12-30-2005

Tree Islands in Everglades Landscapes: Current Status, Historical Changes, and Hydrologic Impacts on Population Dynamics and Moisture Relations, First Annual Report

Michael Ross
Southeast Environmental Research Center, Department of Environmental Studies, Florida International University

Steve Oberbauer
Department of Biological Sciences, Florida International University

Pablo Ruiz
Southeast Environmental Research Center, Florida International University

Nilesh Timilsina
Southeast Environmental Research Center, Department of Environmental Studies, Florida International University

Daniel Gomez
Department of Biological Sciences, Florida International University

See next page for additional authors

Recommended Citation

Ross, Michael; Oberbauer, Steve; Ruiz, Pablo; Timilsina, Nilesh; Gomez, Daniel; Sah, Jay; Stofella, Susanna; and Sternberg, Leonel, "Tree Islands in Everglades Landscapes: Current Status, Historical Changes, and Hydrologic Impacts on Population Dynamics and Moisture Relations, First Annual Report" (2005). *SERC Research Reports.* Paper 83.
http://digitalcommons.fiu.edu/sercrp/83

Authors
Michael Ross, Steve Oberbauer, Pablo Ruiz, Nilesh Timilsina, Daniel Gomez, Jay Sah, Susanna Stofella, and Leonel Sternberg

Tree islands in Everglades landscapes: current status, historical changes, and hydrologic impacts on population dynamics and moisture relations

First Annual Report
December 30, 2005

Michael Ross[1,2], Steve Oberbauer[3], Pablo Ruiz[1], Nilesh Timilsina[1,2], Daniel Gomez[3], Jay Sah[1], Susanna Stoffella[1], and Leonel Sternberg[4]

[1]Southeast Environmental Research Center, [2]Department of Environmental Studies,
[3]Department of Biological Sciences, Florida International University;
[4]Department of Biology, University of Miami

Summary

In 2005 we initiated a project designed to better understand tree island structure and function in the Everglades and the wetlands bordering it. Focus was on the raised portions at the upstream end of the islands, where tropical hardwood species adapted to well-drained conditions usually are the most prominent component of the vegetation. The study design is hierarchical, with four levels; in general, a large number of sites is to be surveyed once for a limited set of parameters, and increasingly small sets of islands are to be sampled more intensively, more frequently, and for more aspects of ecosystem function. During the first year of the 3-year study, we completed surveys of 41 Level 1 (i.e., the least intensive level) islands, and established permanent plots in two and three islands of Levels 2 and 4 intensity, respectively. Tree species richness and structural complexity was highest in Shark Slough "hammocks", while islands in Northeast Shark Slough and Water Conservation Area 3B, which receive heavy human use, were simpler, more park-like communities. Initial monitoring of soil moisture in Level 4 hammocks indicated considerable local variation, presumably associated with antecedent rainfall and current water levels in the adjacent marsh. Tree islands throughout the study area were impacted significantly by Hurricanes Katrina and Wilma in 2005, but appear to be recovering rapidly. As the project continues to include more islands and repeated measurements, we expect to develop a better grasp of tree island dynamics across the Everglades ecosystem, especially with respect to moisture relations and water levels in the adjacent marsh. The detailed progress report which follows is also available online at **http://www.fiu.edu/~serp1/projects/treeislands/tree_islands_2005_annual_report.pdf**

Introduction

Tree islands are a prominent feature in the Ridge and Slough landscape of the Everglades, where they have undergone extensive damage from drought, fire and extreme flooding. They are also prevalent in the short-hydroperiod prairies, where they have been adversely impacted by fire and encroaching exotic plants. Changes in water management associated with hydrologic restoration will result in changes in the internal water economy of tree islands, as well as their risk of fire, which in turn will lead to changes in plant function and species composition. It is therefore important to understand how restoration translates into impacts in these unique ecosystems.

Previous research in tree islands in Everglades Park (Armentano et al. 2002; Ross et al. 2004) have focused on the distribution of tree island types and species, especially in relation to flooding and nutrient availability. More recently, Struhar (2004) studied nutrient release from tree island soils, and Jones et al. (in press) described the response of the major tree island species to experimental flooding treatments (see also Gunderson et al. 1988). Sklar et al (2004) described the structure of a group of tree islands in the Water Conservation Areas, which have been subject to a long history of over-drainage, fire and/or flooding, and addressed the physiologic and hydrologic processes that were affecting them. Heisler et al (2002) determined species richness at high elevations in tree islands in Conservation Area 3, and used these data to develop an index that relates modeled water levels to species richness as a surrogate for tree island restoration goals. Recently, Wetzel et al. (2005) and Ross et al. (in press) have proposed that interactions among marsh hydrodynamics, plant community water use, and nutrient availability play an important role in the development and maintenance of function in Ridge and Slough tree islands.

Though much more information is needed about all elements of South Florida tree islands, four critical needs are addressed by our research. They are: (1) detailing of the current distribution and condition of tree islands with significant areas of tropical hardwood-dominated forest in Shark Slough, (2) analysis of historical changes in the shape and size of these and associated islands, (3) exploration of relationships among the hydrologic regimes of adjacent long- and short-hydroperiod marshes, soil moisture in the hardwood forests, and stress and population dynamics among resident trees and associated plant species, and (4) development of a system-wide understanding of tree island distribution and function that incorporates islands from inside and outside Everglades National Park. In 2005, the first year of our three-year research project, progress on Objectives 1 and 4 was most significant, and will continue through the duration of the study. The sampling infrastructure for Objective 3 was also put in place this year, and our understanding of stress/moisture relations among tree island species will develop as data is collected during 2006-2007. Work on Objective 2 will be reserved till the last year of the project. Progress on all fronts in 2005 is outlined below.

Methodology and preliminary results

Beginning in January 2005, we established a hierarchical research design with the broad intent of gaining a better understanding of those Everglades tree islands with significant portions sufficiently elevated above the surrounding marshes or prairies to support upland tree species. The focus of the research was the upland forest, or hardwood hammock, components of these complex forests, as the relationship between these elevated communities and the swamp forests that surround them had previously been described in Ross et al. (2004). The four levels in our design hierarchy were (arranged from lowest to highest intensity and scope of sampling: (1) Extensive survey islands, i.e., *ca* 100 islands in Shark Slough (SS), Northeast Shark Slough (NESS), and Water Conservation Area 3B (WCA-3B); (2) Low intensity permanent plot islands, which include 5-7 islands in SS, NESS, the Water Conservation Areas, or the prairies of eastern ENP; (3) Medium intensity permanent plot islands, which include 13 islands in the same areas noted above; and (4) High intensity permanent plot islands, which include 3 islands in ENP that will be the sites of our detailed studies of tree island function in relation to hydrology. Sampling protocols and early results from the extensive survey islands (Level 1), the permanent plot structural data from Levels 2-4, and the studies of soil moisture – plant stress in the High intensity islands (Level 4) are described in turn below.

Extensive surveys of tree islands in SS, NESS, and WCA-3B

Methods. Initial reconnaissance of islands in NESS and WCA-3B indicated that our sampling strategy needed to account for the 2-phase structure of many tree islands in these areas --- (1) an annulus of relatively closed forest surrounding (2) an open, disturbed center. Some of the Shark Slough islands that currently do not exhibit an obvious center dominated by herbaceous species nevertheless bear evidence that they once may have had such a 2-phase structure associated with human disturbance, i.e., trees are currently larger and more densely packed along the sides of the raised portion of the island than at its center. We wanted to learn more about the nature of both phases, and perhaps about the process of recovery from herbaceous to forest stage.

Our vegetation sampling methods therefore combined nested circular plots (for total canopy and herb cover, and tree species population structure) and relevee' sampling (relative species cover of herbs and trees). Minimum hammock size was 10 meters on at least 1 axis. Plot sampling was arranged along perpendicular axes, the long axis of the hammock and a sub-axis perpendicular to it. Plot layout differed for axes ≥18 m in length, 14-18 m in length, and 10-14 m in length, as described below.:

1. When hammocks were of sufficient size, 5 points were established, ideally arranged at 25%, 50%, and 75% along 2 perpendicular transects, with the interior (50%) point common to both axes. When either axis was too short to permit the above spacing, the interior point was established midway along the long axis, and the locations of the exterior points were chosen to avoid overlap among plots (see below).

2. If an axis was ≥18 m in length, then herb, shrub/sapling, canopy, and emergent layer sampling (see description below) were carried out at all points per axis.
3. If an axis was 14-18 m in length, then the full, 3-m radius nested sampling were carried out at the interior point, while sampling at the exterior points consisted of herb, shrub/sapling, and canopy tree layers (nested sampling within 2-m radius) only.
4. If the axis was 10-14 m, then full nested sampling was applied at the interior point, while sampling at the exterior points consisted of herb and shrub/sapling strata only (nested sampling within 1-m radius).
5. If the subordinate axis was <10 m in length, then sampling was restricted to the long axis.
6. Points were characterized as Forested or Open (or Transitional). If the island had a 2-phase structure with a significant Open or Forested portion that was not sampled according to the above rules, an additional (sixth) point was established in the center of the minor phase.

Our data collection methods, including plot-based sampling and sampling for the hardwood hammock as whole, are outlined below:

- Plot-based sampling
  - Vegetation
    - Seedlings - 1 m^2 plot (0.57 m radius)
      - Tree and shrub species - density of stems < 30 cm, 30-60 cm, & 60-100 cm in height, by species
    - Herb, shrub and sapling layers - 3.14 m^2 plot (1 m radius)
      - Herb layer - Cumulative cover of all species, stems <1m tall
      - Shrub layer - density of stems > 100 cm height & < 1 cm DBH, by species
      - Sapling layer – density of stems 1-3 cm DBH and 3-5 cm DBH, by species
    - Canopy layer - 12.56 m^2 plot (2 m radius)
      - Trees - density of stems 5-25 cm, in 5-cm DBH classes, by species
    - Emergent layer - 28.26 m^2 plot (3 m radius)
      - Trees - density of stems > 25 cm, in 5-cm DBH classes, by species
    - Canopy cover - 2 densiometer readings per plot, facing in opposite directions
  - Physical variables
    - Elevation change from ambient water surface to edge of hammock, and to as many plots as possible.
    - Soil depth
    - Litter depth
- Sampling for hammock as a whole
  - Vegetation – (if there is 2-phase structure, done separately for Forested and Open zones)
    - Tree species - cover estimated in 6 classes (0-1%, 1-4%, 4-16%, 16-32%, 33-66%, >66%)

- Non-tree species (understory and vines) - ranked in terms of cover on 10-point scale with most abundant species scored with a 10 in each zone in each stand

Physical variables

- Length and orientation of long axis
- Length of short axis
- Length of annuli on each axis, if present
- Type of recent human disturbance (recreational, scientific, other)
- Intensity of disturbance (6-point ordinal scale)
- Impact of disturbance (6-point ordinal scale)
- Evidence of past human use (structures, pottery)
- Fauna observed

Results. Data were collected using the above methods at 41 extensive survey islands (13 in WCA-3B, 11 in NESS, and 18 in SS) (Figure 1). The structure of islands in the three regions is summarized in Table 1. Hammocks in SS were smallest, but had by far the highest seedling and sapling density of the three areas. SS islands were characterized by high tree density, intermediate basal area, and high crown cover. The closed canopies of SS hammocks generally resulted in low cover in the herb layer. In contrast, tree, sapling, and seedling densities were low in the relatively large raised areas in NESS and WCA-3B tree islands, resulting in more open canopies and higher ground cover. Despite their low tree density, WCA-3B hammocks were characterized by high basal area, suggesting canopy dominance by a few very large trees (Table 1).

Table 2 outlines the species composition of tree islands in the three regions. Since the number of tree islands sampled in each group differed, it is not possible to interpret diversity patterns directly from these summarized data. Nevertheless, these preliminary data suggest that dominance may be shared more equally among species in SS and, to a lesser extent, in NESS than in WCA-3B hammocks. For instance, 22 and 19 tree species were present at densities sufficient to be sampled in SS and NESS islands, while only 11 tree species were sampled in WCA-3B hammocks. Of these, only *Ficus aurea* (9 stands) and *Bursera simaruba* (1 stand) were typical of mesic south Florida hammocks, while the remaining species were either non-native (*Schinus terebinthifolius* and *Psidium guajava*), or characteristic of wetter bayhead (*Annona glabra, Chrysobalanus icaco, Ilex cassine, Myrica cerifera, Persea palustris, Salix caroliniensis*) or transitional forests (*Sambucus canadensis, Sapindus saponaria*). Species that are widespread in SS and NESS but absent in WCA-3B include *Bumelia salicifolia, Celtis laevigata, Coccoloba diversifolia, Eugenia axillaris, Sideroxylon foetidissimum*, and *Simarouba glauca*.

Table 1: Forest structure of raised portions of tree islands (hammocks) in WCA-3B, Northeast Shark Slough (NESS) and Shark Slough (SS).

Region	n	Area			Seedlings		Saplings		Trees						Herb	
		Mean Hammock area (m^2)	Range		Density (x10^3 per ha)	S.E. (x10^3 per ha)	Density (x10^3 per ha)	S.E. (x 10^3 per ha)	Density	S.E.	Basal Area (m^2/ha)	S.E.	[2] Crown cover (%)	S.E.	Cover (%)	S.E.
			Min (m^2)	Max (m^2)												
WCA-3B	12	1319	234	3894	16.2 (1.02)[1]	7.0	0.6 (13.8)	0.4	858 (1.23)	274	39.99 (0.22)	6.6	72	4.3	43	5.6
NESS	11	743	113	1517	38.7 (7.6)	15.2	4.1 (5.14)	1.6	771 (1.1)	244	22.74 (2.48)	4.8	55	7.0	51	7.5
SS	18	500	75	2160	87.2 (1.5)	22.5	6.5 (2.7)	1.2	1305 (2.16)	165	31.28 (0.75)	6.3	80	2.7	23	5.1

[1] Numbers in parentheses are % of non-native species.

[2] Crown cover is estimated by spherical densiometer.

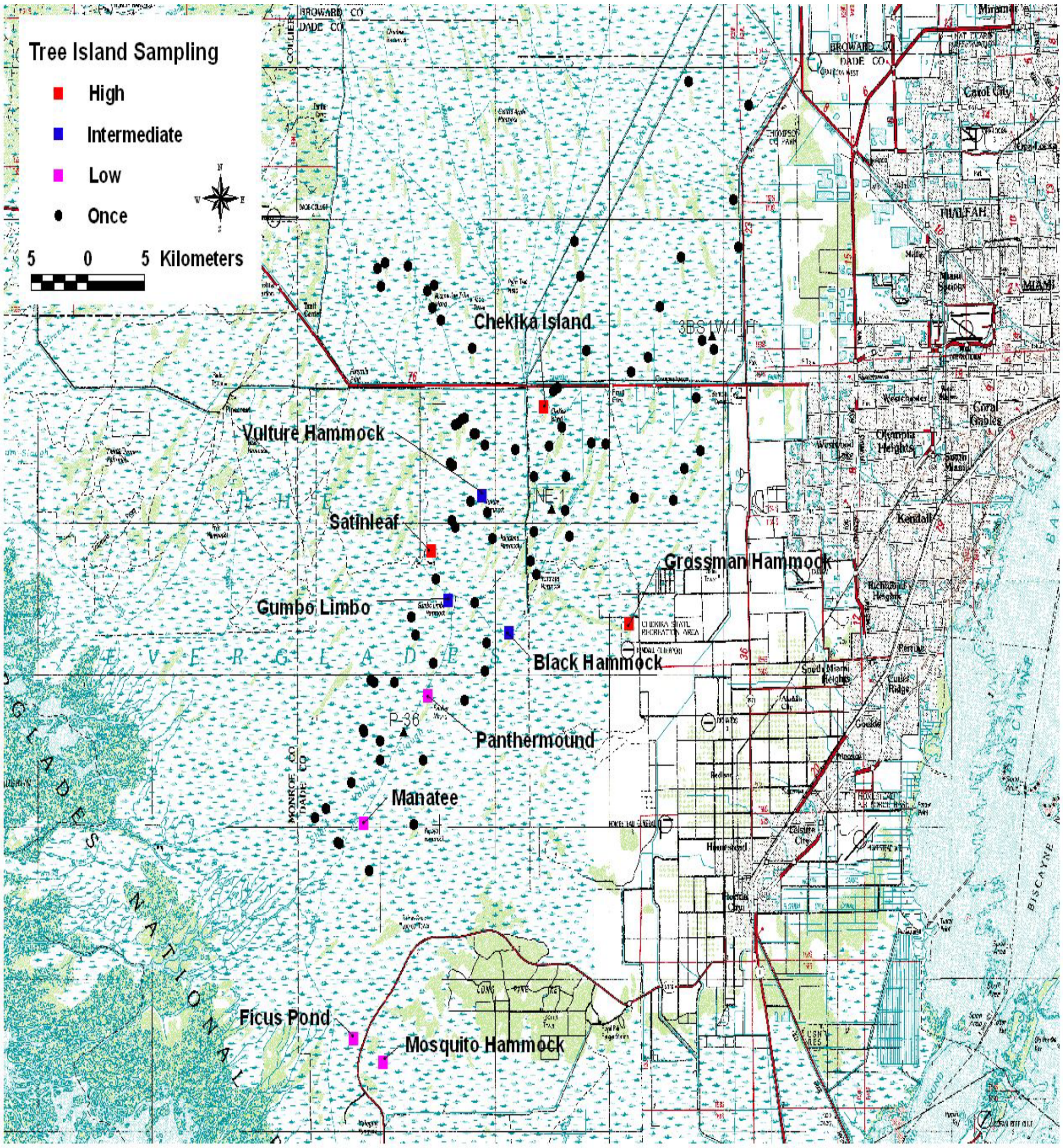

Figure 1: Location of tree island study sites and water level recorders used to calculate tree island surface elevation.

Table 2: Mean Importance Value (IV) of species in raised portions of tree islands in WCA-3B, Northeast Shark Slough (NESS) and Shark Slough (SS). IV is Relative Density for seedling and sapling classes, while tree IV is the mean of Relative Density and Relative Basal Area.

	Seedlings (IV)			Saplings (IV)			Trees (IV)		
Species	WCA-3B	NESS	SS	WCA-3B	NESS	SS	WCA-3B	NESS	SS
Annona glabra	0	0	0.09	4.16	0	0	3.48	0	0
Baccharis halimifolia	0	7.8	0	0	0	0	0	0	0
Bumelia salicifolia	0	0	0	0	0	0	0	0	0.92
Bursera simaruba	0	0.39	0.21	0	0.60	1.54	6.92	22.8	7.40
Carica papaya	0	0	5.12	0	0	0	0	0	0.83
Celtis laevigata	0	2.79	30.70	0	5.45	0	0	6.95	19.64
Chrysobalanus icaco	3.06	5.09	31.47	0	3.03	34.47	4.94	3.49	12.86
Citrus sp.	0	0	0	0	0	0	0	0	2.35
Coccoloba diversifolia	0	0	7.91	0	0	7.01	0	0	9.01
Delonix regia	0	2.5	0	0	0	0	0	4.19	0
Eugenia axillaries	0	35.25	8.88	0	38.54	28.19	0	2.74	0.55
Ficus aurea	0	0	0	0	0	0	64.42	5.73	20.01
Ficus benjamini	0	0	0	0	0	0	0	1.08	0
Ilex cassine	7.39	0	0	0	0	0	1.54	0	0
Morus rubra	0	0	0	0	0	0	0	0	1.71
Myrica cerifera	8.91	0	0	3.33	0	0.33	3.02	0	0
Myrsine floridana	0	6.63	3.28	0	8.48	13.0	0	2.38	3.47
Persea borbonia	7.5	6.64	0.30	8.33	0	0	0	2.25	0
Psidium guajava	8.33	0.95	0	6.66	0	5.55	0	2.24	0.35
Psychotria sulzneri (shrub)	0	4.0	4.23	0	0	0	0	0	0
Quercus virginiana	0	0	0.89	0	0	0	0	0	0
Sabal palmetto	0	0	0.24	0	0	0	0	0.79	2.8
Salix caroliniana	0	0	0	0	0	0	5.08	1.78	0
Sambucus Canadensis	89.81	0	0	8.33	0	0	2.23	0	0
Sapindus saponaria	8.33	0	0	0	0	0	0	0	0
Schinus terebinthifolius	0	4.93	2.46	0	8.78	2.35	8.33	4.50	4.45
Sideroxylon foetidissimum	0	0	23.74	0	0	0	0	8.79	7.03
Simarouba glauca	0	0	0.45	0	0	0.98	0	0	5.65
Solanum donianum	0	1.18	0	0	4.54	0	0	0	0
Solanum erianthum	0	0	0.20	0	0	0	0	0	0.75
Trema micranthum	0	0	0	0	5.68	0	0	7.13	0
Zanthoxylum fagara	0	0	0	0	0	0.58	0	0.32	0.64

Our extensive survey provided us with information regarding the surface elevation of the sample hammocks with respect to the surrounding water table. Because sampling took place from mid-winter through mid-fall of 2005, a meaningful comparison required the surveys to the closest surface water be standardized to a single day. August 1, 2005 was chosen for this purpose. We applied a correction factor which equaled the difference between regional water level on the day each hammock was sampled and water level on August 1at 3 water level recorders (3BS1W1, NE-1, and P-36) chosen to represent WCA-3B, NESS, and SS, respectively. For each island, we calculated a mean, minimum, and maximum *relative* elevation (i.e., relative to the water table of Aug 1, 2005), based on surveys to all sample plots, the hammock edge, and the highest plot center, respectively (Table 3).

Table 3: Estimated elevation above water table on Aug 1 in tree islands of WCA-3B, NESS and SS.

Tree Islands	Mean (cm)	Min (cm)	Max (cm)
WCA3B-01	71.77	55.40	114.50
WCA3B-02	17.58	9.0	23.8
WCA3B-03	20.23	5.18	30.18
WCA3B-04	41.91	0.86	60.66
WCA3B-05	4.08	-3.63	11.36
WCA3B-07	-38.62	-50.44	-19.94
WCA3B-10	-55.17	-67.14	-41.64
WCA3B-12	54.68	6.98	77.48
WCA3B-19	47.76	17.68	83.28
WCA3B-20	70.08	41.78	83.58
WCA3B-25	43.90	13.90	63.4
WCA3B-26	36.1	19.88	56.38
NESS-01	47.89	35.96	54.26
NESS-65	37.75	30.41	45.31
NESS-66	54.94	46.01	65.81
NESS-69	49.32	32.90	64.30
NESS-70	40.64	32.10	49.50
NESS-71	18.16	15.41	20.21
NESS-72	56.0	42.29	67.39
NESS-73	49.37	-6.60	79.79
NESS-74	63.75	29.79	81.99
NESS-76	82.72	69.89	99.69
NESS-77	77.69	68.29	89.39
NESS-93	42.07	14.70	56.60
NESS-94	28.62	6.80	38.0
NESS-95	62.51	47.41	73.81
SS-05	49.48	44.58	53.68
SS-07	42.55	34.85	54.25
SS-13	24.75	22.71	26.81
SS-14	24.63	21.01	27.01
SS-20	15.48	7.68	30.88
SS-23	36.16	21.68	47.58
SS-27	39.35	21.35	47.95
SS-34	46.85	41.95	54.55
SS-36	33.92	24.85	42.85
SS-37	39.14	24.08	51.18
SS-38	48.87	40.55	53.75
SS-41	51.04	43.98	61.28
SS-82	54.48	47.58	59.08
SS-92	47.06	7.77	59.27

Mean hammock elevations averaged 26, 51, and 40 cm above the Aug 1 water table in WCA-3B, NESS, and SS, respectively. The low average elevation in WCA-3B was primarily attributable to two islands (WCA-3B7 & WCA-3B10) which we projected to have been flooded by more than one foot of water on August 1; these were the only hammocks in the entire data set flooded on that day. In general, a high degree of inter-regional variation was characteristic of all three regions, with a range in mean relative elevations of 127, 64, and 39 cm in WCA-3B, NESS, and SS, respectively. Within-island differences in elevation were also substantial, with maximum ranges of 70, 86, and 52 cm within what we perceived to be "hammock" in the same 3 regions (Table 3).

Conclusions. Data collection from the extensive surveys are far from complete after Year 1 of our 3-year study. Tables 1, 2, and 3 include most of the islands with evidence of hammock vegetation in WCA-3B and NESS, but none in WCA-3A, and only a small proportion of the SS islands. Our study does not address bayhead forests or other swamp forest types that comprise the vast majority of Ridge and Slough tree islands. The hardwood hammock communities we described are small, raised units embedded within these wetter forests. Our previous work suggests that the boundary between hammock and bayhead vegetation is very distinct in terms of hydrology. Though we don't have enough data to define it precisely at this time, the hydrology associated with this boundary could be very useful in restoration planning. On the other hand, the large within- and among-site variation in Ridge and Slough hammocks make it difficult to generalize about prevailing hydrologic conditions in these forests at a regional scale.

The considerable variation that we observed in hydrology and structure in R&S hammocks seems to provide fertile material for better understanding of vegetation-hydrology relationships. However, the structure and composition of these forests is also impacted by factors other than hydrology, especially disturbance. The impacts of natural disturbances on forest structure were especially apparent upon re-surveying permanent-plot hammocks following Hurricane Wilma (see next section). Likewise, the contribution of anthropogenic disturbances to current tree island structure cannot be over-emphasized. Islands throughout the Everglades have been utilized for thousands of years. Recent use of tree islands in WCA-3B and NESS is almost certainly the most important factor in their current structure and composition, and attempting to interpret hydrologic relationships from present vegetation in these islands will probably be fruitless. However, much could be learned from experimental treatments involving planting trees on these islands, which our data show are severely below their full stocking levels. In fact, tree planting may be a necessary first step in restoration of many of these communities, since any beneficial impacts of hydrologic restoration may be reduced by the limited species pool available to restock the islands by natural means.

Stand structure and community dynamics in permanent plots

Methods. Stand structural information collected at hammocks selected for low, medium, and high intensity permanent plots share a common design, with the three types differing primarily in the intended frequency of sampling. During the course of the project structural data will be collected only once in low intensity plots, while some structural parameters will be re-sampled each year in medium intensity plots, and at two-month intervals in high intensity plots. The structural and physical measurements that were common to all plots are described in the next two paragraphs.

Plot size and shape were selected to suit the dimensions of each hammock; as a rule, plots were rectangular and 225-625 m^2. Each plot was gridded into 5 x 5 m cells, and seedlings and shrub stems were sampled as in the extensive plots, i.e., in 1 m^2 and 3.14 m^2 plots circular plots surrounding a stake at the center of each cell. Unlike the protocol for extensive plots, however, cover of all seedlings, shrubs, herbs, and vines were estimated by species in the 3.14 m^2 plot. Saplings were counted by size class and species throughout each cell, and trees were tagged and their location coordinates (nearest 0.5 m) determined within the plot as a whole. DBH and height were determined for each tagged tree. The crown profile of each hammock and the position of each species within the canopy were determined by application of a vertical line intercept method (Ross et al. 2004). In this technique, a telescoping height pole is extended vertically at each cell center, and the species and height interval intercepted or approached (within 1 m) by adjacent crowns are recorded. The crown profile measurements at the cell centers complement estimates of canopy variables at the same locations in the permanent plots. These are achieved by densiometer readings as described for the extensive plots, and by hemispherical photos taken from a height of ~1 m at each cell center. The photos will be analyzed to determine the relative availability of light within and among stands, using Gap Light Analyzer (GLA) (Frazer et al. 1999).

Detailed topographic data was collected from an established vertical control datum, either a nearby USGS or ENP benchmark, or one that we established by differential GPS. Surface elevation was surveyed from the benchmark to each grid cell corner and center by auto-level. Determination of soil and litter depth at these points allowed the underlying bedrock topography to be assessed as well. By combining the surface topography with longterm marsh water levels from nearby recorders, it will be possible to estimate how often flooding occurs within each cell, and hence species' realized tolerances to flooding.

Medium intensity plot establishment was not initiated in 2005. Once these plots are established in 2006, annual re-sampling of many of the structural variables described above will allow an assessment of inter-annual variation in community structure. A subset of trees in these plots will be outfitted with dendrometers, which will also provide for some comparison of variation in annual growth among a relatively large set of islands. However, detailed study of seasonal dynamics in population and ecosystem variables will be centered on the three high intensity islands which were established in 2005, as described in the following paragraphs.

In addition to the studies of soil moisture – plant stress relationships, which are described in the next section, an expanded structural monitoring program was initiated in the high intensity plots. Notably, a program for tracking seedling densities at 2-month intervals in these plots was established, with the aim of examining population responses to seasonal variation in moisture availability. A denser network of dendrometers was established in the high than the medium intensity plots (15-20 trees per plot, compared to an anticipated 5-10 trees in the latter). Canopy photographs taken in 2005 will be repeated biannually in dry and wet season in the high intensity plots, in conjunction with densiometer readings. In January 2006, individual litter traps (52.70 x 52.70 x 18.42 cm) will be established in eight cells chosen in each high intensity plot through a stratified random sampling scheme. Litter traps will be emptied [excluding coarse woody debris (CWD) >0.64 cm diameter], dried and weighed at 2-month intervals at Satinleaf and Chekika Islands, but monthly at Grossman Hammock. At the same time, separate monitoring for CWD will be initiated, using a line intercept method developed by van Wagner (1968). We will establish eight transects of 7.07 m, and determine the density and size of freshly fallen branches or twigs that intersect the line. The procedure, which will be repeated at 2-month intervals, allows the calculation of CWD volume on a per hectare basis, and these estimates can be converted subsequently to biomass from empirical relationships that we will develop during the course of the project. Methods for monitoring standing litter biomass in the high intensity plots will also be initiated. All litter will be collected from the surface (to the intersection with the F, or fermentation, layer) inside a 0.25 m^2 quadrat placed 1.5 m north of each cell center, then returned to the lab for drying and weighing. The procedure will be repeated every two months, rotating the location of quadrat placement by 30^0 each time. On the basis of these data and those from the litter traps, we will calculate litter turnover rates per year for each high intensity forest, as the mean annual litterfall divided by mean standing litter biomass (Olson 1963).

Results. We established permanent plots in five islands in 2005. Three were in Level 4 (high intensity) islands: Satinleaf Hammock (25 x 25 m) and Chekika Island (20 x 20 m) in Shark Slough, and Grossman Hammock (one 20 x 20 m and one 15 x 15 m plot) in the East Everglades prairies. We also established plots in two Level 2 (low intensity) islands: Mosquito Hammock (30 x 15 m) and Ficus Pond (15 x 15 m) in the prairies west of Long Pine Key (Figure 1). Stand structure of these hammocks is illustrated in Table 4.

Table 4: Forest structure of five tree islands with permanent plots in Everglades National Park.

Area	Seedlings	Saplings	Trees			Herb Cover (%)
	Density ($x10^3$/ha)	Density ($x10^3$/ha)	Density (#/ha)	Basal Area (m^2/ha)	Crown cover[2] (%)	
Ficus Pond	15.4	15.4	1733	22.10	88	32
Grossman Hammock 1	466.7 (10.7)[1]	8.4	1644	27.70	87	6.5
Grossman Hammock 2	66.1 (3.8)	9.7 (4.1)	1500 (5.0)	19.43	92	4.5
Chekika Island	156.7	9.9	1600 (1.6)	22.64	91	14
Mosquito Hammock	352.4	10.8	2066	19.90	92	21
Satinleaf Hammock	200.1	7.1	1424	40.67	48	10.2
1: Numbers in parentheses are % of non-native species.						
2: Crown cover is estimated by spherical densiometer.						

As a group, these forests are denser than the regional averages for SS, NESS, or WCA-3B (Table 1). Seedling density ranged from 15,000- 467,000 per hectare, but sapling density, tree density and basal area, and crown cover were much more narrowly distributed (Table 4). Like seedling density, ground cover varied widely among sites, but these two variables appeared to be uncorrelated with one another. Based on these five islands, at least, tree islands in the slough

(Chekika, Satinleaf) and in the prairie (Ficus Pond, Grossman, Mosquito) appear to overlap broadly in stand structural characteristics.

A detailed summary of the composition of woody species in the intensive study islands are presented in Tables 5-7.

Table 5: Importance value of seedlings of woody species in Level 2 and 4 tree islands in Everglades National Park in 2005.

Species	Ficus Pond	Grossman Hammock 1	Grossman Hammock 2	Chekika Island	Mosquito hammock	Satinleaf Hammock
Ardisia escallonioides	0	13.21	11.81	0	0	0
Bumelia salicifolia	3.60	0	3.14	0	3.98	10.99
Bursera simaruba	0	0	0	0	0	0
Caesalpinia bonduc	0	0	0	0	0	0
Celtis laevigata	0	0	0.75	44.66	0	16.01
Chrysobalanus icaco	45.75	0	2.38	0	2.86	9.57
Chrysophyllum oliviforme	0	0	0	0	0	45.18
Coccoloba diversifolia	7.29	6.16	5.8	0	0	0
Eugenia axillaris	33.22	18.57	12.67	39.4	5.72	18.22
Exothea paniculata	0	0	0	0	13.46	0
Metopium toxiferum	3.64	0	0	0	5.82	0
Myrcianthes fragrans	0	0	0	0	2.45	0
Myrica cerifera	0	0	0	0	2.69	0
Myrsine floridana	2.81	0	0	15.92	4.0	0
Nectandra coriaecea	2.59	0	45.42	0	2.21	0
Persea borbonia	0	0	0	0	2.86	0
Psychotria nervosa	0	18.88	9.65	0	0	0
Quercus virginiana	0	0	2.38	0	44.2	0
Roystonea elata	0	27.75	0	0	0	0
Schinus terbinthifolius	0	15.42	5.95	0	0	0
Sabal palmetto	3.64	0	0	0	1.88	0
Schoepfia chrysophylloides	0	0	0	0	0.91	0

The seedling assemblages in Mosquito Hammock and Grossman Hammock were the most diverse, with 13 and 11 species represented, respectively, while Chekika Island was least species-rich, with only 3 woody plants (Table 5). As one might expect for isolated subpopulations, the understory diversity patterns were paralleled by those in the sapling and tree layers, where species number was again highest in Mosquito Hammock and Grossman Hammock, and lowest at Chekika Island (Tables 6 & 7). Of course, these species numbers are not strictly comparable, since the areas sampled differed among islands, and species-area curves are not available for these forests. Nevertheless, the data alert us to the interesting possibility that differences in tree species richness between tree islands surrounded by prairie and those embedded in the deeper waters of the marsh landscape may emerge from a larger data set.

Table 6: Importance value of sapling in tree islands with permanent plots in Everglades National Park.

Species	Ficus pond	Grossman Hammock 1	Grossman Hammock 2	Chekika island	Mosquito hammock	Satinleaf hammock
Ardisia escallonioides	0	20.05	10.01	0	0	0
Bumelia salicifolia	5.92	0	4.12	0	6.32	0
Bursera simaruba	2.59	4.74	4.12	0	3.71	0
Celtis laevigata	0	0	4.12	4.71	0	5.61
Chrysobalanus icaco	5.55	0	4.12	0	5.57	19.64
Chrysophyllum oliviforme	2.59	0	4.12	0	0	7.85
Coccoloba diversifolia	2.59	26.58	29.62	0	0	5.61
Eugenia axillaris	72.54	22.69	6.41	78.09	0	61.27
Exothea paniculata	0	0	0	0	5.20	0
Ficus aurea	0	0	0	0	3.71	0
Metopium toxiferum	0	0	0	0	5.11	0
Myrica cerifera	0	0	0	0	6.04	0
Myrsine floridana	5.61	0	7.72	6.73	8.43	0
Myrcianthes fragrans	0	0	0	0	24.87	0
Nectandra coriacea	2.59	9.49	6.37	0	3.71	0
Prunus myrtifolia	0	0	0	0	5.57	0
Psychotria nervosa	0	11.87	0	0	0	0
Quercus virginiana	0	0	0	0	7.43	0
Salix caroliniana	0	0	0	0	5.57	0
Sapindus saponaria	0	0	4.12	0	0	0
Schoepfia chrysophylloides	0	0	0	0	8.67	0
Schinus terebinthifolius	0	0	4.12	0	0	0
Sideroxylon foetidissimum	0	0	4.12	6.40	0	0
Zanthoxylum fagara	0	4.74	0	4.04	0	0

Table 7: Importance value of trees in tree islands with permanent plots in Everglades National Park.

Species	Ficus Pond	Grossman hammock 1	Grossman hammock 2	Chekika Island	Mosquito hammock	Satinleaf hammock
Annona glabra	0	0	0	0	1.2	0
Ardisia escallonioides	0	1.51	0	0	0	0
Bumelia salicifolia	47.92	11.29	2.24	0	4.3	0
Bursera simaruba	20.45	38.03	39.63	0	5.41	49.55
Calyptranthes pallens	0	0	0.96	0	0	0
Celtis laevigata	0	0	0	13.32	0	3.16
Chrysobalanus icaco	5.48	0	0	0	0	5.05
Chrysophyllum oliviforme	0	0	2.06	0	0	12.42
Citrus sp.	0	0	0	0.9	0	0
Coccoloba diversifolia	1.72	43.01	32.84	0	0	1.37
Eugenia axillaris	1.52	1.59	0	528.55	0	26.96
Ficus aurea	0	0	2.55	0	2.43	1.44
Metopium toxiferum	17.54	0	0	0	21.94	0
Myrica cerifera	0	0	0	0	0.64	0
Myrsine floridana	0	3.04	1.16	3.19	0	0
Myrcianthes fragrans	0	0	0	0	20.75	0
Nectandra coriacea	2.03	0	7.34	0	0	0
Persea borbonia	3.28	0	0	0	0	0
Prunus myrtifolia	0	0	0	0	0.65	0
Quercus virginiana	0	0	0	0	35.24	0
Salix caroliniana	0	0	0	0	6.28	0
Schoepfia chrysophylloides	0	0	0	0	1.36	0
Schinus terbinthifolius	0	0	3.73	0	0	0
Sideroxylon foetidissimum	0	0	0	54.01	0	0
Simarouba glauca	0	0	3.39	0	0	0
Zanthoxylum fagara	0	1.51	4.05	0	0	0

The permanent plot network will become increasingly important in documenting change associated with natural and anthropogenic disturbance as well as hydrologic change. For example, a series of surveys illustrate the changes in canopy cover in Grossman's Hammock following the two hurricanes to affect the area during 2005. Canopy cover decreased from a pre-hurricane level of 89% (data of June 14), to 86% after Hurricane Katrina (data of September 6), to 56% following Hurricane Wilma (data of November 4). The data show that canopy reduction due to Hurricane Katrina was minimal in this stand, but Grossman's Hammock was significantly more illuminated following Hurricane Wilma. Local variation within the hammock area was evident; canopy cover was reduced significantly more in the 15 x 15 m plot (mean = 36% cover) than in the 20 x 20 m plot (mean = 67%). Observations of structural damage to individual trees due to the hurricanes were recorded in all 5 plots established in 2005, but have not yet been summarized.

Soil moisture – plant stress relationships in the high intensity plots.

Methods. The objectives of our studies of tree island function are to derive relationships that describe how soil moisture in the forest varies with marsh water level, and in turn, how soil moisture variation among sites and seasons is reflected in recruitment, growth, and stress responses among tree populations. In the following paragraphs, we describe the sampling network and protocols established in 2005 to monitor soil moisture, leaf temperature, and isotope variation in the three high intensity islands.

Soil moisture and other climatic monitoring. Each of the three high intensity sites has been instrumented for continuous monitoring of soil moisture, soil temperature, air temperature, relative humidity, and rainfall using a Campbell CR1000 continuous-memory datalogger. Systems were installed in all three sites by mid-October. A factory defect in one of the dataloggers delayed deployment slightly. Data are retrieved at each visit to the sites using a Pocket PC PDA or laptop. Soil moisture within each high intensity site is being measured at three locations where a pair of Campbell CS 616 frequency domain reflectometry sensors measures volumetric water content (volume of water per volume of soil) at 10 and 30 cm depth. The sensor locations were chosen to represent the gradient of soil elevations represented by the intensive site study plot. Because soil moisture measurements are energy intensive and soil moisture values change slowly, these sensors are only measured and recorded hourly. At each soil moisture location, a copper-constantan thermocouple measures soil temperature at 10 cm. These values will be used to correct for the very slight temperature response of the soil moisture sensors. We are currently using the generic Campbell signal to soil moisture algorithm, but our intent is to calibrate the soil moisture/signal relationship for each of the intensive sites soils in 2006. Along with the soil moisture and soil temperature, we are recording shielded air temperature and relative humidity using a Campbell CS500 sensor package at 1 min intervals within or near the edge of the main study plot. Data are stored as hourly averages. Rainfall is measured using a Texas Electronics tipping bucket rain gauge in the nearest open canopy site to the study plot: Grossman Hammock in the picnic area clearing, Satinleaf Hammock in the marsh, and Chekika Hammock in the human disturbed center clearing. Rainfall is recorded as hourly totals. The recording stations are powered by 7.2 Ah gel cell batteries charged with a 10 W solar panel mounted with the rain gauge. Charging has proven to be more than adequate for our power demands.

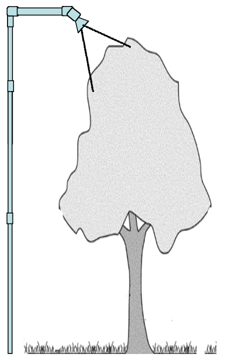

Figure 2. Installation for leaf temperature monitoring

Leaf temperature monitoring. We have installed infrared thermometers above the canopy at a single location within each of the intensive study sites to track leaf temperature of canopy leaves. The purpose of this monitoring is use leaf temperature as an indicator of stomatal closure in response to drought stress or flooding stress (Jones et al, in press). In either case, stomatal closure should lead to increases of canopy leaf temperature relative to air temperature. We are using Omega OS36 copper constantan infrared transmitters to image the canopy surface. Sensors are mounted on 2.5 cm diameter PVC poles between 7 and 9 m above the ground (Figure 2). Poles are stabilized by attachment to tree branches. The sensors, although weatherproof, are protected within a plastic funnel aimed at a 45° angle from the vertical. Fortunately, we did not install these sensors until after Hurricane Wilma. On the other hand, the sensors will not provide reliable data until sufficient canopy leaves reform to form a closed canopy surface in the sensor field of view.

Isotope studies. Isotope studies are designed to test two hypotheses: (1) Variation in plant water sources lead to differences in nutrient limitation among trees occupying different elevational niches within the tree island community, and (2) Trees at the highest elevations near the center of the islands will utilize more locally derived rain water compared to plants rooted closer to flooded areas at the edges of the islands, particularly during the wet season. The character of water used by trees in the lower areas will resemble Shark Slough surface water. To test these hypotheses, the carbon isotope characteristics (an integrative measure of water use efficiency) and nutrient (N & P) content of leaves, and the hydrogen and oxygen isotope characteristics of plant water, and available source waters (rainfall, soil water, ground water) will be monitored bimonthly over the course of two annual cycles. Interpretation will integrate these results with the record of soil moisture collected in the tree island, hydrology in the adjacent marsh, and precipitation collected at the site.

125 trees of 9 species were selected in Satinleaf, Chekika, and Grossman's Hammocks. Trees were tagged and their height and dbh measured. The elevation of the surface at each tree was determined by surveying from established benchmarks. Data collection will begin in January 2006.

Results.

*Soil moisture and other climatic monitoring.*_All three intensive sites were strongly impacted by Hurricane Wilma. At each site the solar panels and rain gauge were disrupted or damaged. Rainfall data after the storm were unreliable until we were able to visits the sites and re-level the sensors and re-install the solar panels. We were able to visit the sites soon enough that battery power was still adequate to maintain data collection and no data except the rainfall data were lost.

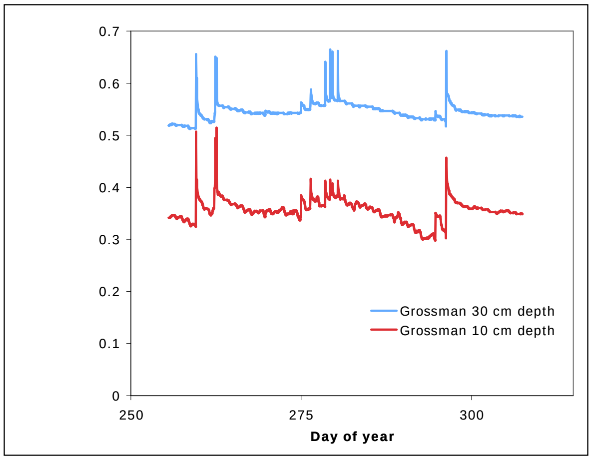

Figure 3. Trace of soil moisture at two depths from Grossman Hammock showing seasonal pattern (9/13/05- 11/5/05). Peaks indicate rainfall events. Peaks on far right are from Hurricane Wilma.

Soil moisture sensors clearly show strong differences between 10 and 30 cm depth (Figure 3). Sensitivities of the sensors are such that when viewed at fine resolution, as in Figure 4, short-term drawdowns of soil moisture are evidents, especially at the 10 cm depth).

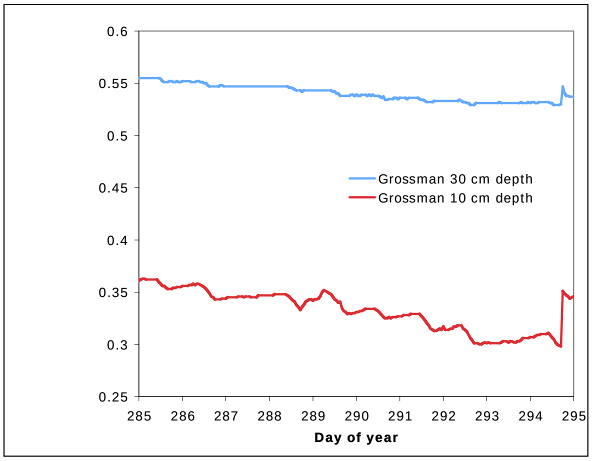

Figure 4. Trace of soil moisture at two depths from Grossman Hammock showing daily fluctuations and short term dry down in recorded soil moisture over a 10 day period (10/13/05- 10/23/05). Some of daily signal may be caused by temperature sensitivity of the sensors.

A statistical analysis of the three sites on two dates at a single time (10/16/05 and 11/3/05 at 6 AM) during the fall was conducted to test for effects of time, island, and depth. The analysis was conducted as a nested 3x2x2 factorial design with 3 replicates per treatment combination (n=3). Raw data for the analysis are presented in Table 8 and an ANOVA summary are in Table 9. The results show a very significant Island effect (p-value < 0.0001). The nested effect of depth within island was also significant, but neither the main effect Time nor any of the interaction effects were not. A Student-Newman-Keuls (SNK) test indicated that soil moisture at Chekika Hammock (mean = 0.290) was significantly lower than at Satinleaf Hammock (mean = 0.519) or Grossman Hammocks (mean = 0.480), which did not differ from one another. Soil moisture decreased with depth at all Grossman Hammock replicates, but the patterns with depth were inconclusive at Satinleaf and Chekika islands (Figure 5).

Table 8. Data for the soil moisture experiment.

	Island					
	Grossman		Satinleaf		Chekika	
	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6
Time 1	0.5470	0.3480	0.4880	0.5120	0.3330	0.2050
	0.4960	0.2770	0.5420	0.3970	0.2600	0.2160
	0.7450	0.5120	0.5580	0.6420	0.2450	0.3630
Time 2	0.5370	0.3520	0.5070	0.4820	0.3530	0.2190
	0.4890	0.2220	0.5320	0.3910	0.2820	0.2280
	0.7320	0.4980	0.5600	0.6160	0.2980	0.4720

Table 9 ANOVA table for the soil moisture experiment.

Source	**DF**	**SS**	**MS**	**F value**	**p-value**	**Sign.**
Island	2	0.361243	0.180622	16.76	<0.0001	**
Time	1	0.000196	0.000196	0.02	0.8939	
Island x Time	2	0.005181	0.002591	0.24	0.7882	
Depth (Island)	3	0.151150	0.050383	4.67	0.0104	*
Time x Depth (Island)	3	0.000680	0.000227	0.02	0.9958	
Error	24	0.258660	0.010778			
Total	35	0.777110				

*Significant, ** very significant p-value at $\alpha = 0.05$ level.

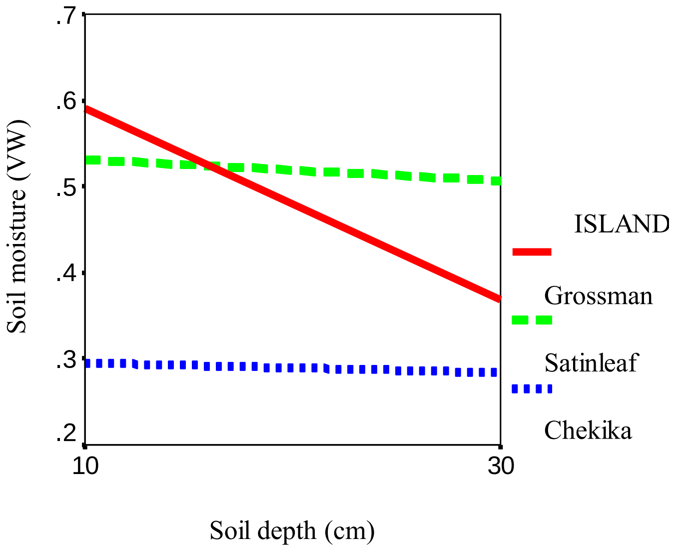

Figure 5. Plot of soil moisture and soil depth in each island.

Clearly, the statistical analyses described above are exploratory in nature at this early stage of the project. We expect that other and possibly clearer patterns may emerge as data accumulate over several annual cycles, in conjunction with parallel data on rainfall, temperature, and marsh water levels.

Literature Cited

Armentano, T.V., D.T. Jones, M.S. Ross, and B.W. Gamble. 2002. Vegetation pattern and process in tree islands of the southern Everglades and adjacent areas. p. 225-282.

Fraser, G,W., C.D. Canham, & K.P. Lertzman. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-color fisheye photographs, Users manual and program documentation. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York; 36 pp

Gunderson, L.H., J.R. Stenberg, & A.K. Herndon. 1988. Tolerance of five hardwood species to flooding regimes. p. 119-132. *In* D.A. Wilcox (ed.) Interdisciplinary Approaches to Freshwater Wetlands Research. Michigan State University Press, East Lansing, MI, USA.

Heisler, L., D. T. Towle, L.A. Brandt & R.T. Pace. 2002. Tree island vegetation and water management in the Central Everglades. p. 283-310. *In* F.H. Sklar and A. van der Valk (eds.) Tree Islands of the Everglades. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Jones, D.T., J.P. Sah, M.S. Ross, S.F. Oberbauer, B. Hwang, and K. Jayachandran. In press. Growth and physiological responses of twelve tree species common in Everglades tree islands to simulated hydrologic regimes. Wetlands.

Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44: 322-331.

Ross, M.S., D.T. Jones, G.L. Chmura, H.C. Cooley, B. Hwang, K. Jayachandran, S.F. Oberbauer, D.L. Reed, P.L. Ruiz, J.P. Sah, S. Sah, D. Stockman, P.A. Stone & J. Walters. 2004. Tree islands in the Shark Slough landscape: interactions of vegetation, hydrology and soils. Final Report to Everglades National Park, EVER 00075. Available at http://www.fiu.edu/~serp1/projects/treeislands/finalreport

Ross, M.S., S. Mitchell-Bruker, J.P. Sah, S. Stothoff, P.L. Ruiz, D.L. Reed, K Jayachandran and C.L. Coultas. In review. Interaction of hydrology and nutrient limitation in the Ridge and Slough landscape of the southern Everglades. Hydrobiologia.

Sklar, F.H., C. Coronado, G. Crozier, M. Darwish, B. Garrett, D. Gawlik, A. Huffman, M. Korvela, J. Leeds, C. J. Madden, C. McVoy, I. Mendelssohn, S. Miao, S. Newman, R. Penton, D. Rudnick, K. Rutchey, S. Senarath, K. Tarboton and Y. Wu. 2004. 2004 Everglades Consolidated Report, Chapter 6: Ecological effects of hydrology. South Florida Water Management District, West Palm Beach, FL, USA.

Struhar, ME. 2004. Relationship between soil moisture and nutrient availability in tree islands of Shark Slough, Everglades National Park. Master's thesis, Florida International University. 115 pp.

Van Wagner, CE. The line intersect method in forest fuel sampling. Forest Science 14:20-26.

Wetzel, PR, AG van der Valk, S Newman, DE Gawlik, TT Gann, CA Coronado-Molina, DL Childers & FH Sklar. 2005. Maintaining tree islands in the Florida Everglades: nutrient redistribution is the key. Frontiers in Ecology & Environment 3 (7): 370-376.