CESI Project Final Report
June 15, 2004

Project:

Development of a simulation model relating hydrology, topography and edaphic factors to landscape plant community structure in freshwater marshes

Location: Northeastern Shark River Slough, southern WCA 3A, southern WCA 3B

Principal Investigators:

John Volin, Florida Atlantic University, 954-236-1115, jvolin@fau.edu
Thomas Givnish, University of Wisconsin-Madison, 608-262-5718, givnish@facstaff.wisc.edu

Project Personnel:

Jordan Muss, Florida Atlantic University, 954-236-1157, jmuss@fau.edu
Dianne Owen, Florida Atlantic University, 954-236-1085, dowen@fau.edu
Michael Lott, Florida Atlantic University, 954-236-1157, mlott@fau.edu

Project Overview:

The objective of this project was to develop a spatially explicit vegetation model that predicts how changes in environmental conditions will affect the structure of the freshwater marsh plant communities within northeast Shark River Slough in Everglades National Park, as well as southern Water Conservation Areas (WCAs) 3A and 3B. Such a predictive model is essential to allow for adaptive assessment of the WCA 3 Decompartmentalization and Sheetflow Enhancement Project of the Comprehensive Everglades Restoration Project (CERP).

To accomplish our objective, we created a detailed GIS database of current vegetation within the study area through extensive field sampling and photointerpretation of high-resolution aerial photography. Based on these data, a predictive model was developed that can be applied at the landscape level to evaluate how changes in environmental conditions may affect landscape vegetation patterns. Data generated from this research will be linked with other ongoing modeling efforts within CERP, providing a timely and vital synergism with the overall objectives of Everglades restoration.

Methods

A vegetation map characterizing the current landscape patterning of vegetation was completed for the northeast Shark River Slough and the southern sections of WCA-3A and -3B. We mapped the vegetation communities within an area of approximately 45,000 Ha using false-color infrared imagery, with a ground resolution of 1 ft and registered in State Plane NAD 83 coordinates by image-to-image georectification with 1995 1m-resolution USGS DOQQs. Vegetation communities were classified as slough, ridge or tree island using a two-step procedure. The imagery was first classified into 12 classes by unsupervised classification (ESRI Image Analysis) with a mapping unit of $400m^2$. This initial classification excluded a 20m buffer around roads and other disturbed areas. These classes were then aggregated into three superclasses corresponding to slough, ridge and tree island communities.

A total of 48 transects with 728 total plots were sampled in three study areas: 188 plots along 13 transects in northeastern Shark River Slough, 240 plots along 16 transects in WCA 3A, 170 plots along 10 transects in WCA 3B and in 130 plots along 9 transects in central WCA 3A. Figure 1 shows the study areas and the transect plots where vegetation and abiotic sampling was performed. Plots were classified as slough, ridge, tree island or ecotone based on plant composition. Figure 2 shows CIR imagery (a) and the classified image (b) of the initial study area with transects. In each transect plot, percent cover and height of individual species were assessed and depth to bedrock and water depth were measured. Soil cores were also extracted at selected plots along each transect.

Transects were oriented either parallel to flow or perpendicular to flow, and extended across the full range of vegetation types. Marsh plots were 1 m^2 and tree island plots were 4 m^2. Percent cover by individual plant species occurring within each plot was estimated visually and total plot coverage was quantified by comparing irradiance above and below the vegetation using a Decagon ceptometer. Plots were located within each community and ecotone encountered, with at least one plot every 200m.

After collection of initial transect data was completed, it was decided that additional transects were needed to better capture biotic and abiotic factors on and adjacent to tree islands within the study area. Three tree islands were chosen for study in each of the four regions. Transects were oriented perpendicular to flow and extended from the head (high point) of the tree island to an adjacent ridge. On the tree island, the canopy layer was described within a $2m^2$ plot while the herb layer was described within a $1m^2$ plot. Plots were placed every 5m along the transect until reaching the edge of the tree island. An additional $1m^2$ plot was placed in a slough and ridge along the transect, adjacent to the tree island. Biotic and abiotic parameters were recorded as described for the original transects. Soil cores were also extracted for analysis of pollen, stomata, charcoal, and plant macrofossils.

Ecotone digital wells to monitor water levels were installed in each of the four study regions and have collected water depth data from 8-17-02 to the present.

As part of this project, we designed a new peat sampler/extruder unit for conducting stratigraphic investigations in the Everglades which was used to collect a set of paired cores for representative sloughs and Cladium ridges (both high and low) in all of the study areas. This apparatus was customized to collect and finely sample sediment cores (7.6 cm in diameter) regardless of the water content or tensile/shear strength of the sediment. One of the most serious challenges we encountered in our early work was the pervasive distribution of relatively thick (10-20+ cm) layers of very loose and nearly liquid sediment at the top of the peat profile. These profiles could not be accurately dated by 210Pb unless this loose sediment was collected and sampled in fine (1 cm) intervals. Therefore we designed a new sampler/extruder that would 1) permit us to precisely determine the location of the sediment/water interface, 2) insure complete recovery of the cored section of the sediment profile, 3) permit continuous sectioning of the sediment profile in fine intervals, and 4) collect sufficient sediment to support multiple analyses. We have submitted a manuscript that describes this new sampler/extruder design for publication in the peer-reviewed journal *Limnology and Oceanography.*

Results and Analysis

Landscape Mapping

Figures 3, 4, and 5 show the CIR imagery (upper figure) and the classified image (lower figure) for southern WCA-3A, WCA-3B and northeast Shark River Slough, respectively. Classification of the CIR imagery revealed clear trends in the distribution of slough, ridge and tree island communities within these regions. The percentages of vegetation types within the three regions are shown on Table 1. Overall, the pattern was as expected, with the highest percentage of slough communities present in southern WCA-3A (51%) while sawgrass ridge communities dominated WCA-3B (51%). Comparison of the classified imagery and the community type assigned on the basis of vegetation data from transect plots (excluding ecotones) gave an average correlation of 0.6 ($p<0.001$) across the entire study area.

Figure 6 shows a comparison between infrared aerial photography taken in 1995 (1m USGS DOQQs) and our aerial photographs from 2002 in Shark River Slough. Classification of the 1995 photography using the same two-step procedure applied to the 2002 photography showed that the extent of slough communities increased from 44% in 1995 to 50% in 2002. Ridge communities decreased from 50% to 43% during the same period. Although individual tree islands showed signs of decline, the total extent of tree island communities did not change appreciably over the seven-year period.

Ordination

We performed two types of ordination analyses to investigate processes governing the slough/ridge/tree island patterns. Figure 7 shows the results of the non-metric multi-dimensional scaling ordination (NMS, as implemented in PC-ORD 1999) of vegetation coverage data from the set of all transect plots. Instability criterion was set at 0.0001, with 40 runs of real data and 50 randomized runs. Rare species, present in fewer than 1% of the plots were removed from the data set. Two significant NMS axes were identified, with the average scores of woody species aggregating near the upper range of both axes (Fig.7, A), ridge species in the middle range (Fig. 7,B), and slough species scoring low on both axes (Fig. 7, C). The graph also reveals the interesting aggregation of species characteristic of the lower areas or margins of tree islands, such as ferns and some woody species (Fig.7, D). Correlations with NMS axes were assessed for the abiotic variables measured at each plot as shown in Table 2.

Figure 8 shows the results of canonical correspondence analyses (CCA, as implemented in PC-ORD 1999) of the same data set, which identified two significant axes ($p=0.01$, MonteCarlo test of 100 randomized runs). Site scores were centered and standardized with unit variance to allow interpretation of the ordination diagram as a biplot, using a rescaling alpha constant of 0.5 for sites and species. The first axis is most highly correlated with water depth at 0.864 (interset correlation), with shallow areas toward the left-hand side of the graph, where woody species aggregate, and deeper areas in the right-hand side, where slough species aggregate. Both the first and second axes are highly negatively correlated (-0.810 and -0.438, respectively) with the normalized difference vegetation index (NDVI), which is used as an indicator of productivity. The aggregation of woody species in the lower left of the graph in Figure 8 is indicative of higher productivity, while slough species aggregate on the right side, corresponding to lower productivity levels

To better characterize the ridge-slough gradient within the each study area, additional NMS analyses were done using a subset of vegetation coverage data that excluded tree island plots (Figure 9). The ridge-ecotone-slough communities show a distinct partitioning along the gradient defined by Axis 1, which is highly correlated with the depth of inundation. When NMS analyses of the ridge-ecotone-slough plots were done separately for each study area, differences in the distribution of ridge-ecotone-slough community along the hydrological gradient are evident among WCA 3A (Figure 9a), WCA 3B (Figure 9b) and northeast Shark River Slough (Figure 9c). In particular, the ridge-slough patterning in WCA 3B and northeast Shark River Slough, basins which have experienced extreme disruption of the natural flow regime during past decades, is significantly less distinct than in WCA 3A, which has experienced more natural water flows.

Soil Cores

Preliminary analyses of cores collected with the peat sampler/extruder unit we designed indicate that the ridge and slough microtopography persisted for long periods in some areas but not in others. The sloughs consistently have finely-decomposed organic sediments with large fractions of detrital particles (rootlets, charcoal etc.). They also have a significant fraction of small quartz grains indicating either aeolian or fluvial transport and occasional bands of marl that were probably desposited in situ around algae and macrophytes. The cores consistently become darker and more decomposed with depth and end in bedrock with the exception of one slough in Shark River Slough.In general there was always a thick layer of very loose organic sediment with high water contents at the top of the peat profile. The Cladium ridges in contrast, are mostly underlain by very coarse sedge fragments with variable amounts of loose liquified sediment at the top of the peat profile. However, we also occasionally found thick marl layers. In Shark River slough these marl layers constituted the bulk of the peat profile indicating that these ridges had recently developed over a marl prairie.

Analysis of landscape patterns

Examination of the relationship between vegetation patterns and hydrology within the relatively flat Everglades landscape requires accurate elevation measurements. Measurements of water surface and substrate elevations with an accuracy of $\pm$2cm are currently being collected throughout the study area as part of a companion CESI project to investigate the processes that determine these landscape patterns. Figure 10 shows the results of preliminary analysis of the relationship between ridge-slough landscape patterns and the regional pattern of substrate elevation derived from USGS elevation data measured at 500m intervals with an accuracy of $\pm$15cm. The dominant pattern predicted for flow across a cost surface derived from the elevational gradient within each study area is shown in Figure 10a. This pattern is consistent with published estimates of the direction of pre-drainage flow. Flow patterns predicted from a cost surface derived from the classified raster coverage of slough-ridge-tree island communities is shown in Figure 10b. Comparison of these theoretical flow patterns shows that in WCA3A, which has experienced relatively less disruption of historic flow than in WCA3B and northeast Shark River Slough, the flow patterns predicted by the elevation coincide well with those predicted by the vegetation pattern. In WCA3B and northeast Shark River Slough the two flow patterns are more divergent, partly as the result of flow into adjacent canals. This type of analysis suggests that inconsistencies in the pattern of water flow predicted by elevational gradients and that predicted by landscape vegetation are characteristic of areas that have experienced disruption of historic flows.

An additional landscape metric that captures the changes in landscape patterns associated with disruption of historic flow regimes is the fractal dimension, a function of the edge to perimeter ratio, $2 * (\ln(P) – \ln(2)) / \ln(A)$, that increases with increasing fragmentation of landscape patterns. The fractal dimension of all three of the study regions was relatively high. The WCA3A ridge-slough-tree island landscape was the lowest of the three study regions (1.83), reflecting the presence of largely intact tree islands and the continuity of the historic slough system that has been preserved in this basin. WCA3b has a somewhat higher fractal dimension (1.85), principally due to the extensive sawgrass invasion of sloughs in this area, creating a fragmented landscape dominated by ridge communities. Northeast Shark River Slough has the highest fractal dimension (1.86), consistent with the degradation of the slough system that has occurred in response to disruption of the historic hydrology.

These landscape metrics, and others, such as adjacency, connectedness and percolation indices that are currently being explored, are highly sensitive to the resolution of the landscape raster coverage. Further investigation will be necessary to determine the optimal resolution for capturing the changes in these metrics that reflect the changes in vegetation patterns associated with changing hydrological conditions.

ArcIMS Spatial Database

The results of this study are currently being incorporated into an NBII-compliant spatial database that will be accessed through an ArcIMS web site maintained on an FAU server. This site will be accessible in the Fall of 2004.

Conclusions

In conclusion, we found a distinctive pattern in the distribution of slough/ridge/tree island communities, supporting our hypothesis that positive and negative feedbacks help determine the self-assembly of the slough/ridge/tree island assembly. Specifically, we found that productivity and hydrology contribute significantly to this pattern. Ordination analysis shows a clear relationship between productivity, as measured by the Normalized Difference Vegetation Index of high-resolution infrared aerial photography, and the ridge-slough-tree island assembly of vegetation communities. The depth and period of inundation also emerge as important determinants of vegetation patterns. The response of vegetation to disruptions of the historic hydrology can be seen in divergence between flow patterns predicted by elevation gradients and flow patterns predicted by the pattern of slough-ridge-tree island communities. Hydrology also influences the continuity of the slough-ridge-tree island pattern, as evidenced by changes in fractal dimension associated with the disruption of historic hydrology. Further study is underway as part of a companion CESI project to substantiate these results and investigate the processes that govern the development and maintenance of these landscape patterns.

Table 1. Percent of tree island, ridge and slough classes in the three initial study areas in 2002.

	Slough	Ridge	Tree Island
WCA 3A	51	38	11
WCA 3B	46	51	3
Shark River	50	43	7

Table 2. Pearson-Kendall Correlations of abiotic variables with NMS ordination axes.

	Axis1	Axis2
Water	0.515*	0.157
NDVI	-0.472*	0.280
Soil Depth	0.171	0.125

*significant, tau>0.40

Figure 1. Study area

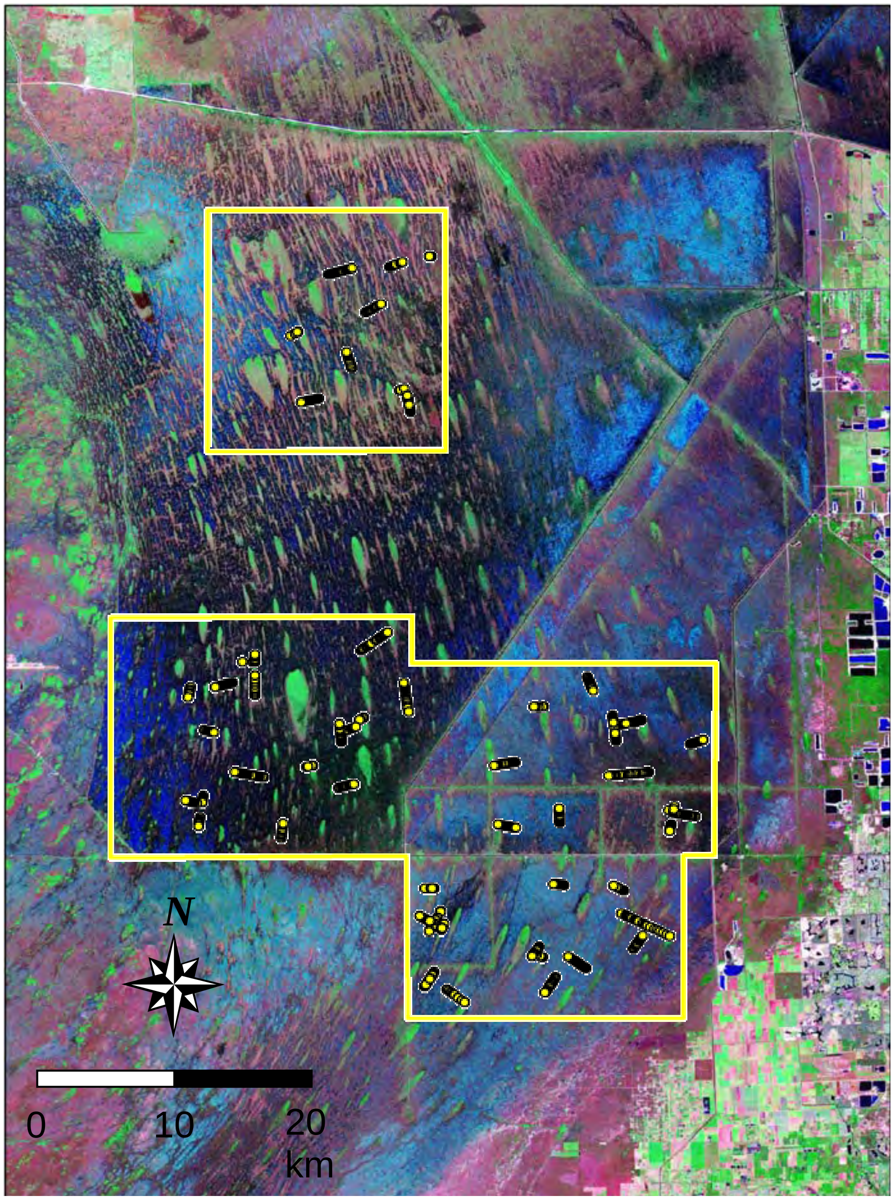

Figure 2a. Infrared imagery of the initial study area in 2002 and the Central WCA3A study area in 2003, showing classification of transect points based on plant composition of plots.

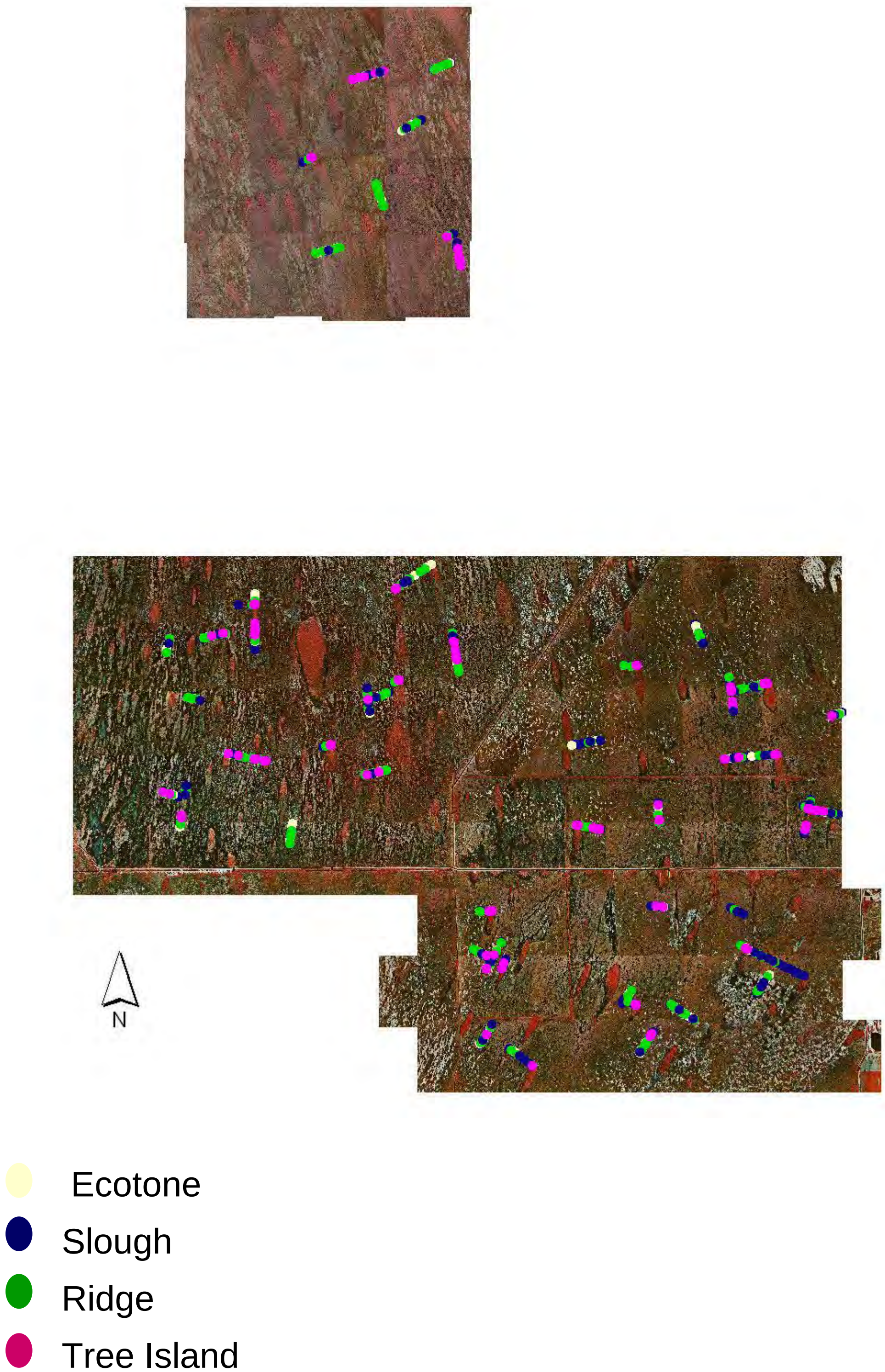

Figure 2b. Classified image of the initial study area, showing classification of transect points based on plant composition of plots.

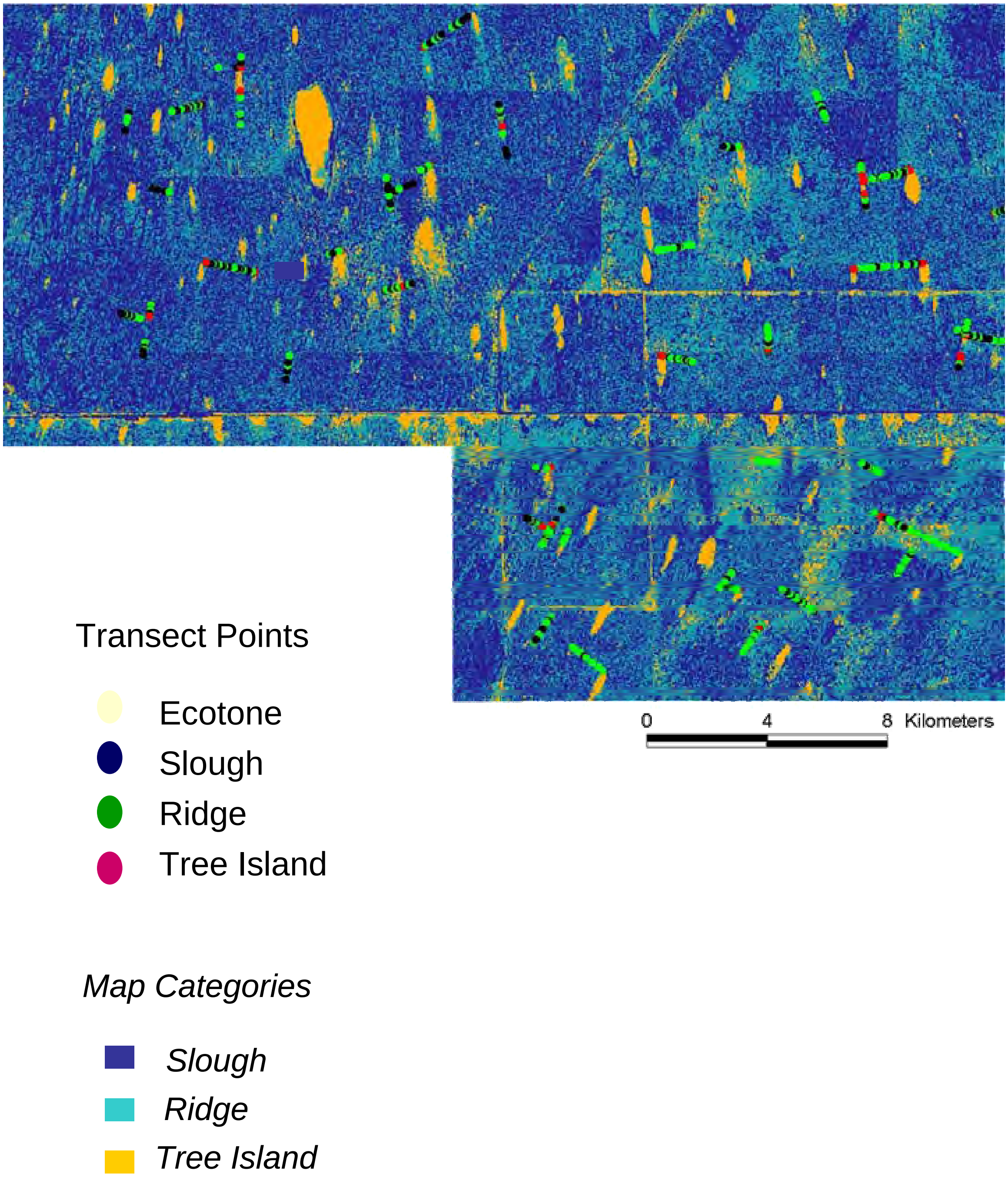

Figure 3. Transect plots in WCA-3A (southern portion) superimposed on CIR imagery (upper figure) and classified image (lower figure).

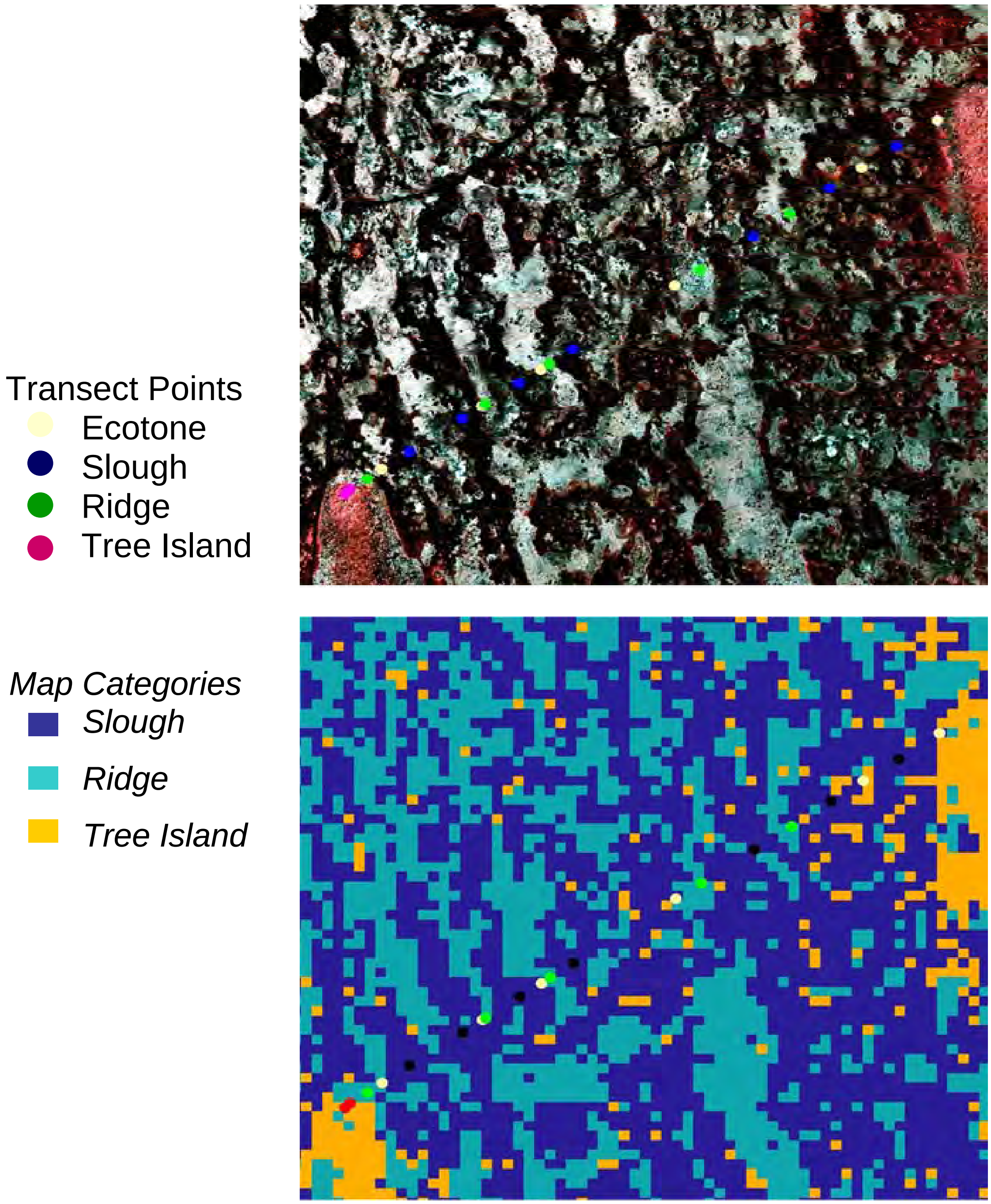

Figure 4. Transect plots in WCA-3B superimposed on CIR imagery (upper figure) and classified image (lower figure).

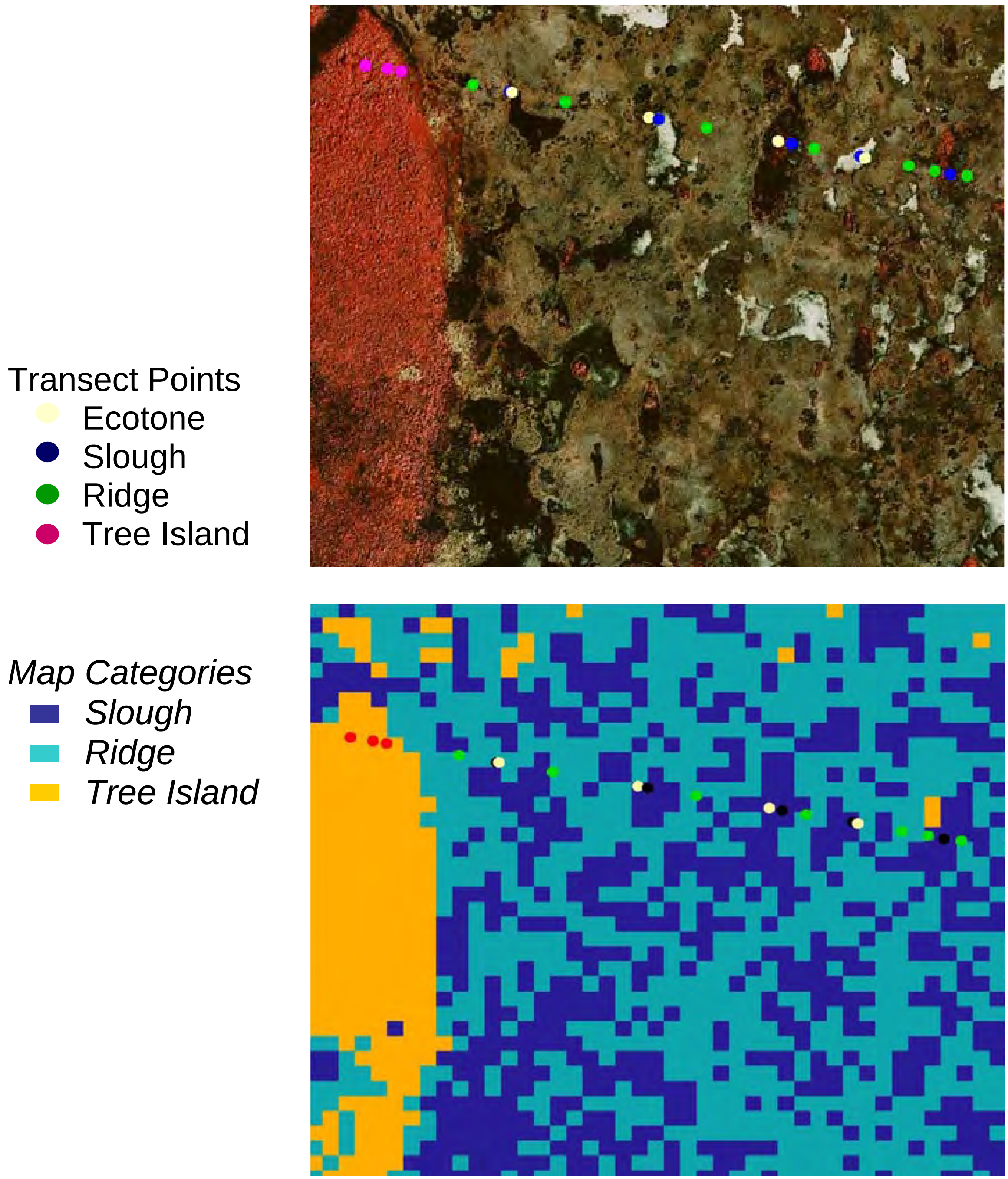

Figure 5. Transect plots in Shark River Slough superimposed on CIR imagery (upper figure) and classified image (lower figure).

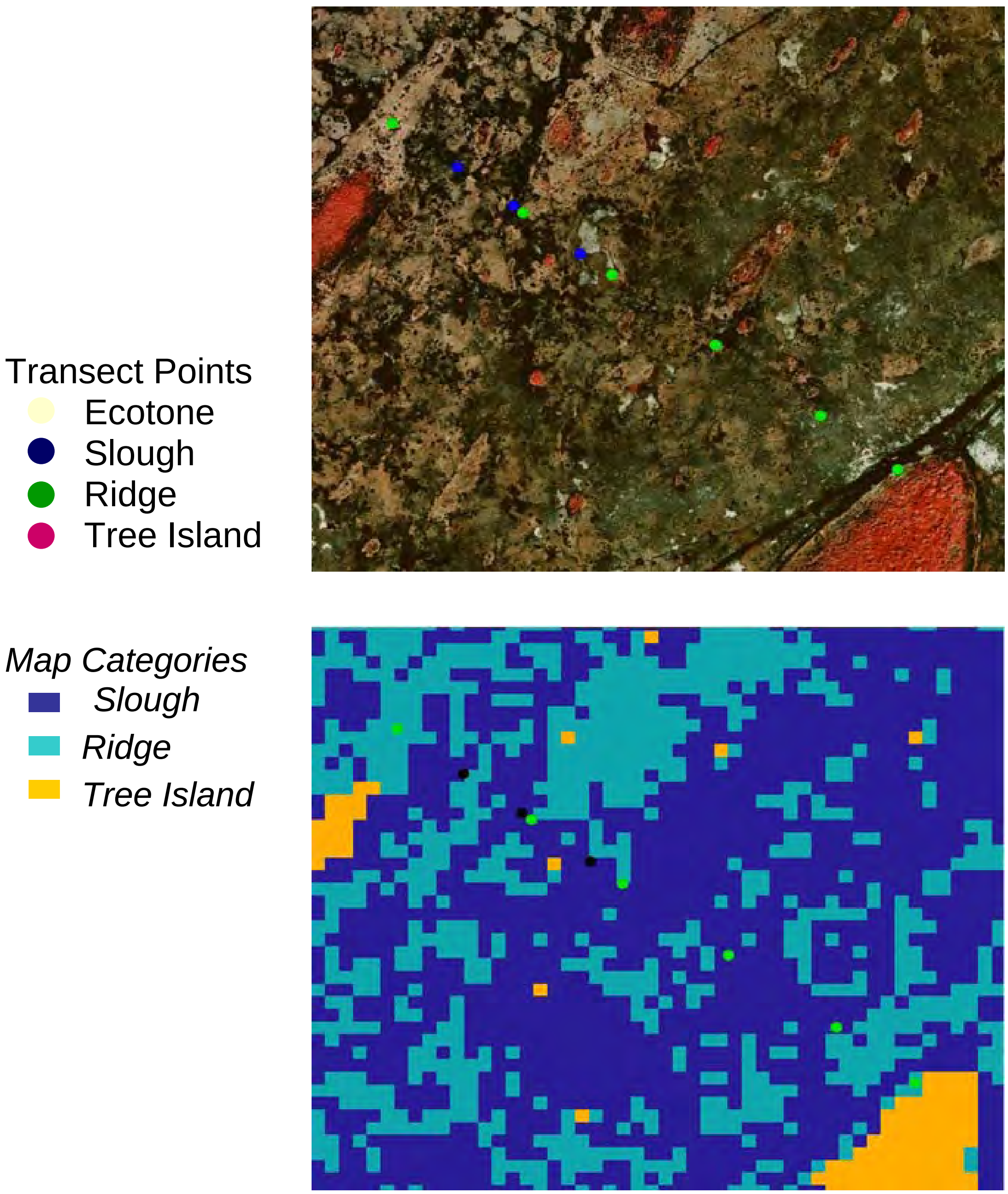

Figure 6a. Comparison of CIR aerial photography of Shark River Slough in 1995 (top) and 2002 (bottom).

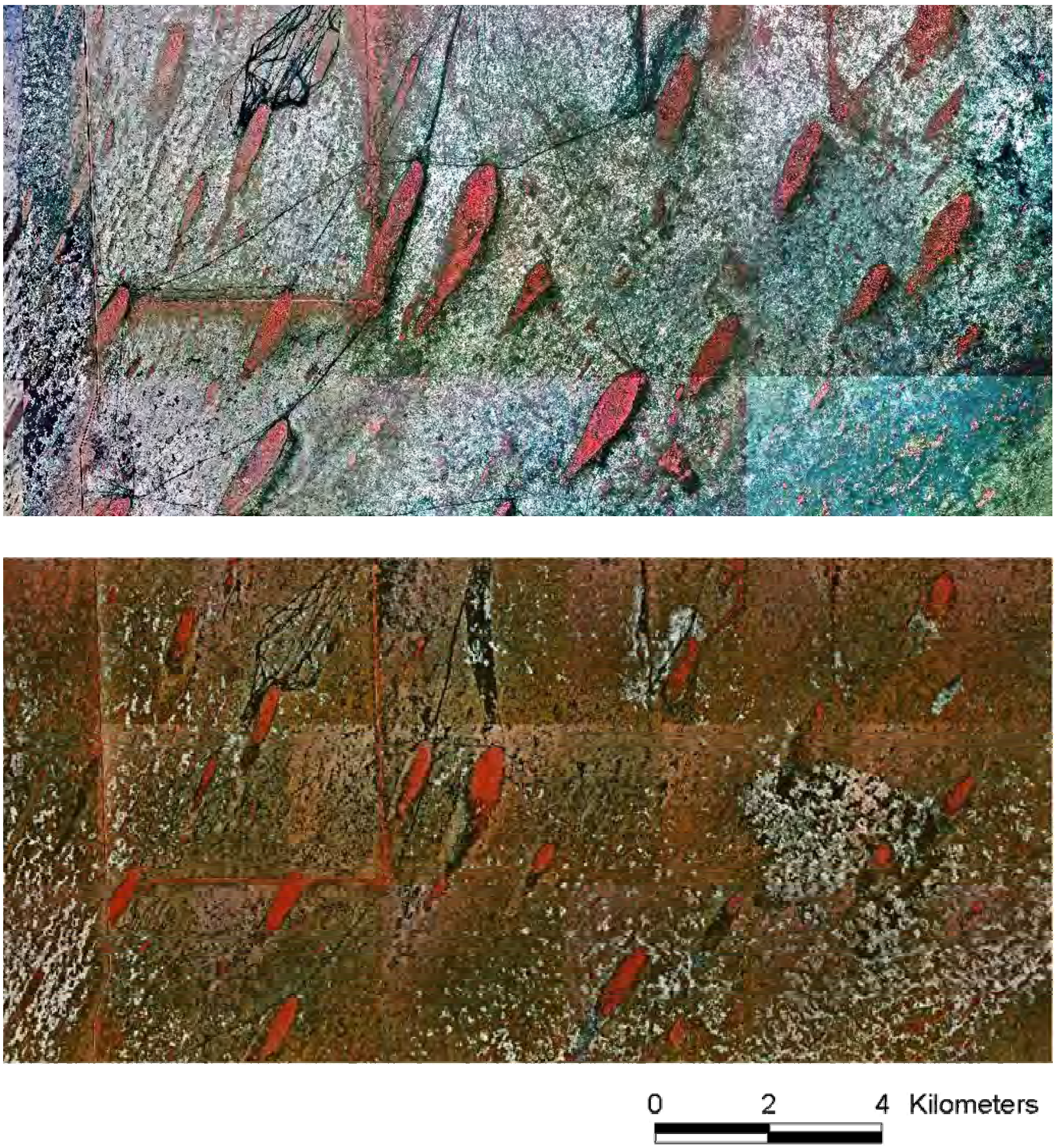

Figure 6b. Comparison of classified image of northeast Shark River Slough in 1995 (top) and 2002 (bottom).

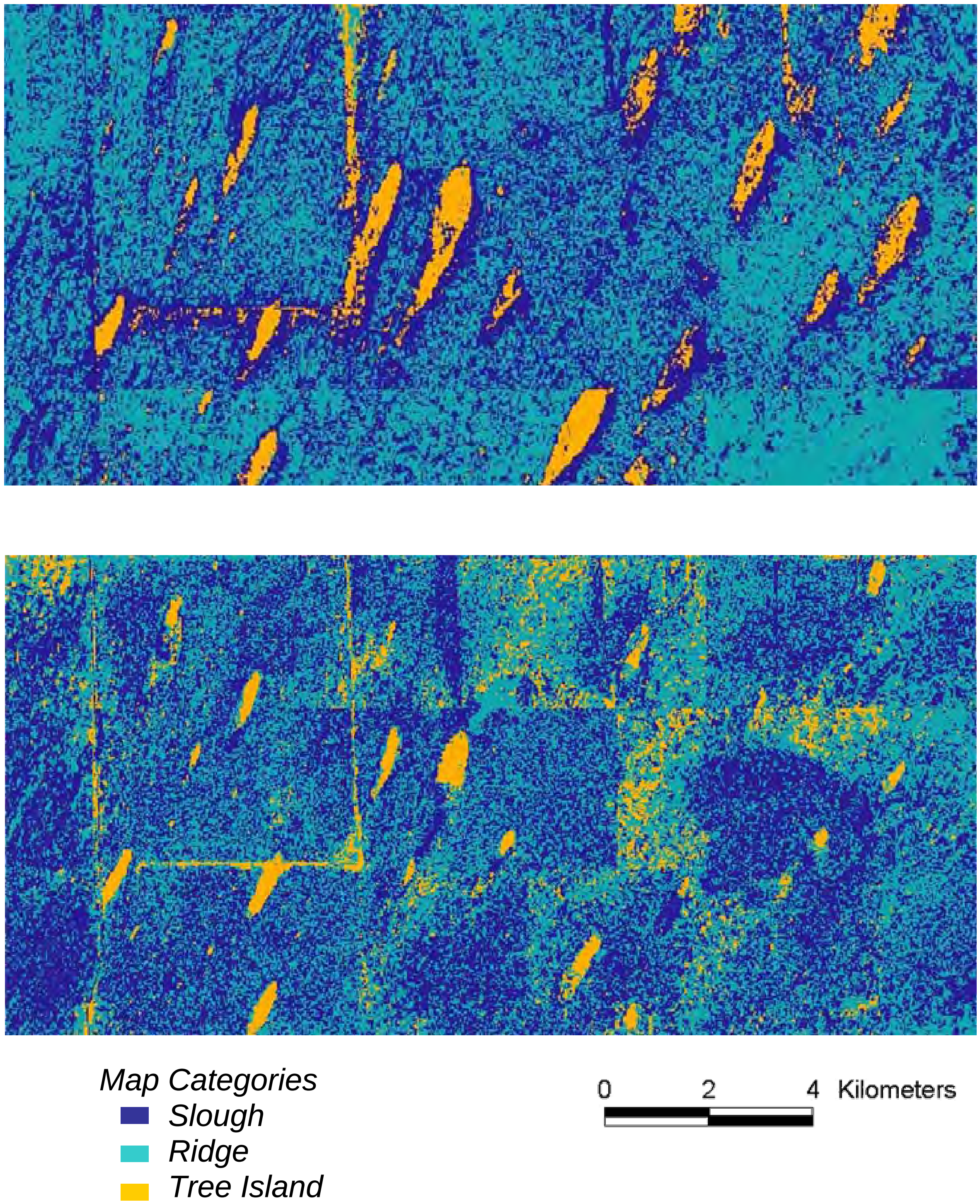

Figure 7. Non-metric multidimensional scaling analysis of vegetation coverage data

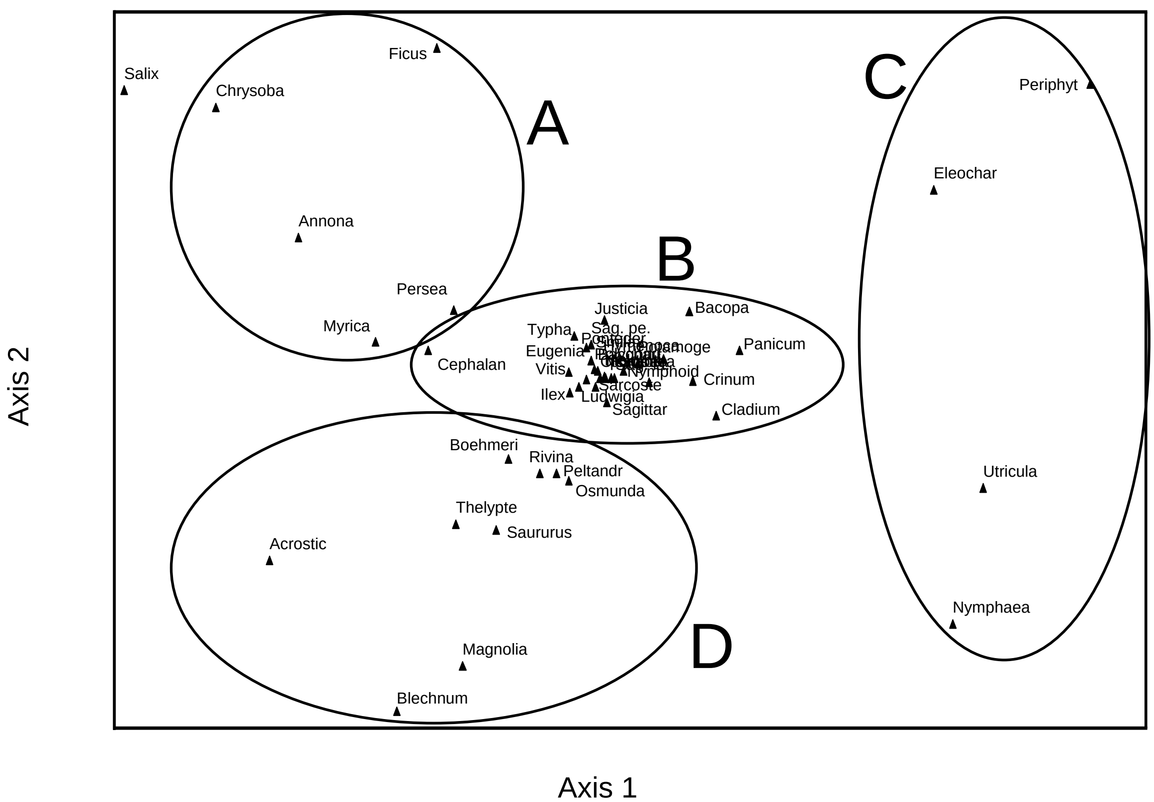

Figure 8. Canonical Correlation Analysis of vegetation coverage data

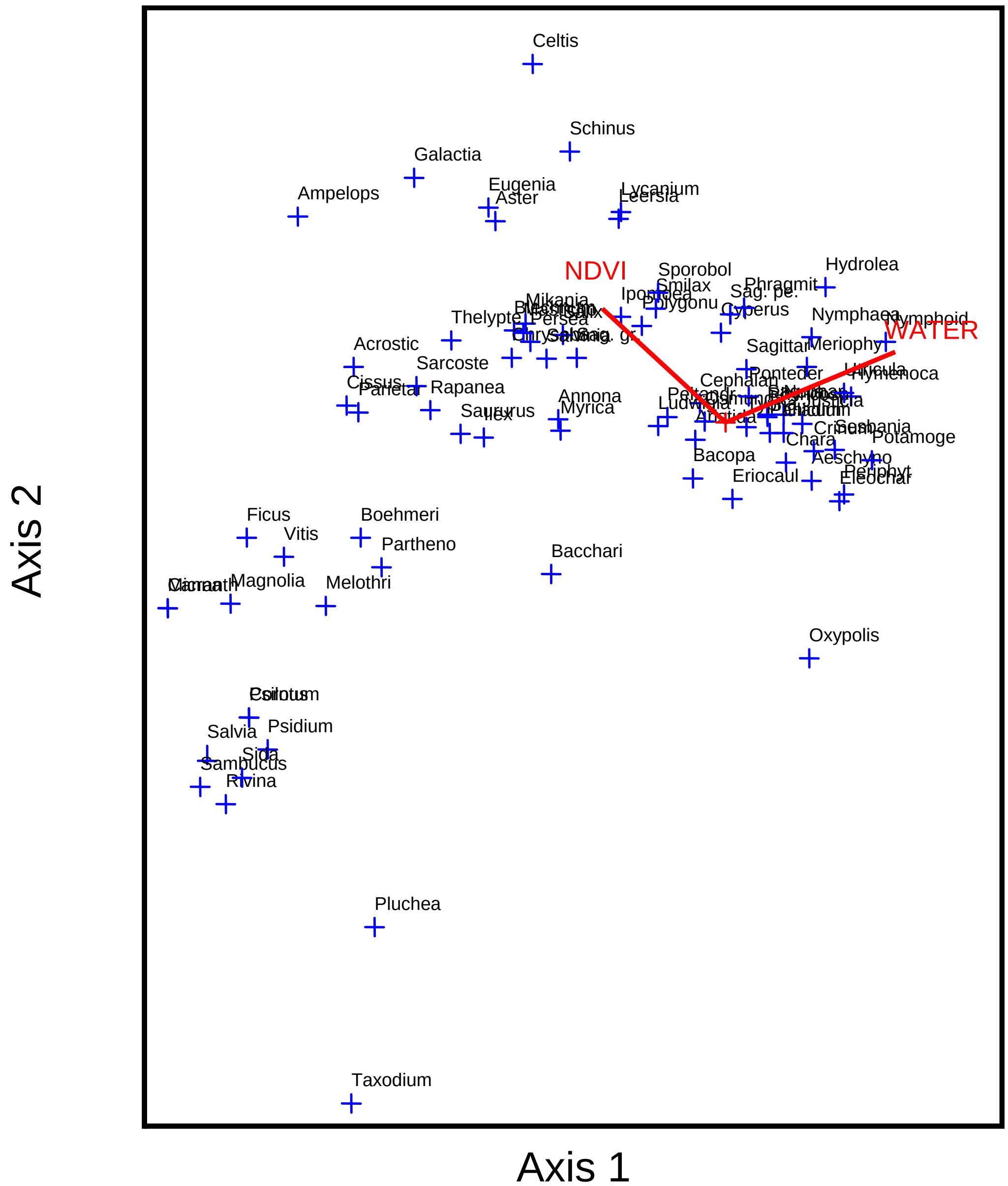

Figure 9: Non-metric multidimensional scaling analysis of ridge and slough commuities in a) southern WCA3A, b) WCA3B and c) northeast Shark River Slough.

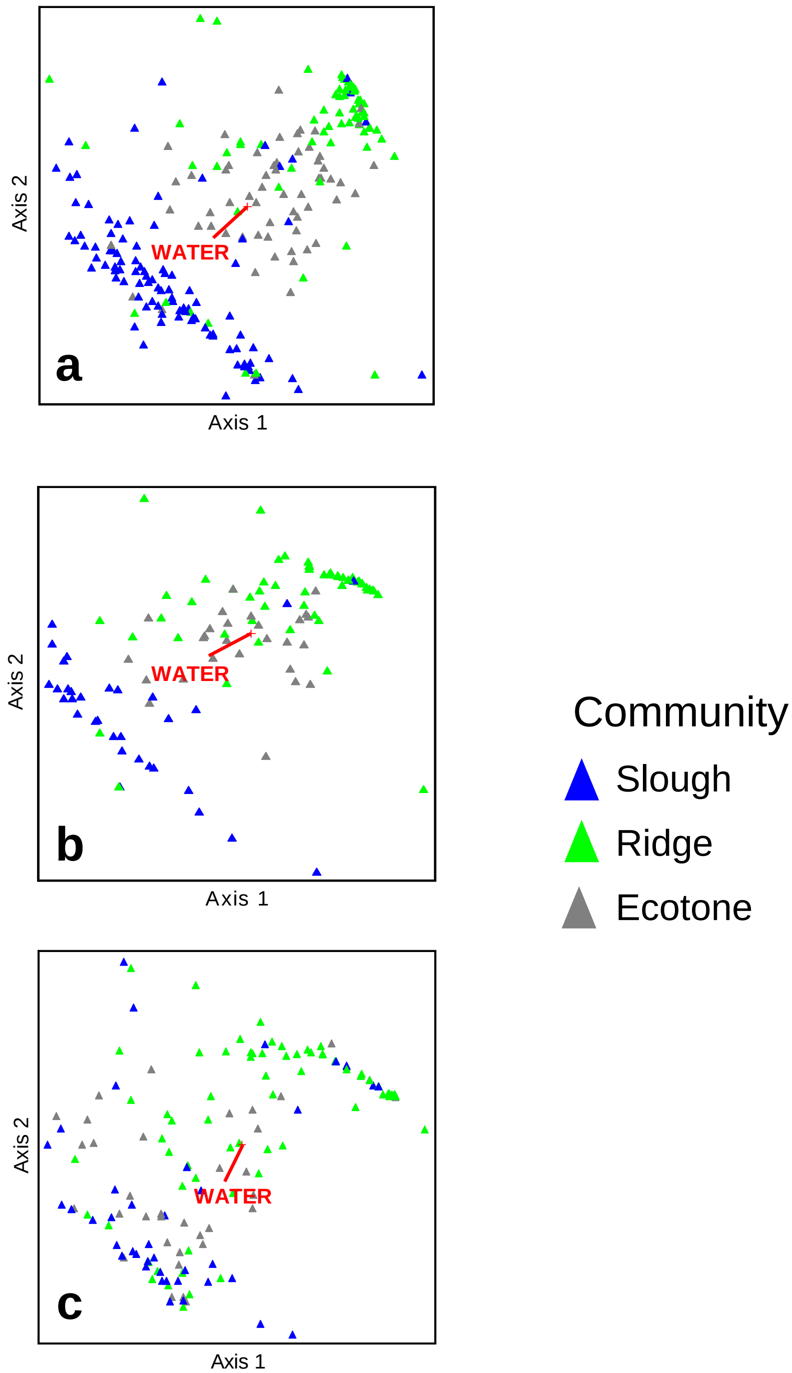

Figure 10: Analysis of relationship between flow predictions derived from a) elevation and b) landscape vegetation patterns