Landscape Pattern- Ridge, Slough, and Tree Island Mosaics

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Cycle-2: Year-4 Report
(2015-2019)

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General Background

The Water Resources Development Act (WRDA) of 2000 authorized the Comprehensive Everglades Restoration Plan (CERP) as a framework for modifications and operational changes to the Central and Southern Florida Project needed to restore the South Florida ecosystems. Provisions within WRDA 2000 provide for specific authorization for an adaptive assessment and monitoring program. A CERP Monitoring and Assessment Plan (MAP; RECOVER 2004, 2006, 2009) has been developed as the primary tool to assess the system-wide performance of the CERP by the Restoration Coordination and Verification (RECOVER) program. The MAP presents the monitoring and supporting research needed to measure the responses of the South Florida ecosystem to CERP implementation. In addition, the MAP also presents system-wide performance measures representative of the natural and human systems found in South Florida that will be evaluated to help determine CERP success.

The general goals of restoration are to stem, and possibly reverse the degradation of the ridge-slough-tree island landscape by redirecting flows to coastal waters across the surface of this landscape (USACE and SFWMD 1999). The CERP MAP, Parts 1 and 2, presented the overarching monitoring framework for guiding restoration efforts throughout the entire process (RECOVER 2004, 2006). This requires not only a comprehensive assessment of the current state of the ecosystem and assessment of restoration endpoints (targets), but also ongoing monitoring and evaluation throughout the process that will aid the implementing agencies in optimizing operational procedures and project designs. The work described below represents the system-wide landscape monitoring project, entitled "*Landscape Pattern - Ridge, Slough, and Tree Island Mosaics*", initiated in 2009 with funding from US Army Corps of Engineers (USACE). Until 2012, the study was led by Dr. James Heffernan (PI), and then by Dr. Michael Ross for next three years (2012-2015). Since the Fall of 2015 (Cooperative Agreement # W912HZ-15-2-0027), the study has been led by Dr. Jay Sah (PI), while Dr. Michael Ross is also actively involved as the Co-PI, and Dr. James Heffernan (Duke University) is a collaborator in the study.

This monitoring effort supports the Greater Everglades Wetlands module of the MAP, and it is directly linked to the monitoring or research component identified in that module as number 3.1.3.6. The monitoring work is designed to address the needs identified in the Greater Everglades wetlands performance measures: (1) GE 15: Wetland Landscape Patterns – Ridge-Slough

Community Sustainability, and 2) Total System Performance Measures - Slough Vegetation (RECOVER 2011). This study specifically addresses the Greater Everglades Wetland Landscape and Plant Community Dynamics hypotheses: (1) ridge and slough microtopography in relation to organic soil accretion and loss; (2) ridge and slough landscape pattern in relation to microtopography; and (3) plant community dynamics in ridge-slough peatlands along elevation gradients as water depths and hydroperiods change (RECOVER 2006). The working hypothesis is, '*Spatial patterning and topographic relief of ridges and sloughs are directly related to the volume, timing and distribution of sheet flow and related water depth patterns*, identified in the hypothesis cluster, "Landscape Patterns of Ridge and Slough Peatlands and Adjacent Marl Prairies in Relation to Sheet Flow, Water Depth Patterns and Eutrophication" (RECOVER 2009).

The primary objective of this monitoring project is to assess the condition of landscapes within the Greater Everglades Wetlands ecosystem. This effort focuses on the condition of wetlands within the historic distribution of the ridge and slough (R&S) landscape, and provides baseline data needed to detect changes/trends in the patterns in microtopography and vegetation communities in response to water management operations, restoration initiatives and episodic events such as droughts, fire and hurricanes. The secondary objective is to integrate knowledge regarding landscape patterning, soil dynamics and community structure and composition with hydrologic data provided by Everglades Depth Estimation Network (EDEN) and other sources.

The specific objectives of the study are:

- To determine extant reference conditions for each of the performance measures described above (including variability of those measures in time and space).
- To establish present status of landscape performance measures throughout the central Everglades, particularly in areas of historic ridge-slough landscape patterning, identify spatial and temporal trends of those performance measures, and quantify their relationships to the present hydrologic regime.
- To detect unanticipated changes in ecosystem structure and processes that result from hydrologic management or manipulation, CERP restoration activities, or climatic variation.

- To provide data in support of scientific studies of inter-relationships among vegetation, microtopography, and hydrologic regime that may provide insight into the causes of unanticipated ecosystem responses.

The work provides indices of system-wide applicability related to the response of the ridge-slough landscape features to the restoration of historic hydrologic conditions, with the goal of informing the adaptive management of Everglades restoration as outlined in the CERP Monitoring and Assessment Plan.

This study takes advantage of the Generalized Random-Tessellation Stratified sampling network (GRTS), an established framework for representative sampling of the entire Everglades landscape (Philippi 2007). The sampling framework divides the Everglades landscape into a grid of 2x5 km landscape blocks (primary sample units; PSUs) of which the 5 km edge is aligned parallel to the historic water flow. Initially, a spatially stratified random sample of 80 PSUs were selected for sampling over a 5-year period (n=16 per year) (Philippi 2007; Heffernan et al. 2009). Those 80 PSUs were drawn to achieve a spatially balanced sample of the modern Everglades compartments (Everglades National Park (ENP), Water Conservation Area 3A North (WCA3AN), Water Conservation Area 3A South (WCA3AS), Water Conservation Area 3B (WCA3B), Water Conservation Area 2 (WCA2), and Water Conservation Area 1 (WCA1)/the Loxahatchee National Wildlife Refuge (LNWR). However, owing to budget constraints since FY 2012 (Cycle-1, Year 3), the number of PSUs and the number of sites within each PSU sampled in successive years were adjusted. Some PSUs that either were not within the historic R&S landscape or were dominated by woody components were later dropped. During Years 3 and 4, monitoring efforts were also shifted to include additional PSUs or modified primary sample units (M-PSUs) outside the original sampling scheme, with the purpose of documenting pre-restoration reference conditions within wetlands influenced by the construction/implementation of the DECOMP Physical Model and two Tamiami Bridges. Over six years (2009-2015), including a pilot project year (2009), 67 PSUs were sampled. Among them, five PSUs were within the marl prairie landscape, and the rest were within ridge and slough landscape. These PSU's represent the full range of contemporary hydrologic regimes, and their vegetative and microtopographic structure range from well-conserved to severely degraded ridge and slough landscape (Ross et al. 2016).

During the Cycle-1 (2009-2015) of the project, monitoring efforts consisted of two core components: (1) mapping vegetation features from aerial photographs, and (2) ground surveys of water depth and plant community structure (in both tree islands and surrounding marsh). The data obtained during ground surveys were used to quantify aspects of the hydrologic regime and distribution and spatial structure of peat elevations, determine relationships between vegetation structure and water depth, and ground-truth broader-scale maps based on remote sensing and aerial surveys. While, these activities were linked both logistically and analytically (Heffernan et al. 2009; Ross et al. 2013), ground sampling of tree island community was discontinued after the pilot phase (2009) and the first year (2010/2011) of the study, and the vegetation mapping was discontinued after the third year (2012/2013) of the study (Ross et al. 2015a,b, 2016).

With the initiation of the 2nd 5-year cycle (Cycle-2) of monitoring in 2015, the study plan focuses on resampling the plots within the previously sampled 62 PSUs. Five previously sampled PSUs within marl prairie landscape were not included in Cycle-2 sampling schedule. Since researchers have reported that prairie and marsh vegetation may change within 3-5 years in response to hydrologic changes (Armentano et al. 2006; Zweig and Kitchens 2008; Sah et al. 2014), re-sampling the plots 5 years after initial sampling provides an opportunity to assess changes in landscape pattern and plant composition over time. This document summarizes results for the Year-1, 2, 3 and 4 (2015-2019) of this five-year cycle (Cycle-2) of the project (2015-2020). The report primarily focuses on the changes in metrics of topographic (distribution of soil elevation variance) and community characteristics (community distinctness and the strength of elevation-vegetation associations) between two surveys, Cycle-1 and Cycle-2.

1. Introduction

The Florida Everglades is a large subtropical wetland with diverse hydrologic, edaphic, and vegetative characteristics. Of the eight major historic landscapes that comprised the greater Everglades, the ridge and slough (R&S) landscape - a mosaic of sloughs, sawgrass ridges and tree islands - encompassed slightly over 50% of the total extent (McVoy et al. 2011). Within this landscape, biotic communities occupied distinct elevational niches that were organized in a characteristic elongated pattern parallel to water flow (Figure 1). Ridges, comprised almost entirely of dense stands of sawgrass, were present in areas of higher topographic relief with shallow water depths, whereas sloughs containing white water lily (*Nymphaea odorata*) and other macrophytes, were at lower elevation with relatively deep water (Loveless 1959, Ogden 2005, McVoy et al. 2011). A transitional community, the wet prairie, was comprised of *Eleocharis cellulosa (*spikerush), *Panicum hemitomon* (maidencane), and *Rhynchospora tracyi* (beakrush), and was usually present at the boundary of ridges and sloughs, in areas of intermediate water depths (Loveless 1959, Ogden 2005).

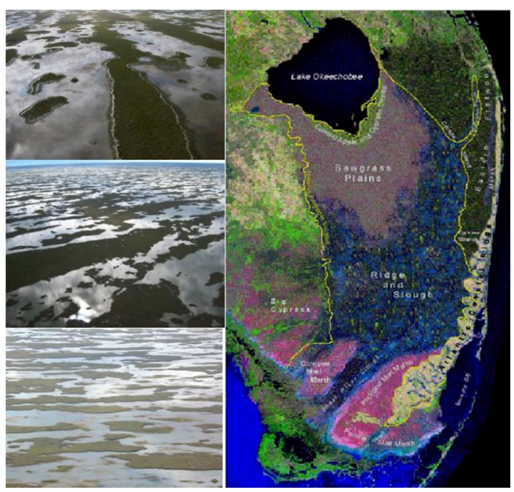

Figure 1: Aerial images and historic distribution of the ridge-slough landscape (Ross et al. 2013, 2016). (Left) Linear, flow-parallel orientation of ridges and sloughs (R&S) under conserved conditions. (Right) Distribution of R&S and other landscape types prior to major hydrologic alteration.

As in all wetlands, the hydrologic regime is a critical factor influencing the distribution and composition of vegetation in the greater Everglades (Gunderson 1994, Ross et al. 2003, Armentano et al. 2006, Zweig and Kitchens 2008, Todd et al. 2010). Local variation in hydrologic conditions resulting from microtopographic differentiation is essential for the maintenance of the distinct vegetation community boundaries that were a feature of the pre-drainage R&S landscape (Loveless

1959, Ogden 2005, McVoy et al. 2011). This landscape, however, has undergone dramatic structural, compositional and functional changes since human modification of the hydrologic regime began in the early 20th century (Davis and Ogden 1994, Ross et al. 2003, Ogden 2005, Bernhardt and Willard 2009, Larsen et al. 2011, McVoy et al. 2011, Nungesser 2011, Harvey et al. 2017). Where hydroperiods have been reduced, ridges have invaded marsh areas (Ogden 2005), and much of the slough component of the landscape has been usurped by both wet prairie and ridge (Davis and Ogden 1994, Olmsted and Armentano 1997, Richards et al. 2011). Woody vegetation might have been uncommon in the ridge community prior to hydrologic modification (Loveless 1959, McVoy et al. 2011), but wax myrtle (*Morella cerifera*) and coastal plain willow (*Salix caroliniana*) now frequently inhabit ridges in drained areas (McVoy et al. 2011).

Hydrologic modification, coupled with flow of phosphorus-enriched water into the system, also had consequences for the landscape-scale structure of the R&S mosaic (Figure 2). Areas of reduced flow have lost the elongated R&S topography, while areas with excessively extended flooding have experienced a decline in the prevalence of ridges and tree islands (Sklar et al. 2004, Ogden 2005). Remaining ridges have lost rigidity, structure, and directionality (or anisotropy; Wu et al. 2006, Watts et al. 2010; Ross et al. 2016), and elevation differences between ridges and sloughs have become less distinct (Figure 3; Watts et al. 2010, Hefferenan et al. 2009; Nungesser 2011; Ross et al. 2016). Moreover, nutrient enriched areas have become dominated by stands of *Typha* with little topographic relief (Urban et al. 1993; Newman et al. 1998).

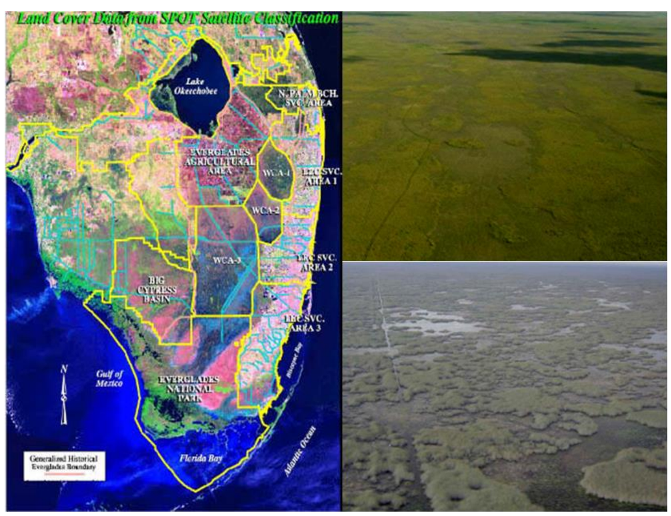

Figure 2: Present configuration of the greater Everglades, and associated changes in ridge-slough structure (Ross et al. 2013, 2016). (Left) The contemporary Everglades, subdivided into distinct management basins subject to varied uses and management objectives. (Right top) Degraded R&S landscape in the area where hydrologic modification has reduced water levels and hydroperiod. (Right bottom) Degraded R&S landscape in the area where impoundment has raised water levels and lengthened hydroperiods.

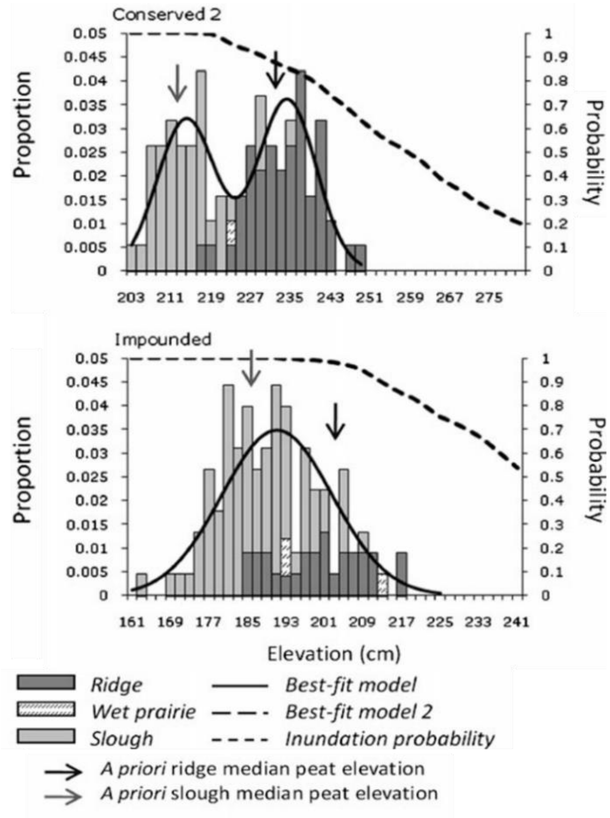

Figure 3: Examples of conserved (top) and degraded (bottom) microtopographic structure. Conserved landscapes are characterized by high topographic heterogeneity and bi-modal elevation distributions. Degraded landscapes have lost these characteristics (Source: Watts et al. 2010). Shadings indicate vegetation communities, and arrows indicate their median elevation. Solid line indicates best-fit model of density vs. elevation. Dashed line indicates probability of inundation over preceding 10 years at each elevation.

The characteristic R&S mosaic has been theorized to be a self-organized landscape maintained by autogenic processes that balance ridge expansion and slough persistence (Larsen et al. 2007, Givnish et al. 2008, Larsen and Harvey 2010, Watts et al. 2010, Cohen et al. 2011, Heffernan et al. 2013, Acharya et al. 2015). Decoupling of soil elevations from underlying bedrock topography in areas of relatively conserved landscape pattern suggests that historic microtopography and R&S landscape structure have arisen largely from internal feedbacks between vegetation, hydrology, and soil development. Whether local geologic features have acted as nucleation sites for ridge initiation remains unresolved. In either case, plant production provides raw material for the development of peat and may increase as soil elevation allows for high productivity of recalcitrant organic matter by sawgrass (Figure 4). Peat depth is maintained by deposition of root biomass, while peat is lost through aerobic respiration (Craft et al. 1995, Borkhataria et al. 2011). Ridges accumulate biomass faster than sloughs, but shallower water depths promote more rapid decomposition that roughly balances higher gross peat production (Larsen and Harvey 2010, Cohen et al. 2011). The production-respiration equilibrium is regulated within both community types at nearly equal rates over long time periods, keeping ridges and sloughs from forming mountains and valleys. Vegetation shifts in microtopographic range when the hydrologic regime changes may help maintain plant zonation, and thus potentially feedback on microtopographic structure (SCT 2003, Larsen and Harvey 2010, Cohen et al. 2011, D'Odorico et al. 2011). Zweig et al. (2018) suggest that once R&S pattern is established, decomposition is more important than production in maintaining the patterned microtopography and associated vegetation types in Everglades R&S landscape.

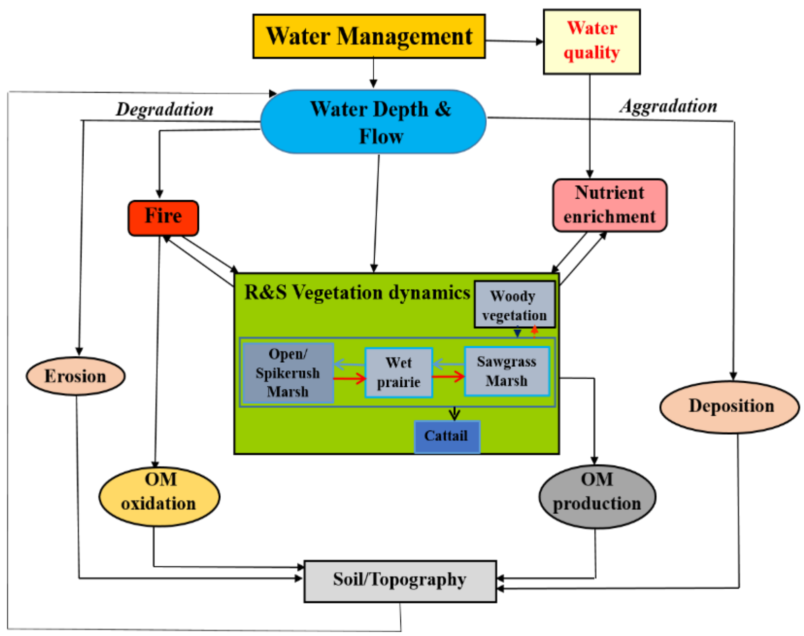

Figure 4: Conceptual model showing the relationships among causal factors such as soil microtopography, water regimes and disturbances (fire and nutrient enrichment) and vegetation dynamics within R&S landscape (Modified from Ross et al. (2006)).

The flow-parallel pattern of ridge and sloughs in the Everglades is believed to be the result of spatial feedbacks that act anisotropically (i.e., differently with direction) (Watts et al. 2010), and water flow is an important component of those feedbacks (Heffernan et al. 2013, Achraya et al. 2015, Harvey et al. 2017). However, the specific mechanisms that create flow-parallel ridges remain unresolved, as multiple plausible mechanisms have been suggested, including sediment entrainment and deposition (Larsen et al. 2007, Larsen and Harvey 2010), transpiration-driven nutrient concentration (Ross et al. 2006, Cheng et al. 2011), and hydrologic competence (Givnish et al. 2008, Watts et al. 2010, Cohen et al. 2011, Heffernan et al. 2013, Achraya et al. 2015, Harvey et al. 2017). While the relative importance of and interactions between these mechanisms remains an active area of research, study of pattern loss in response to hydrologic management, nutrient enrichment, and other disturbances suggests that the disruption of those feedbacks is a primary cause of R&S landscape degradation (Sklar et al. 2004).

The combination of microtopography, hydrology, vegetation composition and productivity, and their responses to hydrologic modification and other disturbances (fire and nutrient enrichment) create challenges in disentangling causal relationships and diagnosing trajectories of change. Therefore, one objective of this ongoing monitoring study has been to assess whether microtopographic structure, vegetation community composition, or relationships between these variables serve as leading indicators of pending change in other landscape characteristics. While it is known that altered microtopography affects vegetation structure after hydrologic modification (Ross et al. 2003, Givnish et al. 2008, Zweig and Kitchens 2008, 2009), vegetation changes may also influence microtopography (Cohen et al. 2011, Larsen et al. 2011, Casey et al. 2015, 2016). It has been hypothesized that topographic changes are more rapid than those of vegetation structure, primarily because drainage and stabilization of the Everglades hydrologic regime leads to more rapid peat loss through aerobic bacterial respiration in higher elevation ridges compared to sloughs, flattening landscape scale topography (Watts et al. 2010). Simultaneously, but over much longer timeframes, drained and stabilized hydrologic regimes facilitate ridge expansion into the more drained sloughs, resulting in vegetation structure homogeneity (Larsen and Harvey 2010).

A system-wide, simultaneous assessment of microtopographic structure and vegetation community composition over six years (2009-2015) suggests that while substantial portions of the R&S landscape are severely degraded (Heffernan et al. 2009, Ross et al. 2016), ground elevation changes often precede vegetation change during critical transitions from patterned to degraded landscape states in the drained landscapes (Figure 5, Scenario 1). In contrast, vegetation change (reduction in vegetation distinctness) may serve as a leading indicator of landscape degradation in impounded conditions (Figure 5, Scenario 3; Ross et al. 2016). This degradation process is expected to slow down or even reverse as the result of restoration activities associated with Comprehensive Everglades Restoration Plan (CERP) that are in place. Nonetheless, the relative timescales of changing vegetation and topographic structure in R&S are not well understood yet.

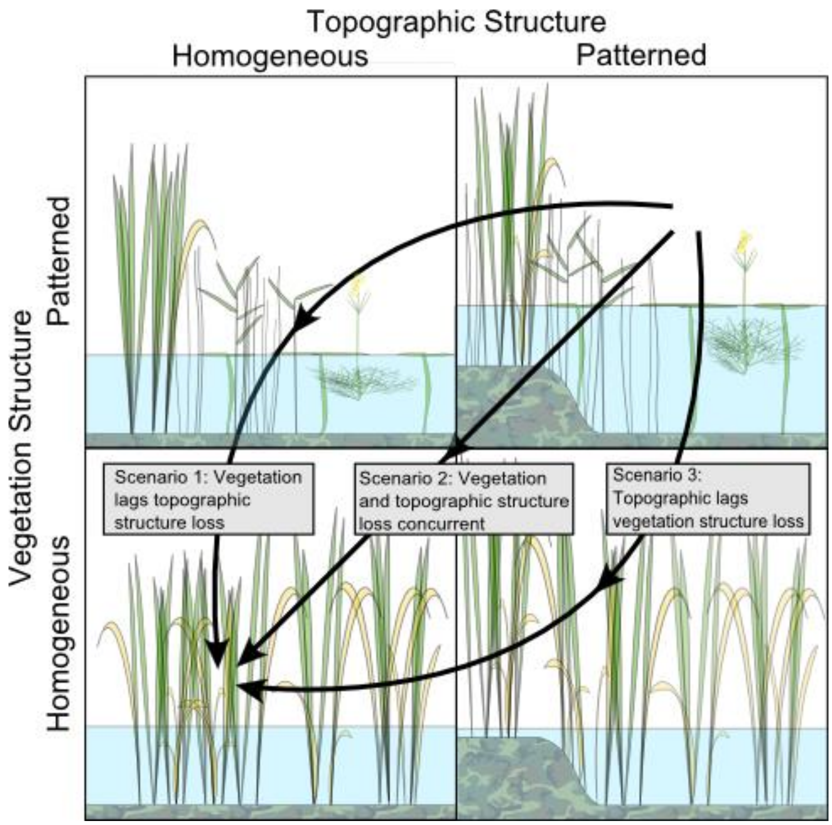

Figure 5: Possible pathways of microtopographic and vegetative degradation in the ridge-slough landscape. In one scenario (uppermost arrow), topographic structure is reduced after modification of the hydrologic regime, followed by a lagged response from the vegetation structure. Alternatively, (lowermost arrow) vegetation patterning may degrade initially in response to modification of the hydrologic regime, followed by a lagged response of topographic patterning. Finally, (middle arrow) microtopographic flattening and vegetation homogenization may occur simultaneously, but both lag behind modification of the hydrologic regime (Source: Isherwood 2013).

In general, vegetation change in the Everglades occurs at different time scales. For instance, in the marl prairie of Taylor Slough, changes in the hydrologic regime over periods as brief as three to four years resulted in concurrent changes in vegetation composition (Armentano et al. 2006, Sah et al. 2014). In the R&S landscape within WCA3A, Zweig and Kitchens (2008, 2009) found that vegetation communities are influenced by both current and historic (up to four years) hydrologic conditions, though vegetation responses to hydrologic modification varied among species. Thus, the current system-wide monitoring of topographic structure and vegetation composition carried out at five-year intervals is expected to capture changes in the composition and spatial patterns of vegetation communities, and to some extent in microtopography, that occur as a result of water management operations, restoration initiatives, and episodic events such as droughts and fire within the Everglades R&S landscape.

2. Methods

2.1 Study Area

The study area includes the historical R&S landscape that currently exists in the Everglades. This study uses Generalized Random-Tessellation Stratified (GRTS) sampling network, an established framework for system-wide representative sampling within the Everglades (Philippi 2007). The primary study design divides the Everglades landscape into a grid of 2x5 km landscape blocks (primary sample units, PSUs), of which the 5 km edge is aligned parallel to the historic water flow. Initially, a spatially stratified random sample of 80 PSUs were selected for sampling over a 5-year period (n=16 per year) (Philippi 2007, Heffernan et al. 2009) (Figure 6a). However, owing to budget constraints since FY 2012 (Cycle-1, Year-3), the number of PSUs and the number of sites within each PSUs sampled in successive years were adjusted. Some PSUs that either were not within the historic R&S landscape or were dominated by woody components were dropped, whereas the areas, in form of modified PSUs (M-PSUs), within the footprint of the DECOMP Physical Model (DPM), and two Tamiami Bridges (completed or under construction) were added. Over six years, (2009-2015), including a pilot phase of the study (2009), 67 PSUs, were sampled (Figure 6b). Though, at the end the study, the detailed data analyses focused on only 62 PSUs that were within the historic distribution of the R&S landscape (Ross et al. 2016).

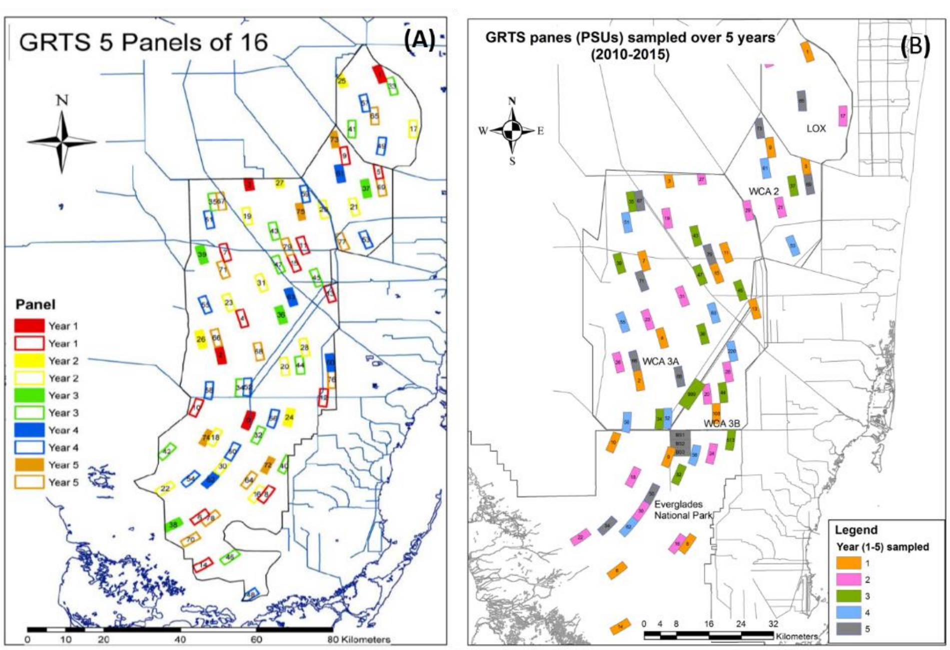

Figure 6: Map of PSUs for landscape sampling. (A) All 80 PSUs that were originally scheduled for sampling over five years (from Philippi 2007). (B) Sixty-seven, PSUs, including the modified ones within the footprint of DPM and downstream of the Tamiami bridges (completed or under construction) sampled over six years (2009-2015) (Modified from Ross et al. 2016). Colors indicate years for sampling of individual PSUs.

In the first four years (2015-2019) of the current 5-year monitoring cycle (Cycle-2), we sampled 47 PSUs: 11 in each of two years, Year-1 (2015/2016) and Year-2 (2016/2017), 12 in Year-3 (2017/2018) and 13 in Year-4 (2018/2019) (Figure 7). Those PSUs were from ENP (11), WCA3AN (12), WCA3AS (11), WCA3B (6), WCA2 (5), and the WCA1/LNWR (2) (Table 1). The PSUs within WCA3A that are north of the Alligator Alley (I-75) and immediate south of the Alley were considered as WCA3AN PSUs. Ten PSUs that were sampled in first two years of the first cycle (2009-2015) of the monitoring work were not sampled this time. Those were either within the marl prairie landscape in the ENP (5) or in recently burned area in WCA3AN (3). Likewise, previously sampled two PSUs, one each in WCA1 and WCA2, were also not re-sampled. In contrast, one PSU in WCA3AN was not sampled in Cycle-1 because it had burned prior to sampling began. That PSU was first time sampled in Year-4 of the current cycle. Two PSUs in ENP were sampled in Year-5 of Cycle-1, but were re-sampled in Year-4 of this cycle.

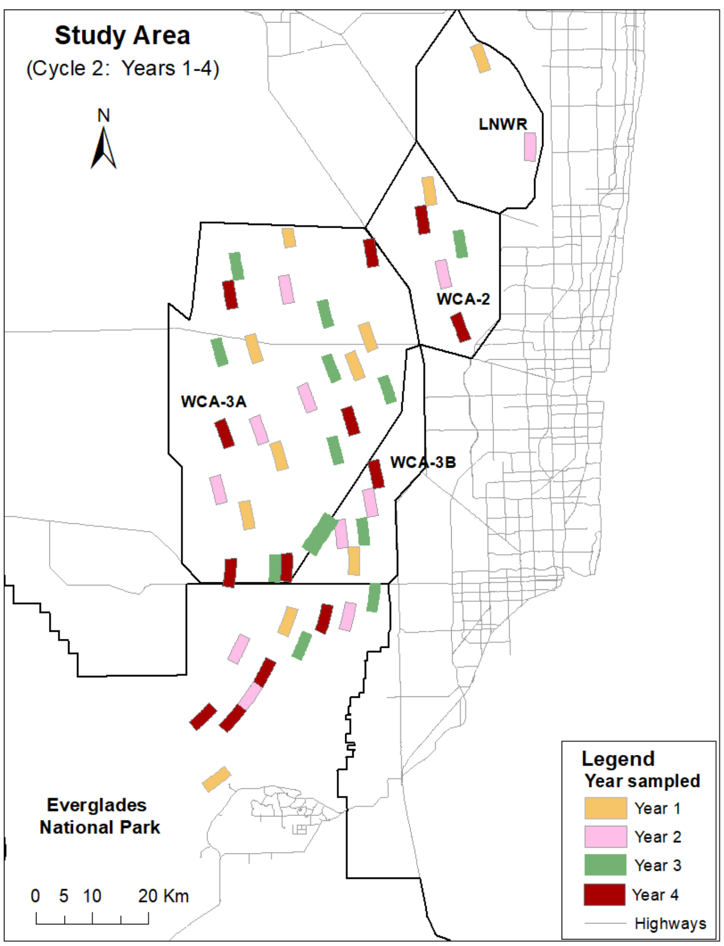

Figure 7: Map showing the PSUs sampled in Year 1-4 (2015-2019) of the current five-year cycle (2015-2020).

Table 1: Characteristics of PSUs sampled in Year 1, 2, 3 and 4 (2015-2019) of the current 5-year project cycle (2015-2020).

PSU	Cycle	Cycle-2 Year	Cycle-1 Sampling Year (WYr)	Cycle-2 Sampling Year (WYr)	Cycle-2 Sampling date	Region*	Historical R&S	X_UTMNAD83	Y_UTMNAD83	Cylce-2 No. of plots
0	2	1	2012	2016	12/11, 12/14/2015; 03/11/2016	ENP	Y	532345.5	2842696.3	135
1	2	1	2010	2016	03/02, 03/04, 03/07/2016	WCA1	Y	566677.9	2942982.1	113
2	2	1	2010	2016	09/28, 09/30/2015	WCA3AS	Y	525056.6	2861614.1	129
3	2	1	2010	2016	02/23, 02/25/2016	WCA3AN	Y	532505.3	2910966.9	71
4	2	1	2010	2016	10/12, 11/02, 11/13/2015	WCA3AS	Y	530756.4	2872127.6	121
6	2	1	2010	2016	11/23, 11/25/2015	ENP	Y	519649.4	2814585.3	129
7	2	1	2010	2016	01/13, 01/25/2016	WCA3AN	Y	526262.4	2891226.1	135
9	2	1	2010	2016	02/08, 02/10/2016	WCA2	Y	557549.6	2919280.2	120
11	2	1	2011	2016	01/08, 01/11/2016	WCA3AN	Y	546603.3	2893273.0	135
15	2	1	2011	2016	02/02, 02/03/2016	WCA3AN	Y	544263.6	2888174.1	135
108	2	1	2011	2016	10/02, 10/07/2015	WCA3B	Y	544130.1	2853456.0	117
17	2	2	2010	2017	11/07, 11/14/2016	WCA1	Y	575467.5	2927079.8	120
18	2	2	2011	2017	1/11/2017	ENP	Y	523582.5	2837739.8	42
19	2	2	2011	2018	07/26, 08/02/2017	WCA3AN	Y	532020.9	2901747.8	88
20	2	2	2011	2017	01/20, 01/23/2017	WCA3B	Y	541840.2	2858248.3	135
21	2	2	2010	2018	08/04, 08/07/2017	WCA2	Y	560020.3	2904486.4	135
23	2	2	2012	2017	02/08, 02/10/2017	WCA3AS	Y	527209.6	2876687.7	132
24	2	2	2012	2017	12/19, 12/29/2016	ENP	Y	543033.6	2843539.1	130
26	2	2	2011	2017	01/30, 02/01/2017	WCA3AS	Y	519957.4	2866106.0	129
28	2	2	2011	2017	01/25, 01/27/2017	WCA3B	Y	547035.4	2863766.4	135
30	2	2	2012	2017	01/13, 01/18/2017	ENP	Y	525597.5	2882440.9	135
31	2	2	2012	2017	02/13, 02/15/2017	WCA3AS	Y	535763.3	2882440.9	135
32	2	3	2013	2018	01/29, 01/31/2018	ENP	Y	534894.8	2838347.8	134
34	2	3	2013	2018	11/22, 12/01/2017	WCA3AS	Y	530097.7	2852094.7	135
35	2	3	2013	2018	10/13/2017	WCA3AN	Y	523207.3	2905898.8	30
36	2	3	2013	2018	01/24, 01/26/2018	WCA3AS	Y	540859.6	2873130.6	126
37	2	3	2013	2018	10/09, 10/11/2017	WCA2	Y	563108.3	2909792.2	111

PSU	Cycle	Cycle-2 Year	Cycle-1 Sampling Year (WYr)	Cycle-2 Sampling Year (WYr)	Cycle-2 Sampling date	Region*	Historical R&S	X_UTMNAD83	Y_UTMNAD83	Cylce-2 No. of plots
39	2	3	2013	2018	10/16, 10/25, 10/27/2017	WCA3AN	Y	520196.3	2890623.0	135
43	2	3	2013	2018	09/25, 09/27/2017	WCA3AN	Y	539077.4	2897449.3	129
44	2	3	2013	2018	01/19, 01/22/2018	WCA3B	Y	545823.9	2858632.9	132
45	2	3	2013	2018	02/07, 02/09/2018	WCA3AN	N	550107.7	2883908.2	102
47	2	3	2013	2018, 2019	02/12, 02/14, 08/27/2018	WCA3AN	Y	540134.9	2887740.3	120
513	2	3	2013	2018	02/02, 02/05/2018	ENP	Y	547619.4	2846243.2	108
DPM	2	3	2013	2018, 2019	03/16, 03/19, 08/22, 08/24/2018	WCA3B	Y	538203.0	2858189.1	215
50	2	4	2015	2019	01/25, 01/28/2019	ENP	Y	528202.2	2833604.6	135
51	2	4	2014	2019	09/24, 09/26/2018	WCA3AN	Y	522037.9	2900773.4	135
52	2	4	2014	2019	02/08, 02/11/2019	WCA3AS	Y	532107.6	2852288.6	117
53	2	4	2014	2019	09/14, 09/17/2018	WCA2	Y	563079.2	2894981.9	126
54	2	4	2015	2019	01/09, 01/14/2019	ENP	Y	517243.7	2825691.9	111
55	2	4	2014	2019	10/03, 10/05/2019	WC3AC	Y	521064.6	2876059.2	129
56	2	4	2014	2019	11/21/2018; 01/11/2019	ENP	Y	538819.5	2843183.1	135
58	2	4	2014	2019	02/15, 02/18/2019	WCA3AS	Y	522023.7	2851319.8	117
59	2	4	-	2019	09/10, 09/12/2018	WCA3AN	Y	547146.9	2908234.8	135
61	2	4	2014	2019	09/05, 09/07/2018	WCA2	Y	556317.0	2914142.6	129
62	2	4	2014	2019	01/16, 01/23/2019	ENP	Y	522506.2	2825415.4	135
63	2	4	2014	2019	10/26, 11/02/2018	WCA3AC	Y	543511.7	2878334.2	135
220	2	4	2014	2019	11/30/2018; 01/18/2019	WCA3B	Y	548070.8	2868866.4	126

* ENP = Everglades National Park, WCA1 = Loxahatchee National Wildlife Refuge (Water Conservation Area 1), WCA 2 = Water Conservation Area 2, WCA3AN,S = Water Conservation Area 3A North and South, WCA3B = Water Conservation Area 3B

The approach for field sampling adopted during this study was the same as described in Ross et al. (2016). In the beginning of the first cycle of the study (2009-2015), the 2x5 km area in each PSU was subdivided in 80 equal area zones (250 m x 500 m) and a sampling cluster was located at a random location in those grid cells (Figure 8). At each cluster, samples were then collected using 1m^2 quadrat, placed at the center and at two randomly selected distances between 3 and 35 m in two cardinal directions, east and north. Thus, there were 240 sample quadrats in each PSU. However, after 2012 (i.e. after two years of study during the first cycle), the number of clusters for sampling was reduced to 45 clusters, resulting in maximum of 135 quadrats in each PSU, and they were located at a random location in 40 500 m x 500 m grid cells. Therefore, in Year-1 and 2 PSUs during the current cycle, we did not revisit all the 80 clusters that were previously sampled. Instead, we sampled the sites at the maximum of 45 clusters (i.e. 135 quadrats) in each PSU, resulting the number of sampling quadrats during this study less than the number of quadrats in those (Year-1 and 2) PSUs in Cycle-1 of the study. In Year-3 and 4 PSUs, however, the number of sampling quadrats were more or less the same as in Cycle-1.

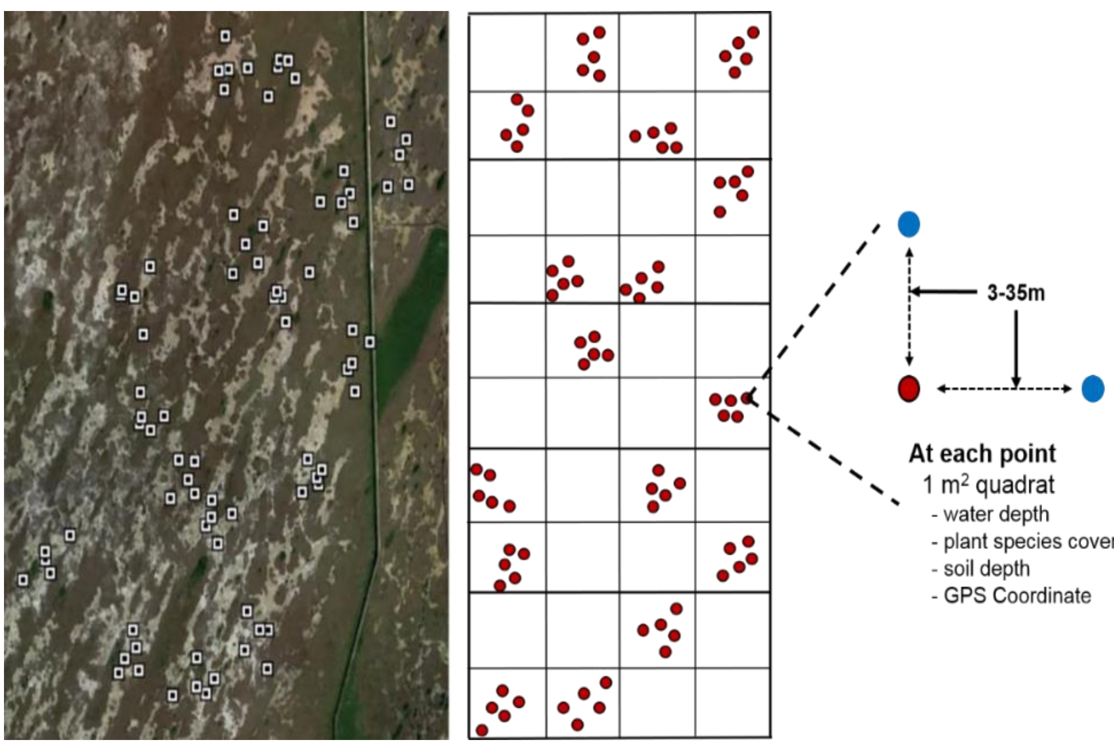

Figure 8: Locations of sampling clusters (red dots) within 2x5 km primary sampling units (PSUs); the location of clusters within 500 x 500 m zone is assigned randomly. At each cluster, 3 sampling locations are visited; sites are situated at the center of each cluster, and at a random distance between 3 and 35 m in the direction of the PSU azimuth and in the orthogonal direction.

Within each quadrat, water depth was measured using a meter stick. Field training of sampling personnel ensured that a standardized amount of pressure was applied to the foot so that the measurement of water depth was uniform across time and space. Water depths were measured with a precision of 0.5 cm. In addition, we determined soil depth, i.e. depth to bedrock at each node, using 1 cm diameter metal rod. At some sites, however, the soil depth was much deeper than the metal rod we used, and thus we were not able to reach to bedrock. Soil depth at those sites were just recorded as >270 cm, the effective length of the metal rod.

Vegetation characterization within each quadrat consisted of identifying all taxa present to species level, and estimating abundance of each species as percentage cover of the plot area at either 1%, 5% or at 10% intervals. Based on visual observation accentuated with these vegetation measurements, the vegetation within a 25 m radius of each sampling location was assigned to a community category (ridge, slough, tree island vegetation, wet prairie and cattail). Where study site spanned a transition from one community type to another, we assigned points to mixed categories (e.g., ridge/wet prairie). The field classifications were also adjusted so that they are better and more directly related to community classifications adopted by Rutchey et al. (2006) and Sah et al. (2010), and the types recently used in mapping from aerial imagery (Ruiz et al. 2017).

Field sampling of the ridge-slough landscape was done via airboat, during periods when sufficient water was present to obtain a reliable measure of water depth at all locations. As such, no dry weather sampling was conducted. For PSUs situated in Everglades National Park, sites were accessed by airboat or helicopter, as allowed by permitting and budgetary constraints.

2.2 Data analysis

2.2.1 Site/Point Hydrology

Since water depths in the field were measured over several months in different hydrological conditions, to establish site hydrologic conditions, we coupled our synoptic measurements of water depths with water surface elevation obtained from Everglades Depth Estimation Network (EDEN) based on the geographic location of PSU centroid. For each sampling point, we established a hydrologic history spanning from the day of sampling back to 1991, by benchmarking measured water depth and EDEN-estimated water elevation at the center point of each PSU. Because PSUs were not spatially situated to maximize proximity to sites where water level is directly recorded, we relied on spatially-interpolated EDEN water surfaces to estimate water depths on the day of sampling and to reconstruct point-scale hydrologic history. We evaluated the assumption of negligible water slope by examining relationships between UTM coordinates (easting, northing) and water elevation. For PSUs with significant relationships between water elevation and coordinates, we divided PSUs into 4 north-south bands and benchmarked points within each band to water elevations at the center point of that band.

To determine the particular hydrologic conditions at a site requires first that soil (ground) elevation be determined from EDEN estimates of water elevation on the day of sampling and water depths. Then, using the daily water surface elevation data, we calculated mean water depth and inundation frequency at each point over the preceding 0.25, 0.5, 1, 2, 5, 10, 20 and ca. 25-28 years (i.e. the complete hydrologic record). Because of strong correlation among these measures within PSUs, we used measures derived from the full hydrologic record as predictors of vegetative and microtopographic condition (Ross et al. 2016).

2.2.2 Microtopography

To assess microtopographic variation and hydrologic regime, we calculated summary statistics of soil elevation and water level, including mean, standard deviation, skew and kurtosis following Heffernan et al. (2009). Standard deviation of water level describes the temporal variability of water level, while standard deviation of water depth (or soil elevation) describes the magnitude of spatial variation in microtopography. To test for bi-modality in the peat elevation distributions, we used the R package 'mclust' to assess goodness-of-fit between the observed histogram of peat elevations, and 1) a single normal, and 2) a mixture of two normal distributions:

$$P_s = N(\mu_i, \sigma_i) \tag{1}$$

$$P_m = q \cdot N(\mu_1, \sigma_1) + (1 - q) \cdot N(\mu_2, \sigma_2) \tag{2}$$

where q represents the probability of falling within the first normal distribution, and N is a normal distribution with mean μ_i and standard deviation σ_i. Model goodness of fit was compared using Bayes' information criterion (BIC). The best-fit model was considered to have the lowest BIC score. Moreover, to evaluate how microtopographic structure responds to hydrologic regime, we examined the relationship between mean annual water depth and the elevation difference between modes of bimodal distributions, where present.

2.2.3 *Vegetation structure and composition*

In the R&S landscape, vegetation communities are generally separated in ridge and slough by clear topographic boundaries in areas with relatively well-maintained hydrologic regimes. However, as the hydrologic regime degrades, this patterning is lost. We assessed variation in community distinctness in response to hydrologic and topographic changes using dissimilarity between R&S vegetation community composition, defined as the distance (in multivariate space) between artificially imposed vegetation clusters (Isherwood 2013). First, using the species cover data from all PSUs sampled over four years (Year 1-4) from the current cycles, we generated Non-metric multidimensional scaling (NMDS) ordination plot. This single global NMDS ordination plot enabled us to 1) obtain a global estimate of the clustering of sampling points containing a set of species among all PSUs; and 2) standardize the among-PSU data. For the global NMDS ordination, we decided to retain five dimensions (5-d) solution as was done in analysing first two-years data of Cycle-1 (Ross et al. 2013). It was different from four dimensions (4-d) solution used in analysis of five-year data by Ross et al. (2016). Each individual PSU was then isolated from the global NMDS ordination plot and coerced into two distinct clusters using k-means clustering. The sum of squares distance between the two cluster centres (BSS) based on their Voronoi sets was calculated for each PSU to obtain a test statistic that we used as a description of vegetation community distinctness (Isherwood 2013). A higher BSS value (greater distance between the two clusters) indicated a more distinct vegetation community structure, whereas more overlapping clusters (smaller BSS) would indicate less distinctness between sites, and a more degraded landscape structure (Isherwood 2013, Ross et al. 2013, 2016).

Since the sample points in ordination space were artificiality grouped into only two clusters, rather than allowing them for multiple clusters, several approaches were used assess the rationality of using R&S community distinctness (Isherwood 2013, Ross et al. 2013, 2016). Those included analysis of the distribution of key indicator taxa (*Cladium, Eleocharis, Nymphaea*, and *Utricularia* species) in the two global clusters, agreement between cluster assignments in the global analysis and within individual PSUs, analysis the covariation among characteristic species of each community in NMDS space, and the distribution of sample points along individual axes of the global NMDS. The rationale for using these approaches and detailed interpretation are given in Isherwood (2013) and Ross et al. (2016). The global NMDS plot was created using the 'metaMDS' function in the *vegan* package (Oksanen et al. 2012). The dissimilarity matrix for the

NMDS was calculated using the 'vegdist' function in *vegan* using the metric Jaccard index which was preferentially chosen over the popular semi-metric Bray-Curtis index, and k-means clusters were created using the R base package stats (R Core Team 2017).

Landscape scale co-variation between elevation and vegetation community composition was assessed by different metrics: bivariate regression between sawgrass abundance and elevation within each PSU, a Mantel test between matrices of between-site dissimilarities in elevation and in community composition, and the difference in elevation between points assigned to the two clusters in the k-means analysis (Isherwood 2013; Ross et al. 2016). This suite of measures provides a more integrated view of vegetative and microtopographic structure of R&S landscapes.

Finally, we determined the change in both topographic and community metrics between Cycle-1 and Cycle-2 and assessed the relationship between those changes and hydrologic conditions across all the study PSUs.

3. Results

3.1 Hydrologic conditions & Microtopography

In the PSUs sampled during 2015-2019, long-term mean water depth (LTMWD: averaged over all points sampled within each PSU) varied from 10.1 cm in PSU-3 to 93.4 cm in PSU-45. The lowest water depths were in units within the northern water conservation area 3A (WCA3AN), whereas moderately-high to high water depths were in southern, central and northeastern portions of WCA 3A. (Table 2; Figure 9). In these PSUs, LTMWD was reasonably consistent across cycles ($r = 0.93$; $p < 0.001$), with few exceptions (Figure 10). One was the DPM area, which had the highest difference (35.4 cm) in LTMWD between the two sampling periods. In general, there was a slight bias toward greater depths in Cycle-2 (Figure 11), though 71% of PSUs differed by less than 4 cm, while only one-fifth of PSUs had differences >8 cm. There was no consistent pattern across the regions. Difference in LTMWD between periods was small in WCA3AS, while several PSUs in ENP, WCA3AN, WCA3B and WCA2 regions had relatively high differences in water depth.

Table 2: Hydrologic and microtopographic characteristics of Cycle-2 Year 1, 2, 3 and 4 PSUs. Additional hydrologic descriptors at the point scale are included in data reports for each PSU.

PSU-Identification			**Water Elevation Statistics**						**Elevation Cluster Analysis**						***Best Model**	**Notes**
			Water Elevation		***Peat Surface***				***Mode 1***			***Mode 2***				
PSU	**Cycle**	**Cycle-2 Year**	**Mean (cm asl)**	**§St. Dev. (cm)**	**MWD (cm)**	**†SD (cm)**	**Kurtosis**	**Skew**	**Depth (cm)**	**†St. Dev. (cm)**	**††Mode Wt (q)**	**Depth (cm asl)**	**†St. Dev. (cm)**	**††Mode Wt (q)**		
0	2	1	181.18	25.03	39.92	7.47	0.02	0.34	39.92	7.44	1.00	-	-	-	1	Large difference in water level between Cycle-1 and Cycle-2 sampling. MWE DoS; delta EV for 2E is similar to Cycle-1 (~10 cm)
1	2	1	450.58	15.84	17.47	5.39	0.33	0.35	17.47	5.37	1.00	-	-	-	1	
2	2	1	253.15	23.68	52.60	8.78	-0.51	-0.57	42.69	4.89	0.35	57.91	4.89	0.65	2E	
3	2	1	304.62	24.21	10.10	4.22	0.19	-1.00	6.32	1.94	0.49	13.75	1.94	0.51	2E	q<0.3
4	2	1	261.20	25.18	41.39	11.30	-0.45	1.13	41.39	11.25	1.00	-	-	-	1	
6	2	1	34.98	21.67	37.21	5.12	-0.84	1.52	23.98	4.11	0.05	37.90	4.11	0.95	2E	2E: q=0.05
7	2	1	286.24	21.53	35.02	6.27	-0.07	-0.97	29.80	3.65	0.49	39.95	3.65	0.52	2E	2E: q=0.08
9	2	1	355.74	24.20	14.91	9.15	0.26	-1.08	8.75	4.99	0.61	24.36	4.99	0.39	2E	HUGE difference in MWE DoS; N-S gradient in WD
11	2	1	269.81	31.68	58.66	9.52	0.76	0.86	58.66	9.49	1.00	-	-	-	1	-
15	2	1	269.48	30.87	79.47	8.71	-0.22	-0.04	79.47	8.67	1.00	-	-	-	1	HUGE difference in MWE DoS; q<0.3
108	2	1	176.72	22.22	31.30	5.20	-0.05	-0.70	31.30	5.18	1.00	-	-	-	1	2E: q<0.03
17	2	2	448.71	19.36	32.14	11.28	0.54	-0.31	26.77	7.14	0.72	46.14	7.14	0.28	2E	Increase in delta elevation, but movement away from 50/50 mixture
18	2	2	153.50	24.13	34.11	4.32	-0.68	-0.04	34.11	4.26	1.00	-	-	-	1	Tiny sample
19	2	2	288.90	21.92	22.51	9.16	0.83	1.27	12.70	1.74	0.24	25.53	8.28	0.77	2V	q<0.3
20	2	2	184.98	15.45	32.54	4.69	-1.24	2.97	18.71	3.56	0.05	33.21	3.56	0.95	2E	q<0.05
21	2	2	328.88	28.14	53.55	14.98	0.79	-0.03	43.49	4.43	0.42	60.76	15.61	0.58	2V	HUGE difference in MWE DoS; delta EV for 2E is similar to Cycle-1 (~11 cm)
23	2	2	265.42	21.72	33.25	10.73	-0.23	-1.21	25.09	6.82	0.56	43.45	3.43	0.44	2V	
24	2	2	157.84	20.54	33.36	6.19	-1.04	2.00	12.24	5.18	0.02	33.89	5.18	0.98	2E	2E:q<0.03
26	2	2	259.57	23.97	44.91	9.64	-0.09	-0.95	36.26	5.46	0.46	52.13	5.46	0.55	2E	
28	2	2	186.44	17.46	36.44	4.64	-0.86	1.16	25.35	3.50	0.07	37.26	3.50	0.93	2E	2E:q<0.07
30	2	2	124.75	20.66	30.96	8.70	-0.18	-0.27	30.96	8.67	1.00	-	-	-	1	

PSU-Identification			Water Elevation Statistics						Elevation Cluster Analysis						*Best Model	Notes
			Water Elevation		*Peat Surface*				*Mode 1*			*Mode 2*				
PSU	**Cycle**	**Cycle-2 Year**	**Mean (cm asl)**	**§St. Dev. (cm)**	**MWD (cm)**	**†SD (cm)**	**Kurtosis**	**Skew**	**Depth (cm)**	**†St. Dev. (cm)**	**††Mode Wt (q)**	**Depth (cm asl)**	**†St. Dev. (cm)**	**††Mode Wt (q)**		
31	2	2	267.94	26.07	38.08	11.77	0.46	-0.39	38.08	11.72	1.00	-	-	-	1	Strong NS gradient in water depth, not yet corrected
32	2	3	161.18	19.39	34.72	7.68	-0.80	0.31	20.63	5.18	0.14	36.97	5.18	0.86	2E	
34	2	3	246.74	22.59	52.51	16.76	-1.36	7.95	33.46	45.39	0.07	53.93	10.78	0.93	2V	
35	2	3	312.55	22.61	11.85	4.61	-0.29	-0.28	11.85	4.53	1.00	-	-	-	1	
36	2	3	256.30	29.81	79.61	9.85	-0.83	0.18	73.44	9.22	0.53	86.68	3.94	0.47	2V	
37	2	3	337.56	23.88	30.98	9.53	1.28	1.86	28.26	6.13	0.88	50.28	6.13	0.12	2E	
39	2	3	290.60	23.36	20.93	6.41	-0.09	-0.82	20.93	6.38	1.00	-	-	-	1	
43	2	3	276.30	25.63	27.69	4.06	-1.02	3.36	17.78	3.42	0.05	28.16	3.42	0.96	2E	
44	2	3	179.99	18.78	31.21	4.93	-0.70	0.60	31.21	4.91	1.00	-	-	-	1	
45	2	3	264.38	33.98	93.18	9.15	-0.49	0.44	93.18	9.09	1.00	-	-	-	1	
47	2	3	271.84	28.35	53.44	18.47	0.90	-0.53	45.16	8.74	0.80	86.56	2.99	0.20	2V	
513	2	3	155.29	23.46	30.68	4.27	-0.57	0.49	30.68	4.25	1.00	-	-	-	1	
DPM	2	3	187.21	14.63	35.45	12.08	-0.02	-0.61	26.33	6.91	0.54	46.14	6.91	0.46	2E	
50	2	4	242.07	24.85	51.93	17.33	1.67	3.64	33.27	10.59	1.00	-	-	-	1	
51	2	4	257.92	28.61	59.99	16.33	-0.12	-0.30	16.92	6.22	1.00	-	-	-	1	
52	2	4	79.37	19.30	28.15	7.50	-0.13	-0.45	47.49	10.39	0.91	94.56	10.39	0.094	2E	q<0.3; large mode difference is artefact of one sampling location
53	2	4	267.47	20.93	37.57	10.26	-0.25	-0.57	43.50	9.83	0.38	70.17	9.83	0.618	2E	NS gradient in water depth,
54	2	4	163.67	17.85	35.99	8.50	1.94	7.81	28.15	7.47	1.00	-	-	-	1	
55	2	4	244.45	22.47	56.21	12.63	-0.45	-0.26	37.57	10.22	1.00	-	-	-	1	
56	2	4	273.95	33.93	13.54	4.59	0.37	1.04	34.56	5.54	0.94	56.43	14.5	0.065	2V	q<0.3
58	2	4	344.53	21.10	25.03	6.62	-0.29	0.06	56.21	12.57	1.00	-	-	-	1	
59	2	4	100.32	20.11	29.65	7.94	-0.26	-0.53	13.54	4.57	1.00	-	-	-	1	
61	2	4	258.99	30.74	77.46	7.69	-0.47	0.58	25.03	6.59	1.00	-	-	-	1	
62	2	4	187.27	16.85	34.07	3.67	-0.17	-0.45	20.39	4.87	0.31	33.85	4.87	0.688	2E	
63	2	4	242.07	24.85	51.93	17.33	1.67	3.64	77.46	7.66	1.00	-	-	-	1	
220	2	4	257.92	28.61	59.99	16.33	-0.12	-0.30	34.07	3.66	1.00	-	-	-	1	

§Standard Deviation of water elevation describes the temporal variability of water level at the center point of each PSU.
†Standard Deviation of water depth describes the spatial variability of soil elevation across all points sampled within each PSU.
†† Mode weight describes the proportion of data that occur within each mode, allowing for imbalance in mode prevalence
* Best fit model selected based on Bayes' Information Criterion; number refers to the number of modes, E and V denote whether variances of the two modes are equal (E) or unequal (V). Where the best fit model included more than 2 modes, data presented are from the best fit model among 1 and 2 mode models.

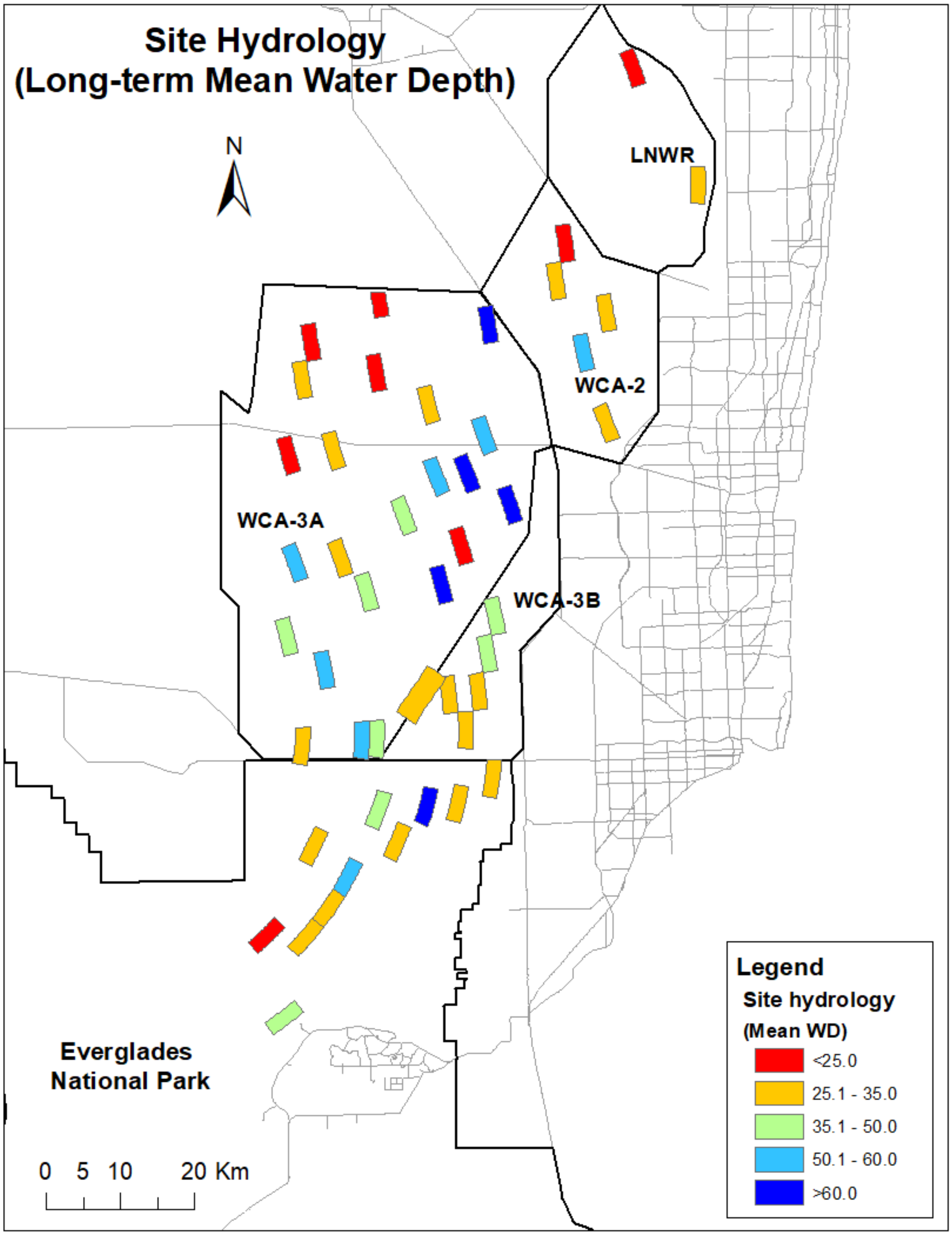

Figure 9: Spatial patterns in Long-term (25-28 years average) water depth in 47 PSUs sampled over four years (Year 1-4) of the current five-year cycle.

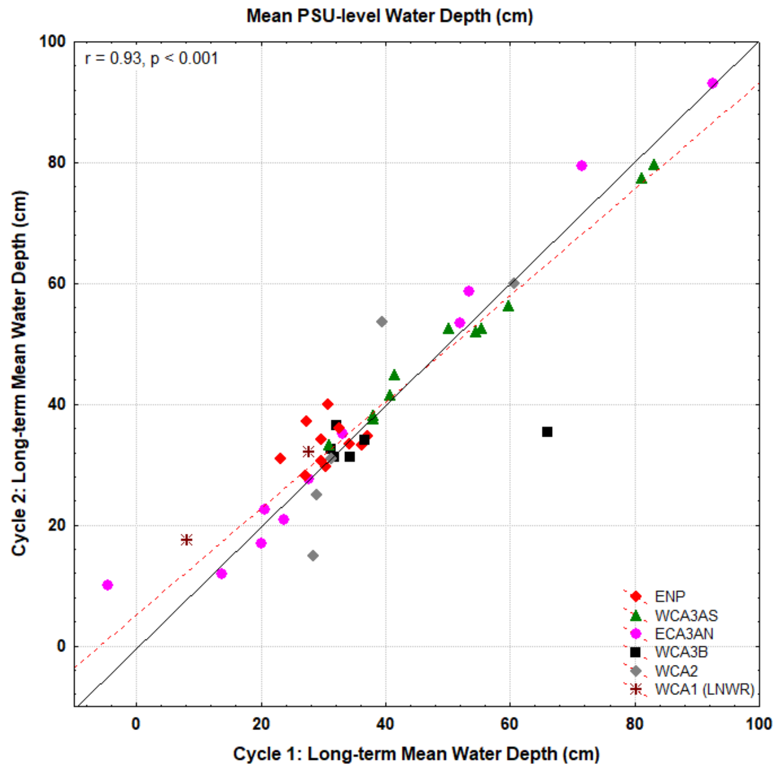

Figure 10: Relationship between long-term mean water depth (cm) in PSUs between Cycle-1 and Cycle-2.

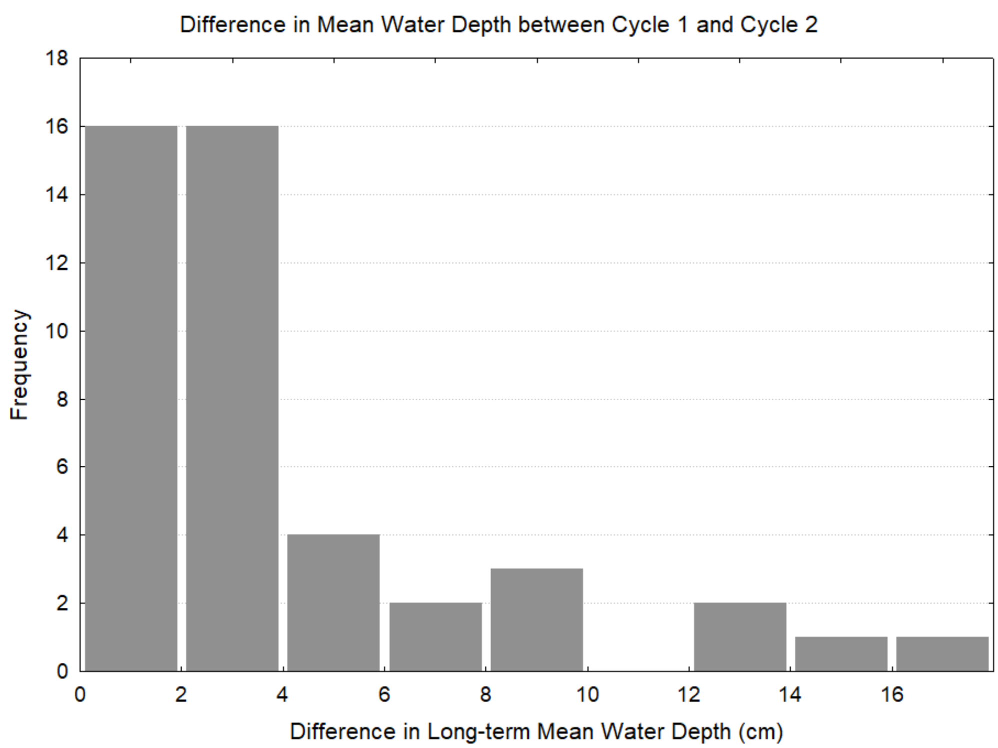

Figure 11: Number of PSUs with a range of difference in long-term mean water depth between Cycle-1 and Cycle-2. About 71% of 45 PSUs sampled over four years (Year 1-4) had < 4 cm difference in water depth. Among 47 PSUs sampled over four years, PSU-35 was not included in analysis, and PSU-59 was sampled only in Cycle-2.

The magnitude and structure of microtopographic relief also varied considerably among 47 PSUs (Table 2; Figures 12-14). Standard deviations of soil elevation (water depth) ranged from 3.7 to 18.4 cm (Table 2), with most values falling between 4.5 and 10.5 cm (Figure 12). As reported in Ross et al. (2016) for PSUs sampled during Cycle-1, the magnitude of topographic relief during Cycle-2 was generally highest in PSUs in central WCA3AS. In contrast, PSU 220 in WCA3B had the least topographic relief. The standard deviation of LTMWD, which is a reflection of variation in soil elevation, was correlated (r = 0.84) across cycles, but with higher uncertainty in Cycle-2 (Figure 13), and with a strong bias toward greater variability in Cycle-2. Uncertainty in microtopographic variation was tied to hydrologic conditions at the time of sampling, and differences in microtopography between cycles were greatest when the sites were sampled under very different hydrologic conditions. For instance, even though the number of PSUs with bimodal distribution in soil elevation (water depth) was less in Cycle-2 (13 PSUs) than in Cycle-1 (21 PSUs) (Table 3), wet conditions during Cycle-2 may have inflated standard deviation of water depths of some PSUs (Table 2). However, it was not clear whether this was real phenomena or a sampling artefact.

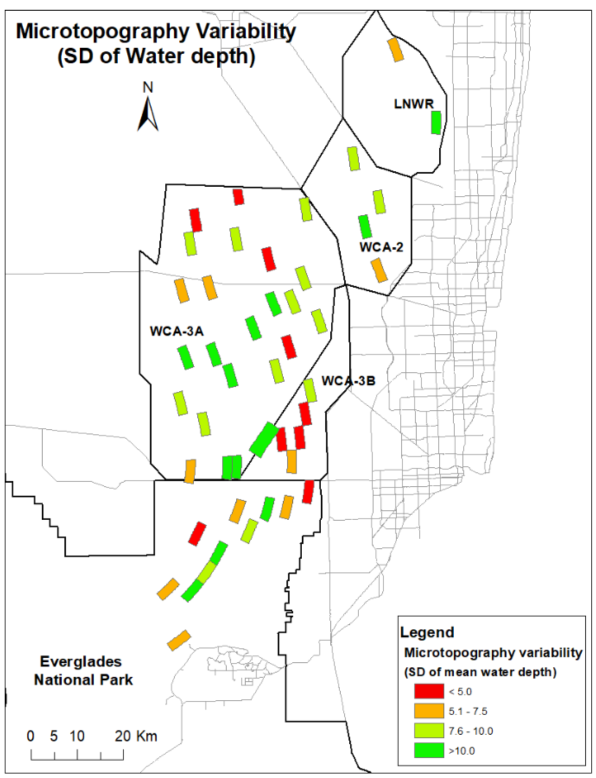

Figure 12: Spatial patterns of elevation variance across historic ridge-slough landscape represented 47 PSUs sampled over four years (Year 1-4) of Cycle-2. Colours indicate the amount of microtopographic relief (measured as the standard deviation of elevation within each PSU).

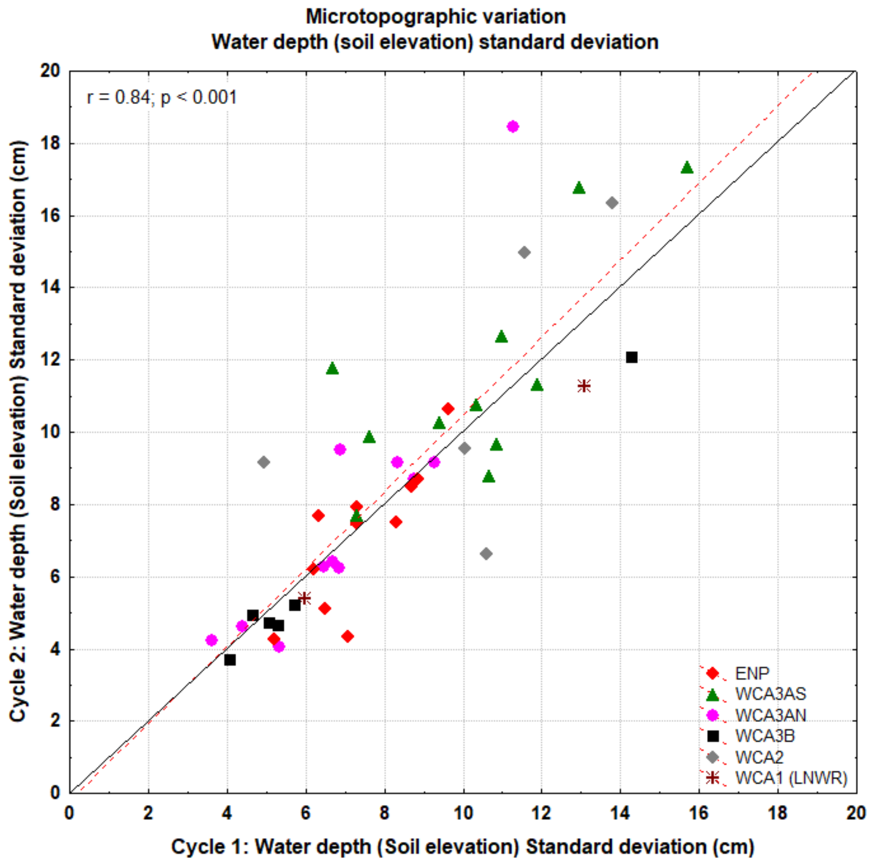

Figure 13: Relationship between microtopography variation (long-term water depth standard deviation (cm)) in PSUs between Cycle-1 and Cycle-2.

In general, fewer PSUs exhibited statistically significant bi-modality in Cycle-2 than was observed in Cycle-1 (Table 2). Ten of thirteen PSUs in which bimodality was observed during Cycle-2 sampling also had conserved topography in Cycle-1 (Table 3). These include PSUs 2, 4, 23, 26 and 52, all located within central WCA3AS, as well as PSUs 17 (WCA1), 19 (WCA3AN), 21 (WCA2) and 53 (WCA2). The DECOMP PSU (DPM) had the greatest elevation separation between ridges and sloughs in Cycle-1, and was again found to have bi-modal soil elevations with an elevation difference near 20 cm. In three PSUs - PSU 36 in WCA3AS, and 56 and 62 in ENP - bi-modality that was not detected in Cycle-1 was present in Cycle-2. Among PSUs in which bi-modality was detected in both cycles, elevation differences between the modes were similar in both, generally around 15-25 cm.

Three PSUs (PSUs 0, 18 and 54) within ENP that had bi-modal soil elevations in Cycle-1 did not have statistically detectable bi-modality during Cycle-2. Other PSUs in which previous bi-modality was not detected include PSUs 3 and 39 (WCA3AN), PSUs 20 and 108 (WCA3B), and PSUs 37 and 61 (WCA2). These PSUs in which bi-modality was observed initially but not in the subsequent cycle generally had relatively small mode elevation differences (5-13 cm) during Cycle-1. Among the three PSUs (36, 56 and 62) that had bi-modal soil elevations in Cycle-2, after exhibiting a unimodal distribution in Cycle-1, two PSUs had the observed Cycle-2 elevation difference of ~13 cm, while the other had of ~20 cm. In contrast, PSUs 37 and 39, located in WCA3AS and WCA2, respectively, were not shown to have bimodal distributions in Cycle-2, after exhibiting bi-modal soil elevation distributions in Cycle-1. In both cases, statistical distributions were best fit by 3 modes (data not shown), rather than 1 or 2, indicating microtopographic structure that deviates from the simple conceptual model of ridges and sloughs.

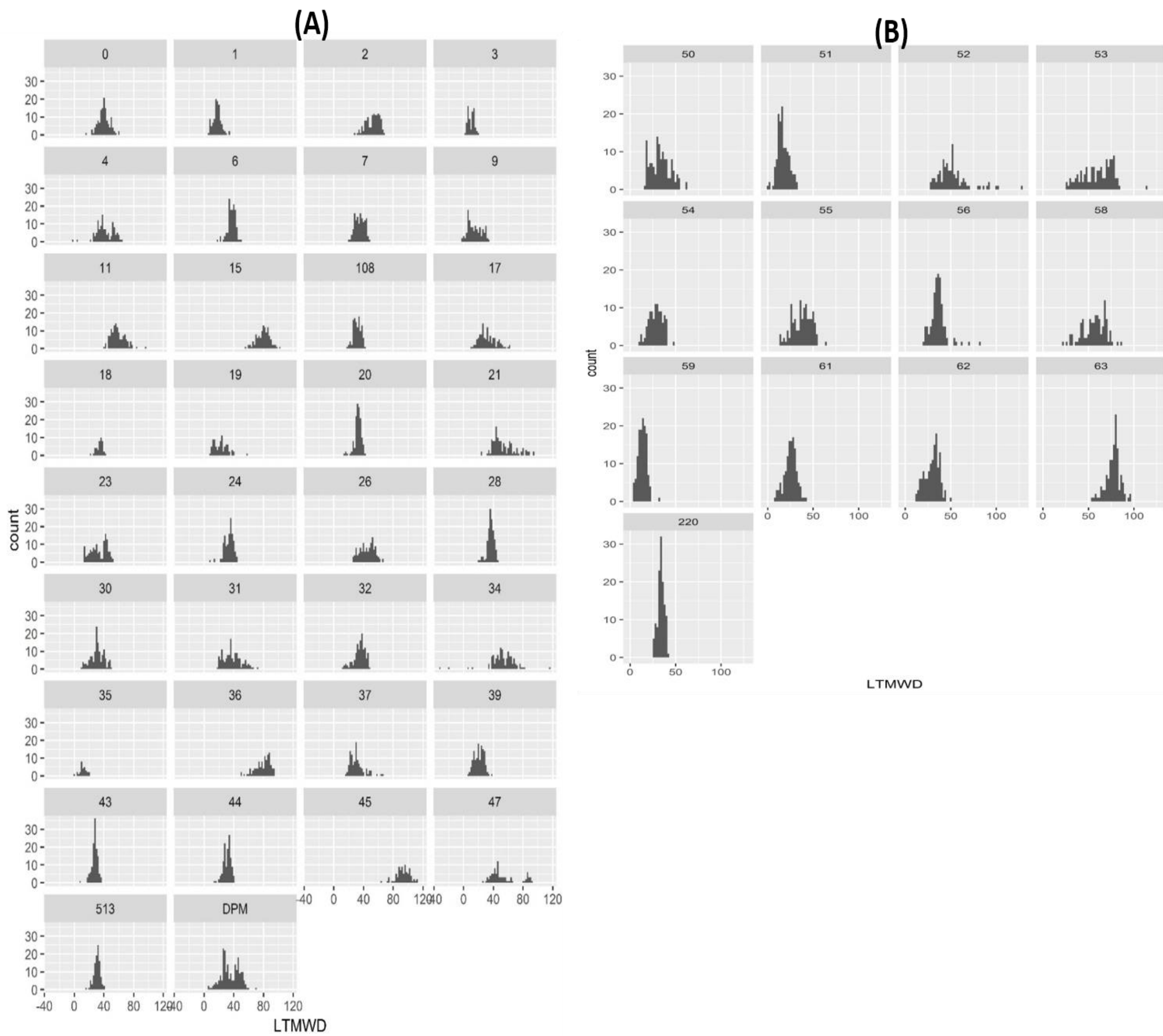

Figure 14: Soil elevation (SD of water depth) distributions of (A) Year 1, 2 & 3, and (B) Year 4 PSUs. Bimodality and high variability in elevation (e.g. PSU 4) are characteristics of conserved conditions, while low variability and unimodality (e.g. PSU 3) are characteristics of degraded conditions.

Table 3: Summary of difference in mean elevation (water depth) between two modes for the PSUs, which were sampled during both Cycle-1 and Cycl-2 and had bi-modal distribution of elevation.

PSU	Area†	Bi-modal in	Elevation	Bi-modal in	Elevation
0	ENP	Yes	11.61	No	0.00
1	WCA1	No	0.00	No	0.00
2	WCA3AS	Yes	18.09	Yes	15.10
3	WCA3AN	Yes	5.78	No*	0.00
4	WCA3AS	Yes	20.08	Yes	18.04
6	ENP	No	0.00	No*	0.00
7	WCA3AN	No	0.00	No*	0.00
9	WCA2	No	0.00	No*	0.00
11	WCA3AN	No	0.00	No	0.00
15	WCA3AN	No	0.00	No*	0.00
108	WCA3B	Yes	12.35	No*	0.00
17	WCA1	Yes	12.72	Yes	19.13
18	ENP	Yes	12.25	No	0.00
19	WCA3AN	Yes	13.59	Yes	13.34
20	WCA3B	Yes	9.24	No*	0.00
21	WCA2	Yes	16.10	Yes	17.76
23	WCA3AS	Yes	18.31	Yes	18.36
24	ENP	No	0.00	No*	0.00
26	WCA3AS	Yes	18.17	Yes	15.87
28	WCA3B	No	0.00	No*	0.00
30	ENP	No	0.00	No	0.00
31	WCA3AS	No	0.00	No	0.00
32	ENP	No	0.00	No*	0.00
34	WCA3AS	No	0.00	No*	0.00
35	WCA3AN	No	0.00	No	0.00
36	WCA3AS	No*	0.00	Yes	13.95
37	WCA2	Yes	16.86	No*	0.00
39	WCA3AN	Yes	9.91	No	0.00
43	WCA3AN	No	0.00	No*	0.00
44	WCA3B	No*	0.00	No	0.00
45	WCA3AN	No*	0.00	No	0.00
47	WCA3AN	No	0.00	No*	0.00
513	ENP	No	0.00	No	0.00
DPM	WCA3B	Yes	23.44	Yes	19.80
50	ENP	No	0.00	Yes	19.80
51	WCA3AN	No	0.00	No	0.00
52	WCA3AS	Yes	3.70	No	0.00
53	WCA2	Yes	22.88	Yes	47.07
54	ENP	Yes	13.69	Yes	26.67
55	WC3AC	Yes	18.62	No	0.00
56	ENP	No	0.00	No	0.00
58	WCA3AS	No	0.00	Yes	21.87
59	WCA3AN	-	-	No	0.00
61	WCA2	Yes	27.27	No	-
62	ENP	No	0.00	No	0.00
63	WCA3AC	Yes	17.78	Yes	13.46
220	WCA3B	No	0.00	No	0.00

* indicates high unevenness in cluster weight, on which basis a unimodal model was deemed the more appropriate fit; ** this PSU was not sampled in Cycle-1.

3.2 Vegetation composition and structure

Vegetation composition varied greatly within and across the PSUs sampled over four years (Year 1-4: 2015-2019) of Cycle-2 (Table 4). The abundance of major taxa followed expected trends with water depth at the scale of system-wide PSUs, a pattern that was also observed in Cycle-1 (Figure 15). The mean percent cover of sawgrass was the highest in PSUs with lower long-term mean water depth, while the characteristic species of sloughs, water lily and bladderworts (*Nymphaea odorata* and *Utricularia* spp.) were most abundant in PSUs with high long-term mean water depths. Though both sawgrass and bladderworts showed high variability in relative cover at low to intermediate water depths (Figures 15a, d). Spikerush (*Eleocharis* spp.) were most abundant in PSUs with intermediate water depths (Figure 15b). Relative cover of major species across PSUs were fairly correlated between Cycle-1 and Cycle-2. However, percent cover of three major taxa, sawgrass, spikerush and waterlily were higher in Cycle-2 than Cycle-1 (Figure 16). In contrast, relative cover of bladderworts (*Utricularia* spp.) decreased in five years. Shift in relative cover of major taxa followed a pattern. For instance, relative cover of sawgrass in eleven PSUs (2 in WCA3AN, 4 in WCA3B, including DPM, and 5 in ENP) was >30% higher in Cycle-2 than Cycle-1. In contrast, PSUs in WCA3AS, had much less increase in sawgrass cover, whereas in three PSUs in this region, sawgrass cover decreased over five years. In two PSUs in WCA3AN and one in LNWR, sawgrass relative decreased by >15%.

Table 4: Vegetation characteristics of Cycle-2 Year 1, 2, 3 and 4 PSUs.

PSU-Identification			Vegetation characteristics				Vegetation composition-Elevation Relationships			
			Species Mean Relative Cover (%)				Community Distinctness (cluster distance)	k-means WD difference (cm)	Mantel's r	r^2 Cladium-WD
PSU	Cycle	Cycle (Year)	*Cladium jamaicense*	*Nymphaea spp.*	*Utricularia spp.*	*Eleocharis spp.*				
0	2	1	62.68	0.70	9.13	16.05	0.662	10.9	0.244	0.2030
1	2	1	17.23	11.71	35.45	4.94	0.461	20.9	0.244	0.4182
2	2	1	34.03	40.64	10.47	7.90	1.130	13.7	0.532	0.5528
3	2	1	70.56	0.00	0.00	0.00	0.402	2.8	0.121	0.0248
4	2	1	41.80	32.52	8.17	7.31	1.183	14.5	0.498	0.3150
6	2	1	56.12	0.00	16.86	22.19	0.299	0.2	0.101	0.0001
7	2	1	51.39	10.99	17.72	8.62	0.944	5.0	0.284	0.0266
9	2	1	65.86	4.65	23.74	2.95	0.198	8.3	0.118	0.3180
11	2	1	47.14	27.13	6.17	2.00	0.586	2.6	0.158	0.1067
15	2	1	27.16	29.55	36.36	0.83	0.547	3.4	0.166	0.0121
108	2	1	66.24	7.17	0.66	8.95	0.602	4.9	0.141	0.1999
17	2	2	43.84	21.25	11.06	12.13	0.871	9.9	0.313	0.1567
18	2	2	28.36	0.86	3.05	56.34	0.298	1.3	0.205	0.1492
19	2	2	37.55	3.22	1.05	0.09	0.790	9.9	0.316	0.1615
20	2	2	72.12	4.21	2.30	7.30	0.277	0.6	0.023	0.0041
21	2	2	55.99	0.00	6.66	31.34	1.007	20.8	0.455	0.4679
23	2	2	28.92	31.59	6.22	7.86	0.986	17.8	0.668	0.5018
24	2	2	64.15	0.22	17.36	8.64	0.383	0.6	0.246	0.0004
26	2	2	25.93	28.25	8.59	9.72	0.829	13.9	0.521	0.4403
28	2	2	51.85	13.53	15.94	6.73	0.358	0.8	0.056	0.0003
30	2	2	56.66	3.57	3.54	21.23	0.813	9.7	0.349	0.2660
31	2	2	49.75	25.02	4.15	6.05	0.798	11.0	0.325	0.3801
32	2	3	76.58	5.59	4.17	7.86	0.590	10.0	0.173	0.2946
34	2	3	27.93	43.73	8.96	3.85	0.837	15.4	0.338	0.0679
35	2	3	5.85	0.26	5.11	27.66	0.629	2.9	0.246	0.1977
36	2	3	20.57	50.71	19.49	0.46	0.665	9.5	0.071	0.1426
37	2	3	53.93	12.53	8.82	1.89	0.585	7.7	0.477	0.1779
39	2	3	36.04	8.75	3.31	16.28	0.930	8.2	0.390	0.3812
43	2	3	70.44	1.03	1.78	2.87	0.565	0.1	0.057	0.0144

PSU-Identification			Vegetation characteristics				Vegetation composition-Elevation Relationships			
			Species Mean Relative Cover (%)				Community Distinctness (cluster distance)	k-means WD difference (cm)	Mantel's r	r^2 Cladium-WD
PSU	**Cycle**	**Cycle (Year)**	***Cladium jamaicense***	***Nymphaea spp.***	***Utricularia spp.***	***Eleocharis spp.***				
44	2	3	62.75	7.80	3.51	20.25	0.329	1.2	0.021	0.0077
45	2	3	39.13	15.71	10.42	5.54	1.079	3.7	-0.069	0.0530
47	2	3	52.59	21.12	3.07	2.07	0.629	9.2	0.101	0.1187
513	2	3	82.07	0.00	6.66	4.22	0.217	0.6	0.216	0.0097
DPM	2	3	74.86	2.54	2.51	13.80	0.898	8.3	0.053	0.0547
50	2	4	74.06	4.56	2.55	14.74	0.633	16.3	0.391	0.3588
51	2	4	13.71	0.19	0.00	27.78	1.187	3.1	0.102	0.0289
52	2	4	33.75	19.33	7.15	17.61	0.991	22.3	0.233	0.1412
53	2	4	35.58	23.36	31.99	6.33	0.849	19.3	0.366	0.3832
54	2	4	64.72	0.06	1.35	28.07	0.569	7.4	0.178	0.1743
55	2	4	31.55	27.50	7.38	17.16	1.086	15.5	0.489	0.5022
56	2	4	77.77	0.15	7.46	9.44	0.396	8.0	0.254	0.2687
58	2	4	33.68	1.41	5.86	42.62	0.903	14.4	0.232	0.2571
59	2	4	91.59	0.00	0.02	0.60	0.203	0.4	0.070	0.0254
61	2	4	54.56	33.18	6.21	2.21	0.851	6.0	0.124	0.1967
62	2	4	76.49	0.01	0.40	16.44	0.491	6.5	0.203	0.0964
63	2	4	12.15	54.72	27.72	1.80	0.365	4.9	0.152	0.0537
220	2	4	87.03	4.53	1.17	3.03	0.335	45.5	0.076	0.0039

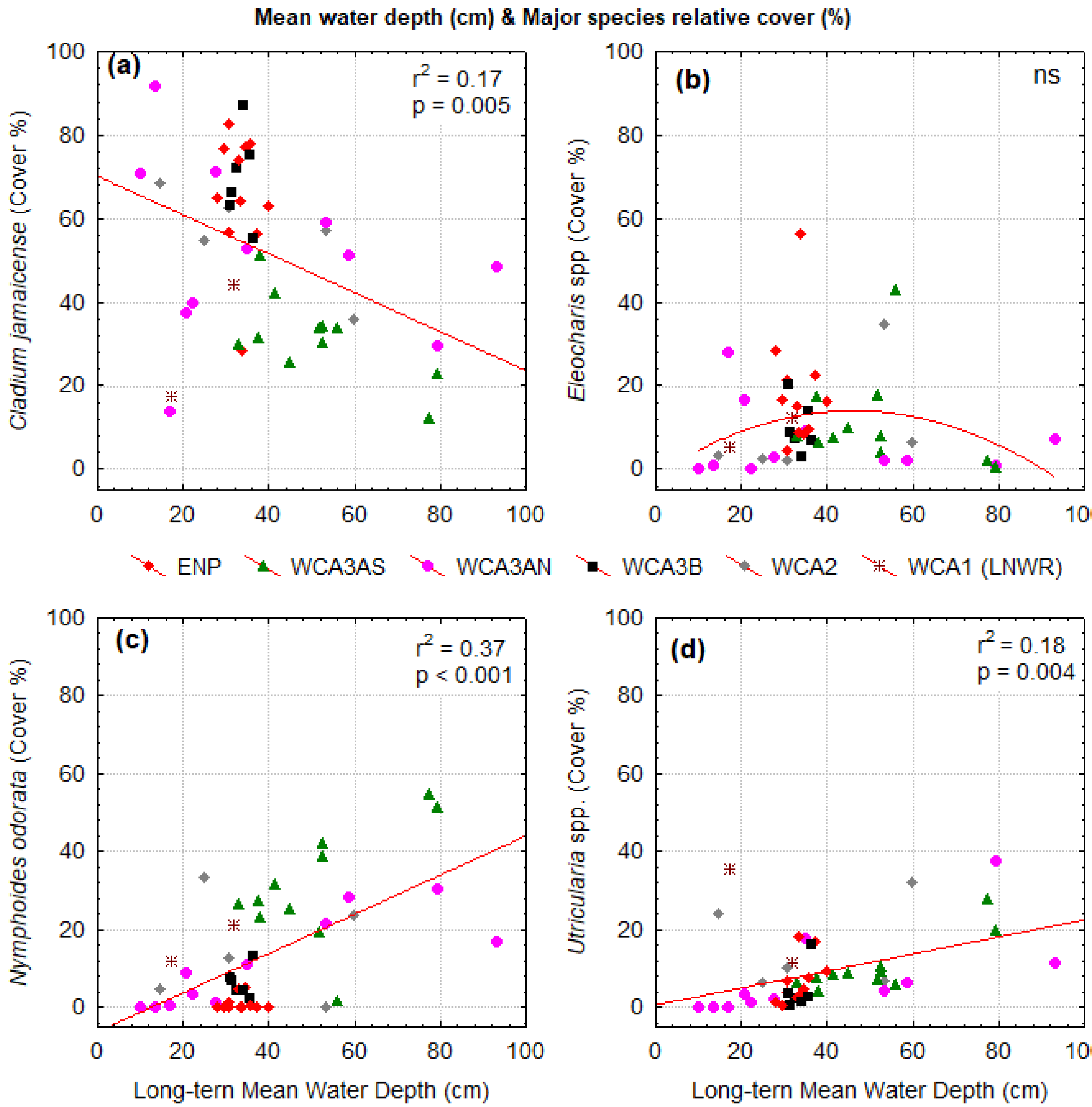

Figure 15: Relationship between long-term mean water depth and relative cover of major species that are characteristics of ridge, slough and wet prairie based on 46 PSUs sampled over four years (Year 1-4) of Cycle-2. The PSU 35 in WCA3AN had very few plots sampled, and thus excluded from the analysis.

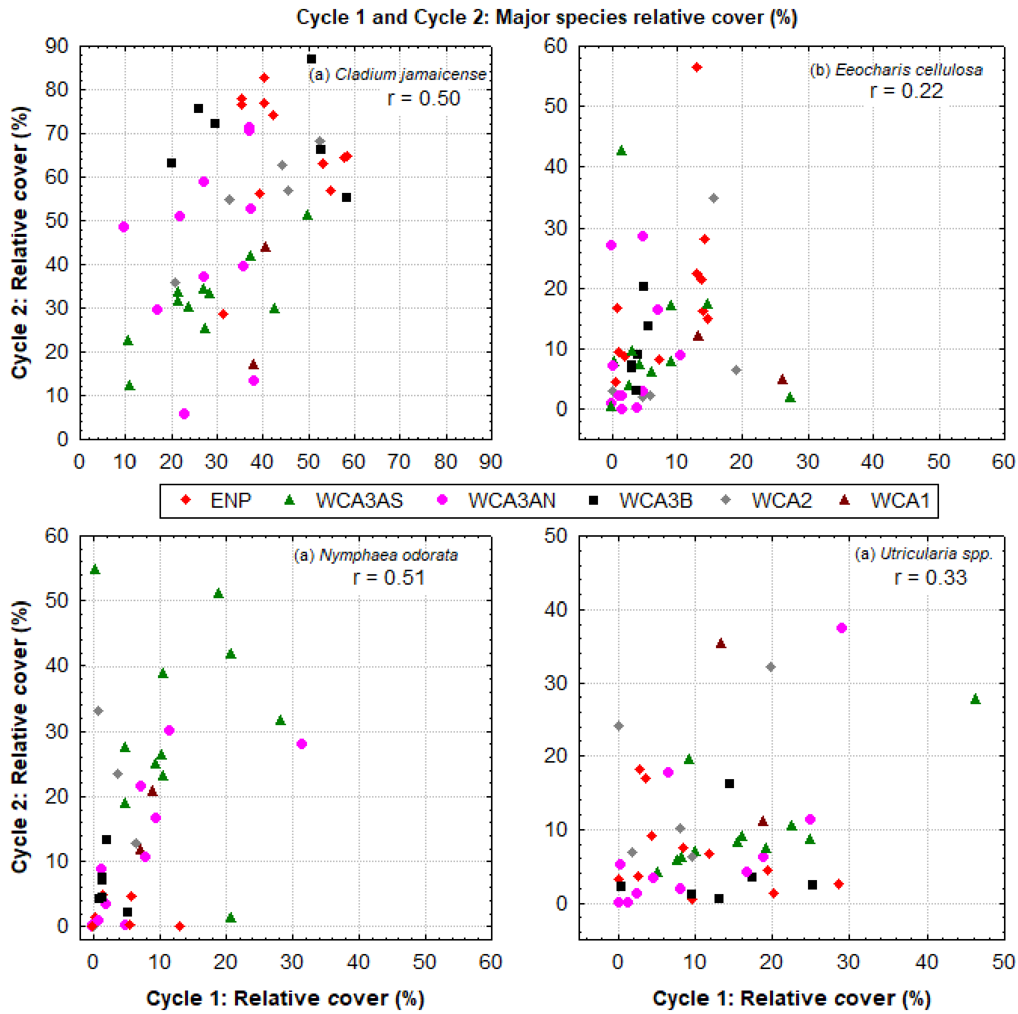

Figure 16: Cycle-1 and Cycle-2 PSU level major species relative cover in 47 PSUs sampled over four years (Year 1-4) of Cycle-2.

In non-metric multidimensional scaling (NMDS) ordination, sites were primarily arranged along hydrologic gradients. Likewise, species in the ordination space also followed the same pattern (Figure 17). Sawgrass and other species common on ridges were clearly separated from slough species along Axis 1, while wet prairie species were intermediate along this axis, and somewhat differentiated along Axis 2. The global k-means clustering analysis for classifying the sites in two groups identified ridges dominated by sawgrass as one dominant cluster, and communities including both wet prairies and sloughs as a second dominant cluster. These groups were somewhat separated on the first ordination axis. Since Cycle-1 data analysis had shown that k-means clustering within individual PSUs mostly corresponded to the global k-means clustering (Ross et al. 2016), in this study also, cluster distance within individual PSUs were used as a measure of community distinctness. In the sampled PSUs, the community distinctness varied from 0.198 to 1.187, and 62% of the sampled PSUs had the values less than 0.80, representing the less distinct to almost indistinct ridge and slough features. Spatially, community distinctness showed similar geographic patterns to those observed for microtopographic variability. For instance, PSUs within central WCA3AS had relatively high community distinctness (Figure 18), suggesting that the R&S pattern are well conserved in that area. In contrast, the PSUs with less distinct communities in WCA3AN, WCA3B and ENP suggested various degree of degradation in R&S landscape in those areas.

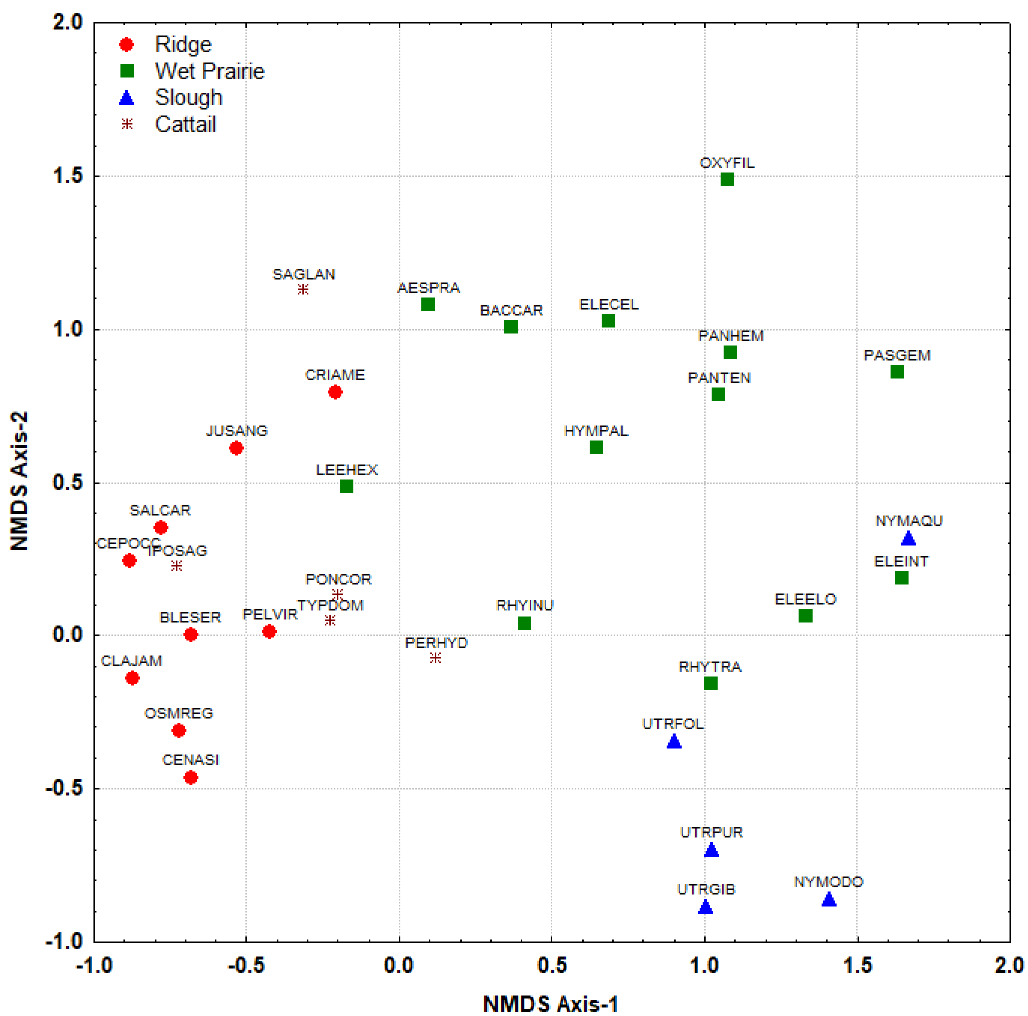

Figure 17: Distribution of major ridge-slough plant species in ordination space. Note coherent clustering of species by community type, which indicates relatively strong fidelity of species to their associated communities across the landscape. Species name are given in Appendix 1.

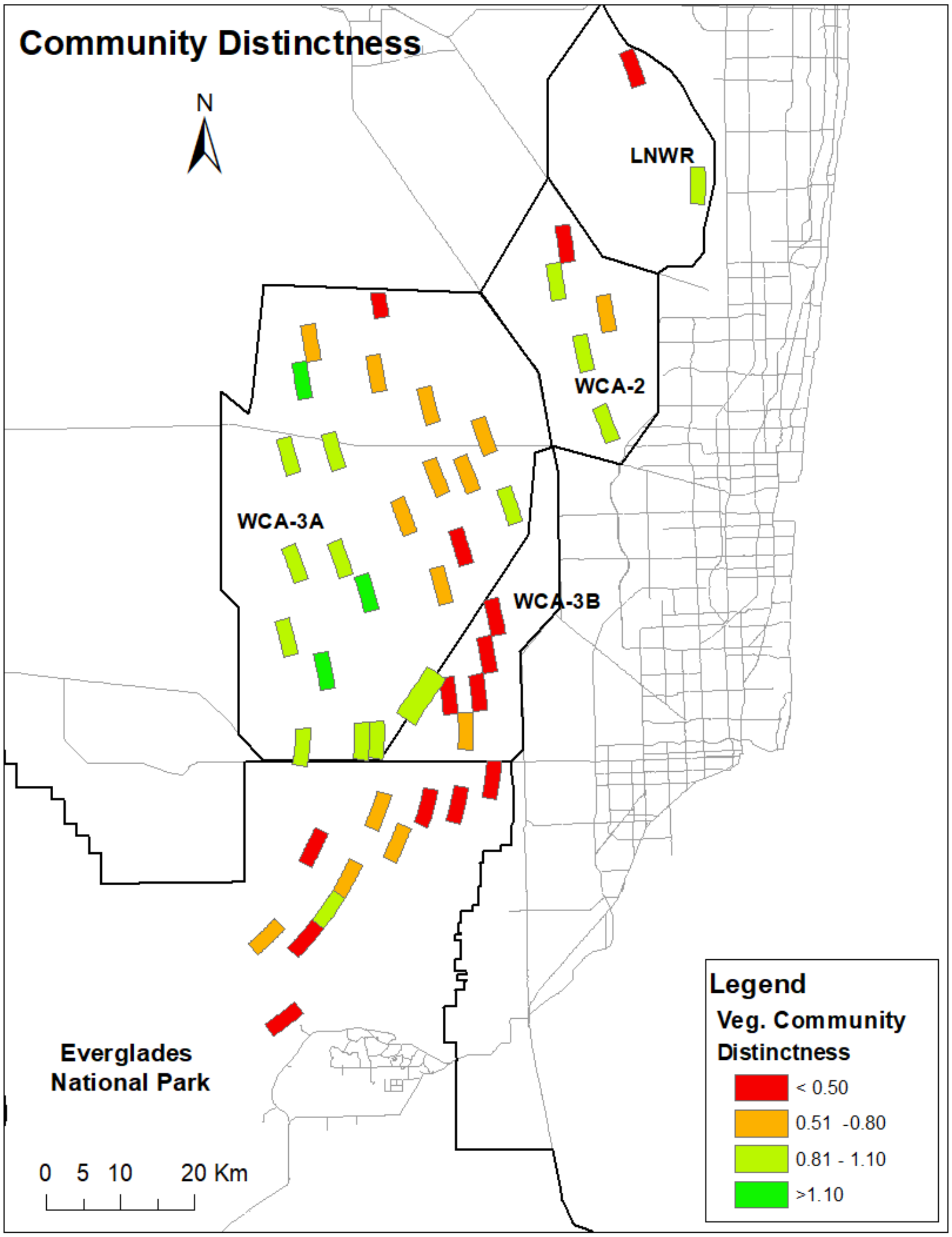

Figure 18: Spatial patterns of vegetation community distinctness measured as a distance between two clusters (k-means clustering) in PSUs sampled over four years (Year 1-4) of Cycle-2.

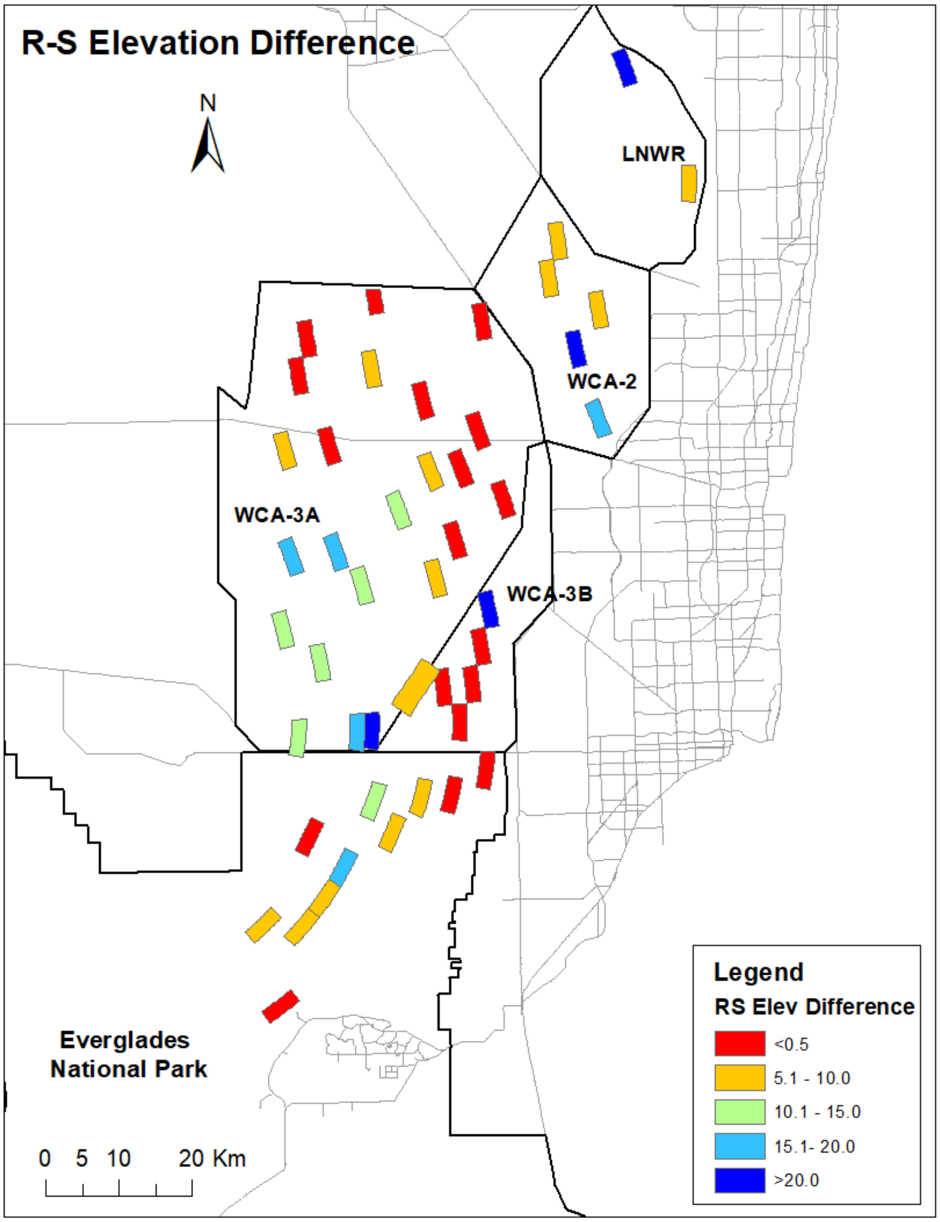

Figure 19: Spatial patterns of difference in long-term mean water level between two clusters (k-means clustering) in PSUs sampled over four years (Year 1-4) of Cycle-2.

Community distinctness was greatly consistent across cycles (r = 0.74; RMSE = 0.212). Though there was slight bias toward greater distinctness in Cycle-1 (Figure 20). Most of PSUs with higher difference ($\Delta > 0.25$) in distinctness between Cycle-1 and Cycle-2 were in WCA3AN, ENP and WCA2 than in other regions suggesting high level of uncertainties. The PSU-21 in WCA2 had the highest difference (increase) in distinctness. In this PSU, the community distinctness was much less in Cycle-2 than in Cycle-1. Twelve PSUs, (4 PSUs in WCA3AS, 4 in

WCA3AN, 2 in ENP and 1 in WCA2) had <0.05 difference in community distinctness between two sampling events. However, in general, the decrease in distinctness was negatively correlated with the community distinctness values in Cycle-1 (Figure 21).

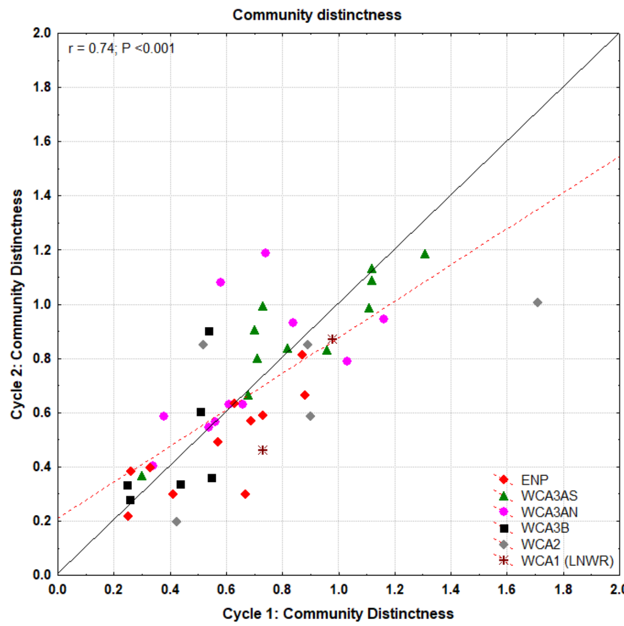

Figure 20: Relationship between Cycle-1 and Cycle-2 PSU community distinctness. Only the PSUs that were sampled over four years (Year 1-4) of both cycles were considered.

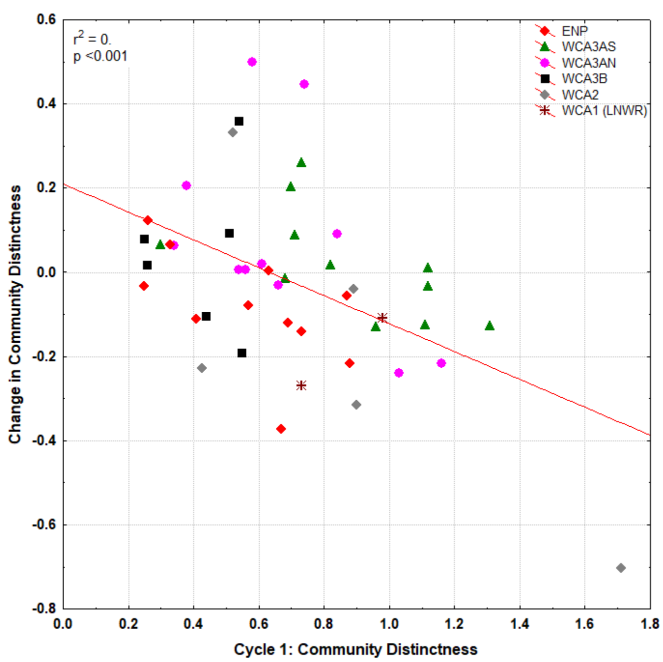

Figure 21: Relationship between Cycle-1 PSU community distinctness and change in community distinctness between Cycle-1 and Cycle-2. Only the PSUs that were sampled over four years (Year 1-4) of both cycles were considered.

The PSUs with high community distinctness also had strong relationship between local water depth and vegetation community composition (as measured by Mantel's r) (Figure 22). An exception was PSU 45, located in WCA3AN, which had high community distinctness, but very low Mantel's r, showing some anomaly in vegetation structure. Spatial distribution of the vegetation-elevation association followed similar patterns to those observed for microtopographic variability and vegetation community distinctness, as the vegetation-elevation correlation was stronger in PSUs within central WCA3AS than in other regions (Figure 23). The vegetation-elevation correlation (Mantel r) is fairly correlated across cycles (r=0.71, p<0.001), but with high variability, rmse = 0.121 (Figure 24).

The difference in community distinctness was negatively correlated ($r^2 = 0.19$; P = 0.002) with change in PSU-level long-term mean water depth. However, change in Mantel r between Cycle-1 and Cycle-2 did not show any significant pattern with change in PSU-level long-term mean water depth. Thus, this was not clear whether such differences real phenomena representing changes in microtopographic and community composition features or simply a sampling artifact.

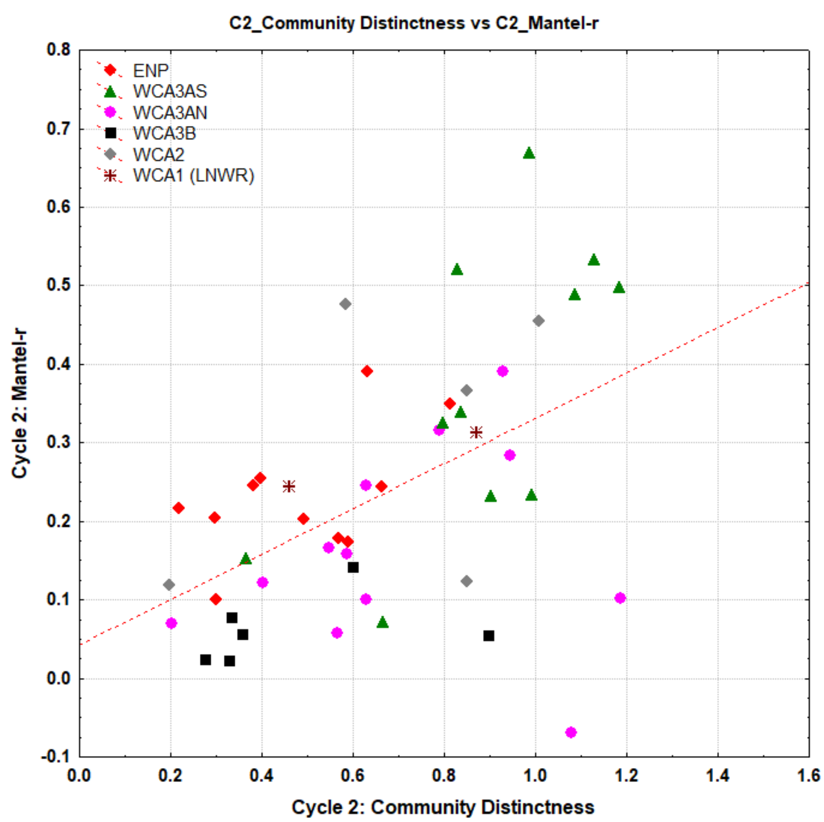

Figure 22: Relationship between community distinctness and mantel r (association between vegetation composition and water depth).

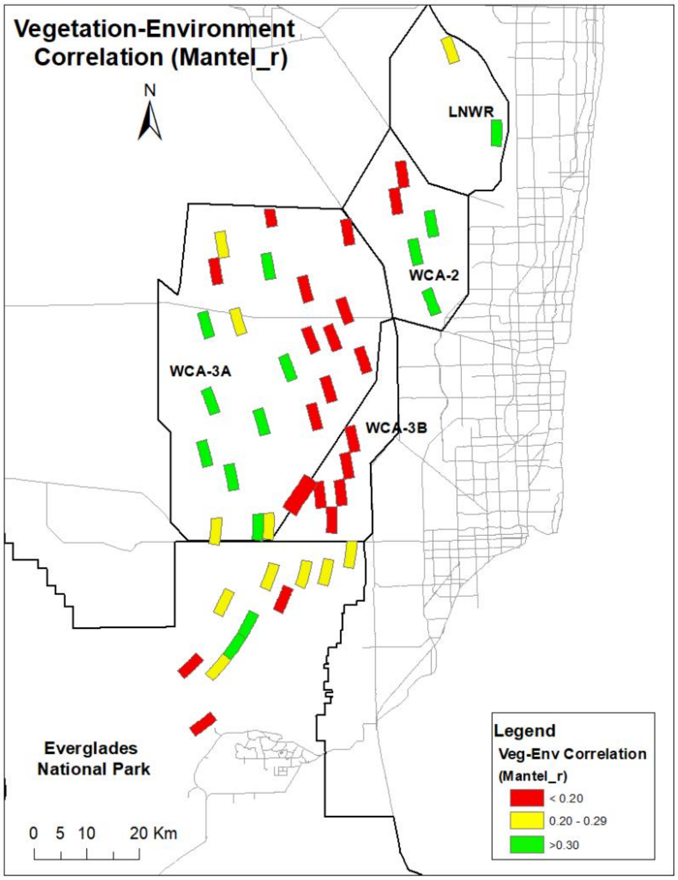

Figure 23: Spatial patterns of elevation-vegetation associations (as measured by Mantel's correlation coefficient [r]) in PSUs sampled over four years (Year 1-4) of Cycle-2.

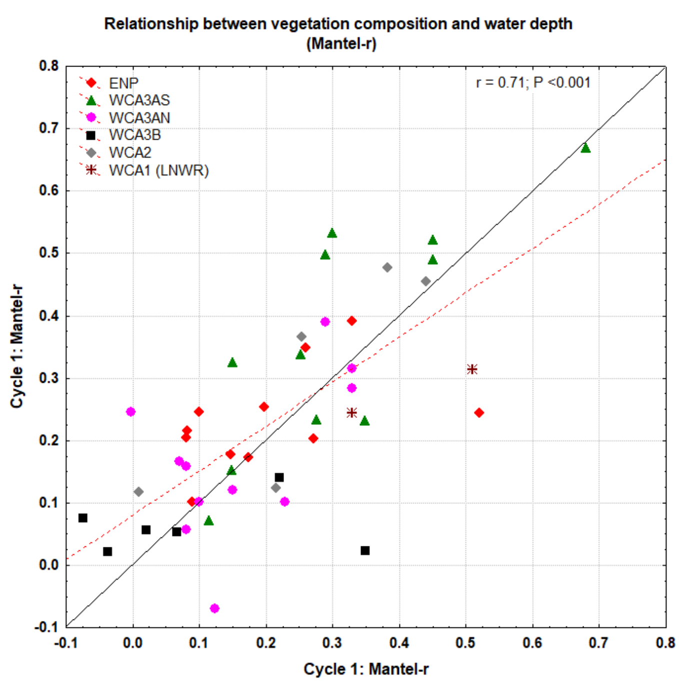

Figure 24: Cycle-1 and Cycle-2 Mantel r (relationship between vegetation composition and water depth (elevation))

4. Discussion

4.1 Microtopographic variation

In the Ridge and Slough landscape, microtopography is one critical component of historic landscape structure. As such, the maintenance and re-establishment of distinct modes of soil elevation (associated with sawgrass ridges and open water sloughs, respectively) is a central goal of Everglades conservation and restoration. Previous monitoring of landscapes throughout the historic Ridge-Slough landscape has identified bi-modality of soil elevations as a key measure of this microtopography (Watts et al. 2010, Ross et al. 2016). The presence of bi-modal soil elevations was found to be largely restricted to PSUs within central WCA3AS (Ross et al. 2016). In these most conserved landscapes, the elevation difference between the high and low elevation mode was generally between 15 and 25 cm, and occurred in PSUs with long-term mean water depths between 30 and 50 cm.

The presence of distinct elevation modes associated with ridges and sloughs is detected by measuring water depths at randomized points within representative 2 x 5 km landscape blocks, which themselves are distributed randomly throughout the Everglades. These water depths are converted into soil elevation measurements by benchmarking water depths on the day of sampling to the multi-annual mean water level. The statistical analysis of bi-modality involves comparing the goodness-of-fit of a single normal distribution with the fit of two normal distributions, which may have equal or unequal variances and equal or unequal weighting. PSUs in which modes whose weights are extremely unequal (i.e., 75% or more points fall within the higher weighted mode) are not considered to have conserved microtopography, both because such uneven modes are more likely to arise as statistical artifacts, and because the historic ridge-slough landscape was composed of approximately equal areas of ridge and slough (McVoy et al. 2011).

Fewer PSUs exhibited statistically significant bi-modality in Cycle-2 than was observed in Cycle-1. However, the shift from detection of bi-modal soil elevations to their non-detection does not necessarily indicate ongoing degradation of remnant pattern in ENP and WCA3B, although this possibility should be a cause for concern. Several factors may contribute to this change. First, in almost all PSUs, fewer points were sampled during Cycle-2 than were sampled in Cycle-1, owing to logistical and budgetary constraints. Detection of bi-modality requires substantial statistical power, and reductions in sampling intensity may have limited our ability to detect subtle bi-modality. Moreover, the shift from statistically significant to non-significant bi-modality does not necessarily indicate a substantial loss of microtopographic relief. For example, in PSU0, a 2-mode model had poorer fit than a 1 mode model, and thus 1-mode model was retained, but the 2-mode model had yielded a similar estimate of elevation differences (10.3 cm) to that observed in Cycle-1. Finally, wet hydrologic conditions through Year 4 of the Cycle-2 sampling period may have influenced estimates of soil elevation distributions. We observed substantial differences in estimates of mean water depth and the standard deviation of water depth in PSUs sampled during wet conditions, probably making hard to keep the measuring stick stable. This additional uncertainty in soil elevation estimates contributes to uncertainty surrounding the presence of multiple soil elevation modes.

4.2 Vegetation characteristics

In the ridge and slough landscape, the distinct zonation of plant communities is shaped by abrupt differences in elevation between ridges and sloughs (Ogden 2005, McVoy et al. 2011). In this study, the distinctness between ridge and slough communities was represented by a test statistic "community distinctness" which was measured using dissimilarity between R&S vegetation community composition, defined as the distance (in multivariate space) between two forcefully imposed vegetation clusters (Isherwood 2013). The high community distinctness values representing highly distinct sawgrass-dominated ridges and *Nymphea*- and *Utricularia*-dominated sloughs observed in conserved landscapes of WCA3AS during Cycle-2 are consistent with the findings during Cycle-1 of this ongoing system-wide monitoring (Ross et al. 2016) and of other studies (Watts et al. 2010; Nungesser 2011). Likewise, in areas subject to increased or decreased water levels due to water management or altered infrastructure, this distinctness is reduced. For instance, the degraded ridge and slough community pattern observed in WCA3N, WCA3B and ENP during both Cycle-1 and 2 was consistent with loss of characteristic microtopography variability in those areas.

While community distinctness was fairly consistent across both cycles (RMSE = 0.29), several PSUs had reduced distinctness in Cycle-2 compared to Cycle-1. The reduction in community distinctness was prevalent in areas (WCA2, WCA3AN, ENP, WCA3B and LNWR) where degraded R&S is prevalent. Although a number of studies have documented rapid shifts (within 3-5 years) in prairie and marsh plant community composition in response to changing hydrologic regimes (Armentano et al. 2006; Zweig and Kitchens 2008; Sah et al. 2014), it is not yet clear whether the difference in community distinctness between two Cycles were the result of changes in hydrologic conditions in that period, though such a shift in species composition at a local scale cannot be ruled out. In general, hydrologic conditions during Cycle-2 were slightly wetter than in Cycle-1, and in some PSUs the difference in mean water depth was greater than 4 cm, which might have extended the hydroperiod as well. During the Cycle-1 (2009-2015), relatively high distinctness values were observed in PSUs that had mean water level between 20 and 50 cm (Ross et al. 2016). Shift in hydrologic conditions outside this range might have caused decreases in distinctness. It becomes a matter of concern, especially when the change in distinctness between two cycles is negatively correlated with the Cycle-1 distinctness (Figure 21). For instance, PSU 21, which showed a much wetter condition in Cycle-2 (LTMWD = 53.5 cm) than in Cycle-1 (LTMWD = 39.5), exhibited the highest decrease in community distinctness. In contrast, in the DPM area, where mean water depth was lower in Cycle-2 than in Cycle-1, had increased community distinctiveness in the most recent sampling.

In degraded areas, where loss in microtopography has primarily been attributed to relatively dry conditions resulting in peat loss (Watts et al. 2010), the reduction in community distinctiveness observed in the last five years might be related to extreme drought conditions that were prevalent in two of 5 years between the two surveys. South Florida witnessed extreme droughts in 2011 and 2014, during which excessive peat decomposition might have occurred, affecting the microtopography of the area. This is somewhat consistent with the pattern observed in microtopography in Cycle-1 and 2. As bi-modality in soil elevations is a key measure of microtopography in this landscape, several PSUs that had bi-modal elevation distribution during Cycle-1, did not show bi-modality during Cycle-2. While many of them also showed much reduced (Δ ~0.3) community distinctness in Cycle-2, there were some PSUs that showed similar shift in microtopography between two cycles, but had slightly improved community distinctness. Moreover, a PSU (PSU 21 in WCA2) had bi-modality in both cycles, but showed the greatest reduction in community distinctness between two cycles. Thus, the reduction in community distinctness may not necessarily indicate ongoing degradation of remnant pattern in WCA3AN and ENP, although this might be a concern, especially when it is hypothesized that in drained areas, loss of microtopography precedes the degradation of R&S plant community distinctness.

Several factors may contribute to the observed changes in community distinctness. Our approach to measuring community distinctness is a newly developed measure based on measurements of distances between two artificially imposed clusters of plant communities in ordination space (Isherwood 2013). While the robustness of representation of ridge and slough features by those two clusters have been vigorously tested, and community distinctness has been found a robust measure of the status of ridge and slough communities (Ross et al. 2016), the factors that affect the ordination might also have impacted the measurement of distances between two clusters within the ordination space. The community distinctness of individual PSUS in Cycle-1 was based on the global ordination of all sites sampled in 62 PSUs, whereas the distinctness in Cycle-2 is based on the ordination of sites in only 47 PSUs. Even among those PSUS, 21 PSUs had fewer points sampled during Cycle-2 than in Cycle-1, owing to logistical and budgetary constraints. Thus, the measure of community distinctness for each PSU might have also been affected by the reduction in sampling intensity.

5. Summary

Measures of both microtopography and plant community distinctness in 47 PSUs revealed a spatial pattern of R&S conditions consistent with system-wide findings based on much large number of PSUs sampled in previous cycle (2009-2015). Some PSUs have experienced shifts in microtopographic variability, changing from bi-modality to unimodal as well as a reduction in community distinctness in some PSUs over the five-year period. However, such shifts do not necessarily indicate ongoing degradation of remnant pattern in some areas such as ENP, WCA3AN and WCA3B. Nevertheless, this possibility should be a cause for concern, especially when two of five years during the first study witnessed extreme drought conditions that possibly had adverse effects on peat soils and microtopography of the area. Several other factors may also contribute to the observed changes in microtopographic variability and community characteristics. While reduced number of sample plots in all the PSUs might have affected the power of detecting bi-modality in soil elevations and community distinctiveness, wet hydrologic conditions at the sampling time during Cycle-2 may also have influenced estimates of soil elevation distributions, adding to the uncertainty observed in this study. Thus, it is likely that bringing the sampling intensity to the previous level may help to improve the efficiency of monitoring this landscape.

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Appendix

Appendix 1: Mean species cover (%) in PSU sampled during Year 1-4 (2015-2019). Only the species that were present in more than 5 plots (among 5429 plots sampled in four years) are listed. The number of 1x1 m plots sampled in each PSU is given in Table 1.

SPCODE	Species	Year-1										
		0	**1**	**2**	**3**	**4**	**6**	**7**	**9**	**11**	**15**	**108**
AESPRA	*Aeschynomene pratensis*	0.04						0.02				0.06
ANNGLA	*Annona glabra*											
BACCAR	*Bacopa caroliniana*	0.27	0.22	0.39	0.15	0.06	0.0	1.61				0.33
BLESER	*Blechnum serrulatum*	0.03		0.02		0.02		0.03				
CENASI	*Centella asiatica*				3.61							
CEPOCC	*Cephalanthus occidentalis*	0.01	0.05	0.20		0.26	0.0	0.61				0.06
CLAJAM	*Cladium jamaicense*	15.2	6.18	13.84	24.93	14.78	9.6	35.04	22.82	29.98	11.69	26.26
CRIAME	*Crinum americanum*	0.36		0.23	0.13	0.33	0.0	1.18		0.01		0.53
DICSPP	*Dichanthelium* sp.				5.70							
ELECEL	*Eleocharis cellulosa*	3.16		0.97		1.10	2.3	7.02	1.37	1.39	1.01	1.79
ELEELO	*Eleocharis elongata*			2.20		2.69				0.01		2.33
ELEINT	*Eleocharis interstincta*		0.02							0.01		
ELESPP	*Eleocharis spp.*		1.16									
FUIBRE	*Fuirena breviseta*	0.01			0.03							
HYDCOR	*Hydrolea corymbosa*					0.02						
HYMLAT	*Hymenocallis latifolia*	0.10			0.21			0.38				
HYMPAL	*Hymenocallis palmeri*											
IPOSAG	*Ipomoea sagittata*											
JUSANG	*Justicia angusta*	0.15		0.34		0.32	0.0	0.71		0.01		0.21
LEEHEX	*Leersia hexandra*		0.01	0.02	0.01	0.03		0.13		0.29		0.02
LUDALA	*Ludwigia alata*	0.01										
LYGMIC	*Lygodium microphyllum*		0.03									
MIKSCA	*Mikania scandens*	0.01			0.72	0.02						
NYMAQU	*Nymphoides aquatica*	0.04		0.65		0.39		0.43				0.07
NYMODO	*Nymphaea odorata*		2.51	18.21		15.82		9.18	2.23	17.81	18.26	3.38
OSMREG	*Osmunda regalis*				0.28							
OXYFIL	*Oxypolis filiformis*							0.11				
PANHEM	*Panicum hemitomon*	0.16	0.39	0.72	0.03	0.65	0.0	0.64		1.52	0.70	0.37
PANTEN	*Panicum tenerum*											
PASGEM	*Paspalidium geminatum*	0.11	0.18	0.11		0.03	0.0	0.33		0.12	0.21	0.02
PELVIR	*Peltandra virginica*	0.19	0.17	0.24	0.15	0.15	0.0	0.16		0.05		0.24
PERHYD	*Persicaria hydropiperoides*	0.01	0.01		0.10					0.58		0.01
PERSET	*Persicaria setacea*											
PLUBAC	*Pluchea baccharis*				0.45			0.04				
PONCOR	*Pontederia cordata*	0.04	0.14	0.28	0.31	0.21	0.0	0.28		1.96	0.14	0.37
POTILL	*Potamogeton illinoensis*											
PROPAL	*Proserpinaca palustris*				0.62							
RHYINU	*Rhynchospora inundata*		0.14	0.05	0.07	0.07		0.04				1.32
RHYTRA	*Rhynchospora tracyi*	0.01	6.04				0.1					4.08
SAGLAN	*Sagittaria lancifolia*	0.04	0.04		0.38		0.0	0.33		0.70	0.01	0.50
SALCAR	*Salix caroliniana*					0.01						
THEINT	*Thelypteris interrupta*		0.02		0.11							
TYPDOM	*Typha domingensis*	0.19		0.08		0.47	0.0	1.26	0.78	4.26	2.23	0.10
UTRFOL	*Utricularia foliosa*	0.41	0.37	1.28		1.02	0.0	3.07	5.79	3.33	4.09	0.01
UTRGIB	*Utricularia gibba*		0.02	0.02		0.03			0.03	0.33		
UTRPUR	*Utricularia purpurea*	1.31	14.68	2.83		2.95	2.5	12.48	4.76	0.67	29.44	0.17

Appendix 1: Contd.

SPCODE	Species	Year-2										
		17	**18**	**19**	**20**	**21**	**23**	**24**	**26**	**28**	**30**	**31**
AESPRA	*Aeschynomene pratensis*		0.39					0.12	0.12			
ANNGLA	*Annona glabra*		0.02								0.04	
BACCAR	*Bacopa caroliniana*	0.02	2.32	0.56	2.35		2.43	0.54	6.55	0.82	2.46	2.37
BLESER	*Blechnum serrulatum*	0.23					0.15		0.20		0.01	
CENASI	*Centella asiatica*											
CEPOCC	*Cephalanthus occidentalis*	0.10		0.33			1.85		1.86	0.07		0.46
CLAJAM	*Cladium jamaicense*	24.1	11.61	15.07	18.96	13.70	9.08	14.88	9.37	16.33	23.34	21.27
CRIAME	*Crinum americanum*			0.64	0.96	0.03	1.04	0.24	1.09	0.44	0.70	0.56
DICSPP	*Dichanthelium* sp.											
ELECEL	*Eleocharis cellulosa*	0.30	21.66	0.04	1.63	0.88	1.84	1.68	2.99	1.40	5.69	0.69
ELEELO	*Eleocharis elongata*	3.86				0.38	1.58		1.98		1.33	1.92
ELEINT	*Eleocharis interstincta*	0.11										
ELESPP	*Eleocharis spp.*											
FUIBRE	*Fuirena breviseta*										0.01	
HYDCOR	*Hydrolea corymbosa*						0.08		0.33			0.01
HYMLAT	*Hymenocallis latifolia*											
HYMPAL	*Hymenocallis palmeri*											
IPOSAG	*Ipomoea sagittata*											
JUSANG	*Justicia angusta*		0.27	0.27	0.19		0.44	0.12	0.95	0.09	0.55	0.05
LEEHEX	*Leersia hexandra*	0.13		0.05	0.02		0.11		0.05	0.05		0.04
LUDALA	*Ludwigia alata*			0.03					0.01		0.01	
LYGMIC	*Lygodium microphyllum*	0.03										
MIKSCA	*Mikania scandens*			0.07			0.04					
NYMAQU	*Nymphoides aquatica*	0.11	0.27				2.30	0.05	1.65	0.19	0.76	0.69
NYMODO	*Nymphaea odorata*	8.19		2.24	1.89		12.16		14.92	6.22	0.52	9.67
OSMREG	*Osmunda regalis*	0.13					3.03		0.01			
OXYFIL	*Oxypolis filiformis*						0.31	0.04			0.01	
PANHEM	*Panicum hemitomon*	0.17	0.66	0.13	0.10	0.06	0.57	0.58	0.66	0.04	0.78	0.19
PANTEN	*Panicum tenerum*		0.24					0.08		0.03		0.01
PASGEM	*Paspalidium geminatum*	0.02	0.61		0.06		0.80	0.12	0.41	0.05	0.45	0.13
PELVIR	*Peltandra virginica*	0.92	0.02	0.15	0.21		0.15		0.94	0.04	0.36	0.13
PERHYD	*Persicaria hydropiperoides*	0.01										
PERSET	*Persicaria setacea*			0.48								
PLUBAC	*Pluchea baccharis*							0.01				
PONCOR	*Pontederia cordata*	1.13		1.49	0.01		0.08	0.25	0.91	0.11	0.39	0.44
POTILL	*Potamogeton illinoensis*										0.04	0.04
PROPAL	*Proserpinaca palustris*										0.04	
RHYINU	*Rhynchospora inundata*	0.10										
RHYTRA	*Rhynchospora tracyi*	0.02						0.52				0.02
SAGLAN	*Sagittaria lancifolia*	0.08		6.08	0.10		0.16	0.02	0.21	0.24	0.47	0.12
SALCAR	*Salix caroliniana*			0.60								
THEINT	*Thelypteris interrupta*											
TYPDOM	*Typha domingensis*	0.38		10.28		0.38	0.39	0.27	0.27	1.56	0.11	0.44
UTRFOL	*Utricularia foliosa*	2.29	1.27	0.31	0.24	0.61	1.91	1.36	3.76	1.15	0.67	1.10
UTRGIB	*Utricularia gibba*											
UTRPUR	*Utricularia purpurea*	1.68			0.46		1.06	2.54	1.95	6.52	0.40	0.62

Appendix 1: Contd.

SPCODE	Species	Year-3											
		32	**34**	**35**	**36**	**37**	**39**	**43**	**44**	**45**	**47**	**513**	**DPM**
AESPRA	*Aeschynomene pratensis*						0.01						
ANNGL	*Annona glabra*												
BACCA	*Bacopa caroliniana*	0.14	0.13	1.4			1.49	0.98	0.63		0.50	0.02	0.39
BLESER	*Blechnum serrulatum*		0.26										
CENASI	*Centella asiatica*												
CEPOCC	*Cephalanthus occidentalis*	0.07	0.49		0.01	0.13	0.71				0.06	0.03	0.33
CLAJAM	*Cladium jamaicense*	35.8	11.1	1.8	11.3	21.6	15.3	20.7	24.8	8.2	20.0	17.1	54.26
CRIAME	*Crinum americanum*	0.09	0.06	0.3	0.01	0.03	0.54	0.50	0.05		0.03	0.12	0.30
DICSPP	*Dichanthelium* sp.												
ELECEL	*Eleocharis cellulosa*	1.56	1.73	4.6	0.01	0.26	1.60	0.35	4.47	0.4	0.52	0.23	3.82
ELEELO	*Eleocharis elongata*		0.58			0.03		0.12			0.16		2.26
ELEINT	*Eleocharis interstincta*	0.10								0.1			
ELESPP	*Eleocharis spp.*												
FUIBRE	*Fuirena breviseta*												
HYDCO	*Hydrolea corymbosa*		0.01				0.01	0.03					
HYMLA	*Hymenocallis latifolia*												
HYMPA	*Hymenocallis palmeri*												
IPOSAG	*Ipomoea sagittata*												
JUSANG	*Justicia angusta*	0.06	0.04	0.0			0.19	0.12	0.05			0.01	0.01
LEEHEX	*Leersia hexandra*	0.03	0.11	0.2			0.06	0.02	0.10		0.50	0.01	0.00
LUDAL	*Ludwigia alata*												
LYGMIC	*Lygodium microphyllum*												
MIKSCA	*Mikania scandens*												
NYMAQ	*Nymphoides aquatica*	0.20	0.49					0.02	0.05		0.01		0.11
NYMOD	*Nymphaea odorata*	1.07	21.5	0.0	27.9	8.61	1.63	0.23	2.20	7.1	9.20		1.11
OSMRE	*Osmunda regalis*		0.01										
OXYFIL	*Oxypolis filiformis*												
PANHE	*Panicum hemitomon*		0.01	0.4			0.74	0.46		0.1			
PANTEN	*Panicum tenerum*		0.11				0.19		0.02			0.02	0.08
PASGEM	*Paspalidium geminatum*	0.29	0.12		0.65		0.19		0.09	0.3	0.17	0.05	0.79
PELVIR	*Peltandra virginica*	0.07	1.08	0.1			0.10	0.03	0.04		0.70		0.17
PERHYD	*Persicaria hydropiperoides*											0.02	
PERSET	*Persicaria setacea*					0.42							
PLUBAC	*Pluchea baccharis*												
PONCOR	*Pontederia cordata*	0.09	1.79	1.0	0.28	0.04	0.04		0.01	0.3	1.66	0.06	0.12
POTILL	*Potamogeton illinoensis*	0.17						0.04					0.01
PROPAL	*Proserpinaca palustris*							0.01					
RHYINU	*Rhynchospora inundata*						0.01						
RHYTR	*Rhynchospora tracyi*							0.01				0.06	
SAGLAN	*Sagittaria lancifolia*	0.06	0.04	3.1	0.05	0.27	0.09	1.83	0.08		0.50	0.03	0.19
SALCAR	*Salix caroliniana*					0.43		0.03			0.28	0.44	
THEINT	*Thelypteris interrupta*		0.15										
TYPDO	*Typha domingensis*	0.23	1.60	0.3	1.57	6.81	0.97	0.58	0.18	2.6	5.66	0.15	0.34
UTRFOL	*Utricularia foliosa*	0.64	3.48	0.6	1.67	1.55	0.42	0.16	0.13	0.2	0.70	0.08	1.21
UTRGIB	*Utricularia gibba*												
UTRPUR	*Utricularia purpurea*	0.29	2.56		17.5	1.56	0.07	0.06	0.60	4.2	0.76	0.83	0.53

Appendix 1: Contd.

SPCODE	Species	Year-4												
		50	**51**	**52**	**53**	**54**	**55**	**56**	**58**	**59**	**61**	**62**	**63**	**220**
AESPRA	*Aeschynomene pratensis*	0.04				0.03	0.02	0.04	0.02			0.12		
ANNGLA	*Annona glabra*	0.15		0.09		0.09			0.47			0.19		0.40
BACCAR	*Bacopa caroliniana*	0.82	3.00		0.04	1.25	1.46	0.84	2.79			0.98		1.06
BLESER	*Blechnum serrulatum*	0.30		0.09		0.09	0.19		0.04			0.02		
CENASI	*Centella asiatica*		0.17											
CEPOCC	*Cephalanthus occidentalis*	0.04	1.88	1.66	0.05		0.36	0.03	0.67	0.46		0.08		
CLAJAM	*Cladium jamaicense*	58.74	11.93	24.79	31.99	53.75	24.74	60.84	24.64	64.81	41.96	67.10	9.78	72.52
CRIAME	*Crinum americanum*		0.53	0.09		0.02	0.71	0.20	0.53	0.08		0.40		0.04
DICSPP	*Dichanthelium* sp.													
ELECEL	*Eleocharis cellulosa*	7.99	16.64	3.44	2.60	20.46	7.94	2.84	18.53	0.52	1.37	9.08	1.13	1.63
ELEELO	*Eleocharis elongata*	0.93		11.38	3.17	0.37	2.11	3.02	13.03			1.92		
ELEINT	*Eleocharis interstincta*								0.13					0.24
ELESPP	*Eleocharis spp.*													
FUIBRE	*Fuirena breviseta*													
HYDCOR	*Hydrolea corymbosa*						0.02							
HYMLAT	*Hymenocallis latifolia*													
HYMPAL	*Hymenocallis palmeri*		0.06			0.05	1.47	0.25	0.04	0.66		0.17		0.22
IPOSAG	*Ipomoea sagittata*	0.01		0.02			0.11	0.05				0.02		
JUSANG	*Justicia angusta*	0.13	0.21			0.19	0.22	0.13				0.10		0.16
LEEHEX	*Leersia hexandra*	0.04	0.55	0.05	0.04	0.07	0.26	0.28	0.03			0.24		0.02
LUDALA	*Ludwigia alata*									0.02				
LYGMIC	*Lygodium microphyllum*													
MIKSCA	*Mikania scandens*													
NYMAQU	*Nymphoides aquatica*	0.14		0.63			3.22	0.10	0.21		0.01		0.11	0.14
NYMODO	*Nymphaea odorata*	2.25	0.02	15.11	20.40	0.05	13.14		0.90		18.02	0.01	33.84	2.14
OSMREG	*Osmunda regalis*													
OXYFIL	*Oxypolis filiformis*		0.11											
PANHEM	*Panicum hemitomon*	0.21	1.59	0.22	0.17	0.63	2.77	0.60	0.62	0.10		0.82	0.04	0.02
PANTEN	*Panicum tenerum*													
PASGEM	*Paspalidium geminatum*	0.18	0.17	0.09	0.42	0.16	0.43	0.24	1.74			0.17	0.40	0.09
PELVIR	*Peltandra virginica*	0.09	0.02	0.75	0.02	0.20	0.04	0.02	0.63	0.10		0.24		0.08
PERHYD	*Persicaria hydropiperoides*							0.01		0.04				
PERSET	*Persicaria setacea*									0.60				
PLUBAC	*Pluchea baccharis*	0.01	0.21			0.01				0.10				
PONCOR	*Pontederia cordata*		0.07	1.48	0.16	0.06	0.02	0.33	0.52	0.11		0.07		0.08
POTILL	*Potamogeton illinoensis*	0.07	0.09					0.02	1.77			0.09		
PROPAL	*Proserpinaca palustris*							0.02		0.01				
RHYINU	*Rhynchospora inundata*						0.09							
RHYTRA	*Rhynchospora tracyi*		1.77				0.29			0.01				
SAGLAN	*Sagittaria lancifolia*	0.04	1.93	0.15	0.21	0.61	0.02	0.04	0.16	2.26	0.06	0.44		
SALCAR	*Salix caroliniana*		0.62	0.04			0.97		0.23	0.63	0.05			0.40
THEINT	*Thelypteris interrupta*													
TYPDOM	*Typha domingensis*	0.30	2.73	8.83	1.15	1.14		0.62	0.68	0.02	2.07	0.88	0.84	0.46
UTRFOL	*Utricularia foliosa*	0.44		0.09	0.71	0.69	0.74	1.51	0.26		1.94	0.23	4.70	0.42
UTRGIB	*Utricularia gibba*													
UTRPUR	*Utricularia purpurea*	1.00		5.85	27.96	0.37	4.42	2.14	4.15	0.01	1.40	0.08	10.81	0.28