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Executive Summary

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 historic hydrological patterns of the Everglades 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). Hydrology, the dominant natural mesoscale process acting in the Everglades has been seriously altered and has caused changes to the remaining vegetation in the system (Davis and Ogden 1994). 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, Richardson et al. 1990) and Davis et al. (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.

Tree islands are a prominent feature of the Everglades wetlands landscape. They are 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, raptors, alligators (Alligator mississippiensis), turtles, deer (Odocoileus virginianus), and small mammals. Tree islands are the resultant of many processes operating over a wide range of temporal and spatial scales including hydrologic processes such as flow volume, inundation depth, and hydroperiod. Feedbacks between dynamic flows and water stages and the biotic structure of tree islands determine the physical structure (size, shape, orientation) of the islands.

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Loxahatchee), is a 57,324 ha area of northern Everglades wetlands mosaic consisting of wet prairie, sawgrass, slough, and tree islands. Located in Palm Beach County, Florida, south and east of Lake Okeechobee, it was once a connected part of the historic Everglades system. Construction of canals to drain the Everglades Agricultural Area and for flood control effectively isolated Loxahatchee from its original watershed. The system changed from a dynamic flow-through, sheet-flow driven fluvial system with flow rates that reached a maximum of approximately 36 m per h (Holling et al. 1994) to an impounded marsh with the majority of overland flow inputs being shunted around the marsh via the exterior canals. Loxahatchee is an ideal area for examining the long-term effects of changes in hydrologic patterns on the landscape. This study quantifies the historic (1950) and current (1991) patterns of tree islands in Loxahatchee. Historic tree island patterns are related to modeled pre-drainage hydrologic patterns. Current tree island patterns are related to post-drainage hydrologic patterns. Changes in tree island shape, size, and distribution are examined in relation to changes in hydrologic processes to better understand the long-term influences of hydrologic processes on landscape pattern.

Because it was not logistically feasible to quantify tree island patterns throughout Loxahatchee using aerial photography a sampling regime was developed so that areas with different size, shape, and densities of tree islands would be sampled and so that samples would be representative of the overall patterns in the refuge. A land cover classification of Loxahatchee was used to represent the overall patterns of tree islands in the refuge. Sample plot size and shape was determined by overlaying a grid of various sizes on the land cover and randomly sampling 100 times 10 to 50% of the grid cells. For each group of 100
random samples number, average size, percent cover, and SD of tree island size were determined. Selection of the final plot size of 200 x 100 pixels (1800 x 900m) was based on consideration of which sampling regime had both the most precise and accurate estimates of the tree island variables when compared to the values of those variables for the entire study area. Once the plot size was selected, plot locations were determined with stratified random sampling. Strata were determined using a cluster analysis on the tree island variables, number, size, percent cover, and SD of size. Plots were selected proportionally from these strata so that the total area of the samples was 10% of the refuge (28 plots).

Tree islands were delineated in each plot using 1950 1:60,000 black and white aerial photography and 1991 1:40,000 color infrared photography. Tree island size, shape, orientation and distribution were quantified for each plot.

Data on hydroperiod, water depth, flow direction and magnitude were obtained from the South Florida Water Management District. Data were 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 throughout 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).

Tree island variables were compared between the two dates on a plot by plot basis and in an analysis of all plots together. Correlation analysis and canonical correlation analysis were used to relate tree island patterns to hydrologic patterns.

Tree island size, shape, and orientation varied considerably throughout Loxahatchee. 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.

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.

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.
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 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 (Fennema et al. 1994).

The historic hydrological patterns of the Everglades 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 abiotic 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 (Davis and Ogden 1994). 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 Kolpiniski 1987, Parks 1987, Worth 1988, Richardson et al. 1990) and Davis et al. (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.

Tree islands are a prominent feature of the Everglades wetlands landscape. They are 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, raptors, alligators (Alligator mississippiensis), turtles, deer (Odocoileus virginianus), and small mammals.

Tree islands are the resultant of many processes operating over a wide range of temporal and spatial scales. At the microscale, processes such as the deposition and removal of substrate around the island, establishment of seedlings, tree growth, and mortality dominate at time scales ranging from seconds to years. These microscale processes are influenced by higher level mesoscale processes/driving forces such as fire frequency, 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 drought 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 feedbacks between colonization, growth, competition, death, and decomposition determine the biotic structure of the tree island. Feedbacks between dynamic flows and water stages and the biotic structure of tree islands determine the physical structure (size, shape, orientation) of the islands.
Tree islands in the Everglades 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 (Davis 1943, Jones 1948).

Circular tree islands may form in areas of lower flow, while elongated tree islands may form in areas of higher more persistent flow. Changes in flow patterns may change the distribution and shape of tree islands and may reflect a change in structuring processes within the system. Alterations in the hydrology in the Everglades ecosystem provide an opportunity to study the effects of changes in landscape patterns in relation to changes in structuring forces such as hydrology. Understanding such relationships will be important for examining potential impacts of Everglades restoration plans on the ecosystems structure and function.

This study quantifies the historic (1950) and current (1991) patterns of tree islands in a remnant of the northern Everglades where the hydrologic regime has been severely altered. Historic tree island patterns are related to modeled pre-drainage hydrologic patterns. Current tree island patterns are related to post-drainage hydrologic patterns. Changes in tree island shape, size, and distribution are examined in relation to changes in hydrologic processes to better understand the long-term influences of hydrologic processes on landscape pattern.
Figure 1. 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.
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 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 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 its original watershed. The system changed from a dynamic flow-through, sheet-flow driven fluvial system with flow rates that reached a maximum of approximately 36 m per h (Holling et al. 1994) 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, expanses of wet prairie, strands of sawgrass (Cladium jamaicense Crantz), patches of brush, and tree islands. The origin of these tree islands is a topic of much speculation. 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 deeper peat wetlands such as 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). Peat “popups” might form in 3 ways: 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 when the peat breaks loose from the bottom and rises to the surface often 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 it’s wallow the underlying substrate is pushed out of the way. The result is either a floating peat mat or a local topographic high, either of which could lead to tree island formation. Once these peat mats reach the surface they can be colonized first by aquatic vegetation such as sawgrass and Eleocharis spp., as these plants die, the mass increases making it possible for larger more woody plants to become established. The location and characteristics of a tree island will be determined by local hydrologic and biotic processes.
Selection of Sampling Regime

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). 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). 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.

We used a classified satellite image to determine what plot size, shape, and locations would accurately and precisely represents the patterns of tree islands within Loxahatchee.

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). All other classes were considered background. Two tree island layers were generated for this analysis; the first was an

Figure 2. 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 Brandt 1997 for correspondence with overall NSAf and WlvfM row and columns.
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) which identifies contiguous groups of pixels of a class.

Two thousand one hundred forty-four tree islands were identified on the classified image. Average tree island size (SD) was 52.6 ± 23.9 pixels (0.4 ha) Tree islands comprised 1.96 percent of Loxahatchee.

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

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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 area.

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<th>Variance</th>
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Changing plot size and percentage resulted in larger changes in precision than in accuracy (Tables 1 to 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.

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 sug-

<table>
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<td>8.78</td>
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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

Figure 4. Location of 1800 x 900 m photo plots in Loxahatchee National Wildlife Refuge. Large squares are the boundaries of the hydrology zones. Hydrology zones are numbered left to right from 2 to 89. See Brandt 1997 for correspondence with overall NSM and WMM row and columns.
enough to contain the largest tree islands, a plot size of 200 x 100 was selected.

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.

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). 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 (Figure 4).
Historic and Current Patterns of Tree Islands and Correlation
With Hydrology

Image sources for photographic 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 Loxahatchee 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.

Boundaries of tree islands larger than 100 m² within each if the 27 photo plots 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 and the visual categorization were used to determine the cut-off criteria for each type of tree island. 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.

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 throughout 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. Range in hydroperiod was
Table 4. Summary statistics for 1950 photo plots from Loxahatchee National Wildlife Refuge. Orientation is 0 to 180 degrees with 0 = north and 180 = south.

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<th>Percent tree island cover</th>
<th>Mean tree island area (m²)</th>
<th>Median tree island area (m²)</th>
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<th>Number of elliptical tree islands</th>
<th>Ratio of elliptical to circular tree islands</th>
<th>Mean elliptical tree island orientation (degrees)</th>
<th>Mean length of tree island long axis (m)</th>
<th>Median length of tree island long axis (m)</th>
<th>Standard deviation of tree island long axis (m)</th>
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Table 4 Continued.
Results

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 Relations 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 sepa-

Figure 5. 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 6. 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.
Table 5. Hydrology data for hydrology zones in Loxahatchee National Wildlife Refuge that contained photo plots.

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rately. 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 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 data.

<table>
<thead>
<tr>
<th></th>
<th>Flow magnitude</th>
<th>NSM 90% hydroperiod</th>
<th>NSM mean ponding depth</th>
<th>NSM range in hydroperiod</th>
</tr>
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<tbody>
<tr>
<td>Tree island density</td>
<td>-0.148</td>
<td>0.456</td>
<td>0.417</td>
<td>-0.526</td>
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<tr>
<td>Percent tree island cover</td>
<td>0.221</td>
<td>0.661</td>
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<td>tree island size (m²)</td>
<td>island area (m²)</td>
<td>deviation of circular tree islands</td>
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<td>0.2</td>
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<td>159.4</td>
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<td>577.8</td>
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<td>2021.2</td>
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<td>1183.4</td>
<td>871.2</td>
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<td>Tree island density (#/tree island)</td>
<td>Percent cover</td>
<td>Mean tree island size (m²)</td>
<td>Median island area (m²)</td>
<td>Standard deviation of area</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
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<td>22.2</td>
<td>777.3</td>
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<td>ce38</td>
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<td>42.6</td>
<td>858.6</td>
<td>594.1</td>
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<td>0.04</td>
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<td>925.71</td>
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<td>SD</td>
<td>0.69</td>
<td>11.6</td>
<td>486.90</td>
<td>260.54</td>
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</table>
Canonical correlation analysis is used to investigate the relations between two sets of variables by deriving a linear combination of the X variables (U = aX1 + aX2 + ... + aXi) and a linear combination of the Y variables (V = aY1 + aY2 + ... + aYi) such that the correlation between U and V is as large as possible (Manly 1994). 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.

Figure 7. 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 8. 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.
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) 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 5). 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 6). Fifty percent of the tree island area was made up of tree islands < 0.16 ha. Ninety-four percent of the 3769

<table>
<thead>
<tr>
<th>Tree island density</th>
<th>Flow magnitude</th>
<th>WMM 90% hydroperiod</th>
<th>WMM mean hydroperiod ponding depth</th>
<th>WMM range in hydroperiod</th>
<th>Elevation gradient</th>
<th>Mean cell elevation</th>
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<tr>
<td>-0.160</td>
<td>-0.079</td>
<td>-0.224</td>
<td>0.091</td>
<td>-0.626</td>
<td>0.313</td>
<td>0.105</td>
</tr>
<tr>
<td>0.416</td>
<td>0.688</td>
<td>0.251</td>
<td>0.645</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent cover</td>
<td>-0.115</td>
<td>-0.115</td>
<td>-0.256</td>
<td>0.191</td>
<td>0.352</td>
<td>-0.519</td>
</tr>
<tr>
<td>0.464</td>
<td>0.561</td>
<td>0.189</td>
<td>0.331</td>
<td>0.066</td>
<td>0.005</td>
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</tr>
<tr>
<td>Mean tree island area</td>
<td>-0.296</td>
<td>-0.559</td>
<td>-0.558</td>
<td>0.443</td>
<td>-0.405</td>
<td>0.562</td>
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<tr>
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<td>0.002</td>
<td>0.002</td>
<td>0.018</td>
<td>0.032</td>
<td>0.002</td>
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<tr>
<td>Median tree island area</td>
<td>-0.252</td>
<td>-0.728</td>
<td>-0.749</td>
<td>0.684</td>
<td>-0.554</td>
<td>0.799</td>
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<td>0.195</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Density of circular tree islands</td>
<td>-0.196</td>
<td>-0.201</td>
<td>-0.303</td>
<td>0.085</td>
<td>-0.600</td>
<td>0.387</td>
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<tr>
<td>0.317</td>
<td>0.305</td>
<td>0.117</td>
<td>0.667</td>
<td>0.000</td>
<td>0.042</td>
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<tr>
<td>Density of elliptical tree islands</td>
<td>-0.118</td>
<td>0.024</td>
<td>-0.122</td>
<td>0.044</td>
<td>-0.508</td>
<td>0.187</td>
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<tr>
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<td>0.902</td>
<td>0.539</td>
<td>0.825</td>
<td>0.006</td>
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<tr>
<td>Ratio of elliptical to circular tree islands</td>
<td>0.043</td>
<td>0.190</td>
<td>0.198</td>
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<td>0.027</td>
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<td>0.827</td>
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<td>0.314</td>
<td>0.896</td>
<td>0.893</td>
<td>0.279</td>
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<tr>
<td>Mean long axis</td>
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<td>-0.608</td>
<td>-0.610</td>
<td>0.584</td>
<td>-0.436</td>
<td>0.636</td>
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<td>0.001</td>
<td>0.001</td>
<td>0.020</td>
<td>0.000</td>
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<tr>
<td>Median long axis</td>
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<td>-0.655</td>
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</table>
Table 9. 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.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Median tree island area (m²)</th>
<th>Significance tested with Wilcoxon Rank Sum Test</th>
<th>Percent cover</th>
<th>Density (tree islands/ha)</th>
<th>Significance tested with Watson F-Test for determining the equality of circular means.</th>
<th>Change in ratio</th>
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<td>jke</td>
<td>137.8</td>
<td>Z=-5.54, p&lt;0.001</td>
<td>7.8</td>
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<td>N.S.</td>
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</tr>
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<td>0.8</td>
<td>N.S.</td>
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</tr>
<tr>
<td>11w</td>
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<td>4.9</td>
<td>0.6</td>
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<td>F=54.85, df=242, p=0.00</td>
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<td>Z=-5.99, p&lt;0.001</td>
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<td>0.4</td>
<td>-22.0</td>
<td>F=20.88, df=132, p=0.00</td>
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<td>0.4</td>
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<td>-0.1</td>
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<td>-11.0</td>
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<td>-0.4</td>
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<td>-0.5</td>
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<td>-0.4</td>
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<td>0.0</td>
<td>21.0</td>
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<td>-16.0</td>
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<td>Z=-5.20, p&lt;0.001</td>
<td>5.7</td>
<td>0.0</td>
<td>3.0</td>
<td>N.S.</td>
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<tr>
<td>Plot</td>
<td>Median tree island area (m²)</td>
<td>Percent cover</td>
<td>Density (tree Orientation islands/ha)</td>
<td>Significance tested with Wilcoxon Rank Sum Test</td>
<td>Change in ratio</td>
<td></td>
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<td>37713</td>
<td>331.9</td>
<td>8.0</td>
<td>0.3</td>
<td>Z=-4.61, p&lt; 0.001</td>
<td>-0.2</td>
<td></td>
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<tr>
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<td>5.6</td>
<td>0.5</td>
<td>Z=-4.93, p&lt; 0.001</td>
<td>1.5</td>
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<tr>
<td>cle38</td>
<td>251.6</td>
<td>20.8</td>
<td>0.1</td>
<td>Z=-8.07, p&lt; 0.001</td>
<td>0.1</td>
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<td>20.83</td>
<td>0.81</td>
<td></td>
<td>3.47</td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>-460.57</td>
<td>-5.73</td>
<td>-0.47</td>
<td></td>
<td>-23.00</td>
<td></td>
</tr>
<tr>
<td>mean</td>
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<td>2.61</td>
<td>0.10</td>
<td></td>
<td>-0.72</td>
<td></td>
</tr>
<tr>
<td>stdev</td>
<td>250.46</td>
<td>5.66</td>
<td>0.34</td>
<td></td>
<td>4.66</td>
<td></td>
</tr>
</tbody>
</table>

Significance tested with Watson F-Test for determining the equality of circular means.
observed tree islands were < 0.16 ha.

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 5). Density of all tree islands and circular and elliptical tree islands were positively correlated with hydroperiod and negatively correlated with hydroperiod range (Table 6). 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 7) 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 7). 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 8). 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.

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 8). 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

Figure 9. Location of photo plots showing changes in percent cover. Down arrow indicates a decrease from 1950 to 1991, up arrow indicates < -5% increase and up arrow +5 indicates > 5% increase.
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 9). Seventeen increased in percent cover and eleven decreased (Figure 9). Density of tree islands in ten plots de-

<table>
<thead>
<tr>
<th>Table 10. 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 &lt; 0.05 is considered significant.</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>---------------------------</td>
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<tr>
<td>Tree island density</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Percent tree island cover</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Mean tree island area</td>
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<tr>
<td>Median tree island area</td>
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<td>Density of circular tree islands</td>
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<td>Density of elliptical tree islands</td>
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<td>Mean tree island long axis</td>
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<td></td>
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<tr>
<td>Median tree island long axis</td>
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<td></td>
</tr>
<tr>
<td>Ratio of elliptical to circular tree islands</td>
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</tbody>
</table>
creased, 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 range, 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 5).

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 10).

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.
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. Dislodged peat can become floating peat mats that are colonized by woody vegetation. The cumulative effect 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. Data presented here 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.

The relation between the hydrology variables is very different now than it was historically indicating a potential change in the structuring processes. Flow, which was important in describing the historic patterns of tree islands, now is virtually nonexistent. Processes such as nutrient transport, seed dispersal, and soil accretion and decrretion 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.

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. Heinselman (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).

Results from this study illustrate the uncoupling of hydrology and landscape patterns that has occurred within the impoundment of the refuge. They also show that variations in hydroperiods and flow magnitudes were important variables associated with tree island patterns and suggest that in the absence of historic flows the once heterogeneous marsh may be becoming more homogeneous. In attempts to restore the Everglades it will be important to consider the importance of flow as well as hydroperiod in future management scenarios.
Literature Cited


Davis, S. M., 1994


Appendix 1

Meta data for photos and imagery used in this report

Photoplot Scanning and Referencing

Data documentation for Loxahatchee photo plot .txt files

Procedures for digitizing tree islands

Post plot digitizing procedure (assumes plot cleaned, built, with labels, and projection)

Plot number, who digitized it, and what additional photo sources were used for reference

p databak.cpp- C++ program Takes an ungenerate file from Arc/Info and puts ids on all vertices.

findaxv2- Splus function that finds the longaxis of each tree island and calculates orientation data.

Photodat.txt- Splus function that will bring data from arc/info unload (id, x, y,area, perimeter, edge, matrix- no matrix for 1950 plots) together with data calculated with findaxes program (azlong, longaxis, secaxis) and puts orientation in range of 0-180.

Addvar50.txt
Addvar91.txt- Splus function that creates variables for circ1, ellipse, shidx(shape index indicating circle, ellipse, irregular, or no shape) for files with id,x,y, area, perimeter, edge, longaxis, secaxis.

Plotsum.txt- Splus function that will print out summary stats for a plot.
Image sources were 21 1:40,000 NAP Color-IR diapositives flown in December 1990, January 1991, and March 1991 (see photometa.xls for sources) and 12 1:60,000 panchromatic diapositives flown in November 1950 and January 1951. Side and end overlap was optimal in the NAP photos and marginal in the 1950/51 photos. Each set of photos was sent to Image Scans in Denver, CO to be photogrammetrically scanned at the appropriate scanning resolutions to result in 2 m ground resolution. The NAP CIR's were scanned at 50 microns in gray scale. The 1950/51 photos were scanned at 33 microns.

In order to perform comparative spatial analysis, it would be necessary to rectify and georeference each set of images to a common coordinate system (UTM). Polynomial rectification would require a minimum of 4 photo identifiable ground survey control points for each image. A traditional field ground control survey was ruled out because of lack of photo identifiable man-made features and accessibility in the study area. Since absolute geographic accuracy is not as important as relative spatial accuracy for the study, it was decided to use a 10 m resolution UTM geocoded Spot satellite image (Silveira 1996- file 623rect.lan and 623rect.sta) to extract coordinates from natural features such as the tips or centers of the tree islands that were uniquely photo-identifiable in all 3 images.

The program chosen to perform the image rectification was ORTHOENGINE from PCI Remote Sensing Corporation. The capability of ORTHOENGINE to perform Bundle Block adjustment model calculations is an important feature in multiple photo projects. Substantially fewer GCP’s are needed, since a single model is created for the entire set of photos. Tie points(photo identifiable points common to 2 or more images) are collected and calculated into the model resulting in much better mosaic edge matching. Ordinarily, a DEM is needed to perform a digital ortho rectification, but ORTHOENGINE also allows the user to choose a constant elevation. Since the study area has very little elevation differential, this made collection of a DEM unnecessary in this case. However, camera model created in ORTHOENGINE would correct for other factors such as radial distortion due to focal length, and the output digital image will have a more constant scale and residual error. A higher order polynomial rectification (rubber sheeting) model would result in higher error in areal measurements.

The ortho images were generated after model calculations of average residual error was acceptable (approximately 2 meters- 1990 and 4 meters 1950). ORTHOENGINE was then used to generate a UTM geocoded mosaic of each set of ortho images for the study area, and files output in LAN format of approximately 250 MB each ((Provided on CD- lox50mos.img and lox91mos.img). Marginal side and end overlap in the 1950/51 photos resulted in a few small “zero data” holes in the final mosaic.
Data documentation for Loxahatchee photo plot .txt files

The name of the file indicates which plot it is as follows:

\( p = \) plot number
\( 100 = \) plot number
\( 50 \) or \( 91 \) indicates the year

Examples:

\( p5550 = \) plot 55 from 1950
\( p559176 = \) plot 55 from 1991, only that part within hydrology zone 76.

Fields within each file are as follows:

id - Tree island number from Arc/Info coverage

10 UTM X coordinate of centroid of tree islands

y UTM Y coordinate of centroid of tree islands

area - Area in square meters of tree island

perimeter - Perimeter in meters of tree island

dedge - Code indicating if the tree island touches the edge of the plot. 1 = tree island touches the edge. 0 = tree island does not touch the edge.

matrix - In 1991 plots only. Indicates the predominant type of vegetation within an approximate 100 m radius around each tree island. Codes are as follows:

0 = open (not sawgrass or brush)
1 = brush matrix/ associated with brush
2 = sawgrass/brush mix
3 = sawgrass
4 = old tree island

azlong - Orientation of long axis of the tree island. 0 = North, 180 = South. Calculated using Splus.

longaxis - Length in meters of long axis. Calculated using Splus.

secaxis - Length in meters of secondary axis perpendicular to the long axis and at the mid point of the long axis. Calculated using Splus.
circ1- Circularity index

ellipse- Ellipse index

shidx- Indicates if the tree island is circular (1), elliptical (2), or no shape (0) based on criteria outlined in Brandt 1997.
Procedures for digitizing tree islands

Log into Pulsar or Enos as lab

Change directories to your directory.
   On Pulsar: cd directory name
   On Enos: cd /castle/lab/directory name

Make sure the .img file of the plot you are going to work on is in your directory.

Start Arc/Info by typing in arc.

At the arc prompt enter display 9999

Get into Arcedit by typing ae.

Set the map extent to the bounds of the .img file by typing mape image filename.img

Set the image to the above file by typing image filename.img.

Display the image by typing draw.

Set the draw environment to arcs and tics by typing de arc tic

Set the input type for coordinates to keyboard using coord keyboard.

Create the cover using createcover covename.

You will be prompted for tics as follows:
   TIC- enter 1 for the first then 2, 3, 4
   X,Y- enter the X and Y coordinates for the corner of the plot you are working on. The upper left is tic 1, upper right is 2, lower left is 3, and lower right is 4.

You will now be prompted to define a box outside of the tic area. Do this by putting the mouse somewhere in the upper left hand corner and dragging it diagonally to the bottom right corner to create the box.

You can move tics using the editfeature tic command.

Set the arcsnap and nodesnap features on by typing:
   arcsnap on 2
   nodesnap first

Create a boundary around the image by connecting the tics
   coord keyboard
   ef arc
   add
   you will be prompted for the coordinates you want to go from and to. Use the corner coordinates.
   Connect 1 to 2, 2 to 4, 4 to 3, and 3 to 1.
Set the coordinate input back to the mouse using coord mouse.

Since you have already specified the feature you want to edit (arcs), you do not have to specify it again, you can begin digitizing by using add. You will see a menu appear on the screen. You must start and end each polygon with a node. You create a node using the second mouse button. After you create your starting node use the first mouse button to create vertices. The vertices define the shape of the polygon. When you have completely digitized the polygon create another node using the second mouse button. Typing 9 from the keyboard when in the image window will exit you out of digitizing mode.

You can zoom in and out by typing zi or zo and then clicking in the image window. Each time you click you will zoom in or out. To exit zoom type 9 in the image window. The same procedure works for the pan command.

The oops command will undo your last action(s).

After you have been working for a while save your work by issuing the save command. Issue the save command before you exit.

After you have digitized your first set of tree islands and saved the file you will need to define the coordinate system. Do this from the arc prompt using the projectdefine command. Enter each of the following lines at the prompts followed by a carriage return:

```
projection UTM
   units meters
   zone 17
   datum nad27
   spheroid clarke1866
   parameters
```

When you have finished digitizing all of the tree islands in the plot you need to clean the coverage using the following command:

```
clean filename cleanfilename # #
```

For the cleanfilename use the same name as the original filename followed by cl.
Post plot digitizing procedure (assumes plot cleaned, built, with labels, and projection)

1. Check position with other plot (compare 1950 and 1991)
2. ADD ITEM FOR MATRIX CODE:
   `additem <infile.pat outfile.pat> matrix 2 2 n`
3. Fill in values for matrix
   0 = open water
   1 = brush matrix
   2 = sawgrass/brush matrix
   3 = sawgrass
   4 = old tree island

Pull up the image and the cover to add code to.
Set the `ef` and `de` to poly
Select many
Click on polygons to get the same code
At the prompt type `calc matrix = codenumber`

`calc $symbol = 4` will change the color of the selected polygons (different numbers are different colors)

Make a backup of this file

4. Move labels to centroid - centroidlabel inside
5. Add xy coordinates - addxy
6. Delete the large polygon created by the boundary lines.
   - Find the area of the largest polygon (it will be a lot bigger than the others)
   - Select this polygon
   - Delete it
   - Another way to do this is in arcedit - click in the interior of the bounding box - this should select that polygon. Now delete it.

7. Build

8. SELECT POLYGONS > MINIMUM MAPPING UNIT (100m²)

At the arc prompt:
   `reselect <covename> <outcovename>
   : res area >= 100`
   enter a blank line after this and answer no to the questions about adding additional selections.

Or: go to arcedit
   `sel area < 100`
   `delete`

The resulting file will have only tree islands >= 0.01ha (100sq meters)

9. Add verticies at every 6 m so that there are enough points all the way around to calculate longest axis.
At arc prompt: densifyarc <plotname> <outcov name> 6 vertex

10 Build
11 ungenerate poly plotname plotname.gen
12 tables
13 sel plotname.pat
14 unload plotname.txt plotnam-ID, x-coord, y-coord, area, perimeter, matrix, edge. (NOTE: no matrix in 1950 photos)

4/22/97
Once files are in .gen and .txt format on FIREBALL (FIREBALL is Laura's home computer)

Remove final end in the .gen file (d:\loxdata\phdata\ungen)
Run C++ (pdatasbak.cpp) file on .gen- output will be .txt in above directory
move .gen file to rancprog directory

FTP new .txt files to Jade (computer with Unix version of Splus) using DOS ftp
move .txt file to onjade directory

Create batch file as follows:
   vi go11050
   p11050ax<-findaxv2("P11050.TXT") note capitalization
Run batch file:
   Splus BATCH go11050 go11050.out

Check to make sure it started
   more go11050.out

After the batch file has finished:
   From Splus create a .dat file
   dput(p11050ax, "p11050ax.dat")

FTP .dat files to FIREBALL (d:\loxdata\phdata\spdat)
   remove .dat and .txt files from jade

In Splus access the spphoto dir
   attach("d:\spluswin\home\spphoto", pos = 1)

Run photodat.50 or photodat.91 to bring data into Splus
   p11050f<-photodat.50("d:\loxdata\phdata\unload\p11050.txt", "d:\loxdata\phdata\spdat\p11050ax.dat")

Run addvar50 or addvar91 to add circ1, ellipse, spindx and correct orientation
   p11050f<-addvar50(p11050f)

Run plotsum to get means, medians etc for plot
   p11050sum<-plotsum(p11050f)

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Ilpdatabak.cpp  L.A. Brandt  2/3/97
Takes an ungenerate file from ARC/INFO and puts ids on all vertices
output is id, x, y

#include <stdio.h>
#include <fstream.h>
#include <string.h>
#include <io.h>
#include <stdlib.h>
#include <ctype.h>

void main(void)
{
    int id, test, test1;
    float cx, cy, vx, vy;

    ifstream fin;
    ofstream fout;

    fin.open("d:loxdata\ung\14750.gen");
    if (fin.fail())
    {
        cerr << "couldn't open file";
        exit(1);
    }

    fout.open("d:loxdata\tmgen\p14750.txt");
    fout << "id" << " " << "x" << " " << "y" << "n";

    do
    {
        fin >> id >> cx >> cy;

        do
        {
            fin >> vx >> vy;
        } while(vx != 69);

        fout << id << " " << vx << " " << vy << "n";

        test1 = fin.get();
        test = fin.get();
    } while(test1 != 69);

    fin.ignore(80, 'n');

} while(!fin.eof());
fout.close()
fin.close()

#Splus program that finds long axis and calculates orientation for data in id,x,y matrix
#J. Harrison- IFAS statistics 1996

findaxv2<-function(a)
{

mtx<-read.table(a, header = T)

squarepatch <- NULL
patchpoints <- as.matrix(mtx)
idtable <- table(patchpoints[, 1])
idvalues <- as.numeric(labels(idtable)$Names)
idfreqs <- as.numeric(idtable)
index <- 1:(dim(patchpoints)[1])
finalist <- matrix(rep(-9, 4 * length(idvalues)), ncol = 4)
for(lp in 1:length(idvalues)) {
  numpoints <- idfreqs[lp]
  {
    extract <- index[patchpoints[, 1] == idvalues[lp]]
    plist <- patchpoints[extract, 2:3]
    numpoints2 <- dim(plist)[1]
    testdist <- round(dist(plist, metric = "euclidean"))
    longdist <- max(testdist)
    cat("Found long axis for ID number", idvalues[lp])
    index2 <- 1:length(testdist)
    locmax <- index2[longdist == testdist]
    # If there are 2 or more pairs with the same maximum distance,
    # keep track of their id numbers in a vector called squarepatch.
    # For now, arbitrarily choose the first such pair.
    if(length(locmax) >= 2)
      squarepatch <- c(squarepatch, idvalues[lp])
    locmax <- min(locmax)
    Index1 <- NULL
    Index2 <- NULL
    for(ii in 1:(numpoints2 - 1)) {
      for(jj in (ii + 1):numpoints2) {
        Index1 <- c(Index1, ii)
        Index2 <- c(Index2, jj)
      }
    }
    which1 <- Index1[locmax]
    which2 <- Index2[locmax]
    whichxy1 <- plist[which1, ]
whchxy2 <- plist[whch2, ]
whchxy <- rbind(whchxy1, whchxy2)
azlong <- ((atan((whchxy[1, 2] - whchxy[2, 2])/(whchxy[1, 1] - whchxy[2, 1])))/(pi) * 180)
slope <- (whchxy[1, 2] - whchxy[2, 2])/(whchxy[1, 1] - whchxy[2, 1])
newslope <- (-1)/slope
midx <- round((min(whchxy[, 1])) + abs((whchxy[2, 1] - whchxy[1, 1])/2)
  )
midy <- round((min(whchxy[, 2])) + abs((whchxy[2, 2] - whchxy[1, 2])/2)
  )

# calculates middle of the line- take min and abs of diff to get correct value
newy <- NULL
xlist <- NULL
ylist <- NULL
for(m in 1:(abs(midx - max(plist[, 1])) + 1)) {
  newy <- round(newslope * m) + midy
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy + 1
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy + 2
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy + 3
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy - 1
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy - 2
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy - 3
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
}
for(m in -1:(midx - max(plist[, 1])) - 1) {
  newy <- round(newslope * m + midy)
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m + midy + 1)
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m + midy + 2)
  xlist <- c(xlist, midx + m)
  ylist <- c(ylist, newy)
  newy <- round(newslope * m) + midy + 3
}
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xlist <- c(xlist, midx + m)
ylist <- c(ylist, newy)
newy <- round(newslope * m + midy - 1)
xlist <- c(xlist, midx + m)
ylist <- c(ylist, newy)
newy <- round(newslope * m) + midy - 2
xlist <- c(xlist, midx + m)
ylist <- c(ylist, newy)
newy <- round(newslope * m) + midy - 3
xlist <- c(xlist, midx + m)
ylist <- c(ylist, newy)

} candidates <- cbind(xlist, ylist)
xymatches <- NULL
plist <- round(plist)
for(kk in 1:dim(candidates)[1]) {
  for(ll in 1:dim(plist)[1]) {
    bothmatch <- as.numeric(all(candidates[kk, ] == (plist[ll, ])))
    if(bothmatch == 1)
      xymatches <- rbind(xymatches, as.vector(candidates[kk, ]))
    if(bothmatch == 1)
      break
  }
}

# See if the list includes at least 2 points in the patch along the secondary diagonal.
checkvector <- as.numeric(xymatches)
if(length(checkvector) <= 2)
  finalist[lp, 1] <- c(azlong, longdist, -11, idvalues[lp])
if(length(checkvector) <= 2)
  next
horizdist <- dist(xymatches, metric = "euclidean")
maxhdist <- max(horizdist)
finalist[lp, 1] <- azlong
finalist[lp, 2] <- longdist
finalist[lp, 3] <- maxhdist
finalist[lp, 4] <- idvalues[lp]

} # end small
return(finalist, squarepatch)
}
#Splus program that will bring data from arc/info unload (id, x, y, area, perimeter, edge, matrix-
# no matrix for 1950 plots) together with data calculated with findaxes
#program (azlong, longaxis, secaxis) and puts orientation in range of 0-180.

photodat.91<-function(z,w)
{
  a<-read.table(z, header = F, sep="",)
  #z="d:\loxdata\phdata\unload\plot3650.txt"- file with size info
  #w="d:\spluswin\home\spphoto\p3650ax.dat"-dumped file from jade

  b<-dget(w)

  a<-merge(a,b$finalist, by.x=1, by.y = 4, all.x = T)
  #merges file with area and perimeter with file with orientation and axis data

  names(a)<-c("id","x","y","area","perimeter","edge","matrix","azlong","longaxis","secaxis")

  a$azlong<-90-a$azlong
  #puts orientation angle on range of 0 to 180 with 0 = north
  return(a)
}

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This program creates variables for circ1, ellipse, shidx (shape index indicating circle, ellipse, irregular, or no shape) for files with id, x, y, area, perimeter, edge, longaxis, secaxis.

```r
addvar50<-function(a) {
  # a = pxxxxf file
  radius<-a$perimeter/(2*pi)
  idarea<-pi*(radius^2)
  circ1<-as.matrix(a$area/idarea)
  ellipse<-as.matrix(a$area/(pi*(.5*a$longaxis)*(.5*a$secaxis)))
  shidx<-rep(0,(length(a$id)))
  out<-cbind(a,circ1,ellipse, shidx)
  names(out)<-c("id", "x", "y", "area", "perimeter", "edge", "azlong", "longaxis", "secaxis", "circ1", "ellipse", "shidx")
  out$shidx[out$circ1 >= .85]<-1
  # codes for circles
  out$shidx[out$shidx != 1 & out$ellipse < 6]<-2
  # codes for ellipses
  out$shidx[out$shidx != 1 & out$ellipse >= 6]<-3
  # codes for irregular
  out$shidx[out$secaxis == -11]<-0
  # codes patches with no sec axis
  out$shidx[out$edge == 1]<-0
  # codes edge tree island shape as 0
  return(out)
}
```

This program creates variables for circ1, ellipse, shidx (shape index indicating circle, ellipse, irregular, or no shape) for files with id, x, y, area, perimeter, edge, longaxis, secaxis.

```r
addvar91<-function(a) {
  #a= pxxxxf file
  radius<-a$perimeter/(2*pi)
  idarea<-pi*(radius^2)
  circ1<-as.matrix(a$area/idarea)
  ellipse<-as.matrix(a$area/(pi*(.5*a$longaxis)*(.5*a$secaxis)))
  shidx<-rep(0,(length(a$id)))
  out<-cbind(a,circ1,ellipse,shidx)
  names(out)<-c("id", "x", "y", "area", "perimeter", "edge", "matrx", "azlong", "longaxis", "secaxis", "circ1", "ellipse", "shidx")
  out$shidx[out$circ1>=.85]<-1
  #codes for circles
  out$shidx[out$shidx != 1 & out$ellipse < 6]<-2
  #codes for ellipses
  out$shidx[out$shidx != 1 & out$ellipse >=6]<-3
  #codes for irregular
  out$shidx[out$secaxis == -11]<-0
  #codes patches with no sec axis
  out$shidx[out$edge == 1]<-0
  #codes edge tree island shape as 0
  return(out)
}
```
This Splus function will print out summary stats for a plot

```r
plotsum <- function(a) {
  # a = pxxxxf file
  numti <- length(a$id)
  numedge <- length(a$edge[a$edge == 1])
  nosec <- length(a$secaxis[a$secaxis == -1])
  noseced <- length(a$secaxis[a$secaxis == -1 & a$edge == 1])
  armeanall <- mean(a$area)
  armenoe <- mean(a$area[a$edge != 1])
  armedall <- median(a$area)
  armednoe <- median(a$area[a$edge != 1])
  arallsd <- sqrt(var(a$area[a$edge != 1]))
  arsdnoe <- sqrt(var(a$area[a$edge != 1]))
  numcir <- length(a$shidx[a$shidx == 1])
  if (numcir == 0) {
    marcir <- NA
    medcir <- NA
    sdcir <- NA
  } else {
    marcir <- mean(a$area[a$shidx == 1])
    medcir <- median(a$area[a$shidx == 1])
    sdcir <- sqrt(var(a$area[a$shidx == 1]))
  }
  numellip <- length(a$area[a$shidx == 2])
  if (numellip == 0) {
    marellip <- NA
    medellip <- NA
    sdellip <- NA
  } else {
    marellip <- mean(a$area[a$shidx == 2])
    medellip <- median(a$area[a$shidx == 2])
    sdellip <- sqrt(var(a$area[a$shidx == 2]))
  }
  numirr <- length(a$shidx[a$shidx == 3])
}
```
if(numirr == 0){
    marirr<-NA
    medirr<-NA
    sdirr<-NA
}

if(numirr > 0) {
    marirr<-mean(a$area[a$shidx == 3])
    medirr<-median(a$area[a$shidx == 3])
    sdirr<-sqrt(var(a$area[a$shidx == 3]))
}

out<-cbind(numti, numedge, nosec, noseced, armeanall, armenoe, armedall,
            armedhoe, arallsd, arsdhoe, numcir, marcir, medcir, sdcir, numellip, marellip, medellip,
            sdellip, numirr, medirr, sdirr)

return(out)
}