grid cell for the NSM and WMM averaged $187.2 \pm$ a standard deviation of 26.9 and 200.1 ± 51.32 respectively and were significantly different (Signed-rank-test, $p=0.028$, $W=-443.0$). Flow magnitude, average hydroperiod and depth, and range in hydroperiod for the NSM and WMM were significantly different (Paired t-test, $p<0.01$, $t=23.3$; Wilcoxon signed-rank-test, $p=0.0001$, $z=3.8158$; $p=0.0032$, $z=2.9525$; $p=0.0011$, $z=-3.2536$; Figure 2-2). For both models cell hydroperiod and depth were highly correlated ($p=0.0001$, $r=0.91$ and $r=0.96$, for NSM and WMM). Hydroperiod and depth were not correlated between the models. Mean cell elevation was highly correlated with WMM hydroperiod and depth ($p=0.0001$, $r=-0.93$ and $r=0.91$), but not with NSM hydroperiod and depth. NSM hydroperiod range was highly correlated with NSM hydroperiod and depth ($p=0.001$, $r=-0.89$ and $r=-0.88$), but WMM hydroperiod range and WMM hydroperiod and depth were not.

Tree Islands

Tree island variables were examined for all tree islands, for tree islands of different shapes and, for tree islands of different size based first on area and then by length. The land cover classification revealed two thousand one hundred forty four tree islands that ranged in size from 0.01 ha to 61.97 ha. Twenty-five percent of the tree islands were < 0.02 ha, 48% $\leq$ 0.04 ha and 75% < 0.15 ha. The distribution of tree island sizes showed many small tree islands and few larger tree islands (Figure 2-3). The distribution of sizes did not fit any of the common distributions (normal, log normal, poisson, exponential, or weibul). Fifty percent of the tree island area was made up of tree islands < 6.22 ha. This is 89% of the observed tree islands.

Nearest neighbor distance averaged 103 ± 152 m and proximity index 80 ± 422 . There was a strong geographic trend in the distribution of tree islands. The general trend reflected more tree islands in the northwest than southwest and more in the east than the west (Figure 2-4).

Six hundred thirty three of the tree islands larger than 0.04 ha met the criteria for being elliptical and 335 as being circular. Circular tree islands were significantly smaller than elliptical tree islands (Wilcoxon rank-sum, $p=0$, $z=-19.2772$). No circular tree islands were > 0.6 ha. Circular tree islands had significantly closer nearest neighbors (mean = 126 ± 150 versus 106 ± 168 m; Wilcoxon rank-sum, $p=0$, $z=5.548$) and had a significantly smaller proximity index than elliptical tree islands (mean 22 ± 168 versus 32 ± 332 ; Wilcoxon rank-sum, $p=0$, $z=-4.090$). There was no difference in the spatial distribution of circular and elliptical tree islands in either the east to west direction or the north to south direction. There was a significant difference in the spatial distribution of smaller (< 0.6 ha)

elliptical tree islands and larger elliptical tree islands in the east to west direction (Kolmogorov-Smirnov goodness-of-fit test; $p=0.00$, $ks = 0.2233$), but not in the north to south direction. Orientation of elliptical tree islands averaged 168.87 degrees with a circular standard deviation of 59.35 degrees. The distribution was not normal, with the majority of the orientations between 150 to 180 degrees and 0 to 50 degrees. Tree islands < 0.6 ha had significantly different orientations than those > 0.6 ha (166.78 ± 66.23 and 172.37 ± 40.86 respectively; $p=0.03$, $F=4.79$). Mean tree island orientation per grid cell was not significantly different from the flow orientation by grid cell for the NSM; however, the difference between the mean tree island direction and the model direction varied by hydrology zone (Figure 2-5). Mean tree island orientation by grid cell was significantly different than the flow orientation by grid cell for the WMM (Signed-rank-test $p=0.00$, $W=-769$).

Elliptical tree islands were not at significantly different elevations than circular tree islands. However, elliptical tree islands > 0.6 ha occurred at significantly lower elevations than smaller elliptical tree islands (one-sided Wilcoxon test, $p=0.009$, $z=2.7055$) and circular tree islands (one-sided Wilcoxon test, $p=0$, $z=-2.7000$). Elliptical tree islands < 0.6 ha and circular tree islands were not in significantly different elevations.

The two methods of clump analysis revealed similar results for both area and long axis. Four potential clumps were identified in the area data (< 1.73 ha, 1.9 to 3.41 ha, 3.82 to 4.61 ha, and > 5.10 ha) and 3 main clumps in the long-axis data (< 40 m, 45-351 m, and 386-1173 m) Figure 2-6 and 2-7.

Summary statistics for the different sized tree islands are presented in Table 2-1. Nearest neighbor distances and the proximity index were significantly different among the

area size classes (Kruskal-Wallis test, $p = 0$, $X^2=62.6269$, $df = 3$; $p=0.001$, $X^2=20.3405$ respectively) and among length size classes (Kruskal-Wallis test, $p = 0$, $X^2=54.81$, $df = 2$; $p=0.001$, $X^2=17.69$ respectively).

Orientation of tree islands were not significantly different among area sizes classes, but were significantly different among length size classes (Kruskal-Wallis test, $p=0.0017$, $X^2=12.735$, $df=2$).

Spatial distribution of tree islands of all size groups, by area, and by length, were significantly different in the east to west direction (Kruskal-Wallis test, $p = 0$, $X^2=28.439$, $df = 3$; $p=0$, $X^2=37.35$, $df = 2$ respectively), but not the north to south direction.

The canonical correlation of the hydrology variables (NSM magnitude, NSM hydroperiod, NSM depth, NSM range in hydroperiod, WMM magnitude, WMM hydroperiod, WMM depth, WMM range in hydroperiod, mean elevation, and elevation gradient) and the tree island variables (mean size, mean long axis, number of circular and number of elliptical tree islands) yielded two significant correlations between the linear combination of the hydrology variables (hydrology index) and the linear combination of the tree island variables (tree island index) ($p = 0.0001$, $r = 0.82$; $p = 0.01$, $r = 0.71$ respectively). Fifty-eight percent of the variability in the first linear combination was explained. An additional 28% of the variability was explained by the second correlation. The hydrology variables most associated with the first canonical index were WMM depth and mean elevation. The tree island variable mean long axis was most associated with the first tree island canonical index (Table 2-2). The second hydrology canonical index represented a contrast between NSM depth and NSM hydroperiod and magnitude while the second tree island canonical index was associated with tree island area.

Similar results were obtained when the tree island variables number of short, medium, and long tree islands (number by length class) or number of small, medium, large, or extra large tree island (number by area class) were used instead of number of circular or elliptical tree islands in the canonical analysis. In both analyses there were two significant correlations ($p = 0.0001$, $r = 0.82$; $p = 0.01$, $r = 0.71$ for number by length class and $p = 0.0003$, $r = 0.81$; $p = 0.04$, $r = 0.74$ for number by area class) that explained 76 and 77% of the variability respectively. In both analyses, the first hydrology canonical index was described by WMM depth and elevation respectively and the second by the contrast between NSM depth and NSM hydroperiod and magnitude. The first tree island canonical index for the length class analysis described the number of small tree islands while the second described the mean length and area of tree islands. The first tree island canonical index for the area class analysis described the number of small tree islands while the second described the length and the number of small tree islands.

To summarize, the three analyses indicated basically the same pattern. The variables of WMM mean water depth and mean elevation are highly associated with the occurrence of small tree islands, and the contrast between NSM depth, NSM hydroperiod, and magnitude are highly associated with tree island size.

Discussion

Our ability to manage and restore ecosystems depends in part on our understanding of the association and linkages between pattern and process. This study is a first step in the process of linking hydrologic variables to the spatial distribution and size of tree islands, a dominant ecologically important element in the Everglades landscape.

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Tree islands in this area of the Everglades can be grouped by shape or size. This study indicates that the distribution of tree islands of different types are related to hydrologic conditions. This provides us with a landscape level tool that can be used to evaluate the potential effects of alternative management scenarios.

Size rather than shape seems to be a better variable for characterizing the differences in the relationship of environmental variables and types of tree islands. Circular tree islands are always small (< 0.6 ha). Elliptical tree islands occur in a range of sizes. Small elliptical tree islands occur in positionally similar locations in the landscape as circular tree islands. Tree islands of different lengths show the most separation spatially with most of the long tree islands found on the east side of the refuge in the area historically categorized as the "wet prairie, tree island, aquatic slough-lakes" (Hagenbuck et al. 1974).

Identification of potential clumps in the tree island size distributions provides the starting point for examining ecological differences among tree islands of different types. Larger, elongated tree islands may be ecologically different than the smaller tree islands. Different size or shaped tree islands may have different origins, different vegetation composition and structure, and may respond differently to changes in water management. Numerous authors have indicated that large tree islands are lower in elevation and have vegetation that is more tolerant to flooding than small tree islands. None of these authors have defined large. Based on the clump analysis performed here, large tree islands in Loxahatchee are > 350 m in length and/or > 3.8 ha in area, while small tree islands are ≤ 40 m in length and/or < 1.73 ha. The next step is to test the hypothesis that tree islands in

the different size classes are different in species composition, vegetative structure and wildlife use by conducting field studies.

Tree islands are an expression of processes operating at a range of temporal and spatial scales. The current distribution of tree islands is undoubtedly related to historic conditions and current conditions as has been shown in the canonical correlation analysis. Current mean ponding depth and elevation are strongly associated with the number of small tree islands. As ponding depth decreases the number of small tree islands decreases. This may be a reflection of two ongoing processes. The first is the expansion of tree islands in the shallower areas. Higer and Kolipinski (1987) noted that in Shark Slough shorter periods of inundation corresponded to an increase in the growth of woody vegetation. This appears to be what is happening in the northern portion of Loxahatchee. The second process is the drowning of tree islands in the lower elevation areas. The elevation gradient in Loxahatchee is generally north to south. The lower elevation areas in the south end of the refuge have experienced the greatest changes in hydrology. A primary result has been the destruction of tree islands due to high water (Richardson et al. 1990). The association of lower elevation areas with lower numbers of small tree islands may simply be a reflection of the lack of tree islands in these areas in general.

Of secondary importance in explaining the relations between the hydrologic and tree island variables were the association between NSM volume, hydroperiod, and depth and the size and number of tree islands. The association of shorter tree islands with areas of higher historic flow was unexpected. It was expected that longer tree islands would be found in areas of higher flow. It may be that areas that had higher historic flow also experienced the most extreme ranges in flow magnitudes and that it is the extremes that

have more of an influence on the tree island size and shape than the average flow. It also may be that the true length of the tree islands was not measured in this analysis. The vegetation classes used are the vegetation classes that make up the core area of the tree island and do not include the lower brush areas that can be associated with tree islands, particularly the downstream tails (Ward et al. 1980). Had those brushy areas been included in the calculation of tree island long axis the results may have been different.

The orientation of elliptical tree islands gives an indication of historic flow patterns and is consistent with the predictions of the NSM. This relation, along with the association between historic flow magnitudes and form and number of tree islands has implications for the prediction of future hydrologic modifications. Primary focus of restoration efforts have been on establishing appropriate hydroperiods and depth. In as little as five years, changes in hydropatterns can cause changes in herbaceous vegetation (Hagenbuck et al. 1974). Changes in water depth can drown tree islands in a matter of years. Relatively little research has been conducted on the influence of changes in flow direction and magnitude in the Everglades system. Flow magnitude and direction have a significant effect on nutrient, sediment and debris transport which in turn influences tree island form and function. Though changes may not be evident over the short term, patterns of tree islands in Loxahatchee are predicted to change in response to the changes in flow dynamics, becoming less oriented in the direction of historic flow and more randomly distributed. A study comparing patterns of tree islands in 1950 to patterns of tree islands in 1991 is currently underway to see what changes have occurred in 40 years.

In interpreting the results of this study several factors relating to the sources and scales of the data sets must be considered. The NSM predicts pre-drainage conditions

based on data from 1965-1990. By 1965 extensive drainage had already occurred in south Florida so NSM values do not represent true historic conditions, but rather a “best guess”. The models used for this analysis were designed to show general patterns across the south Florida ecosystem, and may not be appropriate when analyzed on a cell by cell basis. As such, the 3.2 x 3.2 km grid cell size is very coarse in relation to the processes operating on individual tree islands. The assumption has been made that the tree island values of size, shape, and orientation summarized by cell are related to average hydrology values within each cell. Additionally, the method used for identifying tree islands has the disadvantage that it was created for another purpose in which tree islands were not the focus. Satellite imagery allows for classification of large areas, but has the disadvantage that the elements identified are a function of the pixel size and shape. Only elements whose sizes are multiples of pixel sizes can be properly identified. This can obscure the relation between size of the element and environmental variables. Elements (tree islands) smaller than the minimum pixel resolution will not be identified, and boundaries of elements larger than the minimum resolution may be obscured. A study examining the relation between tree island patterns (size, shape, orientation, and spatial distribution) distinguished from different media is currently underway.

Despite these methodological problems, this study provides insight and quantification of the relation between tree island size, shape, and distribution, and environmental variables. These results support hypotheses on the differentiation of tree islands by size and provides a rough idea of where to start looking for tree islands of specific characteristics. The ability to use landscape level tree island characteristics (length, area, orientation, and location) as indicators of differential ecological characteristics

(elevation and vegetation and hence ecological function) provides us with a valuable tool for evaluating alternative management scenarios.

Table 2-1. Summary statistics for tree islands in Loxahatchee National Wildlife Refuge identified from satellite imagery.

Size Class	n	Median nearest neighbor distance (m)	Mean nearest neighbor distance (m) ±SD	Median proximity index	Mean proximity index ±SD	Mean orientation (degrees)
Small area ≤ 1.73 ha	983	63.0	116.7±157.5	1.2	31.8±292.3	145.5
Medium area 1.74-3.82 ha	34	9.0	72.1±237.7	2.4	4.2±5.5	159.4
Large area 3.83-5.10 ha	6	23.1	78.5±123.7	0.9	1.64±1.8	173.5
Extra large area > 5.10 ha	32	9.0	21.4±30.3	5.5	12.8±20.2	171.9
Small length ≤ 40 m	336	71.5	109.9±135.2	1.1	65.8±481.3	133.7
Medium length 41-351 m	670	56.9	119.6±173.0	1.3	13.8±92.5	150.4
Large length > 351 m	49	9.0	25.4±50.3	3.6	10.0±17.1	168.6

Table 2-2. Canonical variables for analysis using shape classes. Most significant coefficients are bold faced.

U1 = -0.06 NSM magnitude + -1.12 NSM hydroperiod + 0.71 NSM depth + -0.56 NSM hydroperiod range + -0.13 WMM magnitude + 0.96 WMM hydroperiod + **-3.66 WMM depth** + -0.58 WMM hydroperiod range + **-3.07 Mean elevation** + 0.39 Elevation gradient.

V1 = 0.11 Mean long axis + 0.01 Mean area + **-0.88 Number of circular tree islands** + -0.13 Number of elliptical tree islands.

U2 = **-1.03 NSM magnitude** + **-1.14 NSM hydroperiod** + **1.60 NSM depth** + -0.22 NSM hydroperiod range + -0.22 WMM **magnitude** + 0.87 WMM hydroperiod + -0.16 WMM depth + 0.31 WMM hydroperiod range + -0.03 Mean elevation + -0.43 Elevation gradient.

V2 = **0.42 Mean long axis** + **0.64 Mean area** + 0.33 Number of circular tree islands + 0.16 Number of elliptical tree islands.

Table 2-3. Canonical variables for analysis using length classes. Most significant coefficients are bold faced.

U1 = -0.06 NSM **magnitude** + -1.03 NSM hydroperiod + 0.57 NSM depth + -0.84 NSM hydroperiod range + -0.14 WMM **magnitude** + 0.95 WMM hydroperiod + **-3.41 WMM depth** + -0.50 WMM hydroperiod range + **-2.94 Mean elevation** + 0.45 Elevation gradient.

V1 = -0.001 Mean long axis + 0.05 Mean area + **-0.74 Number of short tree islands** + -0.34 Number of medium tree islands + 0.17 Number of long tree islands.

U2 = **-1.09 NSM magnitude** + **-1.31 NSM hydroperiod** + **1.65 NSM depth** + -0.14 NSM hydroperiod range + -0.30 WMM magnitude + 0.80 WMM hydroperiod + -0.18 WMM depth + 0.31 WMM hydroperiod range + -0.34 Mean elevation + -0.42 Elevation gradient.

V2 = **0.63 Mean long axis** + **0.59 Mean area** + 0.28 Number of short tree islands + 0.02 Number of medium tree islands + -0.28 Number of long tree islands.

Table 2-4. Canonical variables for analysis by area classes. Most significant coefficients are bold faced.

U1 = -0.33 NSM magnitude + -1.16 NSM hydroperiod + 0.91 NSM depth + -0.71 NSM hydroperiod range + -0.20 WMM magnitude + 0.88 WMM hydroperiod + **-3.08 WMM depth** + -0.27 WMM hydroperiod range + **-3.03 Mean elevation** + 0.29 Elevation gradient.

V1 = 0.14 Mean long axis + 0.15 Mean area + **-0.96 Number of small tree islands** + -0.14 Number of medium tree islands + 0.19 Number of large tree islands + 0.01 Number of extra large tree islands.

U2 = **1.17 NSM magnitude** + **1.48 NSM hydroperiod** + **-1.74 NSM depth** + -0.01 NSM hydroperiod range + -0.26 WMM magnitude + -0.16 WMM hydroperiod + -0.65 WMM depth + -0.66 WMM hydroperiod range + 0.15 Mean elevation + 0.51 Elevation gradient.

V2 = **-0.90 Mean long axis** + -0.28 Mean area + **-0.78 Number of short tree islands** + 0.55 Number of medium tree islands + 0.31 Number of long tree islands + 0.09 Number of extra large tree islands.

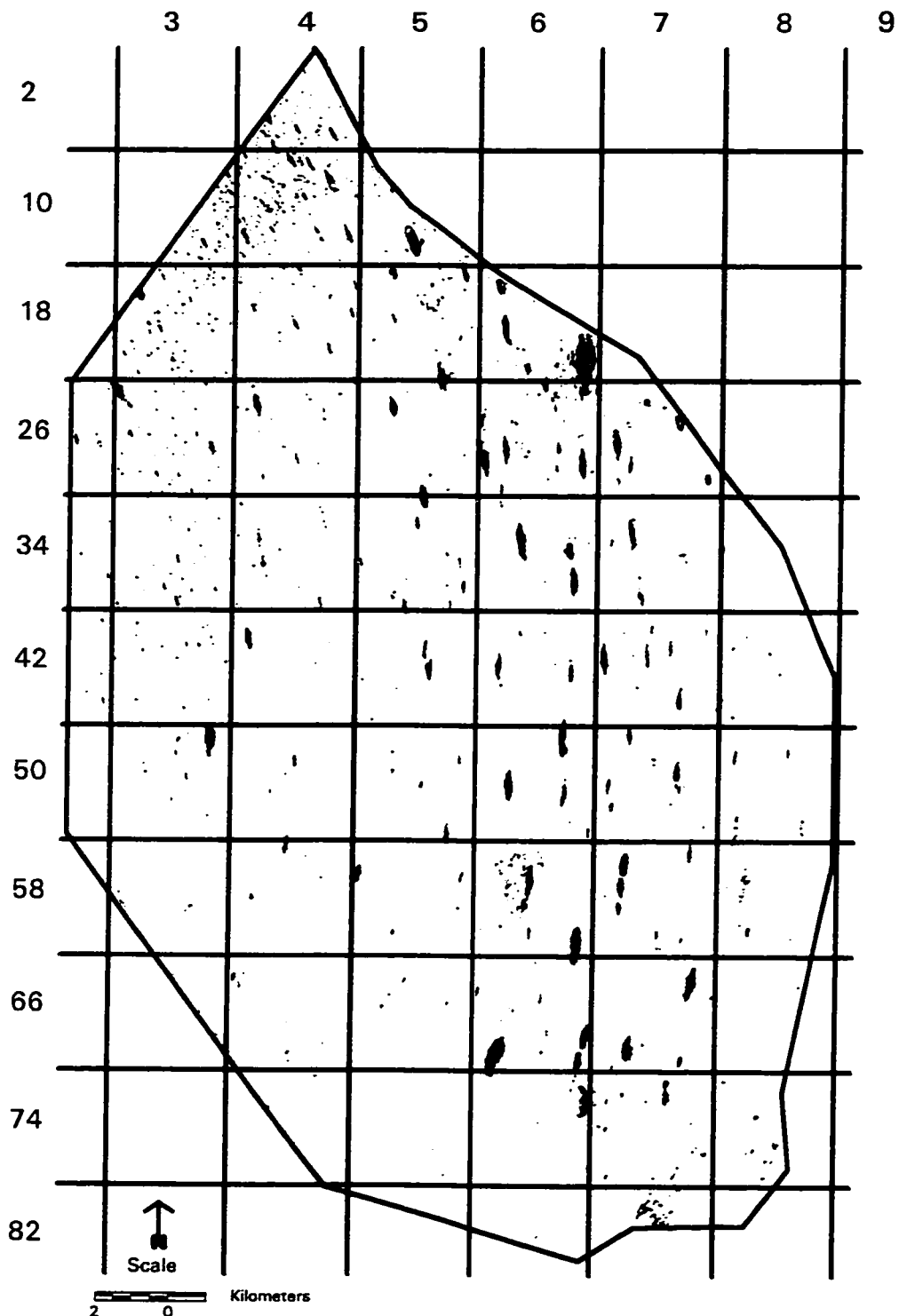


Figure 2-1. Hydrology zone boundaries overlain on tree islands identified from satellite image classification of Loxahatchee National Wildlife Refuge. Classification is from Richardson et al. 1990. Hydrology zones are numbered left to right from 2 to 89. See Appendix A for correspondence with overall NSM and WMM row and columns.

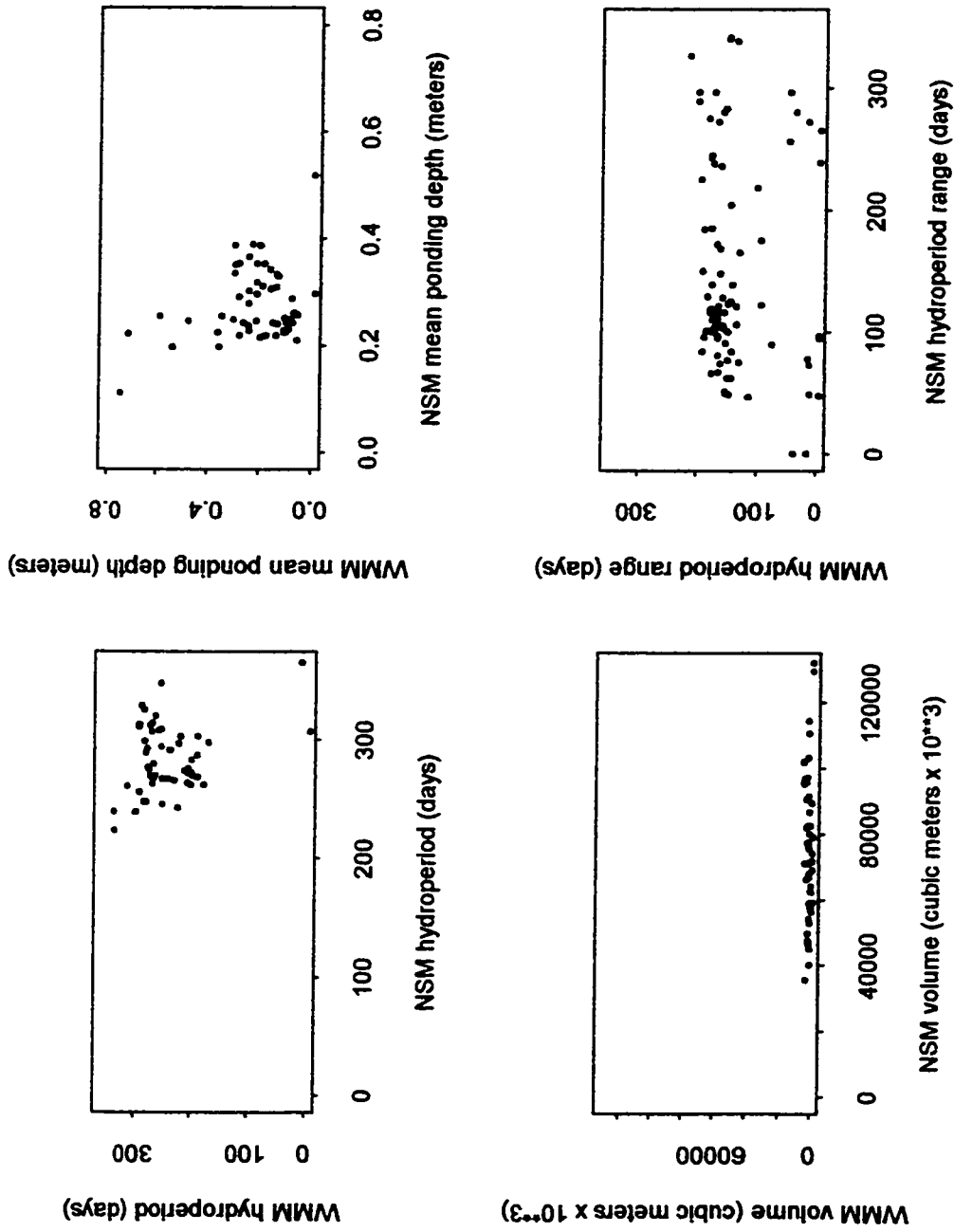


Figure 2-2. Relation between hydrologic variables in the Natural Systems Model (Fennema et al. 1994) and the Managed Systems Model (MacVicar et al. 1984). Values are average values for data from 1965-1990.

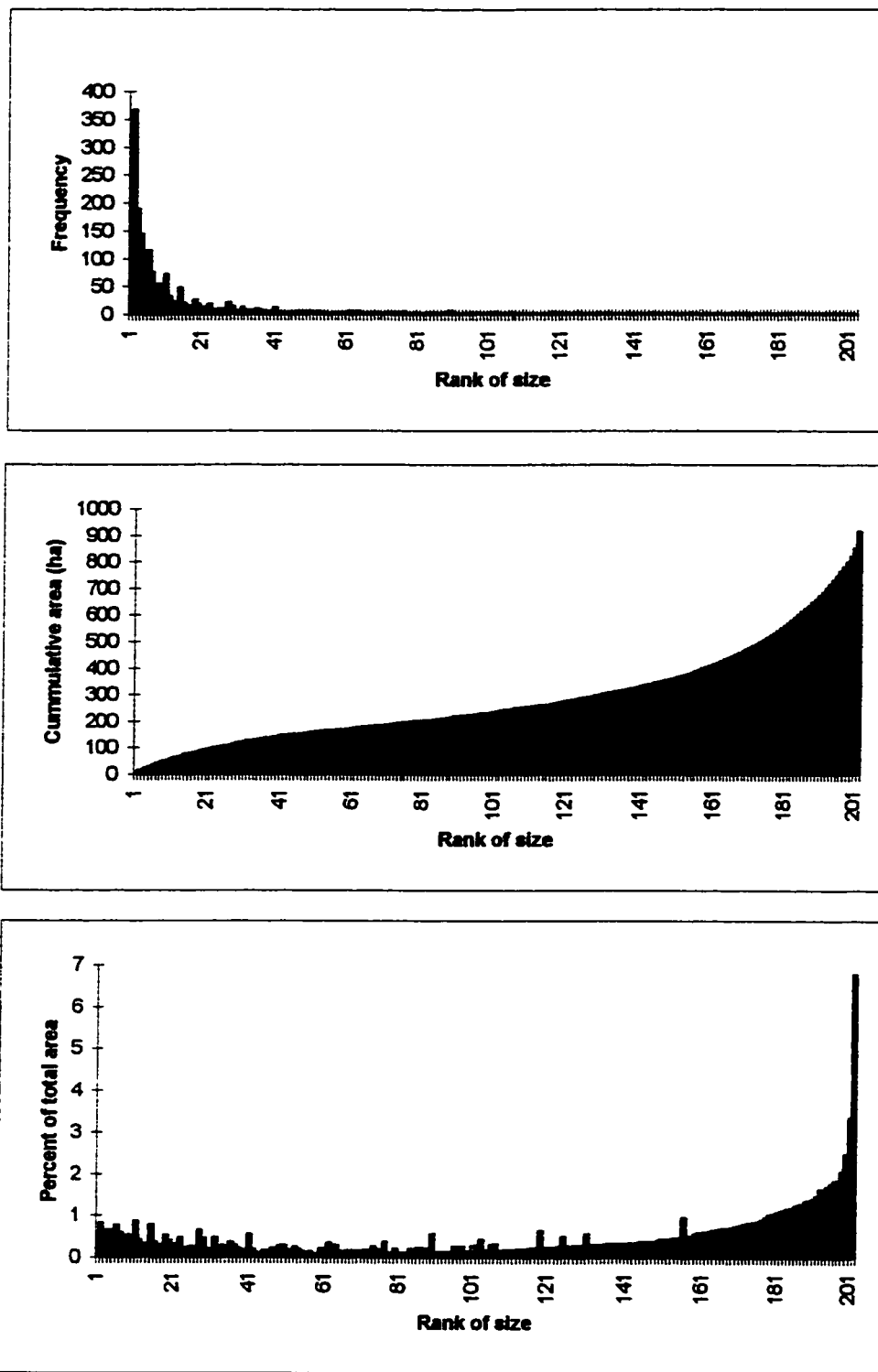


Figure 2-3. Frequency distribution of tree island size (top), cumulative area (middle), and contribution of each size class to overall tree island area. Sizes range from 0.01 to 61.97 ha. Eighty-nine percent of the tree island area is from tree islands ≤ 6.22 ha (rank 169).

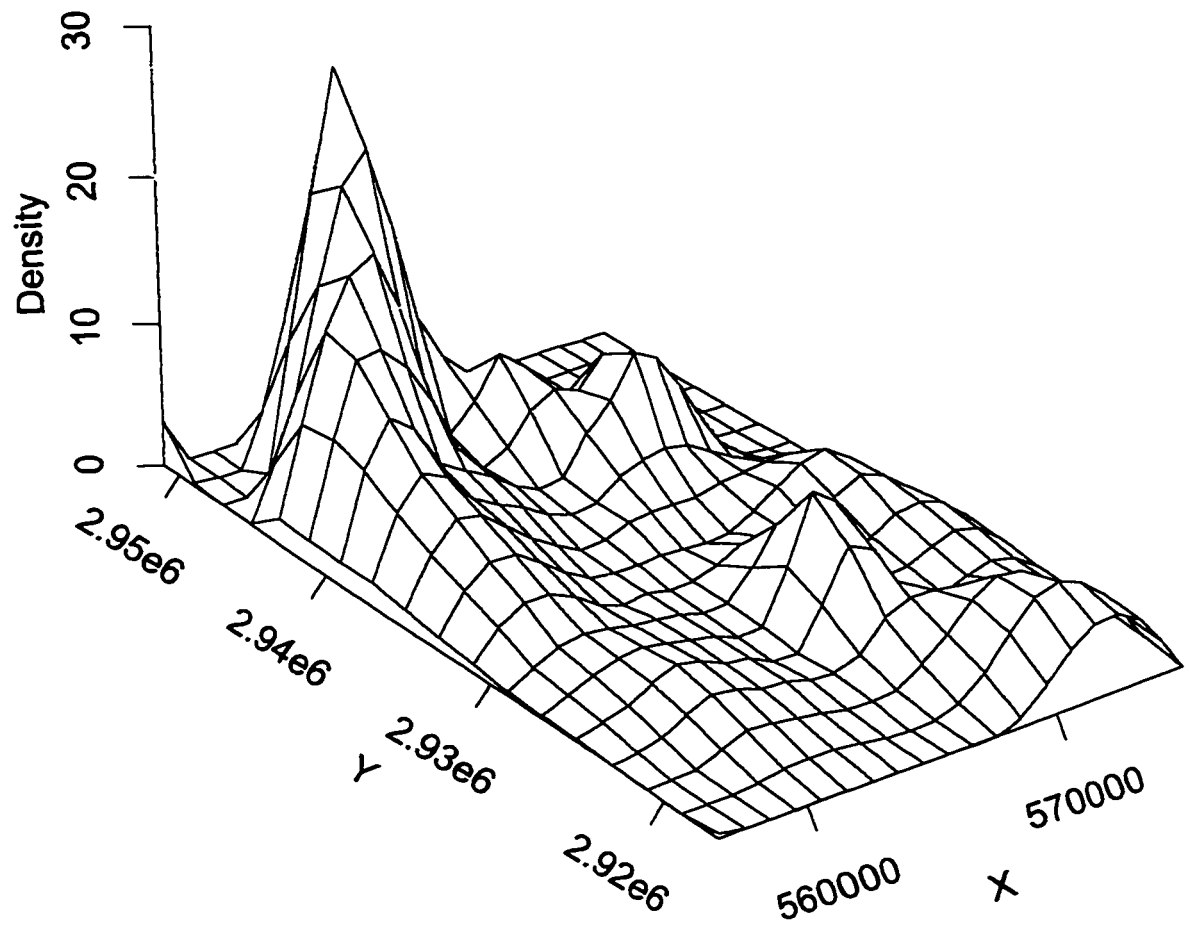


Figure 2-4. Density per grid cell of tree islands in Loxahatchee National Wildlife Refuge. Data are from Richardson et al. 1990. Each cell is 1800 x 900 m. X and Y axis are in UTM coordinates.

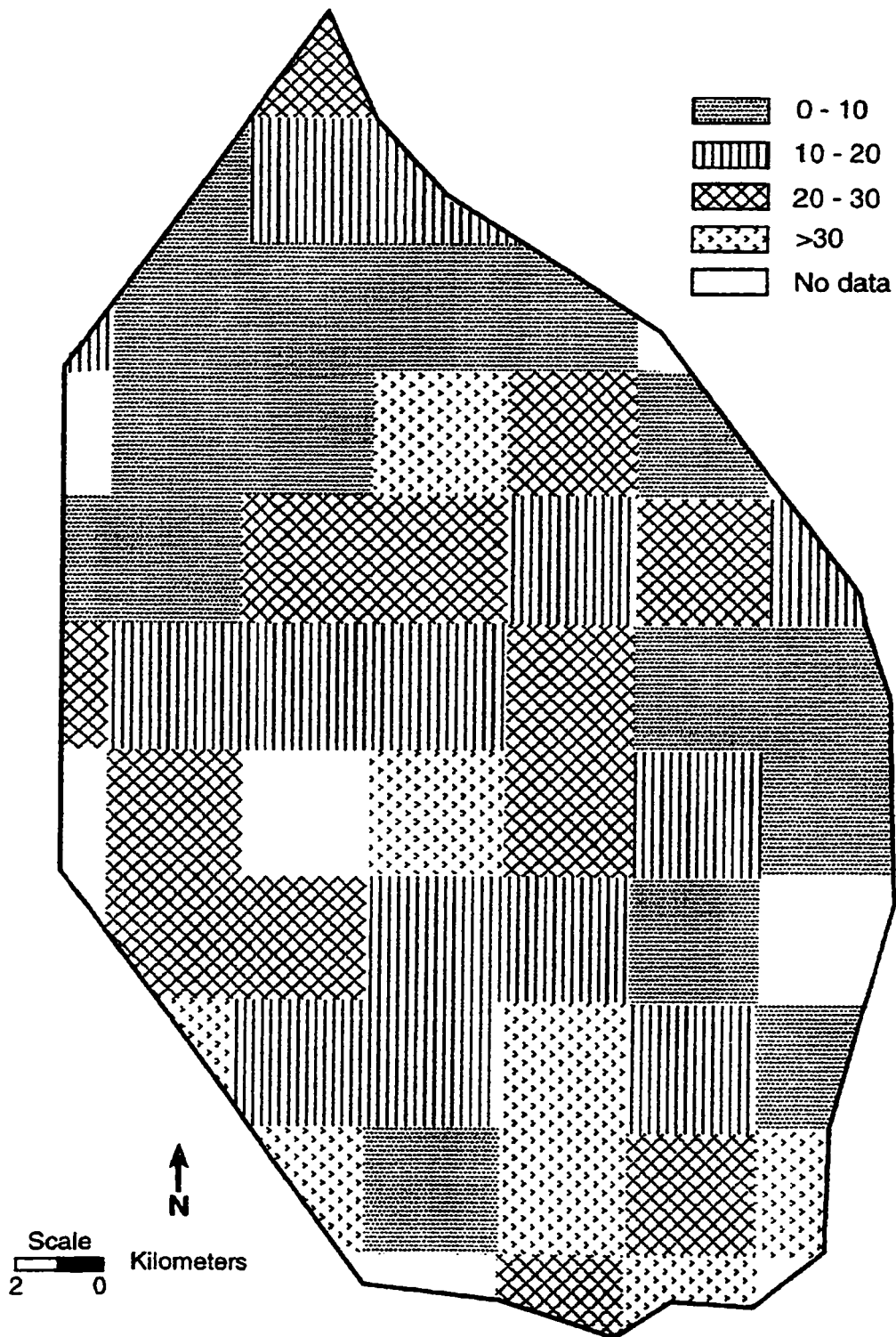
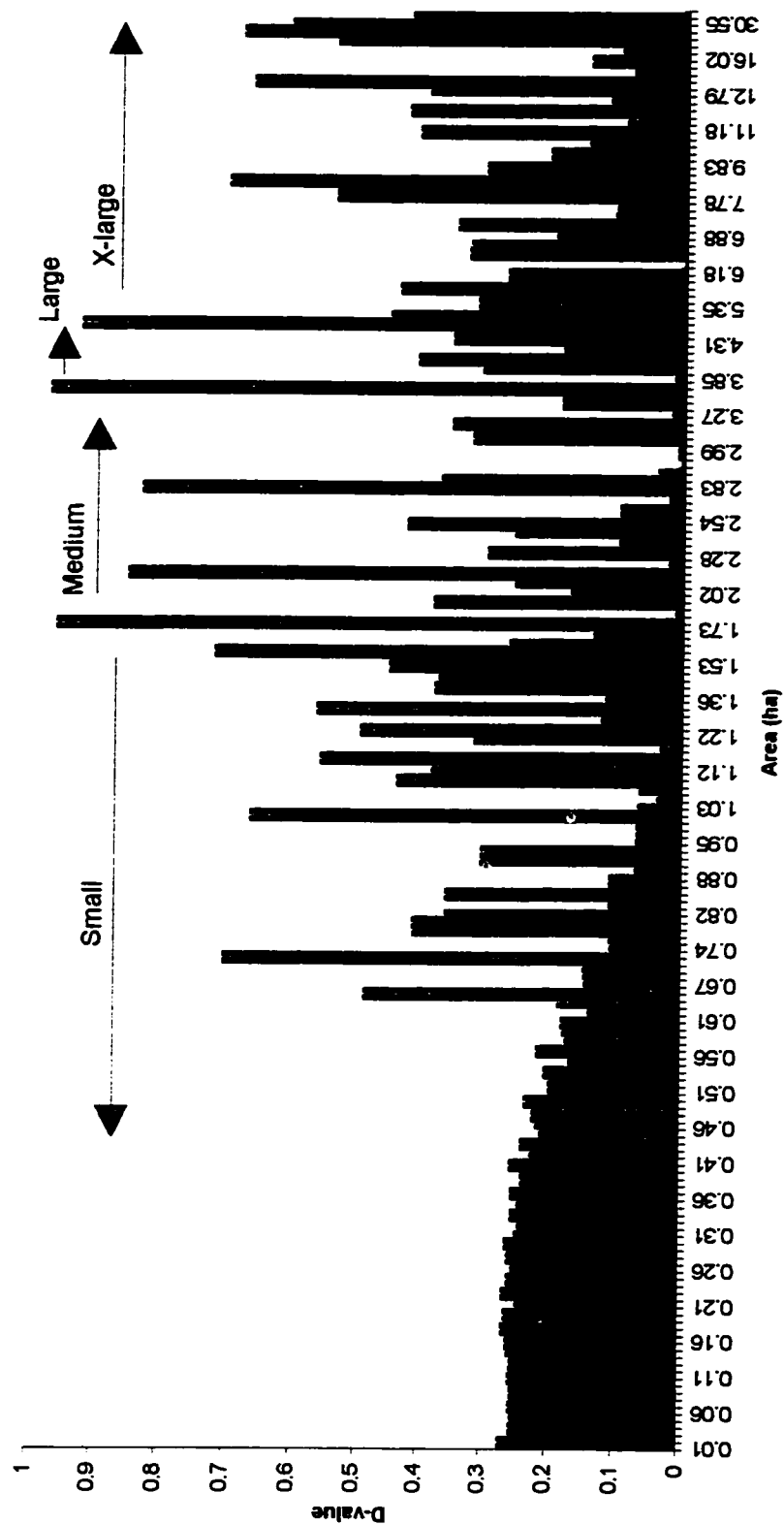
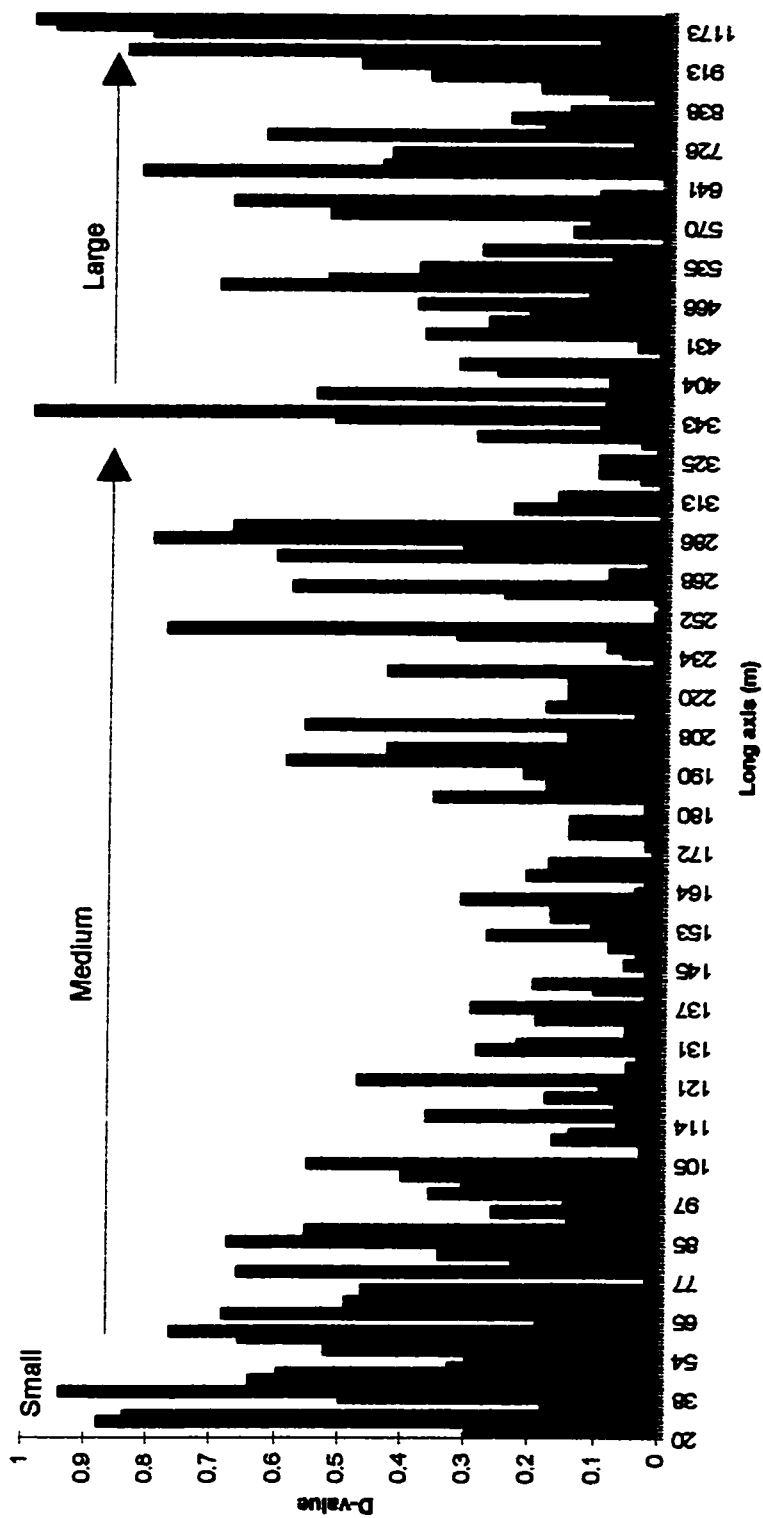


Figure 2-5. Difference in degrees between mean tree island orientation calculated from satellite image classification of Loxahatchee National Wildlife and flow orientation from NSM.





CHAPTER 3 SAMPLING PLOT SIZE AND LOCATION

Introduction

Concern over large scale development and changes in land use have led to the interest in developing methods for examining ecological impacts at broad spatial scales (O'Neill et al 1995). Promising methods include tools such as remote sensing, that can be used to map land covers over large areas, and methods of identifying appropriate sampling regimes and scales for a study.

The availability of remotely sensed data over a variety of spatial and temporal scales makes it possible to examine landscape patterns at different scales and over time. Aerial photography provides the longest temporal record while satellite imagery (available in a variety of formats and scales) provides the largest spatial extent. Both methods have strengths and weaknesses that are related to the minimum mapping unit, delineation of boundaries, and costs of processing (Burrough 1986).

The increasing availability of satellite imagery at pixel resolutions of 10 to 30 m makes it possible to create land cover maps over large areas. While these maps may be appropriate for illustrating broad scale patterns, they may not be appropriate for capturing patterns when the feature of interest is close to the minimum mapping unit or if land cover patterns are needed prior to 1970. In such cases, photointerpretation of aerial photography may be more appropriate. The ability to use both methods together may

strengthen our ability to study landscape spatial and temporal dynamics. Using the methods together requires that the relations between the landscape features and patterns be comparable between the two methods. A number of studies have examined how well the amounts of mapped land cover types agree between different methods (Cushnie 1987, Gervin et al 1985, Jensen et al. 1978, Latty and Hoffer 1981, Quirk and Scarpace 1982). Fewer studies have examined how the quantification of landscape patterns varies among methods (Benson and MacKenzie 1995, O'Neill et al. 1995). A common conclusion of these studies was that agreement between methods varied considerably between study sites and land cover types. These inconsistencies emphasize the importance of understanding the relation between mapping methods used together.

Conducting fine scale analysis across a large landscape often is not logistically feasible. Extrapolating results from a sample to the entire landscape is a difficult task (Allen and Hoekstra 1992, Meentemeyer and Box 1987, Wiens 1989) and will depend on the scale of the patterns being observed and the scale of observation. Determining appropriate sampling units has been a topic of ecological studies for many years (Greig-Smith 1961, Kershaw 1957, Turner et al. 1991). Different sampling methods emphasize different population properties, resulting in collection of different kinds of data. Some methods emphasize estimating species composition or inclusion of representative species. Others strive to minimize the variance in plot to plot measurements. In all cases, plot size and shape should be based on the question being addressed and the size and the spatial distribution of the entity being studied {Green 1979 #4650}. Plots that are too large mask the patterns by averaging the values within the plot, while plots that are too small may be

large inadequate to accurately represent the spatial pattern (Meentemeyer and Box 1987, Milne 1991).

The position of the plots in the landscape influences the interpretation of the results. Sample sites are usually selected randomly when it is assumed that the spatial distribution of the variables of interest are homogeneous across the area of study. Because landscapes are heterogeneous, use of simple random sample locations often is not appropriate or effective. Whenever possible the area should be divided into homogeneous (based on the variables of interest) sub-areas and samples selected at random and in proportion to sub-area size {Green 1979 #4650}. Broad scale land cover developed from satellite imagery provides a method for identifying homogeneous areas within a landscape and is a tool for that can be used to select appropriate sample plot sizes and location.

The objectives of this study were to 1) determine plot size, shape, and locations that accurately and precisely represents the patterns of tree islands as quantified from satellite imagery, 2) compare the values from the sample of the imagery to the values obtained from the imagery for the entire study area, 3) test the hypothesis that tree island patterns in sample plots quantified using a second method, photointerpretation, are not different from tree island patterns quantified using the imagery, and 4) if the patterns are different, determine if simple linear correction factors can be used to relate the patterns in the two methods (Figure 3-1).

Methods

Study Area

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Loxahatchee), is a 57,324 ha area of northern Everglades wetlands. It is a peat-based marsh system consisting of a mosaic of slough, wet prairie, sawgrass (Cladium jamaicensis), brush, and tree islands. Tree islands are one of the dominant features of this landscape and have been described as small and round or large and elongated and oriented in the direction of water flow (Davis 1943, Jones 1948, Gleason et al. 1984). The location, size, shape, and origin of tree islands is thought to be related to geomorphology, hydroperiod, and water flow, though the exact mechanisms are not well understood {Loveless 1959 #4620}. Tree islands are not distributed evenly throughout the refuge (see Chapter 2).

Imagery

Tree islands were identified from an existing land cover classification for Loxahatchee developed from merged, IHS transformed 10 m panchromatic data and 20 m SPOT data (Richardson et al. 1990) and referenced to State Plane coordinates. Details of the classification methods are available in Richardson et al. 1990. The classified image was converted to Universal Transverse Mercator (UTM) resulting in a cell size of 9 x 9 m. Two tree island classes described as: “lower stature tree island community made up of a mix of wax myrtle (Myrica cerifera), dahoon holly (Ilex cassine) and red bay (Persea borbonia)”, and “core of larger tree islands, larger stature trees made up primarily of dahoon holly and red bay...” (Richardson et al. 1990 pp. 40) were used in this analysis (Figure 2-1). All other classes were considered background. Two tree island layers were

generated for this analysis; the first was an image with tree islands coded as 1, all other vegetation classes in Loxahatchee as 2, and the area outside of Loxahatchee as 3. In the second layer each tree island was labeled with a unique number using the Clump command in Erdas Imagine {Erdas Inc. 1995 #4660} which identifies contiguous groups of pixels of a class.

Selection of Plots

The selection of plot size, shape, number and location was sequential process in which the results from the previous analysis determined the starting point for the next analysis. First an appropriate plot size was selected. Next the percentage of the refuge to sample, and hence the number of plots was determined. Finally, the plot locations were selected using stratified random sampling based on the patterns observed in the first analysis.

Plot size was determined by comparing values from a series of regular grids. Regular grids of 50 x 50 pixels, 100 x 100 pixels, 200 x 100, and 200 x 200 pixels (length x width) were generated in ARC/INFO. These grids were imported into Erdas Imagine and overlain on the three class image (background, tree islands, not tree islands) and the clumped image (layer with individual tree islands labeled) using the Erdas Imagine Summary command. Output from these procedures was three data sets for each grid size: 1) the percent cover of tree islands in each grid cell, 2) the number of different tree islands in each grid cell, and 3) the size of each tree island in each grid cell. Mean, median, variance, and standard deviation were calculated for percent tree island cover, number of tree islands and size of tree islands for all grid cells combined at each cell size. These data were used to determine an appropriate plot size.

To examine the effects of different sampling intensity on the accuracy and precision of the results, estimates of tree island size, variance in size, number, and percent cover were calculated 100 times using random samples of grid cells to represent 10%, 20%, 30%, 40%, and 50% coverage of the study area.

Results were compared to the values computed for the entire area (all grid cells of that size) to determine which plot size and coverage percentage were most accurate and precise in representing the size, percent cover, and number of refuge tree islands.

Estimates also were compared to the parameter values calculated for the entire refuge without using the grids. Based on the results from the analysis described in the previous paragraphs, and the knowledge that longer tree islands tend to orient north-south, a plot size of 200 x 100 pixels was selected.

An objective of the resampling analysis at different sampling intensities was to determine the sampling intensity using photography that was both most accurate and precise; however, because of the amount of effort involved in identifying and digitizing tree islands from photography (approximately 15 hours per plot) it was determined that despite the improved precision of a larger sample (see results) only 10% of the refuge (twenty-seven plots) would be sampled.

To ensure that samples selected for photographic analysis represented the range of tree island densities and size within the refuge, cluster analysis using Ward's Cluster Method (SAS Institute Inc. 1989) was used to group grid cells based on percent cover of tree islands, number of tree islands, mean size of tree islands, and the variance of tree island size. Grid cells with no tree islands were not included in the cluster analysis, but were assigned to a cluster of their own. Twenty-seven grid cells (plot locations) were

selected using random samples from each strata based on the proportion of grid cells in that strata.

Photography

Image sources for this analysis were twenty 1:40,000 color-infrared diapositives flown in December 1990 or January 1991. Each photo was photogrammetrically scanned at a scanning resolution to result in 2 m ground resolution. The images were referenced to a 10 m geocoded SPOT satellite image and mosaicked using Orthoengine from PCI Remote Sensing Corporation. The result was a complete image of the refuge with average residual error of approximately 2 m.

Each of the twenty-seven plots was subsetted from the overall mosaic and used as the background in ARC/INFO. Boundaries of tree islands were screen digitized using the original photography as reference. Tree island identification was verified by field sampling.

Number of tree islands, area of each tree island and percent cover of tree islands were calculated for each plot. Comparisons were made between the variables from the photo plots and the image plots on a plot by plot basis and for all plots combined. A cluster analysis was used on the results from the photo plots to see if the grouping of the plots was similar to those from the imagery.

Results

Changing plot size and percentage resulted in larger changes in precision than in accuracy (Tables 3-1 to 3-3). Sampling more of the refuge resulted in lower variance (higher precision) for all variables and all plot sizes. The smallest plot size (50 x 50) had the smallest variance for all variables followed by the 200 x 100 plot size. Only compete

grid cells were used in the above analyses so the amount of the refuge sampled varied slightly among grid sizes.

Two thousand one hundred forty-four tree islands were identified on the classified image without the overlaying grid cells. Average tree island size ($\pm$ SD) was 52.6 ± 23.9 pixels (0.4 ha) Tree islands comprised 1.96 percent of the refuge.

The cluster analysis indicated that grid cells could be divided into five groups based on the number, average size, and percent tree islands within the cell (Figure 3-2).

The number of cells and the proportion of the total cells in each group were:

Group 1- (low number of tree islands, medium average size, low percent cover)- 30 cells , 12%;

Group 2- (high number of tree islands, medium average size, high percent cover)- 185 cells, 73%;

Group 3- (low number of tree islands, small average size, low percent cover)- 5 cells, 2%;

Group 4- (low number of tree islands, large average size, high percent cover)-6 cells, 3%;

Group 5- (no tree islands)-26 cells, 10%.

Samples for photographic analysis were selected proportionally from each group so that 10% of the grid cells were represented. The result was random selection of 4 plots from group 1, 19 plots from group 2, 1 plot from groups 3 and 4, and 2 plots from group 5.

The number of tree islands identified in the plots ranged from 0 to 24 in the image plots and 0 to 400 in the photo plots (Table 3-4, Figure 3-3). The average values for the

samples using the image plots were similar to the values calculated using the entire refuge (Table 3-4). Average size and percent cover were higher in the photo plots than in the image plots (12065 m² compared to 2033 m² and 29% compared to 11% respectively; Figure 3-4 to 3-6). There were significant correlations between mean size of tree islands ($r=0.42$, $p=0.03$), percent cover of tree islands ($r=0.54$, $p=0.003$), and standard deviation of size of tree islands ($r=0.70$, $p=0.00$) for the two media. There were significant linear relations between the two methods for percent cover ($F=5.19$, $p=0.03$, $r^2=0.17$; percent cover in photo = $8.46 + 1.05 \times$ percent cover in imagery) and standard deviation of tree island size ($F=23.9$, $p<0.0001$, $r^2=0.50$; standard deviation from photo = $1848.5 + (1.42 \times$ standard deviation from imagery), but not for number or size of tree islands. Number of tree islands and median size of tree islands in the imagery plots and photo plots were not correlated. The five class cluster analysis performed on the results from the photo plots yielded groups with the following characteristics (Figure 3-6):

Group 1- no tree islands (1 plot);

Group 2- medium number of tree islands, small average size, low percent cover (7 plots);

Group 3- low number of tree islands, large average size, low percent cover (5 plots);

Group 4- high number of tree islands, medium average size, medium percent cover (12 plots);

Group 5- large number of tree islands, large average size, high percent cover (2 plots).

Discussion

Increased interest in landscape analysis presents new challenges in sampling design. In many cases it is not possible to measure variables in detail over the entire landscape or to obtain data from the same source over the time frame of interest. The availability and increasing use of satellite imagery for describing large scale vegetation patterns facilitates a landscape perspective. Presented here is one method for selecting sampling locations based on satellite image classification. Using a resampling technique, the accuracy and precision of different combinations of size, shape, and percentage samples was evaluated. Results from the sample compared favorably to the results for the entire study area. The hypothesis that aerial photo plots and image photo plots would show the same tree island patterns was tested and the relation between the variables quantified using the two methods examined. There were significant differences between the two methods, and only weak relations between some of the tree island variables. The rationale for selection of sampling size and location, reasons the imagery and photography show little relation to each other, and ways to improve agreement between patterns identified from different methods are discussed below.

In unbiased sampling the mean compiled from successive resampling should exactly equal the true mean of the population. The mean and standard deviation of the mean can be used to determine which sampling regime provides the most accurate (closest to the true value) and precise (repeatedly close to the original value) estimates. In this study, mean values were similar for each variable at all percentage samples of Loxahatchee indicating similar accuracy at all percentage samples. As expected sampling a greater

percentage of the refuge resulted in a more precise estimate of the mean. Because of logistical constraints (the effort and cost of a larger sample) sampling percentage was limited to 10% of the refuge. Had a greater proportion of the refuge been sampled the results would be 20–40% more precise. This suggests that some caution should be used in extrapolating results from a 10% sample to the entire refuge.

Estimates of the total number of tree islands in Loxahatchee were closer to the true number when the smaller plot sizes were used, probably because the amount of area sampled was closer to the actual area of the refuge (only plots completely within the refuge boundaries were used). Estimates from the 200 x 100 plots were better than the 200 x 200 or 100 x 100. Likewise, estimates of percent cover using the 200 x 100 plot size were closer to the mean percent cover and had a lower standard deviation than other plot sizes.

As was found by O'Neill et al. 1995, sample plots of different size and shape resulted in different values of the patch (tree island) statistics. Mean tree island size was underestimated in the small plots because of the plots inability to include tree islands of the largest sizes. On the other hand, large plots tended to over estimate the mean size. An explanation for this is that larger plots are more likely to include all of a large tree island at the exclusion of more smaller tree islands, resulting in an increase in the average tree island size in each plot. An advantage of smaller plots is that more plots are needed to sample the same area of the refuge than are needed with larger plots; therefore, the plots can be spread throughout the refuge. The disadvantage is that smaller plots may not represent the spatial distribution of the tree islands because the scale is too fine.

Based on the above analysis, the fact that the spatial patterning of the tree islands seems to be more dominant in the north/south direction, and the added constraint that plots should be large enough to contain the largest tree islands, a plot size of 200 x 100 was selected.

The hypothesis that patterns of tree islands measured from the satellite imagery were not different than the patterns of tree islands identified in the photography was rejected for all of the tree island variables. In addition, there only were weak relations between the results from two methods. The number of tree islands in the imagery were not correlated with the number of tree islands in the photo plots. Mean tree island size and percent cover were weakly correlated, while standard deviation of size had the highest correlation ($r=0.70$). These results indicate that the general patterns of variance may be represented in the imagery, but the true values are not. Only percent cover and standard deviation showed significant linear relation that might allow predictions to be made from this imagery; however, neither predictive relationships were very strong.

Studies comparing land covers developed from different remote sensing methods have shown similar inconsistencies between methods in the amount of a given cover type delineated using each method (Jensen et al. 1978, Quick and Scarpace 1982). Spatial patterns also have been shown to vary among classification methods (Benson and 1995, Moody and Woodcock 1994, O'Neill et al. 1995). There are a number of possible explanations for this lack of agreement between methods including differences inherent in the classification methods (resolution, sensor type, manual versus computer classification), purposes, and level of detail, and no direct aggregation from the vegetation classes in one method to the classes delineated in another.

Satellite image classification and photo interpretation are two very different techniques that both have strengths and weaknesses (Burrough 1986). The strengths of image classification include objective rapid class identification over a large area based on spectral reflectance values. Weaknesses included the blurring of boundaries between classes due to mixed pixel effects and the difficulties associated with spectral differentiation of specific vegetation types. Photo interpretation is much more time intensive and subjective (due to interpreter bias), but can provide clearer boundaries of vegetation types and often a smaller effective minimum mapping unit. In both cases a decision must be made of how much detail (how many classes to use) is required to address the issue for which the land cover map or classification is being developed.

The classified image used in this study was developed primarily to examine the expansion of cattail (*Typha latifolia*) in Loxahatchee (Richardson et al. 1990). The focus was on the separation of vegetation types not on the delineation of tree islands. The tree island classes used in this study only were mature tree island classes and thus represent a conservative estimate of tree island coverage. Originally, a third class representing “brush/tree island” was included as a tree island class; however, the resulting image under represented the shape of tree islands and over represented the tree island coverage (W. Kitchens, Personal communication). Comparison of the tree islands identified in the photo plots with the tree islands identified on the imagery show that much of what was identified as a tree island in the photo plots was classified as brush in the imagery; however, there also were many areas labeled as brush on the image classification that were not identified as tree islands on the photos so adding the brush category would not have necessarily improved the agreement. Additionally, smaller tree islands in a wet prairie matrix were

classified as wet prairie. This resulted from the mixed pixel effect in satellite imagery, where the reflectance value is the average value for that cell. If the reflectance from a vegetation type does not dominate the cell that feature do not appear on the classification.

This raises two issues for consideration when using vegetation classifications for delineating landscape features. What is the feature of interest and how do you describe it? And, which classes of an existing classification can be combined to represent that feature? The first sounds fairly straightforward; however, what theoretically sounds like a good definition of a tree island is often hard to translate to photography and the field. Tree islands have been described as slightly elevated sites with definitive species components and distinct physiognomic structure {Loveless 1959 #4620}. Loveless {Loveless 1959 #4620} also noted that there may be an abrupt demarcation between tree islands and surrounding communities, or that there may be a transition zone with species such as sawgrass, willow (Salix caroliniana), buttonbush (Cephalanthus occidentalis), elderberry (Sambucus spp.), and wax myrtle (Myrica cerifera). There are several practical challenges to this definition. Is the transition zone part of the tree island? At what point does a brush area become a tree island? Do tree islands have a distinctive shape or can they be any area of woody vegetation within a wetland?

For purposes of photo interpretation I defined a tree island as a consolidated group of trees covering at least 100 m². Tree islands could contain brush (and often did) if the brush was part of the consolidated mass. This definition was subject to interpreter judgment as to what was a group of trees. Often a decision was made based on the shape and structure of the vegetation as well as the presence of trees. No such pattern matching was done in the satellite image classification, rather the classification delineated areas of

trees and brush. Often the result was that only the densest group of red bays and dahoon holly were classified as tree islands. Thus very different things were represented by the two methods. The imagery delineated the vegetation type while the photo interpretation delineated tree islands based on the presence of trees and on the association of the trees with other vegetation classes.

This lack of agreement between variables measured by the two methods makes it difficult to expand the patterns observed from a sample to the entire study area. Some of the differences are inherent in the methods (differences in effective minimum mapping unit, boundary definition) and studies have been done that examine these issues. Often the awareness of these differences can be incorporated into the interpretation of the results. Other problems resulting from differences between vegetation classes and landscape features are more problematic. If remote sensing methods are to be used to map landscape features, the features must be described in terms that can be identified by these methods. It is not always possible to select the individual vegetation classes that represent a feature as seen in this analysis. It may be necessary to add spatial factors such as the juxtaposition of vegetation types into the selection of classes. Because of these potential problems, it is recommended that when land covers developed for one purpose are used to address another purpose, careful consideration be given to the applicability of original vegetation class definitions to the purpose of the second study. A pilot comparison between the patterns of interest from a small area of all the methods being used will assist in class definition. Consideration of these problems will increase our ability to correctly interpret patterns measured using multiple methods.

Table 3-1. Number of tree islands per plot based on classification of satellite imagery (Richardson et al. 1990). Pixels are 9 x 9 m. Statistics are based on 100 resamples representing the listed percentage of complete plots of that size. True mean, variance, and standard deviation are for all of the plots of that size. Number of tree islands on imagery = 2144.

Plot size (pixels)	Sample size	Percent	Mean	Variance	SD
200x200	100 samples of 11	10	14.19	21.36	4.62
	100 samples of 22	20	14.36	8.53	2.92
	100 samples of 33	30	14.25	4.39	2.09
	100 samples of 44	40	14.84	2.26	1.5
	100 samples of 55	50	14.19	1.74	1.32
True values	111	100	14.46	226.12	15.03
200x100	100 samples of 25	10	7.59	2.86	1.69
	100 samples of 50	20	7.36	1.14	1.07
	100 samples of 75	30	7.38	0.62	0.79
	100 samples of 100	40	7.39	0.52	0.72
	100 samples of 126	50	7.46	0.25	0.5
True values	252	100	7.42	86.57	9.3
100x100	100 samples of 45	10	4.04	0.59	0.77
	100 samples of 90	20	4.04	0.3	0.55
	100 samples of 135	30	3.96	0.15	0.38
	100 samples of 180	40	3.97	0.09	0.31
	100 samples of 226	50	3.97	0.06	0.26
True values	451	100	3.96	30.2	5.5
50x50	100 samples of 188	10	1.14	0.019	0.14
	100 samples of 376	20	1.11	0.008	0.09
	100 samples of 565	30	1.14	0.003	0.06
	100 samples of 753	40	1.13	0.003	0.05
	100 samples of 941	50	1.12	0.002	0.04
True values	1882	100	1.13	3.64	1.91

Table 3-2. Mean percent tree island cover per plot based on classification of satellite imagery (Richardson 1990). Pixels are 9 x 9 m. Statistics are based on 100 resamples representing the listed percentage of complete plots of that size. True mean, variance, and standard deviation are for all of the plots of that size. Percent cover of tree islands on imagery = 1.96.

Plot size (pixels)	Sample size	Percent	Mean	Variance	SD
200x200	100 samples of 11	10	1.98	0.3	0.55
	100 samples of 22	20	1.9	0.2	0.44
	100 samples of 33	30	1.89	0.09	0.29
	100 samples of 44	40	1.9	0.06	0.24
	100 samples of 55	50	1.91	0.04	0.19
True values	111	100	1.91	4.01	2.00
200x100	100 samples of 25	10	1.88	0.21	0.46
	100 samples of 50	20	1.89	0.15	0.38
	100 samples of 75	30	1.85	0.08	0.27
	100 samples of 100	40	1.85	0.05	0.22
	100 samples of 126	50	1.83	0.03	0.18
True values	252	100	1.85	7.99	2.83
100x100	100 samples of 45	10	1.86	0.42	0.65
	100 samples of 90	20	1.82	0.15	0.39
	100 samples of 135	30	1.88	0.09	0.3
	100 samples of 180	40	1.82	0.06	0.24
	100 samples of 226	50	1.84	0.04	0.20
True values	451	100	1.85	16.23	4.03
50x50	100 samples of 188	10	2.07	0.15	0.38
	100 samples of 376	20	2.03	0.1	0.31
	100 samples of 565	30	1.96	0.05	0.23
	100 samples of 753	40	1.97	0.03	0.17
	100 samples of 941	50	1.97	0.02	0.16
True values	1882	100	2	41.03	6.40

Table 3-3. Mean size (pixels) of tree islands per plot based on classification of satellite imagery (Richardson 1990). Pixels are 9 x 9m. Statistics are based on 100 resamples representing the listed percentage of complete plots of that size. True mean, variance, and standard deviation are for all of the plots of that size. Mean size of tree islands on imagery = 52.6 pixels, variance = 572.3, SD = 23.9.

Plot size (pixels)	Sample size	Percent	Mean	Variance	SD
200x200	100 samples of 11	10	71.68	1052.99	32.45
	100 samples of 22	20	70.57	572.07	23.92
	100 samples of 33	30	74.44	407.28	20.18
	100 samples of 44	40	72.93	188.67	13.74
	100 samples of 55	50	73.53	132.36	11.5
True values	111	100	73.41	14485.1	120.35
200x100	100 samples of 25	10	55.66	370.14	19.24
	100 samples of 50	20	61.58	243.3	15.6
	100 samples of 75	30	57.76	130.08	11.4
	100 samples of 100	40	59.61	69.03	8.31
	100 samples of 126	50	59.9	42.91	6.55
True values	252	100	59.85	12626.47	112.37
100x100	100 samples of 45	10	47.04	497.88	22.31
	100 samples of 90	20	52.88	278.377	16.68
	100 samples of 135	30	51.81	158.88	12.6
	100 samples of 180	40	53.67	89.91	9.48
	100 samples of 226	50	52.61	70.42	8.39
True values	451	100	52.57	28449.05	16.867
50x50	100 samples of 188	10	28.56	82.13	9.06
	100 samples of 376	20	28.01	30.94	5.56
	100 samples of 565	30	27.9	15.48	3.93
	100 samples of 753	40	27.76	11.08	3.33
	100 samples of 941	50	27.97	8.78	2.96
True values	1882	100	27.73	15750.02	125.5

Table 3-4. Summary statistics for plots from classified image and photo plots.

Plot	Imagery				Photo plots			
	Number of tree islands	Percent cover of tree islands	Average size of tree islands (m ²)	SD of tree islands size	Number of tree islands	Percent cover of tree islands	Average size of tree islands (m ²)	SD of tree islands size
36	0	0.00	0		0	0	0	
55	0	0.00	259	227.64	10	0.16	0	0
62	19	10.83	910	1044.38	18	1.01	9230	3830.5
110	1	0.11	767	1790.98	230	10.89	1701	0
124	1	0.04	786	853.32	47	2.28	567	0
144	3	0.03	2034	8532.71	39	4.9	162	0
147	3	3.83	1964	12065.58	90	10.91	20682	3964.66
159	7	1.20	1075	6010.95	159	10.55	2766	617.00
173	6	0.54	1180	2237.48	202	14.71	1458	282.03
205	1	0.03	640	660.53	256	10.11	405	0
210	10	0.69	2018	1973.87	19	2.37	1118	109.39
215	3	0.19	777	1378.92	117	5.61	999	86.48
227	7	0.84	1079	2260.46	332	22.12	1932	357.57
238	7	0.69	1014	2554.68	166	10.39	1597	402.21
257	11	1.45	1662	3266.14	39	4	2128	413.02
260	4	0.15	815	1080.21	124	6.24	608	105.34
306	13	0.33	729	526.19	135	6.08	405	37.29
310	11	2.91	644	2124.33	400	15.9	4278	1322.37
325	24	2.94	1686	2351.85	57	5.93	1981	313.29
328	7	0.21	848	744.51	137	7.18	474	26.20
377	16	3.34	1540	3899.51	174	16.54	3377	1183.97
cl911e	10	9.12	1482	10558.95	321	29.36	14823	4878.00
cl911w	10	0.76	783	1166.55	394	19.04	1215	198.00
jk911e	9	0.65	847	1632.10	267	13.96	1134	234.00
jk911w	2	4.27	972	6674.24	269	16.14	34587	5373.00
l911e	5	1.89	766	3338.15	345	16.32	6156	1449.00
l911w	9	9.11	1310	10862.89	304	24.59	16362	4221.00
Min	0	0	0	0	0	0	0	227.64
Max	24	10.83	34587	5373.00	400	29.36	2034	12065.58
Average	7.37	2.08	4820	1130.94	172.26	10.64	1059	3454.5
SD	5.90	3.03	8016	1720.62	125.30	7.67	509	3460.18
Entire area	7.42	1.85	4261					

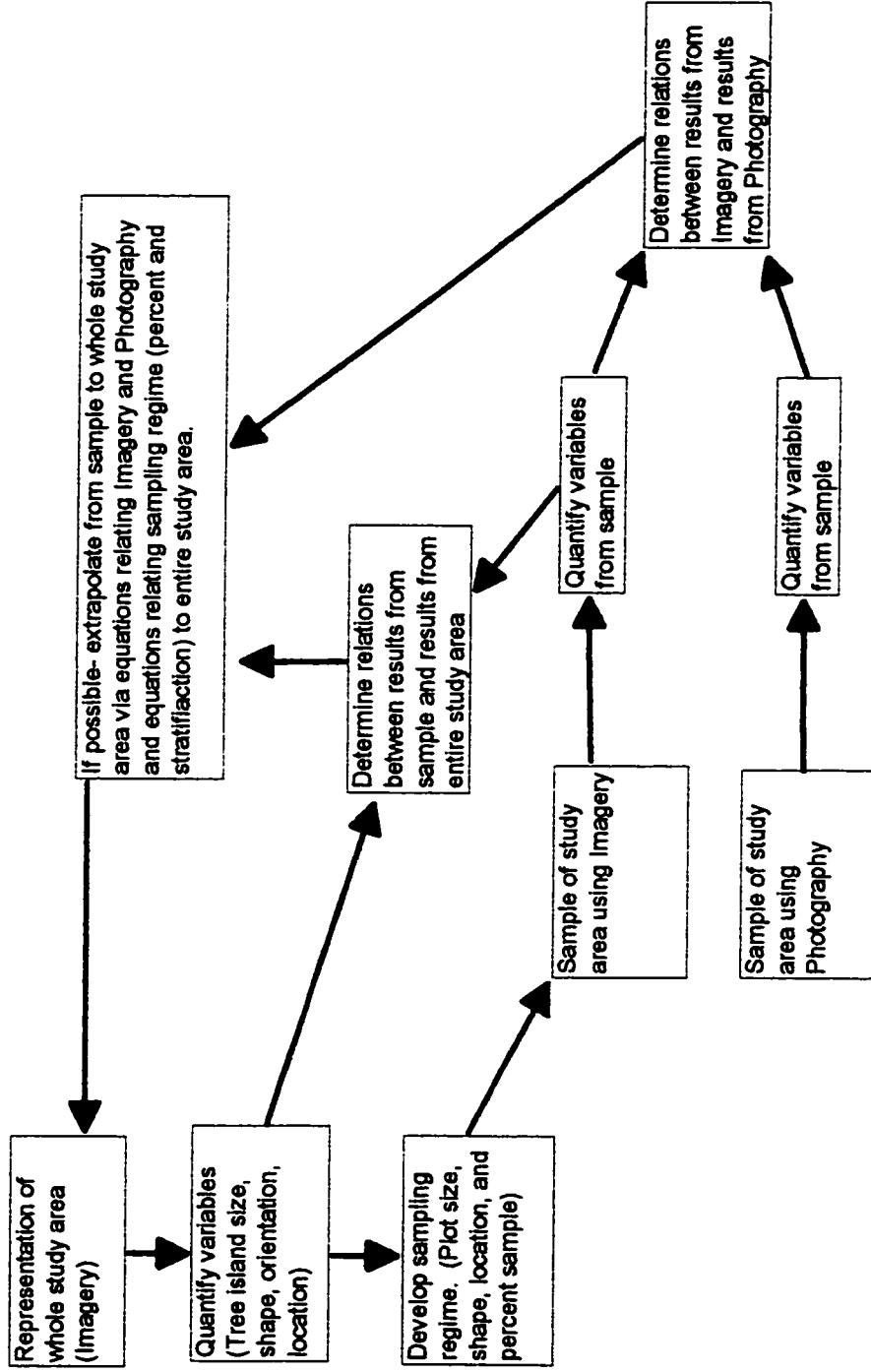


Figure 3-1. Framework developed to relate patterns of tree islands quantified using a classified satellite image of all of Loxahatchee National Wildlife Refuge and patterns quantified using aerial photography covering 10% of the refuge.

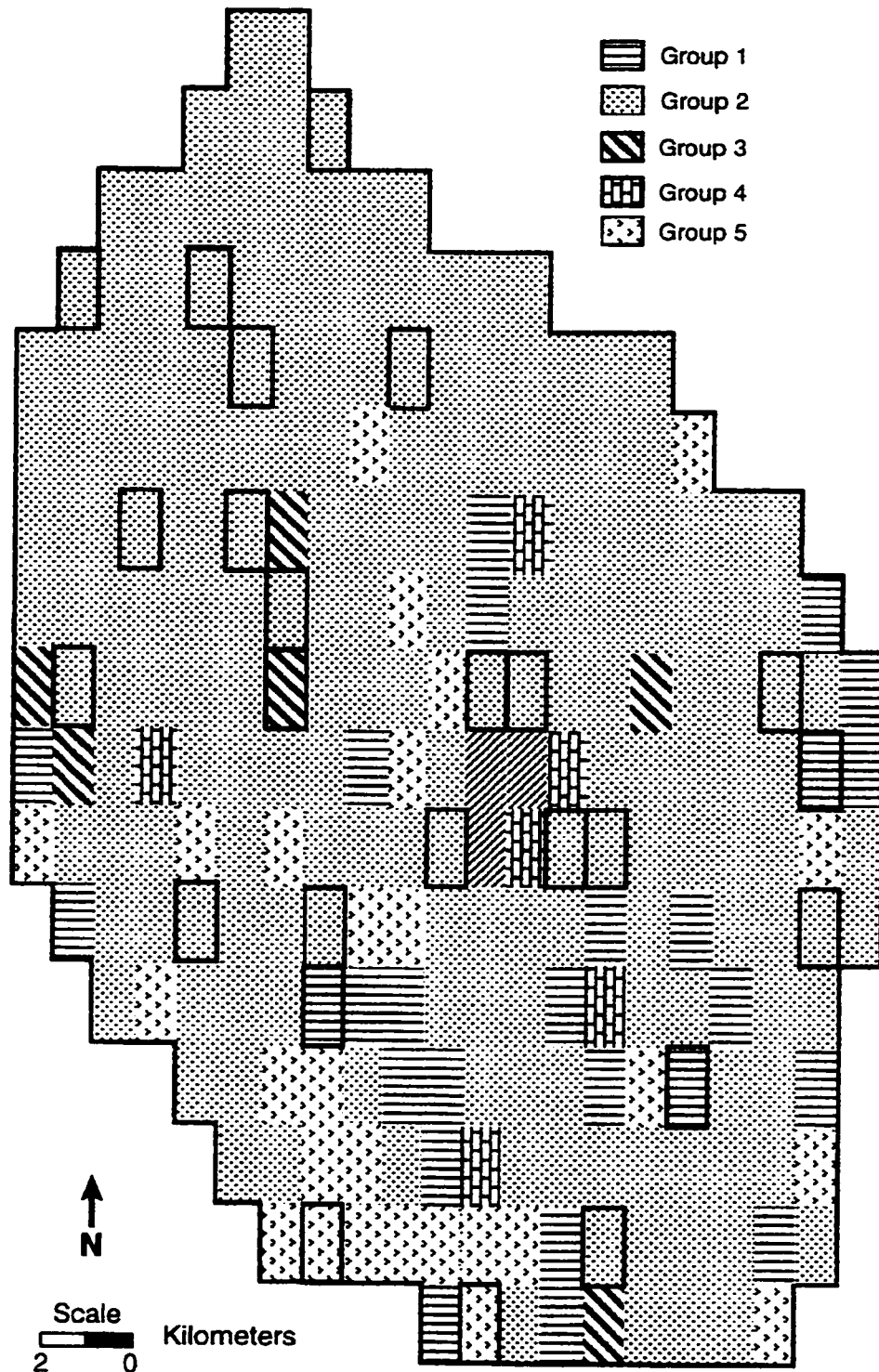


Figure 3-2. Location of groups resulting from 5 class cluster analysis from satellite image classification using the tree island variables number per cell, mean size, SD of size, and percent cover

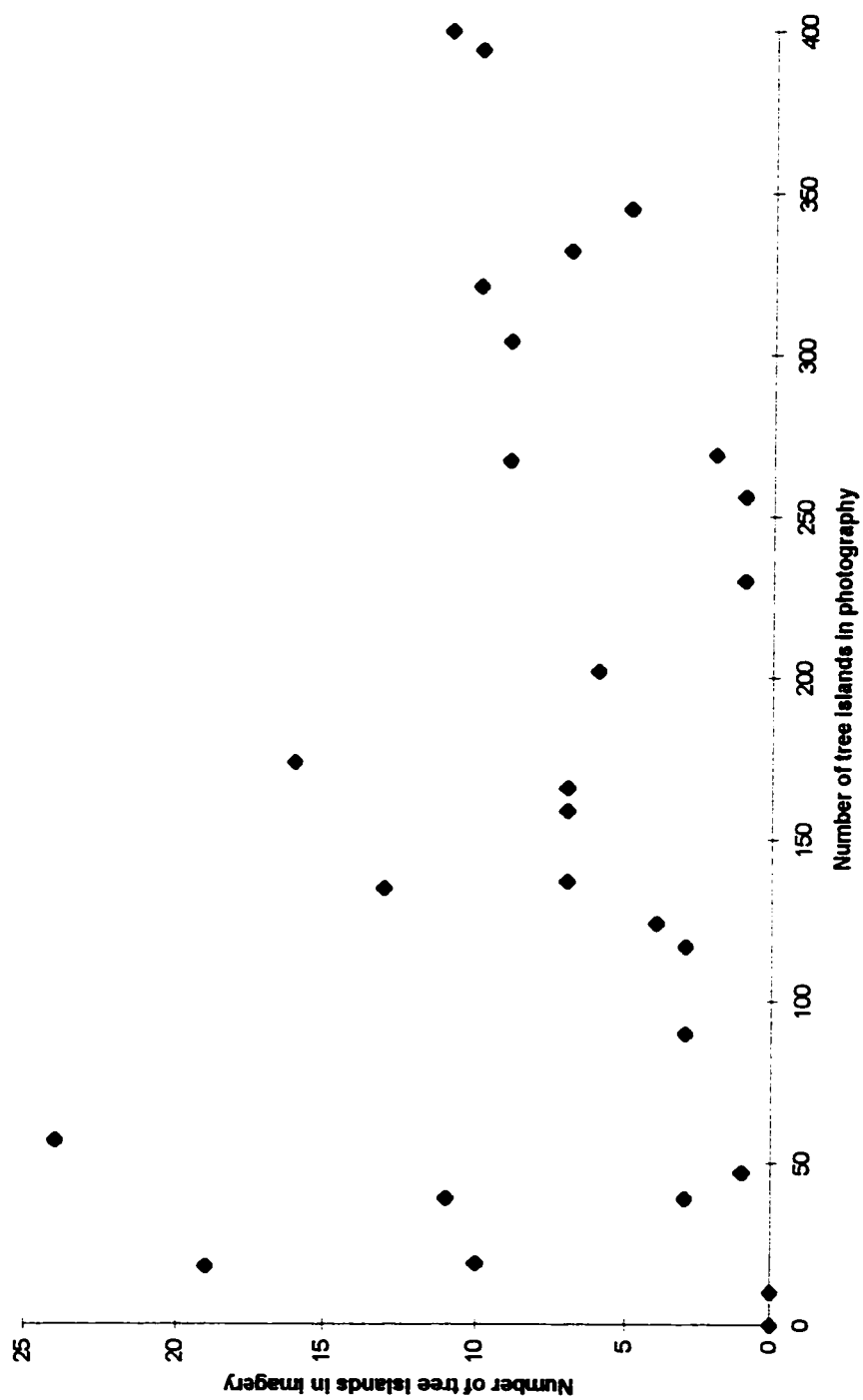
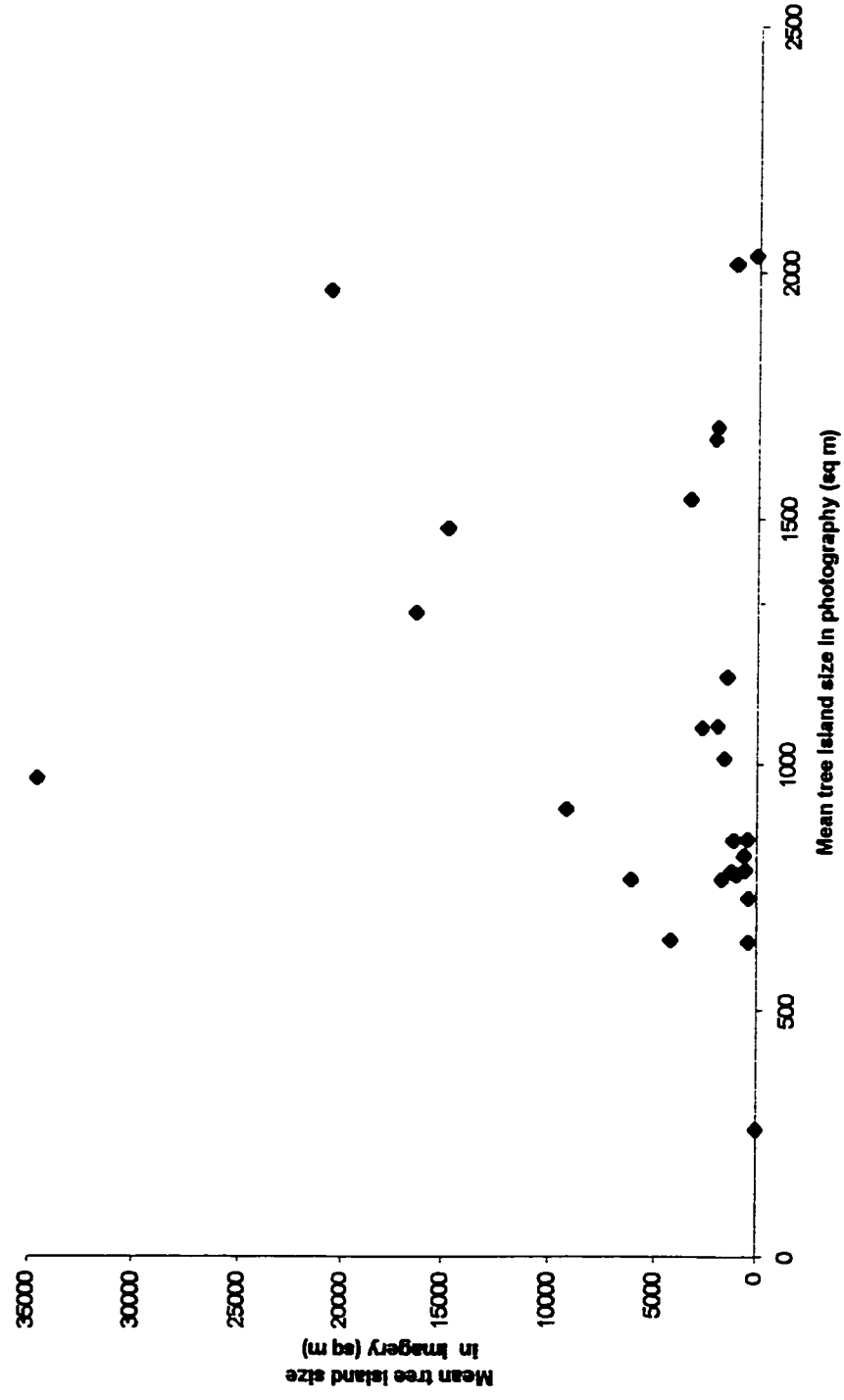


Figure 3-3. Relation between number of tree islands in satellite image and photo plots of Loxahatchee National Wildlife Refuge. Plots are 1800 x 900 m.



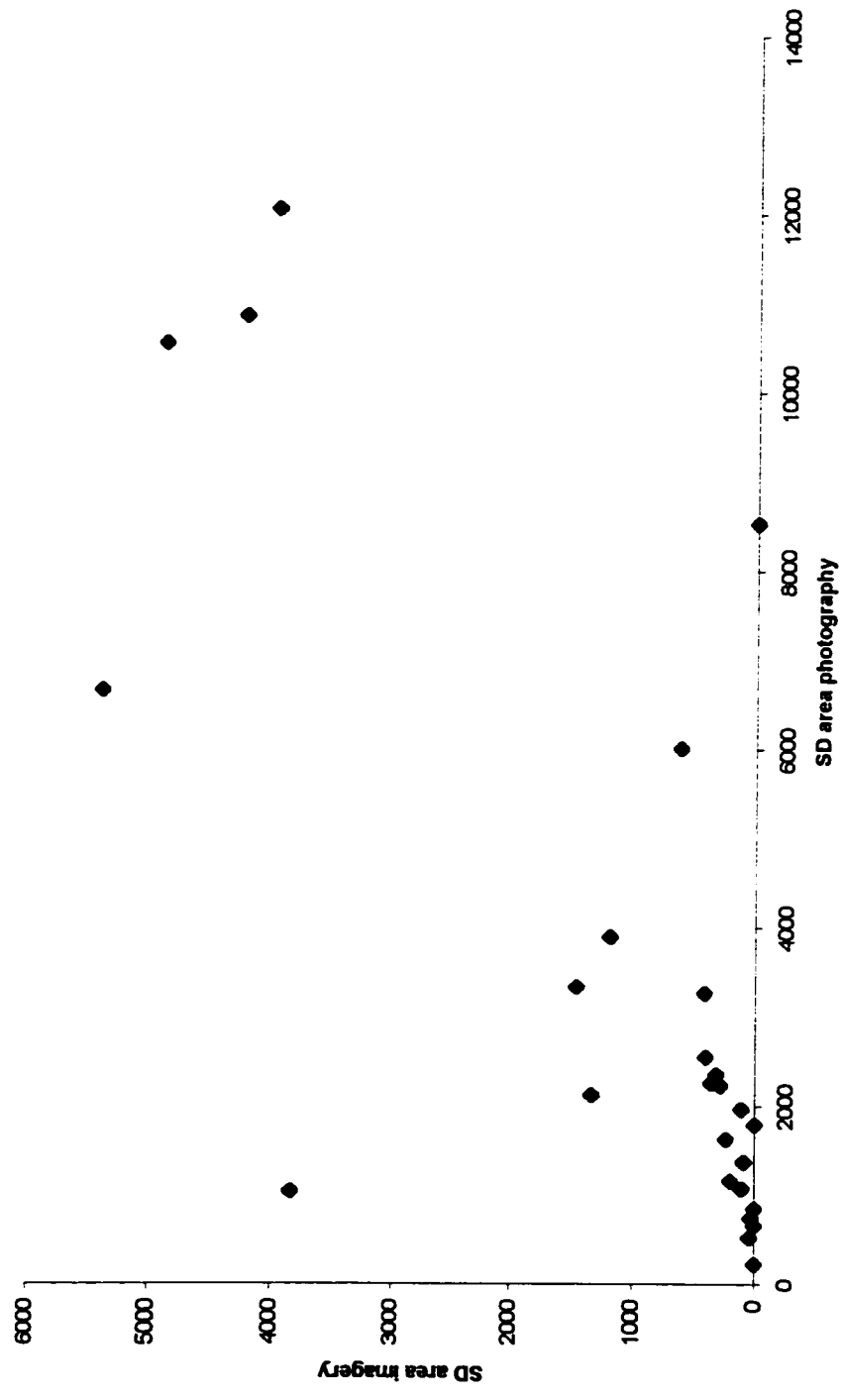


Figure 3-5. Relation between SD of size of tree islands in satellite image and photo plots of Loxahatchee National Wildlife Refuge. Plots are 1800 x 900 m.

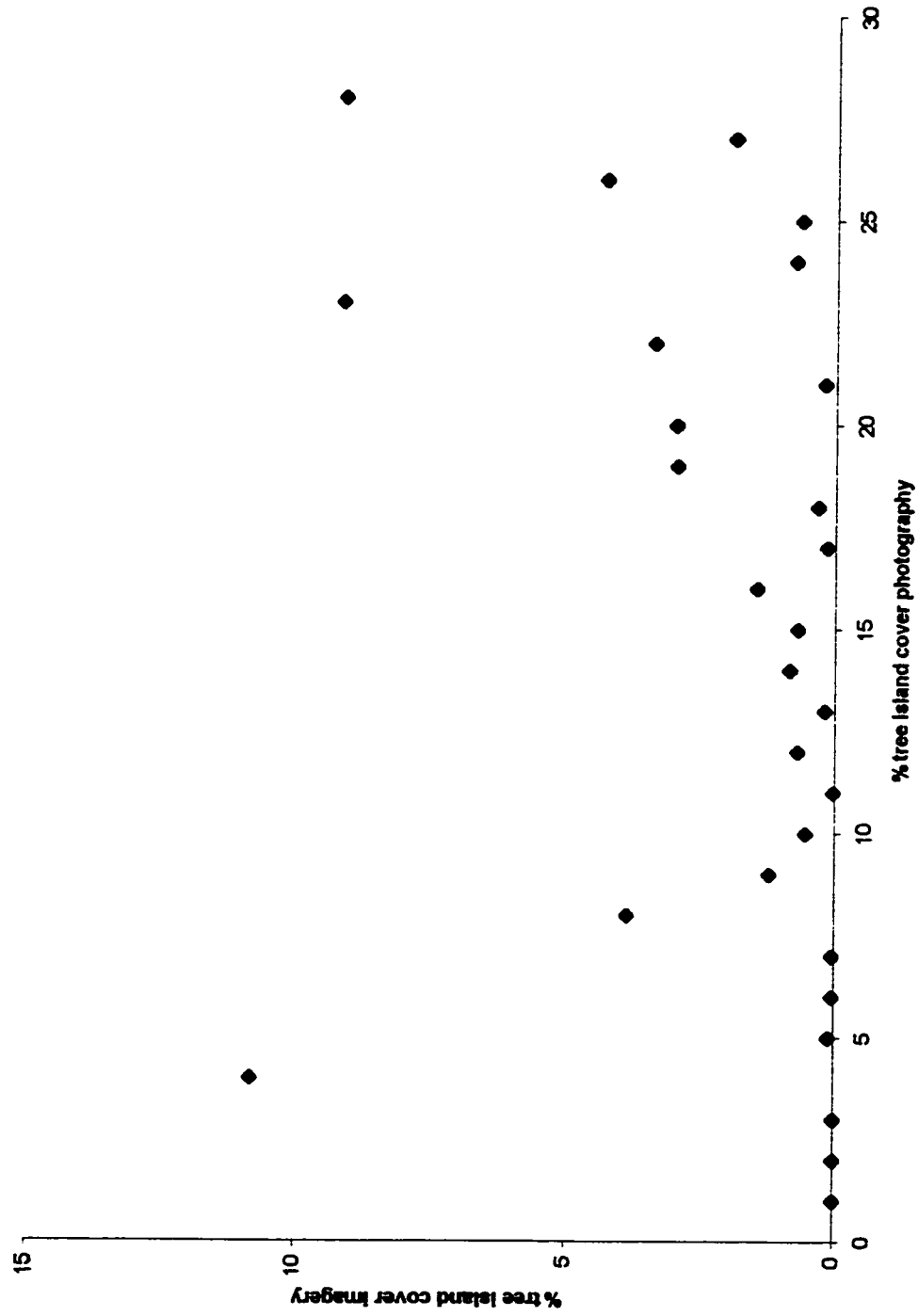


Figure 3-6. Relation between percent cover of tree islands in satellite image and photo plots of Loxahatchee National Wildlife Refuge. Plots are 1800 x 900 m.

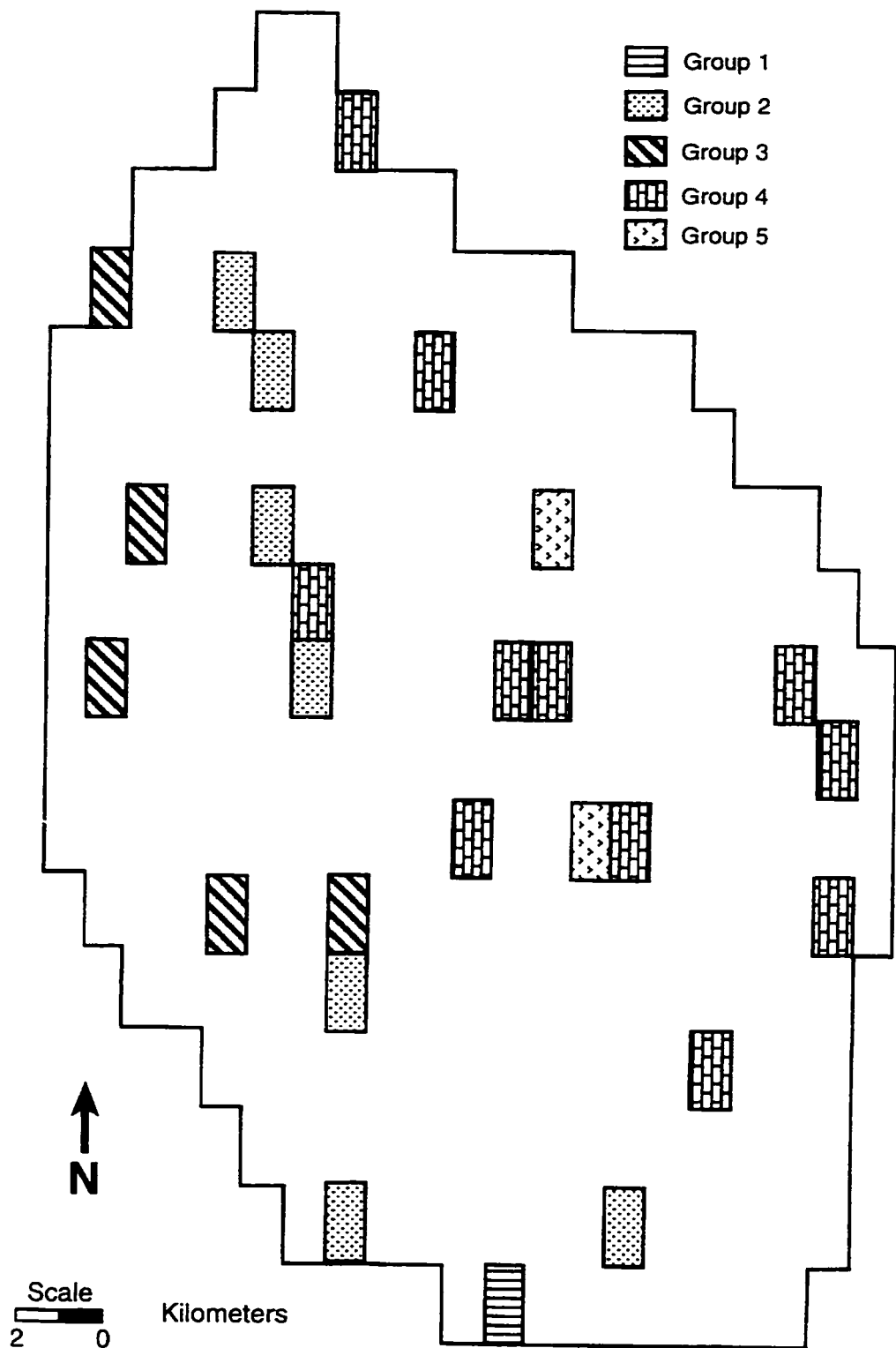


Figure 3-7. Location of groups resulting from 5 class cluster analysis of photo plots using the tree island variables number per cell, mean size, SD of size, and percent cover.

CHAPTER 4
PATTERNS OF CHANGE IN TREE ISLANDS IN A.R.M. LOXAHATCHEE
NATIONAL WILDLIFE REFUGE FROM 1950 TO 1991

Introduction

The Everglades, once a vast dynamic flow-through wetland extending from the Kissimmee chain of lakes south to Florida Bay, has been severely altered in the last century. The development of south Florida has led to the conversion of portions of the historic system to urban and agriculture and the conversion of the once sheet-flow system into a series of highly regulated impoundments and canals. The vast mosaic of marsh, slough, tree islands, and pinelands has been reduced to a fraction of the historic 3.6 million ha (Davis and Ogden 1994). In addition, what remains is subject to hydrologic regimes that, in places, bear little resemblance to pre-drainage patterns (Fennema et al. 1994).

The historic hydrological patterns were vital in creating and maintaining the heterogeneity of the landscape, which in turn, contributed to the persistence and resilience of the system (Holling et al. 1994). The Everglades, like other ecosystems, is the product of the interaction of biota and forces such as climate, hydrology, nutrient inputs, and disturbance (DeAngelis and White 1994). These processes, operating over a range of spatial and temporal scales, interact to form the current landscape patterns. Changes in macroscale processes such as geology and climate occur over long time scales and are generally not noticeable within a human lifetime. At the other extreme, changes in microscale processes such as nutrient transfer occur very rapidly and the consequences to

wetland vegetation can be observed in a season. In between are mesoscale processes that act on a scale of kilometers to tens of thousands of kilometers and over time scales of decades to centuries. Hydrology is the dominant natural mesoscale process acting in the Everglades. It is also the process that has been most seriously altered and has caused the largest changes to the remaining vegetation in the system. Changes in hydrologic patterns have contributed to the reduction in plant community heterogeneity, the change and decrease in wildlife populations, and changes in the historic functioning of the Everglades (see Davis and Ogden 1994). Changes in vegetation structure and composition have been noted in many regions of the Everglades (Loveless 1959, Alexander and Crook 1984, Higer and Kolipinski 1987, Parks 1987, Worth 1988) and Davis and Ogden (1994) have documented massive loss or conversion of entire landscape types. However, the total extent of these changes is unknown, and it is unlikely that the magnitude of the changes will be completely understood.

Restoration of the Everglades ecosystem will require an historical reference on what vegetation communities existed and in what spatial arrangement, an understanding of how historical processes contributed to the landscape patterns, and wherever possible, an understanding of the relation between anthropogenic changes in structuring processes and current landscape patterns.

This study examines the historic patterns (1950) of tree islands in a remnant of the northern Everglades and relates these patterns to pre-drainage hydrologic processes. The current patterns (1991) of tree islands, the relationship of those patterns to post-drainage hydrology, and the relation between the magnitude of change in tree island patterns and

hydrologic patterns then are examined in an attempt to understand better the influence of hydrologic processes on landscape patterns.

Methods

Study Area

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Loxahatchee), is a 57,324 ha area of northern Everglades wetlands. Located in Palm Beach County, Florida, south and east of Lake Okeechobee, (Figure 2-1) it was once a connected part of the historic Everglades system. Loxahatchee is located over the Loxahatchee Channel, a shallow peat filled depression extending from Lake Okeechobee south and east that may have acted as an overflow valve for Lake Okeechobee shunting water east and south (Gleason et al. 1984). Changes to the flow patterns in and around Loxahatchee started as early as the 1800s with the construction of the Caloosahatchee canal, which moved water from Lake Okeechobee to the west. Additional changes occurred with the completion of the Hillsboro Canal in the 1920s, with the completion of the St. Lucie canal in 1931, and the with the complete enclosure of the area by the L-7 canal on the west and the L-40 canal on the east during the 1950s (Light and Dineen 1994). The construction of these canals effectively isolated Loxahatchee from it's original watershed. This changed the system from a dynamic flow-through, sheet-flow driven fluvial system to an impounded marsh with the majority of overland flow inputs being shunted around the marsh via the exterior canals.

Loxahatchee is a peat-based wetland system consisting of a mosaic of aquatic sloughs and expanses of wet prairie strands of sawgrass, patches of brush, and tree islands.

Tree islands are one of the most conspicuous and dominant features of the landscape and provide habitat for a large number of wildlife species including deer, alligators, and wading birds.

Photography

Image sources for this analysis were twelve 1:60,000 panchromatic diapositives flown in November or December 1950 and twenty 1:40,000 color-infrared diapositives flown in December 1990 or January 1991. Each set of photos was photogrammetrically scanned at the appropriate scanning resolution to result in 2 m ground resolution. The images were referenced to a 10 m geocoded SPOT satellite image and mosaiced using Orthoengine from PCI Remote Sensing Corporation. The result was two complete images of the Refuge with average residual errors of approximately 4 m for 1950 and 2 m for 1991. Because plots not individual tree islands were the unit being compared this level of error was deemed acceptable.

Twenty-seven 1800 x 900 m photo plots, approximately 10% of the refuge, were selected for this analysis (Figure 4-1). Selection of photo plot location was designed to sample the range of tree island density, tree island size and variation in tree island size found on the refuge and was based on a stratified random sampling regime (see Chapter 3 for details).

Boundaries of tree islands larger than 100 m² were screen digitized in ARC/INFO using scanned images of the original photography. The original photography was used for reference for both years. Additional 1:24,000 black and white photography was used as reference for the 1950 plots. Tree island identification on the 1991 photography was verified by field sampling.

Number, area, perimeter, and centroid locations (X and Y coordinates) for all tree islands were obtained directly from ARC/INFO. Length of long axis and secondary axis were calculated using a program developed in S-plus (Statistical Sciences, Inc. 1995). Tree islands were classified as circular, elliptical (shaped) or irregular (no shape) using a combination of a circularity index (Miller 1953) and ellipse index. These indices are the ratio of the area of the tree island to the area of a circle, or ellipse, respectively given the same long axis and secondary axis. An index of 1 indicates complete agreement (an exact circle or ellipse). Values above or below 1 indicate deviation from the ideal shape. Index thresholds were determined by randomly selecting tree islands and visually categorizing them as circular, elliptical, or irregular. The calculated index values were compared and cutoff criteria developed based on the number of tree islands in that range identified as a particular type. Tree islands with a circularity index of 0.85 or larger were considered circular. Tree islands with a circularity index < 0.85 were elliptical if their ellipse index was < 6 . All remaining tree islands were classified as irregular. Orientation was determined for elliptical tree islands by calculating the direction of the long axis using a program developed in S-plus (Statistical Sciences, Inc. 1995). Orientation ranges from 0 to 180 with 0 as north and 180 as south. No attempt was made to distinguish between the leading and trailing edge of the tree island.

Hydrology and Elevation

Data on hydroperiod, water depth, flow direction and magnitude were obtained from the South Florida Water Management District. Data are from two models 1) the South Florida Water Management Model Version 2.10(WMM) developed to simulate the hydrology of the water management system in south Florida (MacVicar et al. 1984) and 2)

the Natural Systems Model version 4.4 (NSM), adapted from the WMM to simulate the hydrologic response of pre-drainage south Florida using climatic data from 1965-1990 (Fennema et al. 1994). Both models have a grid cell size of 3.2 x 3.2 km (2 miles x 2 miles). Grid cells are referred to as hydrology zones though out this text. Depth, flow direction and magnitude are the yearly average values for each grid cell calculated over the entire period of record (1965-1990). Direction of flow was standardized to 0-180 degrees to match the range used for the tree island orientation and then transformed using $\tan(\theta/2)$. Two variables were used to represent hydroperiod: the first was the 90% hydroperiod or the hydroperiod that was exceeded in 90% of the 26 years. The second hydroperiod variable was range in hydroperiod. This was used to reflect the variability among the hydrology zones. The assumption is that tree islands are the resultant of processes operating over time and that tree islands in 1950 and the NSM output reflect pre-drainage hydrology. Likewise, the assumption is made that 1991 tree islands and WMM output reflect the last 40 years of post drainage patterns.

The topographic surface generated by Richardson et al. 1990 for Loxahatchee was used for this analysis. The grid cell resolution of this surface was 183 x 183 m. The 3.2 x 3.2 km cell boundaries for the hydrology models were overlain on the elevation surface and average elevation and elevation gradient calculated for each cell of the hydrology model. Because the relation between current and historic elevation is unknown the topographic information was used only with the 1991 photo plots.

Plot Comparisons and Relationship to Hydrology

Because initial plot selection was done independent of the hydrological analysis, all of the plots did not fall completely in one hydrology zone. In cases where the plots were

in more than one zone, analysis was done for each zone separately. At least one third of the plot had to be in the hydrology zone for it to be considered. Tree island numbers were converted to densities to allow comparison among plots of different sizes. Median area and median long axis were used as size variables for the plot comparisons because individual area and long axis of tree islands within the plots were not distributed normally, and could not be normalized using simple transformations. Partial plots did not have significantly different median tree island size or densities than full plots. The following analysis was done on the resulting 28 plots.

Density, percent cover of tree islands, median area, median long axis, ratio of elliptical to circular tree islands, ratio of non-shaped to shaped tree islands, and mean orientation of tree islands were compared between the two years. Data that were non normally distributed were transformed as indicated in Table 4-1 prior to analysis. Hydroperiod, mean ponding depth, range in hydroperiod, flow magnitude, and flow orientation data from the NSM and WMM also were compared.

The relations between tree island variables and hydrologic variables were examined using canonical correlation analysis for the 1950 and NSM data, the 1991 and WMM data, the 1950 tree island data, the 1991 tree island data, and the NSM and WMM data. Canonical correlation analysis is used to investigate the relations between two sets of variables by deriving a linear combination of the X variables ($U = aX_1 + aX_2 + \dots + aX_i$) and a linear combination of the Y variables ($V = aY_1 + aY_2 + \dots + aY_i$) such that the correlation between U and V is as large as possible (Manly 1986). A non-significant result indicates that the largest canonical correlation can be accounted for by sampling variation alone. Canonical correlation combines the multiple variables into a single index variable (U or V).

Examination of the coefficients of the individual variables that make up U or V indicates the contribution of that variable to the overall index. Variables with higher coefficients are more important.

The size structure of the tree islands (both long axis and area) was examined using a clump analysis (Holling 1992, Marples unpublished) designed to identify significant breaks in size distributions. A significant clump indicates the presence of a process functioning to structure the landscape. Changes in the clumping pattern over time indicate a potential change in the processes structuring the landscape. These methods are similar to cluster analysis in that they find natural groupings in the data. The first step is to test if randomly sampled data can explain the clumping pattern in the data. The second step is to measure the discontinuities between the rank-size-order data. The result is a D-value (discontinuity value) that indicates whether a clump is significant or not at a specified level of significance (0.05 in this case).

Results

1950 Plots and NSM Hydrology

Density of tree islands per plot ranged from 0.08 tree islands/ha to 2.16 tree islands/ha. Percent cover ranged from 0.2 to 26.7%. Median tree island size ranged from 187 m² to 755 m² and median long axis from 20 to 46 m. The ratio of elliptical to circular tree islands varied from 0.3 to 25 (Table 4-2) and the ratio of non-shaped to shaped from 0.15 to 8.12. Mean orientation of elliptical tree islands ranged from 1 to 180 degrees with most between 1 to 30 or 150 to 180 degrees (Figure 4-2). Density of tree islands was correlated with location (X-Y coordinates of plot centroid). Higher densities of tree

islands occurred in the northern and eastern plots. There was no correlation between the area or long axis of tree islands and location. The ratio of elliptical to circular tree islands increased from north to south indicating relatively fewer elliptical tree islands in the more northern plots.

The distribution of tree island sizes from all plots combined showed many small tree islands and few larger tree islands (Figure 4-3). Fifty percent of the tree island area was made up of tree islands < 0.16 ha. Ninety-four percent of the 3769 observed tree islands were < 0.16 ha.

Clump analysis for the 1950 data, using a D-value of 0.9 indicated that there were three potential clumps in tree island area: < 0.81 ha, 0.96-1.61 ha, > 2.15 ha and three potential clumps for long axis: < 247 m, 271-303 m, > 357 m (Figure 4-4).

Mean hydroperiod for the NSM in the cells in which photo plots occurred ranged from 240 to 329 days and mean ponding depth from 0.2 m to 0.4 m. Range in hydroperiod was as little as 47 days and as great as 272 days (Table 4-3). Density of all tree islands and circular and elliptical tree islands were positively correlated with hydroperiod and negatively correlated with hydroperiod range (Table 4-4). Overall density of tree islands and density of elliptical tree islands were correlated with mean depth. Median area of tree islands was positively correlated with mean ponding depth and negatively correlated with range in hydroperiod. Median long axis was not correlated with any of the hydrology variables. Mean tree island orientation was not significantly different from orientation of NSM flow.

Canonical correlation analysis was performed with the tree island variables density, area, and ratio of elliptical to circular tree islands and the hydrology variables NSM

magnitude, hydroperiod, mean ponding depth, and hydroperiod range. It was performed again replacing area with long axis. In both instances only the first canonical correlation was significant ($p=0.0002$, $r=0.85$; $p=0.0003$, $r=0.85$ respectively). In both analyses the hydrology variables NSM hydroperiod range and NSM magnitude (coefficients of -0.82 and -0.62 and 0.78 and 0.61 for hydroperiod range and magnitude in the two analyses respectively) were the most important, as was the tree island variable ratio of elliptical to circular tree islands (coefficients of -0.74 and 0.77). Eighty-eight and eighty-seven percent of the variation between the linear combinations were explained.

1991 Plots and WMM Hydrology

Density of tree islands per plot ranged from 0.01 tree islands/ha to 2.31 tree islands/ha. Percent cover ranged from 0.03 to 30.2%. Median tree island size ranged from 132 m² to 1429 m² and median long axis from 18 m to 59 m. Ratio of elliptical to circular tree islands from 0 to 6.7 (Table 4-5) and ratio of non-shaped to shaped from 0.16 to 17.00. Mean orientation of elliptical tree islands ranged from 1 to 180 degrees with most between 1 to 30 or 150 to 180 degrees (Figure 4-5). Density of tree islands was correlated with location, with a trend of higher densities in the east than in the west. Median tree island area and long axis were correlated with location, with larger tree islands in the north and tree islands with shorter long axis in the south and east. The ratio of elliptical to circular tree islands was not significantly correlated with location.

As with the 1950 photo plots, the distribution of tree island sizes showed many small tree islands and few larger tree islands (Figure 4-6). Fifty percent of the tree island area was made up of tree islands < 0.13 ha. Eighty-seven percent of the 4392 identified tree islands fell into this category.

Clump analysis for the 1991 area data indicated that there were no significant clumps at $D \geq 0.9$. But, if a D-value of 0.8 was used, three clumps emerged: < 1.15 ha, $1.37\text{-}1.44$ ha, > 1.84 ha. There were four potential clumps in long axis at D-value ≥ 0.9 : < 150 m, $150\text{-}218$ m, $251\text{-}329$ m, >418 m (Figure 4-7).

Mean WMM hydroperiod in the cells within which photo plots occurred ranged from 183 to 344 days with a range between 47 and 272 days. Mean ponding depth ranged between 0.07 m and 0.73 m. Density of tree islands, and density of circular and elliptical tree islands were correlated with elevation gradient (Table 4-6). Density of circular tree islands also was correlated with mean cell elevation. Median tree island area and median long axis were negatively correlated with hydroperiod, mean ponding depth, and elevation gradient and positively correlated with hydroperiod range and mean elevation. Mean tree island orientation was not significantly different from WMM flow orientation or NSM flow orientation.'

Canonical correlation analysis was performed with the tree island variables density, area, and ratio of elliptical to circular tree islands and the hydrology variables WMM magnitude, hydroperiod, mean ponding depth, and hydroperiod range. The analysis was performed again replacing area with long axis and a third and fourth time with the addition of mean elevation and elevation gradient. In all cases, there were two significant canonical correlations.

In the first two analyses (without elevation), the first significant correlation ($p=0.001$, $r=0.85$ and $p=0.0003$, $r=0.79$) was between the hydrology variables WMM hydroperiod range and mean ponding depth (coefficients of 0.49 and 0.43 and 0.58 and -0.41 respectively) and the tree island variable representing size (coefficients of -0.98 and -

0.96 for area and long axis respectively). Seventy-seven and sixty-seven percent of the variability was explained by the first significant correlation. The second significant correlations explained an additional 21 and 20% of the variability respectively. The important variables in the second correlations were mean ponding depth and hydroperiod (coefficients of 4.96 and -4.56 and 4.93 and -4.60 for analysis using area and long axis respectively). In both cases, the important tree island variable was tree island density (coefficients of -0.98 and -0.94 respectively).

When the elevation variables were added to the analysis, mean elevation and mean ponding depth (coefficients of 1.54 and 0.73) were the most important hydrology variables in the first significant correlations ($p=0.0001$, $r=0.91$ and $p=0.0001$, $r=0.86$). Median area was the most important tree island variable when size was represented as area (coefficient of 0.82). Both tree island density and long axis (coefficients of -0.77 and -0.70) were important when length was used. Seventy-six and sixty-nine percent of the variability was explained by the first sets of correlations. An additional 20 and 27% of the variability was explained by the second significant correlations. The most important hydrology variables in the second set of correlations were hydroperiod (coefficients of -3.10 and -3.29 for analysis using area and long axis respectively). Tree island density (coefficient of -0.84) was the most important variable when area was used to represent size. Both long axis and density (coefficients of 0.72 and -0.63 respectively) were important when long axis was used to represent size.

Comparison Between Individual Plots

Twenty of the twenty eight plots showed significant differences between the median size of tree islands between years (Table 4-7). Seventeen increased in percent

cover and eleven decreased (Figure 4-8) Density of tree islands in ten plots decreased, in three plots stayed the same and increased in fifteen plots. Eleven plots had significant changes in mean tree island orientation, fourteen did not. Sample size in the remaining plots was too small for comparison. The ratio of number of elliptical to circular tree islands in 1991 was larger in fourteen plots, smaller in twelve plots and the same in two plots. The ratio of non-shaped to shaped tree islands was larger in 20 plots and smaller in eight plots.

All Plots Together

When analyzed together in a pair-wise analysis, median tree island area, median long axis, and ratio of non-shaped to shaped tree islands were significantly different between years (Wilcoxon signed-rank $W=240$, $p=0.006$; $W=225$, $p=0.01$; $W=248$, $p=0.0001$ respectively). Density of tree islands were not significantly different, nor was the number of elliptical and circular tree islands per plots, ratio of elliptical to circular tree islands, or the orientation of the tree islands.

Canonical correlation analysis was performed using the tree island variables density, area, and ratio of elliptical to circular tree islands for 1950 and 1991 to examine changes in the relation of the variables between the time periods. Only the first canonical correlation was significant ($p=0.0001$ $r=0.94$). Ninety percent of the variation was explained by this analysis. Density and area from 1950 and 1991 had similar coefficients (0.82 and 0.90 for density and 0.22 and 0.29 for area respectively). The coefficient for ratio of elliptical to circular tree islands was slightly more important in the 1950 data than in the 1991 data (-0.37 and 0.14 respectively).

A similar analysis was performed using the hydrology data for the two sample periods. In this analysis the first two correlations were significant ($p=0.0001$, $r=0.88$ and $p=0.020$, $r=0.67$ for the first and second correlations respectively). Unlike the pattern for the tree island variables, the coefficients between the two years were not similar. In the first correlation, hydroperiod range (coefficient of 1.10) was the most important NSM hydrology variable followed by NSM depth (coefficient of 0.71), NSM magnitude (coefficient of 0.61), and hydroperiod (coefficient of 0.18). WMM depth (coefficient of 1.06) was the most important WMM hydrology variable with hydroperiod range (coefficient of 0.06), hydroperiod (coefficient of -0.03), and magnitude (coefficient of 0.01) contributing little. The order of importance for the second correlation was similar to the first for the NSM data (coefficients of 1.28, 1.05, 0.91, and -0.75 for hydroperiod range, depth, hydroperiod, and magnitude respectively). The importance of the WMM variables was not similar to that seen in the first correlation and was not similar to that of the NSM data (coefficients of 2.56, -1.96, 0.87, -0.29 for hydroperiod, depth, hydroperiod range, and magnitude).

All hydrology variables except for flow orientation were significantly different between the two time periods (hydroperiod- $t=-2.8$, $p=0.01$; hydroperiod range- $W=176.0$, $p=0.02$; mean ponding depth- $W=-169.0$, $p=0.02$; flow magnitude- $t=14.0$, $p<0.0001$). Mean water depths were generally shallower and hydroperiods shorter for the WMM than for the NSM. Depth and hydroperiod were more variable under WMM, while hydroperiod range and flow magnitude were less variable (Table 4-3).

A decrease in flow magnitude was correlated with a decrease in tree island area and long axis. Decreases in hydroperiod and depth were correlated with increases in area.

Decreases in hydroperiod range were correlated with decreases in the number of tree islands (Table 4-8).

Change in density was positively correlated with location, with a greater change in density in the east than the west. Change in area and change in long axis were not correlated with location. The change in the ratio of elliptical to circular tree islands increased from north to south.

Comparison of the location of the clumps in tree island size show differences (Figure 4-9). For area, the smallest and largest size clumps are much wider than in 1950 and the middle clump is much narrower. For the long axis data the opposite pattern is seen with the width of the smallest and largest size clumps larger in 1950 than in 1991 and the middle clump narrower in 1950 than in 1991.

Discussion

Historically, in Loxahatchee, there were more tree islands in areas of longer hydroperiod and greater depth. These areas also were less variable in hydroperiod range. The multivariate analysis demonstrated that hydroperiod range and flow magnitudes are important in explaining the ratio of elliptical to circular tree islands. Areas that were less variable with lower flow had lower ratios of elliptical to circular tree islands (e.g. more circular than elliptical tree islands). In addition, areas with less variation in hydroperiod had more tree islands of larger size that covered a larger area. These results support the hypotheses that flow is important in shaping tree islands and that battery tree islands form under conditions of greater hydroperiod and depth.

The relation between the tree island variables and hydrology variables in 1991 is very different from 1950. There were no significant correlations between the individual tree island variables and hydrology as there were with the 1950 data. The multivariate analysis shows that of the variables used here, hydroperiod and depth were the most important in explaining tree island size. Areas of longer hydroperiod and depth had smaller tree islands.

Loxahatchee can be grouped into three zones according to the patterns of change of tree islands observed from 1950 to 1991. 1) the edge of the refuge adjacent to the canals, 2) the eastern interior of the refuge, and 3) the western interior of the refuge. The general trend is for tree islands along the edge of the refuge to have decreased in size, number, and percent cover, while those on the interior increased in size, number, and percent cover.

The patterns of change are what is expected given the changes in hydrology. Areas of extreme hydroperiod and increased ponding depth should have a decrease in tree island area due to drowning of the vegetation on the tree islands. This is seen primarily along the southern boundary of the refuge. The plots along the Hillsboro Canal have obvious remnants of drowned tree islands. These plots also are the plots that did not show a significant difference in median tree island area between 1950 and 1991, possibly because the greatest changes in tree islands in these areas occurred after the construction of the canal in 1915. Areas of shorter hydroperiod and shallower ponding depth should show an increase in tree island area as woody vegetation colonizes the drier sites. In this analysis, decreases in hydroperiod and depth were correlated with increases in tree island

area. The ultimate consequence of these changes are to change a heterogeneous wetland into a more homogeneous upland.

Hagenbuck et al. (1974) expressed concern that an increase in the aquatic setting in Loxahatchee (e.g. extended hydroperiod and greater depth) might lead to an increase in the formation of battery islands. These islands form in areas where hydroperiods are longer and detritus settles to the bottom and forms loose peat mats. These then can become dislodged and become floating peat mats that are colonized by woody vegetation. The cumulative effect of this is to diminish the total water storage capacity of the area and reduce the amount of available wetland habitat (Hagenbuck et al. 1974). This may be happening in portions of Loxahatchee; however, because of the coarseness of the hydrology data, it is not possible to determine if the increase in the number of small circular tree islands thought to be battery tree islands within a plot, is due to increases in hydroperiod or other factors. In some of the plots, especially those along the edge of the refuge, where there has been an increase in the number of circular tree islands there has been a decrease in the median area of the tree islands. It may be that tree islands that were not circular in 1950 are circular in 1991 due to loss of area.

In other areas of the refuge, particularly in the northern interior, an increase in the percent cover and size of tree islands indicates that tree islands are expanding in size. Much of this area has had shorter hydroperiods and lower mean ponding depths in the recent past, both of which would seem to promote tree island growth. This pattern of increase in percent cover of tree islands in the northern areas was noted by Richardson et al. (1990), Silveira 1996, and Hagenbuck et al. in 1974. Hagenbuck et al.(1974) hypothesized that this expansion would continue to occur in areas of shorter hydroperiod.

These data support that. It may not be the changes in the mean hydrology variables themselves that result in the changes, but the loss of the dynamic pulsing nature of the historic processes.

An indicator that historic structuring processes have been lost in this system is seen when examining the results of the clump analysis. In 1950 there are potential clumps in tree island size that may correspond to processes operating at particular scales. Using the same criteria ($D \geq 0.9$) these clumps are absent in the 1991 data. Additionally, the relation between the hydrology variables is very different now than it was historically. Flow, which was important in describing the historic patterns of tree islands, now is virtually non existent. Processes such as nutrient transport, seed dispersal, and soil accretion and decretion are influenced by flow magnitudes. The results of removal of this structuring force from the system may be more subtle than changing hydroperiods, but just as important.

These analyses provide evidence that changes in flow magnitudes as well as other hydrologic variables contribute to the changes in the nature of tree islands in Loxahatchee. Several assumptions made in these analyses now should be considered. It has been assumed that tree islands are the resultant of processes operating in previous years and that these processes are related to the average values of structuring forces of flow, hydroperiod, and depth. Another assumption is that the relationship between the hydrologic variables in the 26 years averaged by the NSM are similar to the hydrologic variables that the landscape experienced in the 26 years prior to 1950. Because historic data do not exist, this represents the best available information. Because of the magnitude of changes that have occurred in terms of hydrology, the model outputs probably give a

good relative idea of the magnitude of the changes that have occurred. As long as the errors in the model are similar across the refuge, and between the two time periods, the associations between the tree islands and hydrology should be valid. From this study it can be concluded that: 1) the relations between the hydrology variables is different pre and post drainage; 2) patterns of tree islands have changed from 1950 to 1991; 3) the patterns of change in tree islands is different throughout the refuge; and 4) greater changes in hydrology lead to greater changes in the patterns of tree islands.

Table 4-3 continued.

Plots	Hydrology zone	NSM hydro-period (days)	WMM hydro-period (days)	NSM range in hydro-period (days)	WMM range in hydro-period (days)	NSM mean ponding depth (m)	WMM mean ponding depth (m)	NSM orientation (degrees)	WMM orientation (degrees)	NSM flow magnitude (m ³ x10 ³)	WMM flow magnitude (m ³ x10 ³)	Mean cell elevation (m)	Cell elevation gradient (m)
173	53	289	287	100	176	0.31	0.26	28	25	82469	3532	4.6	0.2
lw	54	293	285	110	170	0.30	0.22	20.5	175	56722	1672	4.6	0.2
le	55	299	289	97	170	0.32	0.22	10	171	86734	2857	4.6	0.1
20556	56	314	274	62	147	0.37	0.26	5	180	103286	3688	4.6	0.1
12460, 14460, 147	60	275	280	168	166	0.25	0.32	21	18	96903	5473	4.5	0.3
12461	61	263	275	185	182	0.24	0.26	25	25	77555	3218	4.5	0.3
15964	64	329	294	47	118	0.39	0.31	7	180	90610	1332	4.5	0.2
110	71	313	299	84	147	0.34	0.31	31	38	62436	1643	4.5	0.1
5576	76	240	344	256	53	0.23	0.73	23	90	129521	789	4.0	0.5
5577	77	261	319	175	100	0.26	0.61	32	18	95372	5800	4.1	0.5
6278, 36	78	248	290	272	171	0.20	0.37	42	31	66459	4582	4.4	0.7
6279	79	267	273	225	200	0.23	0.25	33	34	35614	4657	4.5	0.2
min		240	183	47	53	0.20	0.07	5	0	35613.62	456.39	4.00	0.06
max		329	344	272	200	0.40	0.73	178	180	129521.15	5800.20	4.93	0.70
mean		280.96	254.68	128.32	159.52	0.28	0.23	5.4	3.0	71838.28	2920.50	4.63	0.21
stdev		23.39	43.30	57.46	31.41	0.06	0.16	42.1	58.6	23292.67	1355.93	0.23	0.15

Table 4-3. Hydrology data for hydrology zones in Loxhatchee National Wildlife Refuge that contained photo plots. See Appendix A for relation of hydrology zone to NSM and WMM rows and columns.

Plots	Hydrology zone	NSM hydro-period (days)	WMM hydro-period (days)	NSM range in hydro-period (days)	WMM range in hydro-period (days)	NSM mean ponding depth (m)	WMM mean ponding depth (m)	NSM orientation (degrees)	WMM orientation (degrees)	NSM flow magnitude ($\text{m}^3 \times 10^3$)	WMM flow magnitude ($\text{m}^3 \times 10^3$)	Mean cell elevation (m)	Cell elevation gradient (m)
37712	12	283	205	129	188	0.25	0.09	127	95	49844	3617	4.9	0.1
37713	13	297	228	109	171	0.34	0.14	133	0	59242	456	4.9	0.2
325	19	287	195	103	159	0.27	0.08	158	160	57955	1962	4.9	0.2
328	20	262	183	121	169	0.21	0.07	158	155	40160	2224	4.9	0.1
306	28	270	203	101	190	0.23	0.10	170	155	46447	2621	4.8	0.2
310	29	276	210	106	139	0.25	0.11	174	135	47647	3157	4.8	0.2
257	35	272	204	118	184	0.26	0.12	172	22	62857	1883	4.8	0.2
23836, 260	36	264	213	125	148	0.23	0.12	178	171	52889	2596	4.8	0.1
le	38	291	243	104	171	0.31	0.17	8	160	77281	3914	4.7	0.2
210	43	274	218	119	181	0.24	0.14	176	18	64257	1638	4.7	0.2
23836	44	243	229	148	167	0.22	0.15	8	3	66914	3249	4.7	0.2
jke,jkw, 215	46	294	258	95	170	0.32	0.20	16	170	76126	3133	4.6	0.1
227	48	320	269	49	151	0.40	0.24	7	180	110655	3318	4.6	0.1

Table 4-2 continued.

	Tree island density (#/ha)	Percent tree island cover	Mean tree island area (m ²)	Median tree island area (m ²)	Standard deviation of area	Number of circular tree islands	Number of elliptical tree islands	Ratio of elliptical to circular tree islands	Mean elliptical tree island orientation (degrees)	Mean length of tree island long axis (m)	Median length of tree island long axis (m)	Standard deviation of long axis
12460	0.5	1.4	330.3	187.1	388.8	11	21	1.9	179	26.3	22.0	14.0
12461	0.3	1.2	487.1	242.5	624.8	5	16	3.2	177	32.5	23.0	19.7
14460	0.3	7.6	570.1	224.8	854.0	13	14	1.1	173	31.9	25.0	24.2
15964	0.7	20.4	1256.6	538.8	2013.4	25	52	2.1	8	55.1	36.5	51.5
20556	0.8	10.0	1239.5	755.0	1366.8	16	42	2.6	5	57.3	46.5	39.0
22748	1.6	33.7	1419.3	752.0	2803.7	111	62	0.6	179	51.4	38.0	46.1
23836	0.8	7.4	968.6	451.4	3254.8	51	17	0.3	164	37.5	29.0	42.7
37712	0.9	9.4	1501.4	491.0	6452.5	30	24	0.8	151	45.1	31.0	66.8
37713	0.8	6.0	790.1	539.2	734.2	43	26	0.6	154	40.9	34.5	21.8
le55	1.5	14.6	654.7	258.1	4241.8	111	45	0.4	175	28.4	23.0	40.7
ce38	1.7	13.3	496.0	342.5	741.7	156	46	0.3	175	30.1	26.0	21.7
min	0.08	0.3	259.24	187.10	171.23	1	5	0.29	1	22.26	20	7.25
max	2.16	33.7	10711.6	755.04	45070.75	164	139	25	180	57.83	46.5	66.78
mean	0.81	9.7	1143.42	376.97	3352.45	49.04	41.86	2.36	127.93	37.00	28.28	32.24
stdev	0.49	7.9	1922.43	165.36	8354.22	45.43	29.53	4.62	68.88	10.76	7.00	17.01

Table 4-2. Summary statistics for 1950 photo plots from Loxahatchee National Wildlife Refuge. Orientation is 0 to 180 degrees with 0 = north and 180 = south.

	Tree island density (#/ha)	Percent tree island cover	Mean tree island area (m ²)	Median tree island area (m ²)	Standard deviation of area	Number of circular tree islands	Number of elliptical tree islands	Ratio of elliptical to circular tree islands	Mean elliptical tree island orientation (degrees)	Mean length of tree island long axis (m)	Median length of tree island long axis (m)	Standard deviation of long axis
jkle	1.1	10.0	542.4	287.9	1688.1	47	100	2.1	1	31.2	24.0	26.8
jklw	0.8	11.9	963.8	273.1	6845.8	59	46	0.8	180	32.0	24.0	59.2
llw	1.2	31.8	318.7	247.8	284.6	85	86	1.0	176	25.0	22.0	11.0
110	1.0	8.7	517.5	253.7	1793.0	77	55	0.7	19	28.1	22.0	31.1
173	0.8	9.5	589.2	269.4	1999.6	60	44	0.7	10	31.0	24.0	39.6
210	0.1	4.0	1819.5	674.7	2275.0	6	5	0.8	165	56.2	40.5	38.6
215	0.6	6.1	648.8	384.9	963.3	40	31	0.8	168	36.3	29.0	24.5
257	0.5	12.8	1279.6	360.2	3086.3	22	43	2.0	174	46.7	31.0	52.7
260	0.9	6.4	426.1	259.1	764.3	60	58	1.0	160	28.0	23.0	21.6
306	1.0	8.8	521.5	440.8	300.7	98	36	0.4	146	31.4	29.0	11.2
310	2.2	11.8	259.2	215.4	171.2	164	139	0.8	157	22.3	21.0	7.3
325	0.7	10.7	874.8	262.3	1619.2	18	62	3.4	156	39.1	25.0	34.4
328	0.7	5.3	453.7	346.3	386.5	49	35	0.7	145	29.0	26.0	12.7
5576	0.4	4.1	1429.1	593.0	2130.7	1	25	25.0	169	57.8	42.0	56.3
5577	0.2	2.3	10711.6	310.9	45070.7	3	15	5.0	173	44.1	24.0	55.3
6278	0.1	0.2	285.1	202.7	192.1	1	5	5.0	34	24.7	20.0	10.0
6279	0.7	2.6	661.5	390.5	820.7	11	22	2.0	9	36.7	31.0	22.3

Table 4-1 continued.

Variable	Description	Transformation 1950 1991	Significance
Difference in depth	Change in mean ponding depth within a cell from the NSM to WMM simulation	1950 depth - 1991 depth	If depth is an important factor in determining patterns of tree islands, cells that have experienced the greatest change in depth should show the greatest change in tree island variables. Cells with shallower depth should show an increase in tree islands while those with deeper depths should show a decrease in existing tree island area and possibly an increase in the number of small circular islands due to the formation of battery islands.

Table 4-1 continued.

Variable	Description	Transformation 1950 1991	Significance
Difference in flow magnitude	Change in flow magnitude within a cell from the NSM to WMM simulation.	1950 magnitude - 1991 magnitude	If tree island shape is related to flow magnitude, cells with greater changes in flow magnitude should show greater changes in the ratio of elliptical to circular tree islands.
Difference in hydroperiod	Change in hydroperiod within a cell from the NSM to WMM simulation	1950 hydroperiod - 1991 hydroperiod	If hydroperiod is an important factor in determining patterns of tree islands, cells that have experienced the greatest change in hydroperiod should show the greatest change in tree island variables.
Difference in hydroperiod range	Change in hydroperiod range within a cell from the NSM to WMM simulation	1950 hydroperiod range - 1991 hydroperiod range	If range in hydroperiod is an important factor in determining patterns of tree islands, cells that have experienced the greatest change in range in hydroperiod should show the greatest change in tree island variables.

Table 4-1 continued.

Variable	Description	Transformation 1950 1991	Significance
	to 1991 within a plot.	density	formation and lose of tree islands within a plot.
Difference in percent cover	Change in percent cover of tree islands from 1950 to 1991 within a plot.	1950 percent cover - 1991 percent cover	Higher percent cover within a plot indicates the expansion of tree islands and the decrease in wetland vegetation.
Difference in area	Difference in median tree island size from 1950 to 1991 within each plot.	1950 area - 1991 area	An increase in tree island area indicates the predominance of accretion processes while a decrease indicates the predominance of decrection processes.
Difference in long axis	Difference in median long axis from 1950 to 1991 within a plot.	1950 long axis - 1991 long axis	A shorter median long axis indicates the predominance of decrection processes.
Difference in ratio of elliptical to circular	Change in ratio of elliptical to circular tree islands from 1950 to 1991 within a plot.	1950 ratio - 1991 ratio	An increase in the elliptical to circular ratio indicates either the increase in the number of elliptical tree islands or the decrease in the number of circular tree islands.

Table 4-1 continued.

Variable	Description	Transformation 1950	Transformation 1991	Significance
Range in hydroperiod	Difference in days between the minimum and maximum hydroperiod for the 26 year simulations.	None	None	accumulation can lead to the formation of battery tree islands. Often it is not the average values, but the variance in values that influences vegetation patterns. Range in hydroperiod illustrates the variability of hydroperiod for each cell.
Mean ponding depth	Mean depth of water (m) in a cell over the 26 year simulation.	Ln	None	Inundation depth influences which species can survive in a cell. Cells with greater depth should support more aquatic vegetation and less upland vegetation (tree islands).
Elevation gradient	Magnitude of change in elevation within a cell.	None	None	Elevation gradient is an indicator of the heterogeneity of the cell. Cells with a greater gradient should be more variable in tree island variables than those that are flatter.
Mean elevation	Average cell elevation.	None	None	Mean cell elevation provides a measure of the similarity of the topographic position of the cell in relation to other cells. Cells with higher elevation tend to be dryer than cells with lower elevation.
Difference in density	Change in density from 1950	1950 density	1991 density	Changes in density are an indication of the

Table 4-1 continued.

Variable	Description	Transformation 1950	Transformation 1991	Significance
Ratio of elliptical to circular tree islands	Number of elliptical tree islands divided by the number of circular tree islands	None	None	Both elliptical and circular tree islands occur within each plot. It is hypothesized that plots that experience greater flows should have more elliptical than circular tree islands (higher ratio) than those that experience lower flows.
Ratio of non-shaped to shaped tree islands	Number of irregular tree islands divided by number of elliptical + number of circular tree islands	None	None	It is hypothesized that plots that experience greater flows should have more shaped than non-shaped islands (lower ratio)
Orientation of tree island	Direction of long axis with 0 indicating north and 180 indicating south. Values are mean for all elliptical tree islands in the plot.	$\tan(\theta/2)$	$\tan(\theta/2)$	Historically it has been said that tree islands are oriented in the direction of flow. Quantifying orientation will help us to better understand historic flow directions.
Flow magnitude	Mean magnitude (m^3) of water in a cell over the 26 year simulation.	None	None	Magnitude of flow can influence the shape and size of landforms by transporting and depositing nutrients and soils. Areas with higher flow should show more distinctive patterns of shape and size.
Hydroperiod	Hydroperiod exceeded in 90% of the years of the 26 year simulation.	None	None	Hydroperiod influences which species can grow in an area and influences the amount of detritus that can accumulate in a cell. Additional detritus

Table 4-1. Variables used, description, transformation, and significance of variable

Variable	Description	Transformation 1950 1991	Significance
Density of tree islands	Number of tree islands per hectare	None	Number of tree islands is an indication of the suitability of the plot for tree islands.
Percent cover of tree islands	Percent of each plot occupied by tree islands (Sum of tree island area)	None	Indicator of relative abundance of upland versus wetland vegetation within a plot. An increase in tree island area would indicate a decrease in the amount of marsh in that plot.
Median size of tree islands	Median of individual tree island area within a plot.	ln	Tree island area is an indication of accretion and decretion processes operating in the system. Tree islands increase in size as succession proceeds and decrease in size in response to disturbances such as fire, extreme flooding, and hurricanes.
Median long axis of tree islands	Median of individual tree island long axis within a plot.	1/median	In fluvial systems the length of features is influenced by the flow velocity and consistency of flow (Mills 1980). Lengths of elliptical tree islands may help us to better understand the patterns of historic water flow.

Table 4-4. Correlations between tree island variables and hydrology variables for 1950 photo plots. Top number is correlation coefficient, bottom number is p value. A p value < 0.05 is considered significant.

	Flow magnitude	NSM 90% hydroperiod	NSM mean ponding depth	NSM range in hydroperiod
Tree island density	-0.148 0.453	0.456 0.015	0.417 0.027	-0.526 0.004
Percent tree island cover	0.221 0.259	0.661 0.000	0.653 0.000	-0.665 0.000
Mean tree island area	0.363 0.058	0.055 0.782	0.171 0.384	-0.095 0.630
Median tree island area	0.205 0.295	0.229 0.241	0.284 0.042	-0.373 0.050
Density of circular tree islands	-0.177 0.368	0.384 0.044	0.352 0.066	-0.461 0.014
Density of elliptical tree islands	-0.037 0.852	0.422 0.025	0.400 0.035	-0.418 0.027
Mean tree island long axis	0.418 0.027	0.169 0.390	0.256 0.189	-0.233 0.231
Median tree island long axis	-0.275 0.156	-0.177 0.367	-0.240 0.219	0.287 0.139
Ratio of elliptical to circular tree islands	0.527 0.004	-0.404 0.033	-0.238 0.222	0.450 0.016

Table 4-5. Summary statistics for 1991 photo plots from Loxahatchee National Wildlife Refuge. Orientation is 0 to 180 degrees with 0 = north and 180 = south.

	Tree island density (#/ha)	Percent tree island cover	Mean tree island size (m ²)	Median tree island area (m ²)	Standard deviation of area	Number of circular tree islands	Number of elliptical tree islands	Ratio of elliptical to circular tree islands	Mean elliptical tree island orientation	Mean length of tree island long axis (m)	Median length of tree island long axis (m)	Standard deviation of long axis
jk1e	1.5	22.6	852.1	425.8	1678.2	41	130	3.2	1	42.2	32.0	29.9
jk1w	1.6	26.2	964.6	345.8	6851.8	39	128	3.3	4	33.5	27.0	20.2
ll1w	1.8	39.8	463.8	342.1	433.3	83	158	1.9	149	31.9	27.5	16.6
110	1.3	17.6	764.8	423.6	1830.5	109	79	0.7	177	35.8	28.0	30.2
173	1.2	23.8	1037.6	573.9	1679.2	49	80	1.6	19	45.6	36.0	36.6
210	0.1	3.8	2314.0	1429.4	2263.9	2	8	4.0	171	66.7	59.0	42.2
215	0.7	9.1	697.3	465.2	961.8	35	48	1.4	157	37.3	31.0	23.9
257	0.2	6.5	1687.0	518.6	3387.4	16	11	0.7	161	52.0	34.0	55.3
260	0.7	10.1	813.1	536.3	1102.9	44	52	1.2	176	39.6	39.3	28.0
306	0.8	9.8	724.9	601.8	531.4	80	32	0.4	169	36.3	33.0	15.0
310	2.3	25.8	521.7	333.6	704.9	117	197	1.7	168	31.4	27.0	19.1
325	0.3	9.6	1563.8	790.0	2137.9	11	25	2.3	149	54.9	44.5	42.1
328	0.8	11.6	848.5	659.2	744.5	58	50	0.9	160	40.5	36.0	20.9
5576	0.0	0.06	207.4	132.5	153.7	1	2	2.0	169	20.0	18.0	6.2
5577	0.1	0.2	281.8	159.4	260.6	2	5	2.5	50	23.0	18.0	10.2
6278	0.0	0.04	363.6	363.6		1	0	0.0		27.0	27.0	
6279	0.3	1.6	1034.8	478.3	1160.6	5	9	1.8	9	45.1	33.5	27.6

Table 4-5 continued.

	Tree island density (#/ha)	Percent tree island cover	Mean tree island size (m ²)	Median tree island area (m ²)	Standard deviation of area	Number of circular tree islands	Number of elliptical tree islands	Ratio of elliptical to circular tree islands	Mean elliptical tree island orientation	Mean length of tree island long axis (m)	Median length of tree island long axis (m)	Standard deviation of long axis
12460	0.2	1.4	736.7	449.1	903.4	4	7	1.8	7	40.3	31.0	30.8
12461	0.3	2.3	672.0	458.7	603.0	3	20	6.7	20	39.6	32.0	22.3
14460	0.2	7.4	667.9	289.9	899.9	10	16	1.6	14	36.5	27.0	28.7
15964	0.9	13.5	1216.9	365.3	7212.9	39	42	1.1	172	39.6	27.0	73.9
20556	1.4	8.2	577.8	384.7	594.2	48	59	1.2	168	34.4	30.0	19.0
22748	1.9	29.3	976.7	620.0	1332.2	125	82	0.7	1	42.1	35.0	30.8
23836	1.1	11.8	1090.8	619.7	3185.6	55	35	0.6	158	42.5	34.5	41.4
37712	0.9	13.5	2021.2	977.1	6313.9	41	12	0.3	154	54.7	41.0	65.1
37713	1.1	13.2	1183.4	871.2	872.6	61	23	0.4	152	47.3	40.5	20.3
le55	2.0	22.2	777.3	387.2	3730.7	73	139	1.9	151	35.7	28.0	38.6
ce38	1.8	42.6	858.6	594.1	1185.9	139	61	0.4	168	38.3	33.0	24.5
Min	0.01	0.04	207.41	132.45	153.70	1.	0	0.00	1.00	20.00	18.00	6.2
Max	2.31	42.6	2314.01	1429.44	7212.92	139	197	6.67	177.00	66.69	59.00	73.9
Mean	0.92	13.7	925.71	521.29	1952.48	46	54	1.65	113.11	39.78	32.49	30.4
SD	0.69	11.6	486.90	260.54	1976.01	41	53	1.38	72.39	9.74	7.97	15.6

Table 4-6. Correlations between tree island variables and hydrology variables for 1991 photo plots. Top number is correlation coefficient, bottom number is p value. A p value < 0.05 is considered significant.

	Flow magnitude	WMM 90% hydroperiod	WMM mean ponding depth	WMM range in hydroperiod	Elevation gradient	Mean cell elevation
Tree island density	-0.160 0.416	-0.079 0.688	-0.224 0.251	0.091 0.645	-0.626 0.000	0.313 0.105
Percent cover	-0.115 0.464	-0.115 0.561	-0.256 0.189	0.191 0.331	0.352 0.066	-0.519 0.005
Mean tree island area	-0.296 0.126	-0.559 0.002	-0.558 0.002	0.443 0.018	-0.405 0.032	0.562 0.002
Median tree island area	-0.252 0.195	-0.728 0.000	-0.749 0.000	0.684 0.000	-0.554 0.002	0.799 0.000
Density of circular tree islands	-0.196 0.317	-0.201 0.305	-0.303 0.117	0.085 0.667	-0.600 0.000	0.387 0.042
Density of elliptical tree islands	-0.118 0.548	0.024 0.902	-0.122 0.539	0.044 0.825	-0.508 0.006	0.187 0.342
Ratio of elliptical to circular tree islands	0.043 0.827	0.190 0.333	0.198 0.314	0.026 0.896	0.027 0.893	-0.212 0.279
Mean long axis	-0.235 0.229	-0.608 0.001	-0.610 0.001	0.584 0.001	-0.436 0.020	0.636 0.000
Median long axis	-0.281 0.147	-0.665 0.000	-0.655 0.000	0.547 0.003	-0.465 0.013	0.669 0.000

Table 4-7. Differences between variables from 1950 to 1991. N.S. indicates no significant difference. Positive value for density, percent cover and change in ratio indicate an increase from 1950 to 1991. Positive change in orientation magnitude indicates a clockwise change in orientation. A negative change indicates a counter clockwise shift.

Plot	Median tree island area (m ²)	Significance tested with Wilcoxon Rank Sum Test	Percent cover	Density (tree islands/ha)	Orientation	Significance tested with Watson F-Test for determining the equality of circular means.	Change in ratio
jke	137.8	Z=-5.54, p<0.001	7.8	0.5	0.0	N.S.	1.0
jkw	72.7	Z=-2.63, p=0.008	8.8	0.8	4.0	N.S.	2.5
l1w	94.4	Z=-4.91, p<0.001	4.9	0.6	-27.0	F=54.85, p=0.00, df=242	0.9
110	169.9	Z=-5.99, p<0.001	5.5	0.4	-22.0	F=20.88, p=0.00, df=132	0.0
173	304.4	Z=-6.74, p<0.001	8.8	0.4	9.0	N.S.	0.9
210	754.7	N.S.	-0.1	-0.1	6.0	N.S.	3.2
215	80.4	N.S.	1.8	0.1	-11.0	N.S.	0.6
257	158.4	N.S.	-3.9	-0.3	-13.0	N.S.	-1.3
260	277.2	Z=-5.80, p<0.001	2.3	-0.1	16.0	F=9.66, p=0.00, df=108	0.2
306	161.0	Z=-3.56, p<0.001	0.7	-0.2	23.0	F=12.58, p=0.00, df=66	0.0
310	118.2	Z=-6.71, p<0.001	8.6	0.2	-11.0	F=7.23, p=0.00, df=334	0.8
325	527.8	Z=-3.41, p<0.001	-0.7	-0.4	7.0	N.S.	-1.2
328	312.9	Z=-6.60, p<0.001	3.9	0.1	15.0	F=5.88, p=0.00, df=83	0.1
5576	-460.6	N.S.	-5.7	-0.4			-23.0
5577	-151.4	N.S.	-2.4	-0.2			-2.5
6278	160.9	N.S.	-0.2	-0.1			-5.0
6279	87.8	N.S.	-1.9	-0.5	0.0	N.S.	-0.2

Table 4-7 continued.

Plot	Median tree island area (m ²)	Significance tested with Wilcoxon Rank Sum Test	Percent cover	Density (tree islands/ha)	Orientation	Significance tested with Watson F-Test for determining the equality of circular means.	Change in ratio
12460	262.0	N.S.	0.1	-0.4	8.0	N.S.	-0.2
12461	216.2	N.S.	1.2	0.0	23.0	F=5.70, p=0.02, df=34	3.5
14460	65.2	N.S.	-0.1	0.0	21.0	F=5.56, p=0.03, df=28	0.5
15964	-173.5	Z=4.60, p<0.001	-5.4	0.1	-16.0	F=6.77, p=0.01, df=92	-1.0
20556	-370.4	Z=5.36, p<0.001	-1.8	0.6	-17.0	F=10.15, p=0.00, df=99	-1.4
22748	-132.1	Z=3.29, p=0.001	-3.5	0.3	-2.0	N.S.	0.1
23836	168.2	Z=-2.52, p=0.011	4.4	0.3	-6.0	N.S.	0.3
37712	486.1	Z=-5.20, p<0.001	5.7	0.0	3.0	N.S.	-0.5
37713	331.9	Z=-4.61, p<0.001	8.0	0.3	-2.0	N.S.	-0.2
le55	129.1	Z=-4.93, p<0.001	5.6	0.5	-24.0	F=23.83, p=0.00, df=182	1.5
cle38	251.6	Z=-8.07, p<0.001	20.8	0.1	-7.0	N.S.	0.1
max	754.70		20.83	0.81			3.47
min	-460.57		-5.73	-0.47			-23.00
mean	144.32		2.61	0.10			-0.72
stdev	250.46		5.66	0.34			4.66

Table 4-8. Spearman correlations between change in tree island variables and change in hydrology variables for 28 photo plots in Loxahatchee. Top number is correlation coefficient, bottom number is p value. A p value < 0.05 is considered significant.

	Flow magnitude	90% hydroperiod	Mean ponding depth	Range in hydroperiod
Tree island density	-0.123 0.531	-0.074 0.708	-0.230 0.239	0.610 0.001
Percent tree island cover	0.315 0.103	-0.229 0.241	-0.314 0.104	0.286 0.140
Mean tree island area	0.528 0.004	-0.529 0.004	-0.415 0.028	0.070 0.723
Median tree island area	0.499 0.007	-0.511 0.006	-0.392 0.039	0.017 0.931
Density of circular tree islands	-0.160 0.414	-0.052 0.972	-0.035 0.859	-0.030 0.881
Density of elliptical tree islands	-0.046 0.814	-0.046 0.816	-0.164 0.403	0.522 0.004
Mean tree island long axis	0.457 0.014	-0.340 0.077	-0.252 0.195	0.018 0.927
Median tree island long axis	0.436 0.020	-0.370 0.053	-0.272 0.161	-0.029 0.884
Ratio of elliptical to circular tree islands	0.236 0.227	-0.258 0.184	-0.295 0.128	0.326 0.090

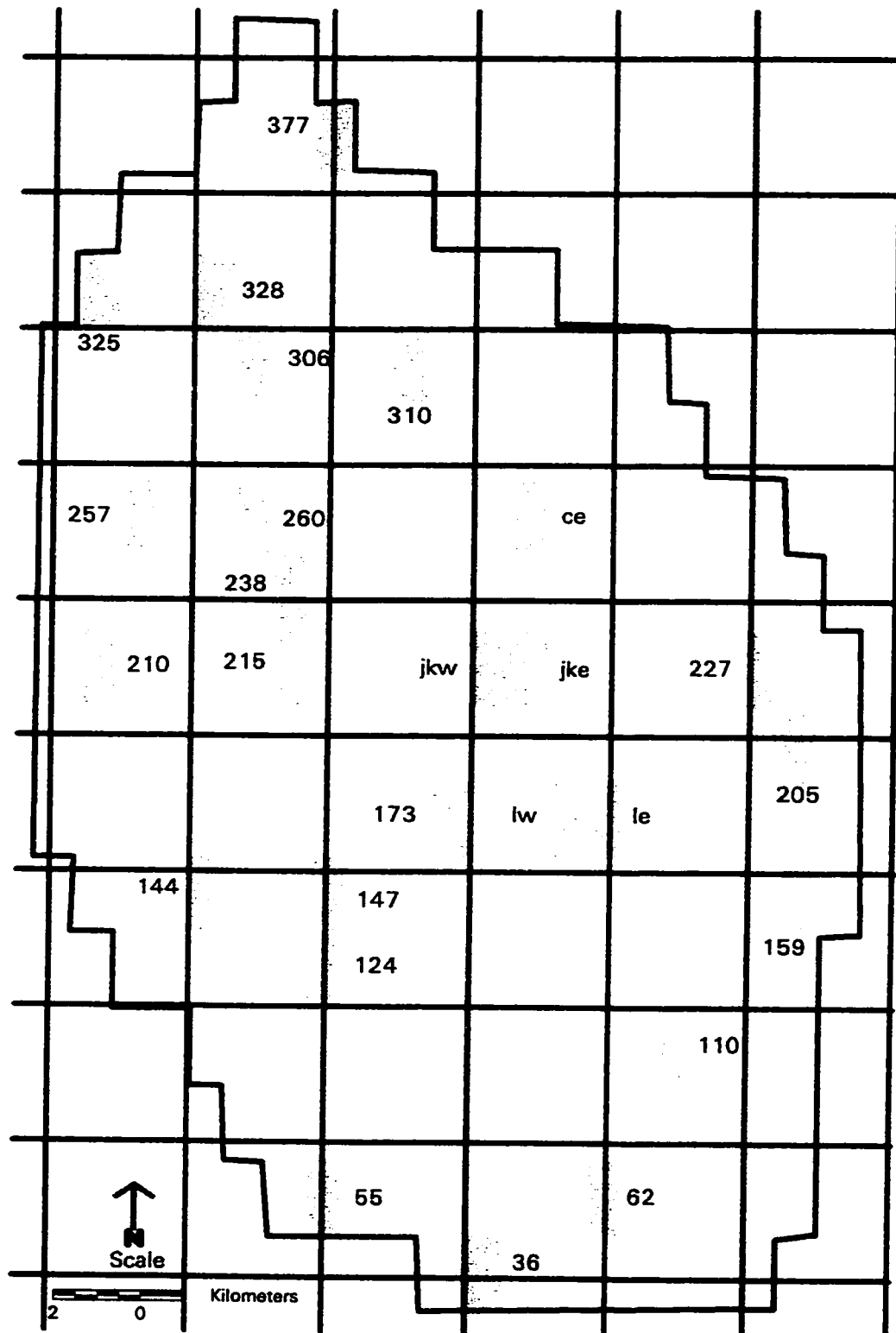


Figure 4-1. Location of 1800 x 900 m photo plots in Loxahatchee National Wildlife Refuge. Large squares are the boundaries of the hydrology zones.

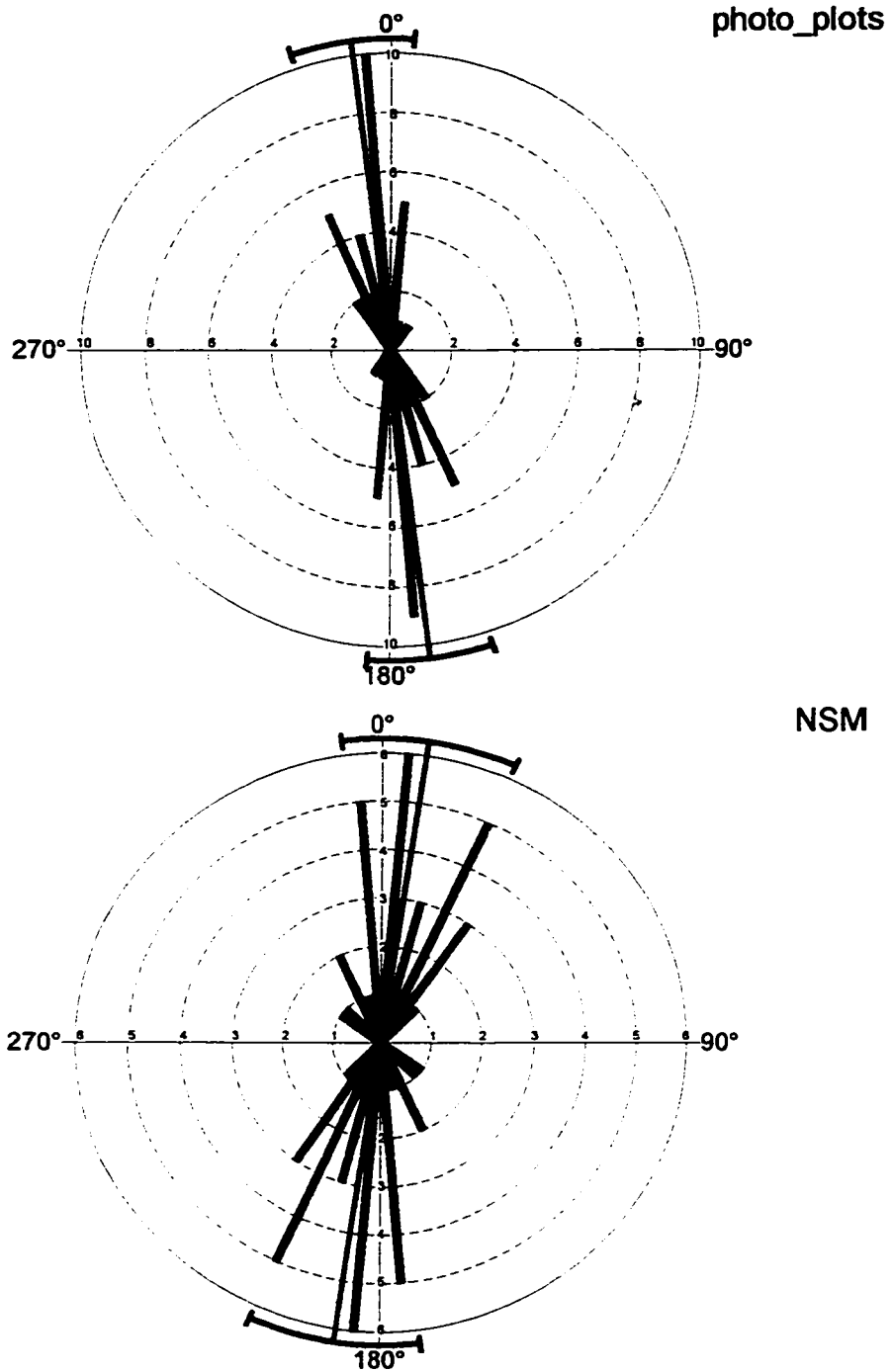


Figure 4-2. Histograms of mean orientation of tree islands from 1950 photo plots (top) and orientation of NSM flow for grid cells containing photo plots (bottom).

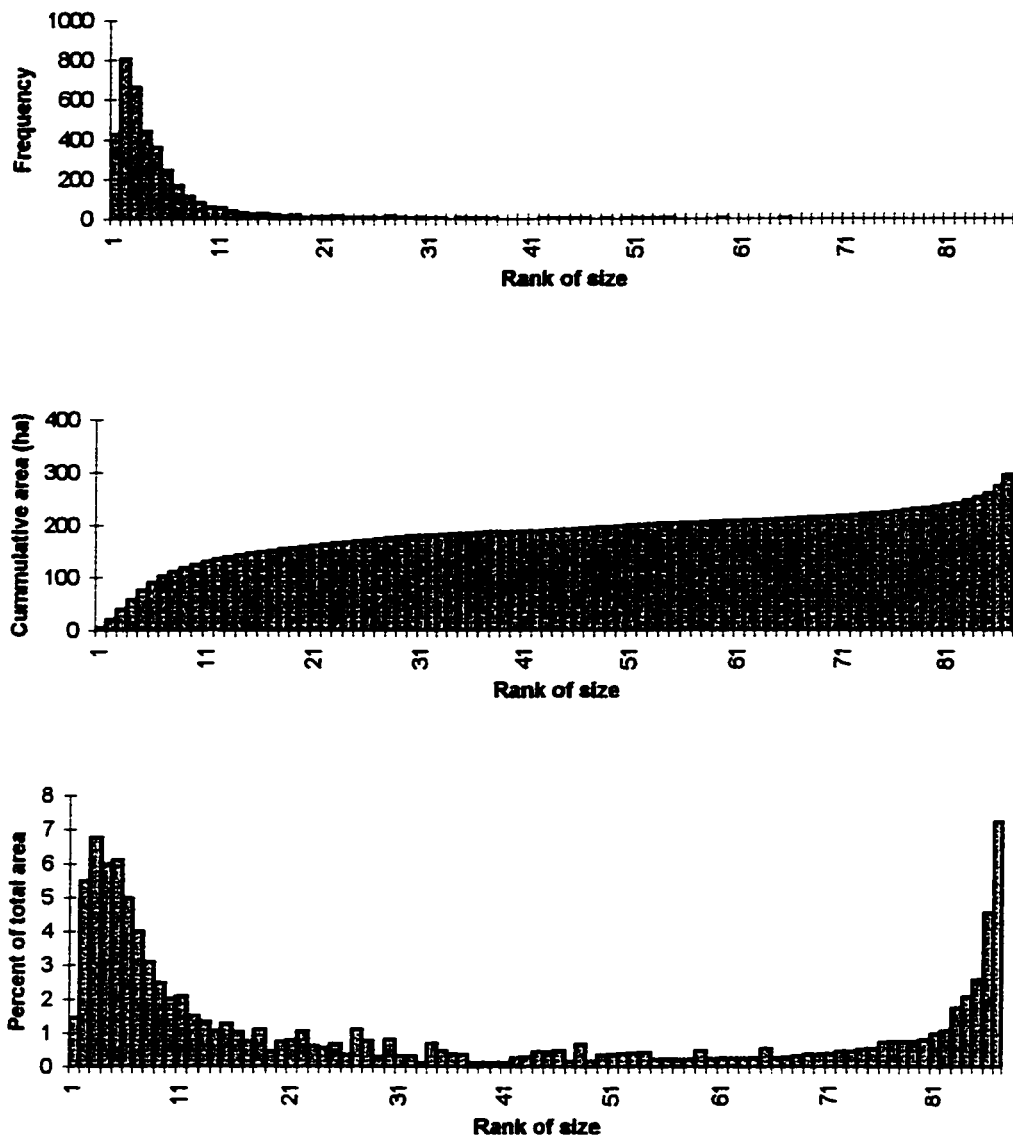


Figure 4-3. Frequency distribution from all 1950 photo plots of tree island size (top), cumulative area (middle), and contribution of each size class to overall tree island area. Sizes range from 0.01 to 21.22 ha. Tree islands < 0.16 ha (rank of 16) make up 50% of the total tree island area.

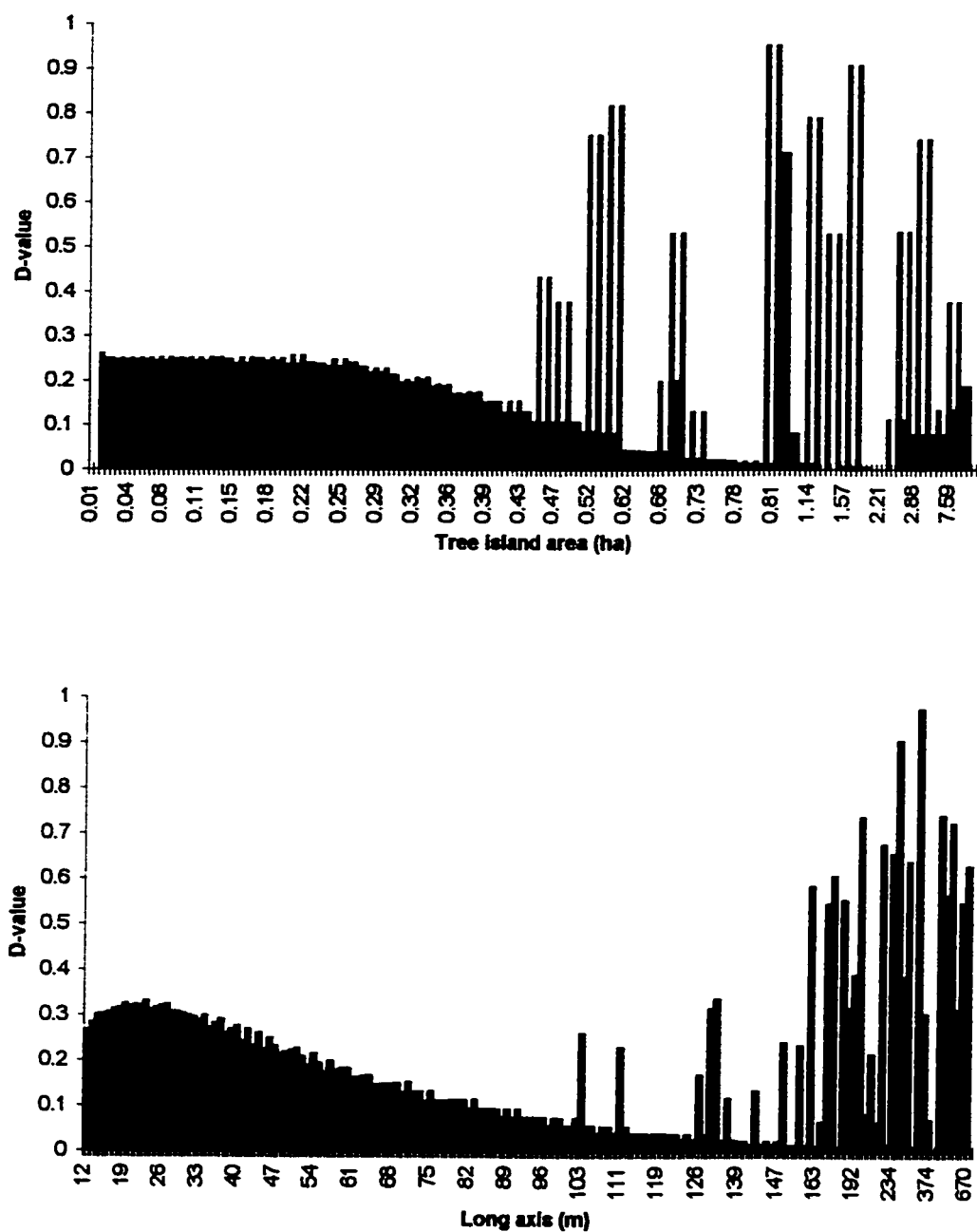


Figure 4-4. Rank order of tree island area (top) and long axis (bottom) for 1950. Boundaries of potential clumps are indicated by bars that extend above $D \geq 0.9$.

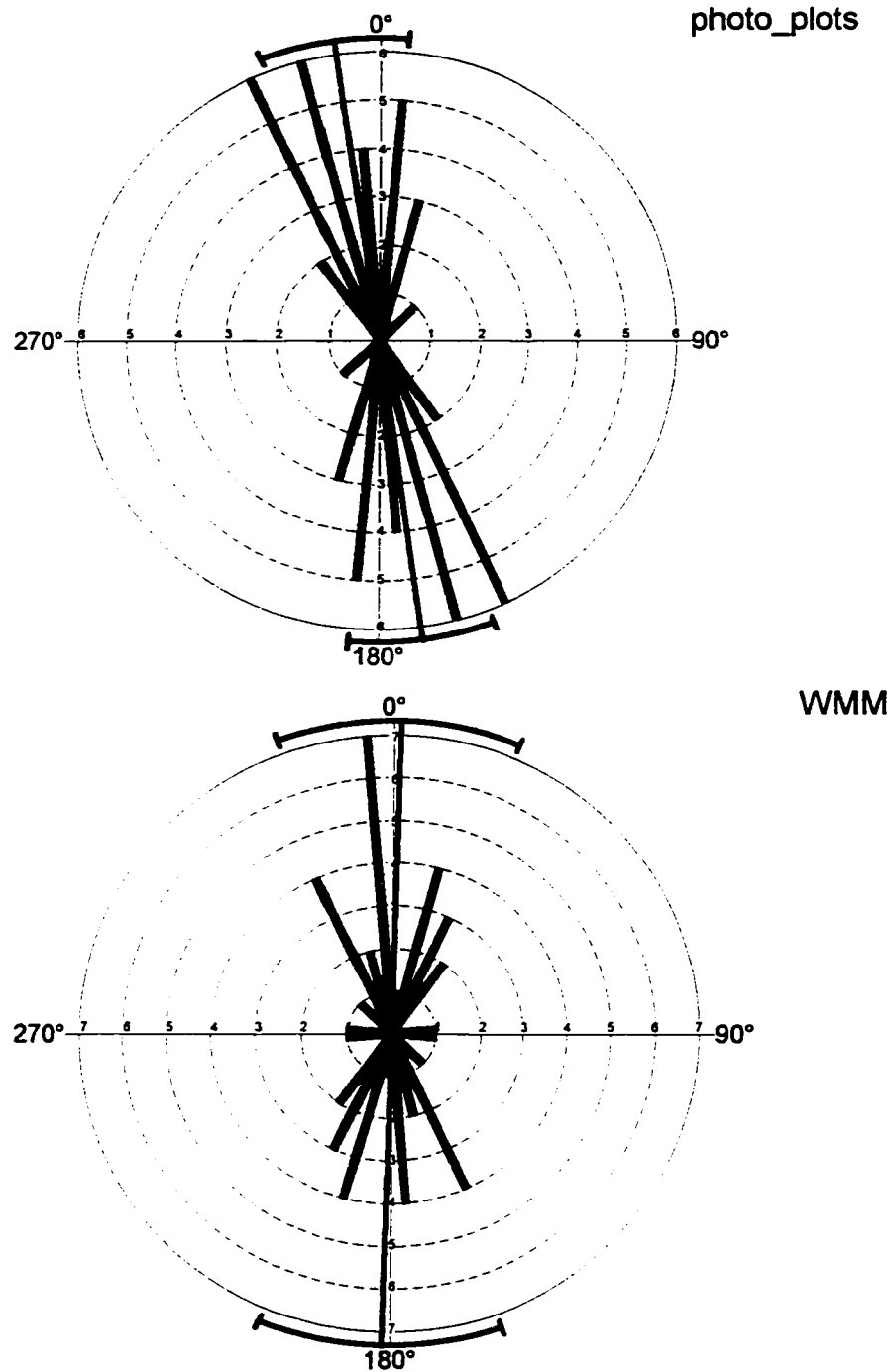


Figure 4-5. Histograms of mean orientation of tree islands from 1991 photo plots (top) and orientation of WMM flow for grid cells containing photo plots (bottom).

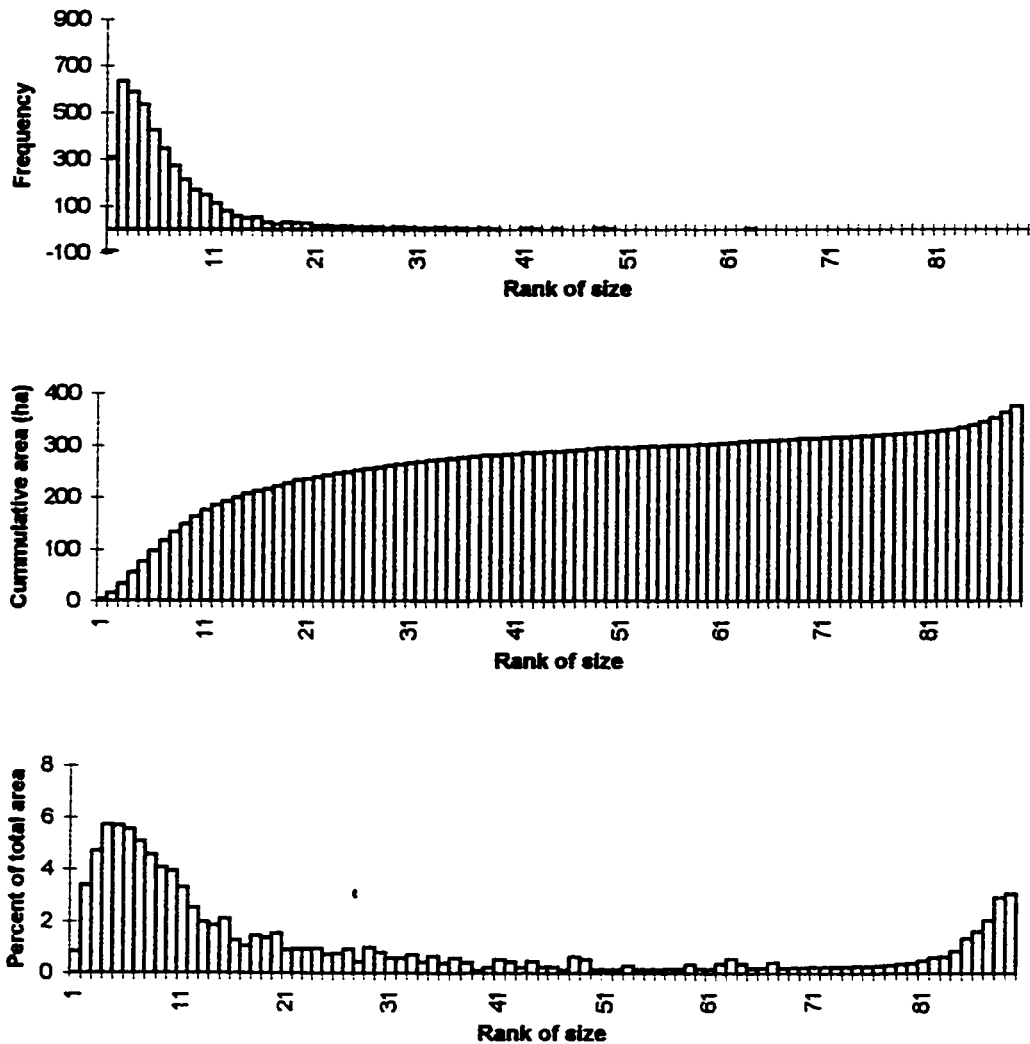


Figure 4-6. Frequency distribution from all 1991 photo plots of tree island size (top), cumulative area (middle), and contribution of each size class to overall tree island area. Sizes range from 0.01 to 11.50 ha. Tree islands < 0.13 ha (rank of 13) make up 50% of the total tree island area.

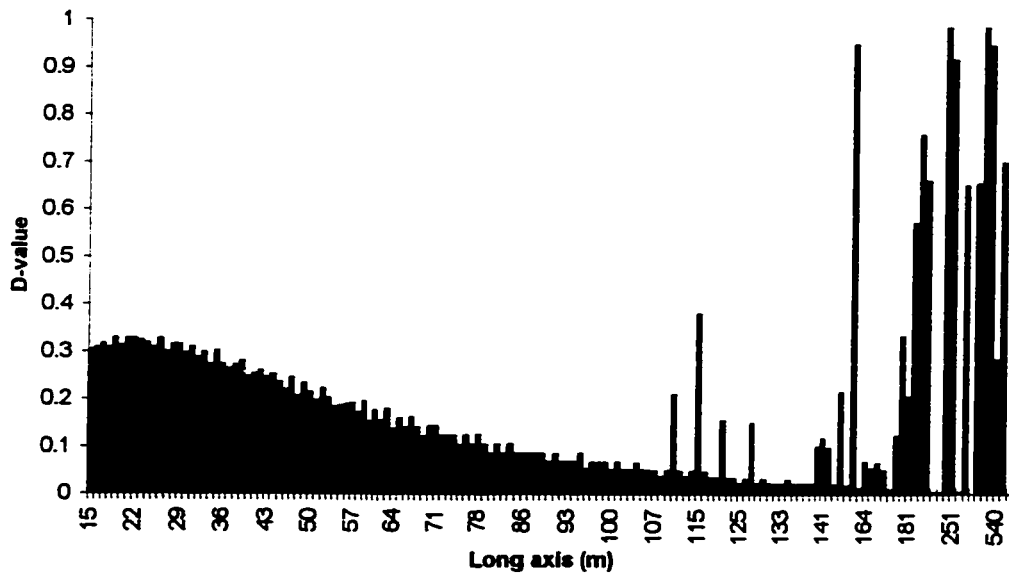
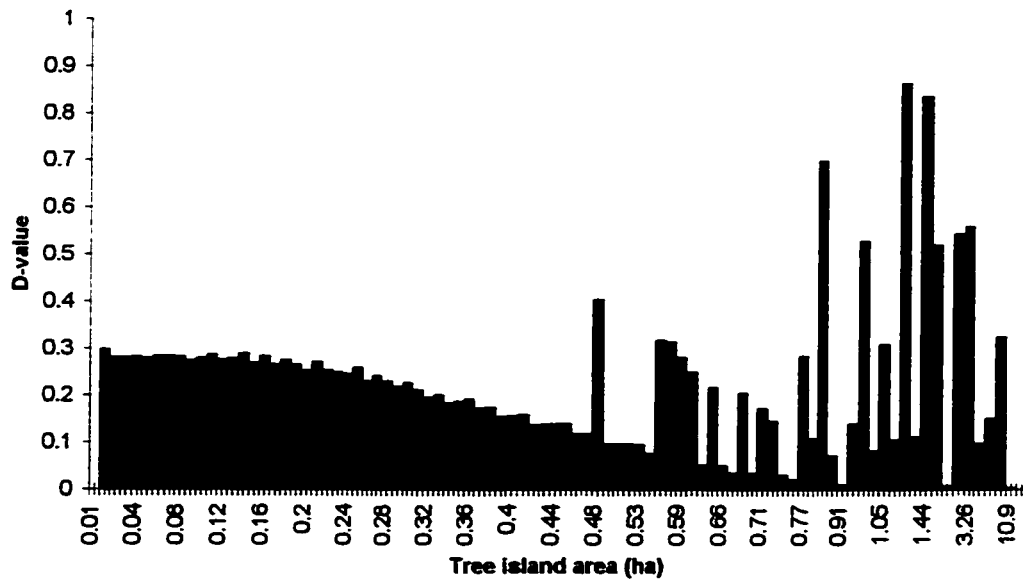


Figure 4-7. Rank order of tree island area (top) and long axis (bottom) for 1991. Boundaries of potential clumps are indicated by bars that extend above $D \geq 0.9$.

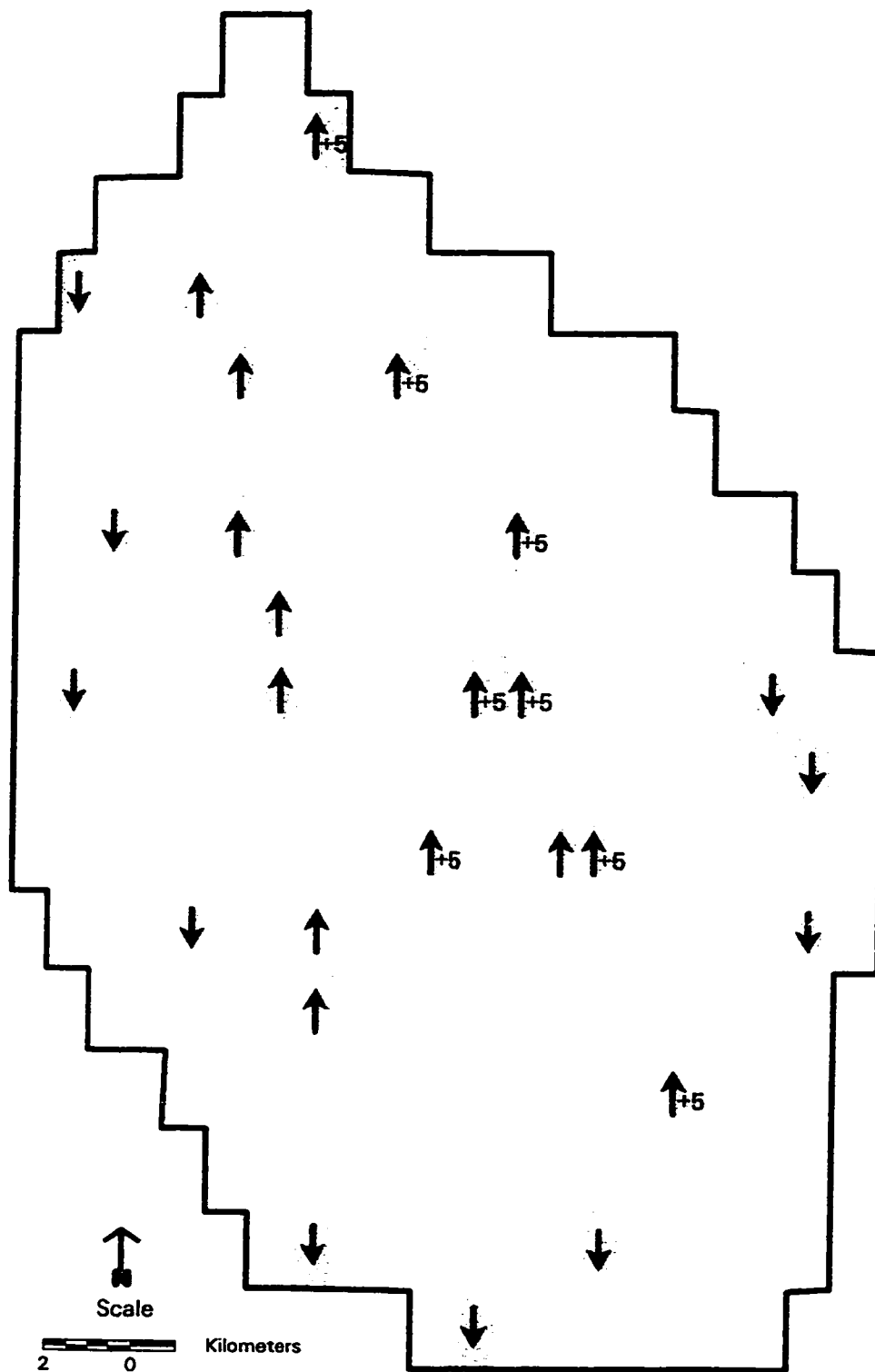


Figure 4-8. Location of photo plots showing changes in percent cover. Down arrow indicates a decrease from 1950 to 1991, up arrow indicates $\leq 5\%$ increase and up arrow +5 indicates $> 5\%$ increase

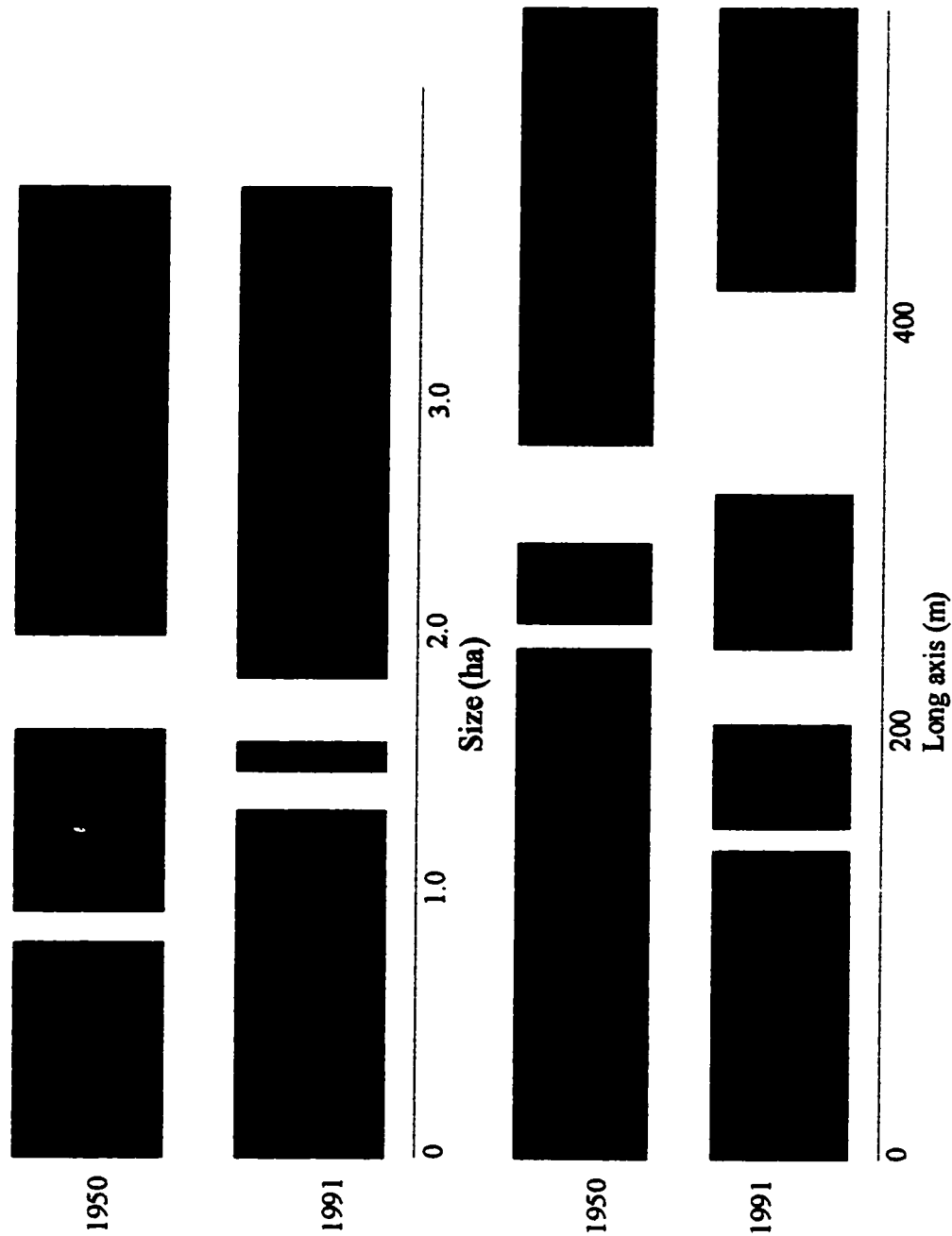


Figure 4-9. Location of potential area clumps using a criteria of $D \geq 0.85$ (top) and potential long axis (bottom) clumps using a criteria of $D \geq 0.9$ for 1950 and 1991.

CHAPTER 5 SUMMARY AND CONCLUSIONS

Summary

The objective of this research was to identify and quantify patterns of tree islands in the Arthur R. Marshall Loxahatchee National Wildlife Refuge and to relate the patterns to one of the major structuring forces in the Everglades--hydrology. Tree island patterns were quantified using two different methods and at two different dates (1950 and 1991). The results from the two different methods were compared as were the results for the two dates. Hydrology was selected as the process of study for several reasons: hydrology has been shown to be a major structuring force in vegetation communities of wetlands (Mitsch and Gosselink 1986); the hydrologic changes to the system are the result of human activity and future changes may be under human control; and hydrology is a major focus of Everglades restoration efforts.

This study first took a broad-brush approach that identified and quantified current patterns of tree islands, and quantified the range in variation in tree island variables. These results then were used to develop a sampling protocol for looking at historic and current patterns of tree islands. Finally, the patterns identified at the two dates were evaluated in terms of historic and current hydrologic and topographic patterns.

The first set of analyses were conducted on a classified satellite image of the entire refuge. The objective was to gain an overall view of the patterns of heterogeneity of tree

island size, shape, orientation, location, and their relation to elevation and hydrologic variables. The results indicated that the tree islands that could be classified as circular were always small and that those that could be classified as elliptical were both small and large. There was some indication that different sized tree islands show different spatial relation to each other, to elevation, and to location within the refuge. Larger, longer tree islands occurred more often in the eastern part of the refuge, while small tree islands occurred throughout the refuge. Current (WMM) hydrologic variables were more important in describing tree island variables than historic (NSM) hydrologic variables. Mean ponding depth and elevation were the important variables determining the location of small tree islands. Overall, the orientation of elliptical tree islands was not different from the orientation of water flow indicated by the NSM; however, the difference between tree island orientation and model orientation varied from cell to cell (Figure 2-5). The heterogeneous distribution of tree islands throughout the refuge was evident both visually and in the distribution of the tree island variables. These differences in broad scale patterns and the desire to sample the range of variation of the tree island variables, formed the basis for the development of the sampling regime discussed in Chapter 3.

Chapter 3 begins by addressing the questions of sampling frame (plot size, shape, location, and percent of area to sample) and concludes with a comparison of the data obtained from the satellite imagery and the photography. Patterns obtained from different remote sensing methods may be different and it is important to carefully describe what you are sampling-is it a vegetation class or a landscape feature. The two are not interchangeable.

An assumption made in the development of the sampling regime was that the patterns of tree islands identified in the satellite image classification were related to the patterns on the ground and in the photography. This assumption was tested and found to be weakly true. This was not unexpected since it is known that different remote sensing methods have biases that can lead to differing results. General patterns of more tree islands in the north and in the east and the relation between tree island orientation and NSM flow were similar between the two media. Number of tree islands, size of tree islands, and percent cover of tree islands showed little relation between the two methods.

This analysis illustrates several points that have important implications for the use of broad scale classifications in describing and monitoring landscape patterns. As has been noted by Turner (1989), selection of the entity to measure is of utmost importance in conducting any analysis. Land cover classifications done for one purpose may not be appropriate for other purposes.

The identification of the landscape feature to study sounds straight forward; however, in reality it may not be. There are two components to the identification, 1) definition of the feature from a ground perspective and 2) definition of the feature in terms that can be identified from the remote sensing technique being used.

The confusion between the identification of vegetation classes and landscape features will become more problematic as more land covers are developed for different purposes. Most people do not see the landscape as individual vegetation classes, but as a conglomeration of associated plant communities (landscape features) that are meaningful to them, e.g., tree islands in slough. Davis' (1943) map of the Everglades has various forest, marsh, swamp, and prairie communities. These represent large-scale features that

consist of various vegetation communities. The boundaries between these communities, though not distinct in nature, become distinct in our minds when viewed in map form. Examining landscape patterns using remote sensing techniques will be necessary to address broad scale issues such as Everglades restoration. The challenge is to take our images of tree island and slough and translate them into something that can be identified using remote imagery techniques.

The major focus of this work (Chapter 4) was to look at historic and current patterns of tree islands in relation to potential hydrologic structuring forces. Examination of past relation between landscape patterns and structuring forces and patterns of landscape change can provide information that can help in the prediction of future conditions. Patterns of changes in tree islands over a 40 year period were examined and several important points illustrated in Chapter 4. The relation between modeled historic hydrologic conditions and tree islands was very different than the relation between current hydrologic conditions and tree islands. Lost in the 1991 data are the individual correlations between the tree island variables and the hydrologic variables, or an uncoupling of the pattern and process. Patterns of change in tree islands seems now to be more influenced by hydroperiod and depth than by range in hydroperiod and flow magnitudes. Historically, the ratio of elliptical to circular tree islands and the mean length of tree islands were correlated with flow magnitudes. The 1991 data show no such relationship. Additionally, potential clumps in tree island size that could indicate different structuring processes were evident in the 1950 data, but not in the 1991 data. Not unexpectedly, plots located closer to the canals showed a decrease in the size and percent cover of tree islands, while those in the interior showed increases in size and percent

cover. Within the interior, plots in the east-central portion of the refuge showed the greatest increase in percent cover. The plots decreasing in percent cover had the greatest mean ponding depth (0.32 m), the lowest elevation (4.50 m) and the greatest elevation gradient (0.32 m over 1800 m). This suggests that further increases in depths along the edge of the refuge could further reduce tree island area.

Ecological Consequences

Tree islands and changes in tree islands not only reflect the nature of historic processes and changes in macroscale processes such as hydrologic flows, but also are a potential indicator of changes in lower level processes such as system productivity, heterogeneity, and connectivity that are associated with flows. Additionally, tree islands are habitat patches for a wide range of wildlife (Gunderson and Loftus 1993) and changes to the pattern of tree islands have the potential to change the dynamics of wildlife populations.

The shape of a landscape feature can indicate its origin and its current function (Forman 1995). Streamlined shapes such as the elongated tree islands in this study indicate the action of constant or repeated processes. The maintenance of patterns of defined shapes requires the input of energy. In the absence of energy inputs a system will tend toward randomness. The change in tree islands from more defined shapes to what appears to be more irregular shapes may well be a reflection of the change in the energy inputs to the system. Associated with this change in energy may be a change in primary productivity, decomposition, nutrient cycling, and import and export of organic matter, etc.. Heinzelman (1970) found that as flow-through conditions increased in northern

peatlands that plant species diversity increased. Additionally, Mitsch and Gosselink (1986) demonstrated that primary production in wetlands was enhanced by flowing conditions and a pulsing hydroperiod and that stagnant conditions often depressed these processes. In a low energy system such as the Everglades, small decreases in energy inputs through the suppression of flow, may have major long term effects by changing the nutrient dynamics. The result is an even more nutrient poor system that can not support the range of species that it did historically, and a system that is more susceptible to invasion by non-native species.

Water and energy flows provide topographic heterogeneity and create channels and pathways for the movement of materials. Topographic heterogeneity is an important feature in the Everglades landscape. High spots provide the base for the start of tree islands while depressions provide pools that retain water for longer periods during the dry season and provide habitat for fish and other aquatic animals. Transitional wetland areas, such as those that occur in Loxahatchee have been shown to be extremely important for wading birds (Hoffman et al. 1994). Hoffman et al. (1994) identified the tree island dominated marshes of Loxahatchee as extremely important foraging sites for great blue heron, white ibis, and wood stork. They further stated that it was the local relief that resulted in the presence of transitional wetlands as well as the presence of trees for roost sites that was important. They recommended that tree island dominated marshes should be preserved and that an effort be made to preserve or create the micro-topography.

Few quantitative data are available on wildlife use of tree islands. Gunderson and Loftus (1993) present a list of species that occur on tree islands and review briefly how tree islands are used by different species. Tree islands provide the only high and dry sites

within the wetland system and their size, shape and spatial arrangement may influence the movement and persistence of terrestrial and semi-aquatic wildlife. They are a patch within a wetland matrix. The principles of patch dynamics can be used to speculate on the importance of tree islands and implications of tree island change on ecosystem function.

There is evidence that species richness and the occurrence and abundance of some species are strongly correlated with patch size (Robbins et al. 1989, Findlay and Houlihan 1997). It is expected that larger tree islands would support more species than smaller tree islands. Additionally, larger tree islands could provide a more refuge sites in periods of high water. The reduction of tree island area due to flooding could be particularly important for the population dynamics of terrestrial species such as deer (Odocoileus virginianus).

There is little information on the importance of patch shape on ecological processes. The majority of studies have focused on the relationship between shape and edge (McGarigal and Marks 1995), though patch shape has been shown to influence small mammal migration (Buechner 1989) and woody plant colonization (Hardt and Forman 1986). Tree islands of different shapes may support different species because of different amounts of edge, differences in the flow dynamics around the island resulting in different microhabitats, or because they have different structure. The differences in vegetative structure may be a result of both differences in origin, and differences in nutrient and sediment transfer that is a result of shape. In Loxahatchee, the small round tree islands are more elevated than the large elongated tree islands. In this case, it may not be the shape that is important in determining species use, but the elevation and structure.

The spatial arrangement of patches has been suggested to influence local dynamics of plant and animal populations (Kareiva 1990). Interpatch distance is a critical factor in island biogeography theory (MacArthur and Wilson 1967), and Opdam (1991) presented a review of studies that empirically demonstrated the isolation effect on bird communities in various habitats. In the Everglades, Smith and Vrieze (1979) studied small mammal use of tree islands in Taylor Slough and found that saturation of hammock tree islands by small mammals was determined by tree island size and spacing. Both Peromyscus gossypinus and Sigmadon hispidus tended to move only between close hammocks. The change in the spacing of tree islands has the potential to change the dynamics of local populations. Construction of the canals around Loxahatchee undoubtedly created a barrier between the refuge and surrounding areas for some species and changed large scale population dynamics. The effect this will have on the persistence of populations should a catastrophic event such as a hurricane or severe fire occur is unknown.

The spatial arrangement of tree islands also may influence the spread of disturbance. For example, a large elongated lower elevation tree island made up of mature trees may act as a fire break, halting the spread of fire. Conversely, a tree island that is formed mostly from brush, is irregularly shaped, and drier may increase the spread of fire by providing more fuel and more connection across the system. Gardner et al. (1987) have shown that as the percentage of a land cover increases, the connectivity increased and disturbances spread through the landscape, while the spread of disturbance was slowed in landscapes with small non percolating clusters. The natural heterogeneity of Loxahatchee may have historically helped to mitigate the effects of disturbances such as

fire. A more homogeneous landscape may not provide such an effect and the effects of what historically might have been small disturbances may be exaggerated.

Connectivity also is important from the stand point of wetland species. For an aquatic species such as fish and amphiumas, the edges of tree islands may provide both habitat and barriers. An increase in the area covered by tree islands may benefit terrestrial species, but may hamper the movement and dynamics of aquatic species.

Future Directions

The linkage of pattern and process is not a simple endeavor. It requires the identification and quantification of both the patterns of interests and their potential structuring processes all at the appropriate temporal and spatial scales. This study has provided a landscape view of tree island change in Loxahatchee and provides a start to this process. It has shown that changes have occurred in broad scale patterns of tree islands, that these changes are correlated with changes in hydrologic variables, and that they can be measured over the period of record for which data exist (40 years). There are many unanswered questions regarding tree island origin, distribution, and ecological function as well as the influences of temporal variation in hydrologic variables. Questions such as whether tree islands of different shape are of different origin? or whether tree islands of different size and shape provide different ecological functions? will only be answered by finer scale studies. Data collected at the landscape level can be used as a starting point for these studies by identifying tree islands of different types and regions within the refuge that have shown different patterns of change.

The analyses presented focused on the average or median values within a plot and average values for hydrologic variables. Additional studies should focus on the relation between the dynamic nature of the hydrologic variables and tree island change and the relationship between within-plot patterns and hydrologic variables. Average flow may not be as important in structuring tree island patterns as extreme flow events that create new channels and transport nutrients and sediments.

Examination of individual tree island shape parameters such as distance from the broadest portion of the island to the tail, similarity to a lemniscate, and the arrangement of tree islands within the plots may give us a better picture of the direction and magnitudes of historic flows. Baker (1979) compared the relation between length and width ratios of streamlined forms on Mars to data from empirical studies of channeled scabland and used that information to speculate on the magnitude and nature of structuring processes. He reasoned that because the features on Mars were more elongated than the channeled scablands that they had developed under slightly higher flow velocities and/or greater flow depths. Examining relationships such as these may prove useful in elucidating the relative magnitude of flow within different regions of Loxahatchee and between other regions of the Everglades (though the relation between flow and shape is expected to be different among regions with different water depth and substrate)

Understanding the relation between patterns and process is an important element in successful ecosystem management. Everglades management will require knowledge of historic conditions (both landscape patterns and structuring processes), current conditions, and the relationship between changes in patterns and changes hydrologic processes. It is unlikely that the Everglades will ever function as it did historically. To do that the spatial

extent and dynamic storage capacity, and sheet flow would need to be returned. This would require that development in south Florida is stopped and reversed. Even if this could happen, the template over which vegetation and animal communities would develop has been seriously altered from historic conditions so it is unlikely that the same assemblages would persist. The best that restoration efforts can do is protect and restore features of the landscape that are believed to be important. Decisions on what is important will be based on social, political, and scientific objectives. This research has applied basic concepts of landscape ecology to identify and quantify spatial patterns of one landscape feature (tree islands) and has examined those patterns in relation to changes in hydrologic processes in the hopes that this information can be used in decisions on Everglades management. Outlined below are some of the potential applications of this study.

The methods developed in Chapter 2 can be used to examine patterns of tree islands in other areas of the Everglades. Identifying areas with similar patterns of tree islands will provide information about which areas have similar ecological functions and which areas may respond similarly to changes in hydrology. Further examination of the patterns of orientation of large elongated tree islands in different areas will provide information on direction of pre-drainage flows.

The results from Chapter 3 illustrate the importance of understanding how different land cover maps represent the landscape. The increasing availability of land covers created for different purposes increases the probability that a land cover produced for one purpose will be inappropriately used for another purpose. Problems such as this can be avoided by clearly describing the landscape features of interest and conducting a

pilot study using the available land cover to assess if the features of interest are accurately represented.

The results of Chapter 4 illustrate the uncoupling of hydrology and landscape patterns that has occurred with the impoundment of the refuge. They also show that variations in hydroperiods and flow magnitudes were important variables associated with tree island patterns. The data collected documenting changes in tree islands in Loxahatchee provide a basis for the development and testing of hypotheses on the linkage of patterns and process.

APPENDIX A
NATURAL SYSTEMS MODEL AND WATER MANAGEMENT MODEL ROW AND
COLUMN FOR HYDROLOGY ZONES

Hydrology zone	Row, column of NSM and WMM	Hydrology zone	Row, column of NSM and WMM	Hydrology zone	Row, column of NSM and WMM
2	(53,28)	32	(50,34)	62	(46,32)
3	(53,29)	33	(50,35)	63	(46,33)
4	(53,30)	34	(49,28)	64	(46,34)
5	(53,31)	35	(49,29)	65	(46,35)
6	(53,32)	36	(49,30)	66	(45,28)
7	(53,33)	37	(49,31)	67	(45,29)
8	(53,34)	38	(49,32)	68	(45,30)
9	(53,35)	39	(49,33)	69	(45,31)
10	(52,28)	40	(49,34)	70	(45,32)
11	(52,29)	41	(49,35)	71	(45,33)
12	(52,30)	42	(48,28)	72	(45,34)
13	(52,31)	43	(48,29)	73	(45,35)
14	(52,32)	44	(48,30)	74	(44,28)
15	(52,33)	45	(48,31)	75	(44,29)
16	(52,34)	46	(48,32)	76	(44,30)
17	(52,35)	47	(48,33)	77	(44,31)
18	(51,28)	48	(48,34)	78	(44,32)
19	(51,29)	49	(48,35)	79	(44,33)
20	(51,30)	50	(47,28)	80	(44,34)
21	(51,31)	51	(47,29)	81	(44,35)
22	(51,32)	52	(47,30)	82	(43,28)
23	(51,33)	53	(47,31)	83	(43,29)
24	(51,34)	54	(47,32)	84	(43,30)
25	(51,35)	55	(47,33)	85	(43,31)
26	(50,28)	56	(47,34)	86	(43,32)
27	(50,29)	57	(47,35)	87	(43,33)
28	(50,30)	58	(46,28)	88	(43,34)
29	(50,31)	59	(46,29)	89	(43,35)
30	(50,32)	60	(46,30)		
31	(50,33)	61	(46,31)		

APPENDIX B
UTM COORDINATES OF PHOTO PLOTS IN LOXHATCHEE NATIONAL
WILDLIFE REFUGE

Plot number	Centroid X	Centroid Y	Upper left X	Upper left Y	Lower right X	Lower right Y
36	567352.3	2918382	566902.3	2919282	567802.3	2917482
55	563746.4	2920183	563296.4	2921083	564196.4	2919283
62	570041.6	2920180	569591.6	2921080	570491.6	2919275
110	571851.8	2923775	571401.8	2924675	572301.8	2922875
124	563741.9	2925571	563291.9	2926471	564191.9	2924671
136	574550.6	2925580	574100.6	2926480	575000.6	2924680
144	561055.7	2927379	560605.7	2928279	561505.7	2926479
147	563746.4	2927381	563296.4	2928281	564196.4	2926481
159	574550.6	2927380	574100.6	2928280	575000.6	2926480
173	566452.3	2929176	566002.3	2930076	566902.3	2928276
205	574550.6	2930982	574100.6	2931882	575000.6	2930082
210	558348.7	2932774	557898.7	2933674	558798.7	2931874
215	562848.2	2932775	562398.2	2933675	563298.2	2931875
227	573648	2932770	573198	2933670	574098	2931870
238	562848.2	2934575	562398.2	2935475	563298.2	2933675
257	559251.9	2936378	558801.9	2937278	559705.9	2935474
260	561939.3	2936377	561489.3	2937277	562389.3	2935477
306	561954.6	2939972	561504.6	2940872	562404.6	2939072
310	565559	2939971	565109	2940871	566009	2939069
325	558348.7	2941782	557898.7	2942682	558798.7	2940882
328	561052	2941782	560602	2942682	561502	2940882
377	563749	2945374	563299	2946274	564199	2944474
jkw	567610.4	2933296	567160.4	2934196	568060.4	2932363
jke	568468.4	2933296	568018.4	2934196	568918.4	2932363
cw	567170.8	2936887	566720.8	2937787	567620.8	2936028
ce	568028.8	2936887	567578.8	2937787	568478.8	2936028
lw	569515.4	2930146	569065.4	2931046	569965.4	2929213
le	570448.6	2930146	569998.6	2931046	570898.6	2929213

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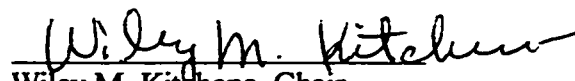
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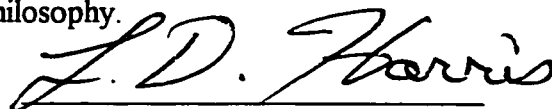
BIOGRAPHICAL SKETCH

Laura Ann Brandt was born in Pittsburgh, Pennsylvania, on 23 August 1962. Her parents are Gerald Bennett Brandt and Susan E. Brandt. She received her elementary education at Turner and Semple Elementary schools, and Wilkinsburg Jr. High School, Wilkinsburg, Pennsylvania. She completed her secondary education at Edgewood High School, Edgewood, Pennsylvania, in 1980. In September 1980 she entered the Pennsylvania State University and was graduated with a BS degree in biology with a minor in marine sciences in December 1983. While at Penn State she worked as a research assistant conducting field and laboratory studies on American alligators and crocodiles. From 1985-1986 she was employed at the University of Georgia's Savannah River Ecology Laboratory. In 1986 she entered Florida International University where she studied the ecology of the American alligator. In 1989 she was graduated with an MS degree in biological sciences. After working for over 3 years as an Assistant in Wildlife Ecology at the University of Florida coordinating the field portion of a project examining the effects of citrus development on fish and wildlife in southwest Florida, Laura entered a doctoral program at the University of Florida. While there she worked on various landscape level projects including a study of temporal and spatial patterns of tree islands in Loxahatchee National Wildlife Refuge. She is currently studying the spatial patterning and ecological role of tree islands and alligator holes in the Everglades.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Wiley M. Kitchens, Chair
Associate Professor of Wildlife Ecology
and Conservation

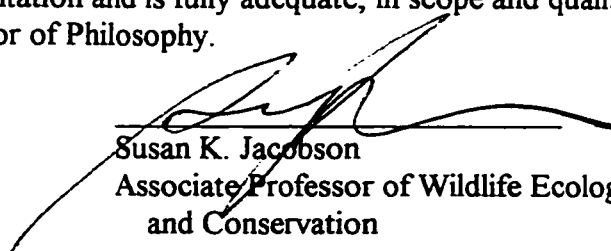
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Larry D. Harris
Professor of Wildlife Ecology and
Conservation

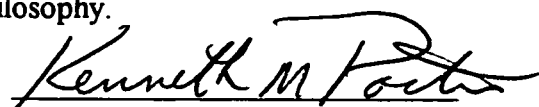
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Crawford S. Holling
Arthur R. Marshall, Jr., Professor of
Ecological Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

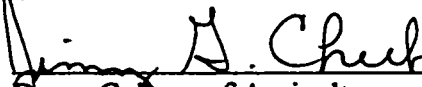

Susan K. Jacobson
Associate Professor of Wildlife Ecology
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

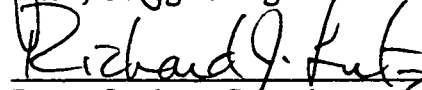

Kenneth M. Portier
Associate Professor of Statistics

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1997

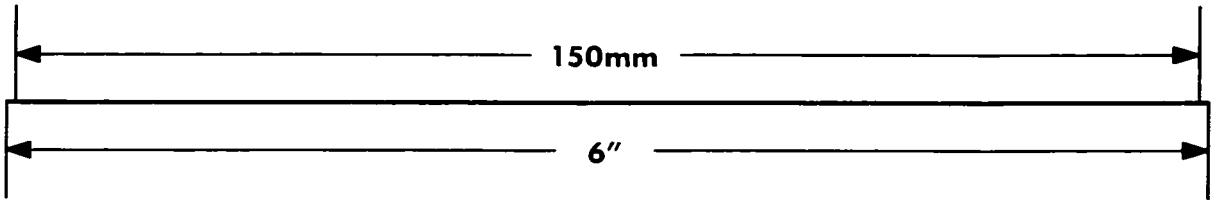
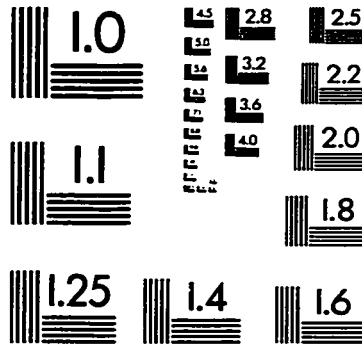
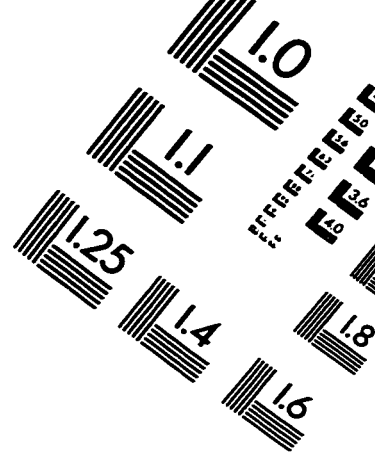
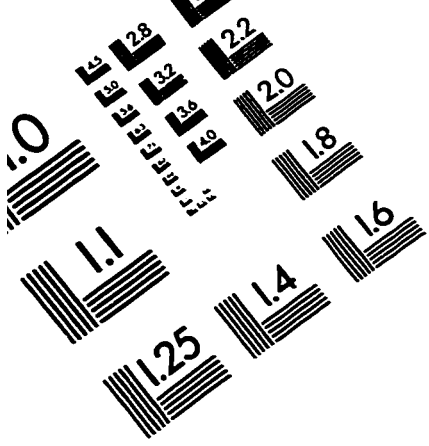
A handwritten signature in cursive script, reading "Jimmy S. Chubb".

Dean, College of Agriculture

A handwritten signature in cursive script, reading "Richard J. Futz".

Dean, Graduate School

TEST TARGET (QA-5)



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