

Monitoring of Tree Island Condition in the Southern Everglades Year-5 Report (2019-2024)

(Cooperative Agreement #: W912HZ-19-2-0032)



Submitted to: **Ms. Sherry Whitaker**

U.S. Army Engineer Research and Development Center (U.S. Army - ERDC) 3909 Halls Ferry Road, Vicksburg, MS 39081-6199 Email: Sherry.L.Whitaker@usace.army.mil

Jay Sah, Ximena Mesa, Daniel Gann, Michael Ross, Bianca Constant, Susana Stoffella, Santiago Castaneda, Juliana Alvarez

> Institute of Environment Florida International University, Miami, FL

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Authors' Affiliation

Jay P. Sah, Ph.D. – Research Professor

Institute of Environment Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-1658; Email: sahj@fiu.edu

Daniel Gann, Ph. D. – Assistant Professor

Department of Biological Sciences / Institute of Environment Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-1971; Email: gannd@gmail.com

Michael S. Ross, Ph.D. – Professor

Department of Earth & Environment / Institute of Environment Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-1420; Email: rossm@fiu.edu

Ximena Mesa – *Ph.D. Student/Research Assistant*

Institute of Environment Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-6066; Email: xmesa@fiu.edu

Susana Stoffella – Research Analyst

Institute of Environment, Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-0493; Email: stoffell@fiu.edu

Bianca Constant – Research Analyst

Institute of Environment, Florida International University 11200 SW 8th ST, Miami, FL 33199 Tel. (305) 348-6066; Email: biconsta@fiu.edu

Santiago Castaneda – * – Lab Manager II

Institute of Environment, Florida International University 11200 SW 8th ST, Miami, FL 33199
Tel. (305) 348-6066; Email: scastane@fiu.edu
**Currently: Miami, Dada Division of Environment and Man

*Currently: Miami-Dade Division of Environment and Management (DERM)

Juliana Alvarez – Sr. Field/Lab Technician

Institute of Environment, Florida International University 11200 SW 8th ST, Miami, FL 33199

Tel. (305) 348-6066; Email: jalvarez062001@gmail.com

*Currently: Research Volunteer, Institute of Environment, FIU

Cover Photo: Bayhead forest featuring a pond apple (*Anona glabra*) trunk surrounded by a dense understory vegetation dominated by giant leather fern (*Acrostichum danaeifolium*). *Photo courtesy: Erica Garcia*.

Table of Contents

Ge	neral	l Background	5				
1.	Effects of hydrology and hurricane on vegetation dynamics in tree island hardwood hammocks of the southern Everglades						
		Introduction					
	1.2	Methods	10				
		1.2.1 Study Area	10				
		1.2.2 Data Collection	11				
		1.2.3 Data Analysis	13				
	1.3	Results	15				
		1.3.1 Hydrologic conditions	15				
		1.3.2 Tree mortality and ingrowth	21				
		1.3.3 Tree layer vegetation dynamics	29				
		1.3.4 Herb and shrub layer vegetation dynamics	34				
	1.4	Discussion	39				
2.	Hydrologically driven vegetation dynamics in bayhead and bayhead swamp portion tree islands						
	2.1	Introduction	44				
	2.2	Methods	45				
		2.2.1 Study Area	45				
		2.2.2 Data Collection	46				
		2.2.3 Data Analysis	48				
	2.3	Results	50				
		2.3.1 Hydrologic conditions	50				
		2.3.2 Tree/Sapling-layer vegetation dynamics	57				
		2.3.3 Shrub and herb layer vegetation dynamics	63				
	2.4	Discussion	67				
3.	_	ntial Distribution of Plant Communities Mapped from Multispectral Satellite and borne LiDAR Data and their Realized Hydrological Niche Spaces across Tree	d				
	Isla	ands in Northern ENP (Ximena Mesa and Daniel Gann)	70				
	3.1	Introduction	70				

3.2 Methods	71
3.2.1 Study Area	71
3.2.2 Plant Community Classification Schemes	72
3.2.3 Data Selection and Processing	73
3.2.4 Spectral Signature Evaluation	74
3.2.5 Morphological Filtering of Vegetation Maps	75
3.2.6 User-Based Accuracy Assessment	75
3.2.7 Woody Community Class Distribution	75
3.2.8 Absolute and Relative Elevation by Island and Vegetation Class	76
3.2.9 Hydrology by Island and Vegetation Class	76
3.2.10 Canopy Height Model from Historic Stereophotography	76
3.3 Results and Discussion	77
3.3.1 Map Accuracy Assessment	77
3.3.2 Class Distribution, Relative Elevation and Hydrology by Island	79
3.3.3 Accuracy of ASP Point Cloud DSM	171
Acknowledgments	176
Literature Cited	176

General Background

Tree islands, an integral component of the Everglades, are abundant in both the marl prairie and ridge and slough landscapes. They are also likely to be sensitive to large-scale restoration actions associated with the Comprehensive Everglades Restoration Plan (CERP) which was authorized by the Water Resources Development Act (WRDA) of 2000 to restore south Florida ecosystems. Specifically, changes in hydrologic regimes associated with ongoing restoration projects and plans (such as the construction and operation of two Tamiami Bridges, implementation of Central Everglades Planning Project (CEPP) components, and the Combined Operational Plan (COP) (USACE, 2014; USACE, 2020)) will continue influencing the impact of existing local and landscape-level drivers and stressors, such as hydrology, invasive exotics, windstorms, and fire (Wetzel et al., 2017).

While alterations of these drivers and stressors influence the landscape- level spatial distribution of tree islands, the hydrologic alterations also affect the internal water economy of islands in both inland and coastal wetlands. This in turn influences tree island plant community structure and function by affecting the following: species composition, tree regeneration and growth (Sah et al., 2018; Ross et al., 2022; Stoffella et al., 2022), soil characteristics (Steinmuller et al. 2021), wildlife use of islands (Bozas 2024), and microbial communities (Almeida et al. 2022). In the Greater Everglades Conceptual Ecological Model (CEM), researchers have identified tree island plant community composition and structure as one of several ecological attributes that are affected by changes in hydrologic characteristics, fire regimes and other stressors. When these stresses become severe, the forest's structure and function can be in peril, leading to tree island loss. For restoration purposes, it is important to predict when natural and/or management-induced hydrologic conditions and other stressors will surpass the ability of islands to remain ecologically functional. Several examples of such adverse episodes have been reported. For instance, Everglades researchers showed that loss of tree islands in the Water Conservation Areas was primarily caused by management-related high water levels due to compartmentalization of the system after the 1960s (Patterson & Finck, 1999; Brandt et al., 2000). Likewise, an analysis of multi-year historical aerial photography suggested that decline in the aerial extent of tree islands also occurred within Everglades National Park (ENP) between 1952 and 2004 (Sklar et al., 2013). Although reasons for the decline in ENP islands have not been fully explored, one possibility is that it reflects the effects of alterations in the Everglades' hydrologic regime either directly, or through their impact on other stressors such as fire. Thus, a strategy for tree island work that focuses on both local and landscapescale effects is critical for the RECOVER monitoring program.

To better understand inter-annual variability as well as the long-term trends and mechanisms that drive them, it is essential to delineate patterns of community composition and configuration at high spatial precision. This allows for detection of short-term fluctuations and differentiation from persistent long-term change. An approach that concentrates effort on linking intensive ground surveys with extensive community patterns derived from satellite data, aerial photography, and topographic variation derived from LiDAR is likely to help in reaching a more nuanced understanding of past change in tree island structure. This will also help in projecting responses to

future changes in water level resulting from natural variations in rainfall and ongoing restoration activities.

To strengthen our ability to assess the "performance" of tree island ecosystems and predict how hydrologic alterations translate into ecosystem responses, an improved understanding of tree island plant community structure and function, and its interactive responses to disturbances such as fires and hurricanes is important. Built on a baseline study of vegetation structure and composition and associated biological processes over three years (1999-2002) on three tree islands in Shark River Slough (Ross and Jones, 2004), a broader study was initiated in 2005 and has been continued through today. While the initial (1998-2003) tree island work was supported by the National Park Service (NPS) through the Department of Interior's Critical Ecosystems Study Initiative (CESI), for four years (2005-2009) the project was funded alternatively by the US Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD), directly or indirectly through ENP. Since 2009, the study has been funded by the US Army Corps of Engineers (USACE) through its contracting office US Army Engineers Research and Development Center (ERDC). Until the Fall of 2014, the study was led by Dr. Michael Ross. Thereafter, the study has been led by Dr. Jay Sah, while Dr. Michael Ross and Dr. Daniel Gann are actively involved as the Co-PIs in the study. The comprehensive results of work accomplished through 2014 are described in Ruiz et al., (2011, 2013a) and Sah et al., (2012, 2015). The results of the thorough analysis of vegetation dynamics over 20 years (1999-2019) and detailed results of work accomplished between 2014 and 2019 are described in Sah et al., (2020). A new phase of the project was initiated in Fall 2019 (Cooperative Agreement # W912HZ-19-2-0032). The results of the study completed each year during the first four years (2019-2023) of this phase are described in four annual reports (Sah et al., 2021, 2022, 2023, and 2024), respectively.

The major goal of ongoing monitoring of southern tree islands is to assess structural and compositional responses of tree island vegetation to natural and management-induced hydrologic change, alterations in relative proportions of forest communities on the islands, and the expansion or contraction of islands within their surrounding marshes. This research addresses the relevant RECOVER performance measures (PM), (1) GE-15: 'Ridge and Slough Sustainability', and (2) 'Total System Performance Measure (RECOVER, 2011). The working hypothesis of the study is expressed as 'the loss of elongated patterns of ridges, sloughs, and tree islands in the direction of water flow in the ridge and slough landscape of the Everglades is attributed to disrupted sheet flow and related changes in water depth' identified in the hypothesis cluster of the sub-section 3.3.7.1 of the 2009 CERP Monitoring and Assessment Plan (RECOVER, 2009). The ongoing work is also linked to the most recent update of the Greater Everglades Landscape hypothesis cluster, namely "Interrelationships of Sheet Flow, Water Depth Patterns, Oligotrophic Nutrient Status, and Landscape Patterns" (*in progress: Jenna May – personal communication*). In addition, the results from this work are likely to be used in developing tree island performance measures which are currently in progress.

Since 2012, the study has linked field sampling (in a network of permanent plots and along transects) and remote sensing activities to establish a more complete, spatially explicit inventory

of vegetation patterns within individual tree islands, one that can be used to monitor vegetation change in a consistent and repeatable way.

The specific objectives of our ongoing research are:

- 1. To assess temporal changes in the structure and composition of both swamp forest and hardwood hammock.
- 2. To determine the relationships among the hydrologic regimes of adjacent marshes, other stress variables, and dynamics of vegetation communities on tree islands.
- 3. To develop a tree island plant community/vegetation classification based on canopy and understory vegetation types along the full elevation gradient from hardwood hammock to surrounding marshes for each tree island.
- 4. To develop and validate classification algorithms based on bi-seasonal spectral reflectance models and LiDAR derived canopy height models that allow for consistent and repeatable delineation of vegetation assemblages and delineate their boundaries and changes of boundaries.
- 5. To scale the vegetation classes to remote sensor resolutions that are available for the past 35+ years and to map the communities at multiple spatial resolutions and multiple thematic class details.
- 6. To detect and map changes and trends in aerial extent of the relative proportion of different vegetation communities from the long-term remotely sensed record from the lower resolution spectral data.
- 7. To investigate the correlation of spatially explicit long-term vegetation changes in response to hydrological regime changes.

This document describes the results of the work accomplished over 5 years (2019-2024) of the project (Cooperative Agreement # W912HZ-19-2-0032). Section 1 focuses on tree layer and understory vegetation dynamics in hardwood hammock portions of eight tree islands in ENP. Detailed vegetation study in the hardwood hammock plots was done on eight islands during the first year of this phase of the project, and on only four islands thereafter. However, during the third of the project, a hardwood hammock plot was also established and sampled for the first time on an additional island (NP-202). The primary focus of this section of this year's report is on vegetation responses to annual hydrologic changes and recovery after Hurricane Irma. Section 2 summarizes vegetation changes in bayhead forest and bayhead swamp portions of four Shark River Slough tree islands. Additionally, this section also describes vegetation composition and structure in bayhead swamp forests sampled for the first time in 2022/2023 on four additional tree islands. Section 3 summarizes plant community distributions determined by fine-scale vegetation mapping from multispectral satellite and airborne LiDAR data and their realized hydrological niche spaces on eleven tree islands, five located in the Shark River Slough (SRS), five in Northeast Shark River Slough (NESRS) and one in prairie along the eastern border of the Everglades National Park (ENP).

1. Effects of hydrology and hurricane on vegetation dynamics in tree island hardwood hammocks of the southern Everglades

1.1 Introduction

Tree islands are a prominent feature in both the marl prairies (MP) and ridge and slough (R&S) landscapes of the Everglades. In the R&S landscape, flow-induced teardrop-shaped tree islands often include different plant communities - tropical hardwood hammock, bayhead forest (hereafter called 'bayhead') and bayhead swamp - arranged along topographic, hydrologic and soil nutrient gradients (Armentano et al., 2002; Sah, 2004; Espinar et al., 2011; Sah et al., 2018). Despite the small areas they cover, the hardwood hammock-dominated heads are of great ecological significance, as both biodiversity and phosphorus 'hotspots' within the homogeneous oligotrophic landscape (Ross and Jones, 2004; Wetzel et al., 2008; Bozas 2024), and of cultural significance, as the these hammocks have been used by native tribes for centuries (NASEM 2024). While hydrology plays an important role in the development and maintenance of the ridge-slough-tree island patterned landscape, the associated plant communities also influence the hydrodynamics and spatial distribution of soil resources, which in turn affect ecological processes on tree islands (Ross and Jones, 2004; Ross et al., 2006; Givnish et al., 2008; Hanan and Ross, 2010; Espinar et al., 2011; Ross and Sah, 2011; Sullivan et al., 2011, 2013; Wetzel et al., 2005, 2017; Sah et al., 2018) (Figure 1.1).

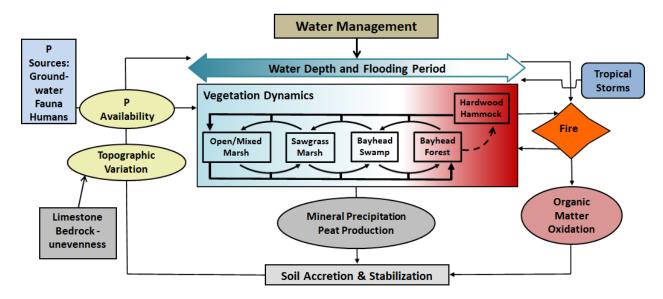


Figure 1.1: A conceptual model: vegetation dynamics in tree islands and surrounding marsh.

Beyond the physiographic template, the species assemblages and areal extent of different plant communities on the R&S tree islands, and between tree islands and adjacent marsh, fluctuate significantly over time depending on the climate and anthropogenically-induced changes in flooding and fire regimes (Stone and Chmura, 2004; Bernhardt and Willard, 2009). In R&S tree islands, the swamp forests and tails are usually the areas that respond most noticeably to hydrologic changes. This may suggest a difference in resilience along the island's resource gradient (Sah et

al. 2018). Since 2015, increases in water delivery into ENP under the Increment Field Tests associated with the Modified Delivery Project (MOD) and the Combined Operation Plan (COP) followed by the implementation of the Plan in 2020, has resulted in increased water level in NESRS (Sarker et al., 2020). This has caused marsh vegetation to shift towards a wetter type (Nocentini et al., 2024; Sah et al. 2025). In fact, after the full implementation of the COP in August 2020, water delivery into ENP, especially to NESRS, has significantly increased. For instance, in WY2021 and 2022, the volume of water delivered to NESRS across Tamiami Trail was 71.0% and 84.6% higher than the volume delivered in WY2020 (USACE, ENP and SFWMD, 2023). In addition, the unusually high dry season rainfall in WY 2015/16, WY 2020/21, WY 2022/23, WY 2023/24, and 2023/2024 prompted emergency operations to move water from WCAs into Everglades National Park (ENP) which also added to the increase in water depth in the NESRS region. The vegetation community on a tree island (SS-81) in that region has already been showing impacts of increased water level in the area (Sah et al., 2023, 2024). Since the volume of delivery to the NESRS region is projected to increase further in coming years, it is likely to continue affecting vegetation composition on the tree islands in that region.

In the hardwood hammocks, which are rarely flooded and often have a mean annual water table below 40 cm, tree species composition is also the legacy of the long-term interaction between water levels, recurrent tropical storms, and other physical processes (Ruiz et al., 2011, 2013a; Sah et al., 2018). In these islands, plant communities recover within a few years after a hurricane. However, vegetation recovery also depends on the post-hurricane environmental conditions. On September 10, 2017, Hurricane Irma made landfall in the Florida Keys as a Category 4 hurricane, then struck the southwest coast of Florida as a Category 3 hurricane (Cangialosi et al., 2018). However, its impact was felt in most of south Florida. An analysis of 2017 (WY 2017/18) and 2018 (WY 2018/19) tree data revealed severe damage to trees in eight tree islands for which pre-Irma data were available (Sah et al. 2020). Post-Irma assessment of tree damage in these hardwood hammocks served as baseline data to follow the vegetation recovery from the damage. An assessment of recovery from hurricane damage for the six post-Irma years has shown a difference in responses among species on the monitored islands (Sah et al., 2024). A continued assessment of vegetation dynamics on these islands is expected to reveal the islands' resilience, i.e., their capacity to recover from the last disturbance.

This section of the report includes the results of the continued monitoring of both tree and herb layer vegetation structure and composition in hardwood hammocks on a subset of four tree islands within a 16-island network established in ENP for long-term monitoring and assessment (Shamblin et al., 2008; Ruiz et al., 2011). It also includes the post-Irma assessment of vegetation on those four islands and an additional four islands for which pre-Irma vegetation composition data were available.

1.2 Methods

1.2.1 Study Area

The eight recently monitored tree islands represent a subset of those 16 islands that were intensively studied between 2005 and 2010. These islands include one prairie island (Grossman Hammock) along the eastern border of the ENP, four islands (Black Hammock, Gumbo Limbo, Satinleaf, and Vulture Hammock) in Shark River Slough (SRS), and three (Chekika, Irongrape and SS-81) in Northeast Shark River Slough (NESRS) (Figure 1.2). In addition, a hardwood hammock plot was established and sampled for the first time on one additional tree island (NP-202). Two islands, SS-81 and Chekika are located immediately downstream from the 1-mile (eastern) and 2.6-mile (western) bridges on Tamiami Trail, respectively, and they are likely to exhibit the impacts of increased flow from the WCAs into ENP as time goes on.

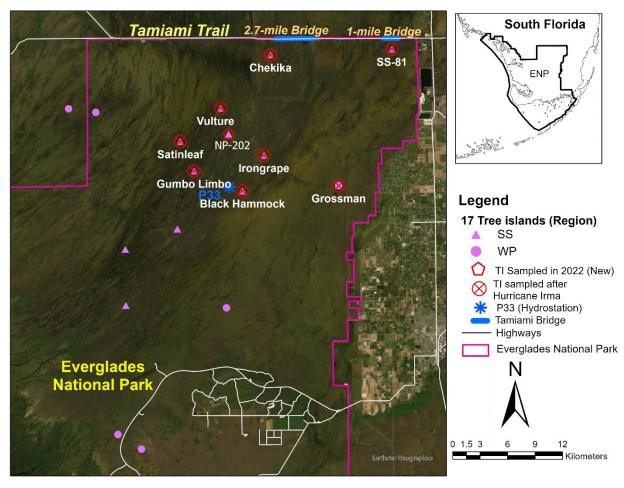


Figure 1.2: Location map of tree islands that have permanent plots in hardwood hammocks. The plots have been sampled during various periods between WY 2000/01 and 2023/24. In the first three years (WY 2017/18, 2018/19, 2019/20) after hurricane Irma, vegetation was re-sampled on eight tree islands, and in the next four years (WY 2020/21, 2021/22, 2022/23 and 2023/24) sampling was done on only four islands. Additionally, a hardwood hammock plot was established and sampled for the first time on one tree island (NP-202).

1.2.2 Data Collection

1.2.2.1 Vegetation sampling

The vegetation sampling in the hardwood hammock plots was organized in a nested design that accounted for all the major forest strata (trees & saplings, shrubs, seedlings, and herbaceous macrophytes). The sampling protocol followed the methodology described by Sah (2004) and Ruiz et al., (2011). Between WY 2011/12 and 2016/17, the tree layer vegetation was sampled in the hardwood hammock plots on four islands: Black Hammock (BL), Gumbo Limbo (GL), Satinleaf (SL) and SS-81 (Heartleaf: HL). However, following Hurricane Irma, both tree and herb layer vegetation were sampled for the seven years (WY 2017/18 to 2023/24) on those four islands, and for three years (WY 2017/18 to 2019/20), on another four islands (Chekika Island (CH), Grossman Hammock (GR), Irongrape (IG), and Vulture Hammock (VH). In addition, a hardwood hammock plot was established and sampled for the first time in WY2021/22 on one additional tree island (NP-202). The size of monitoring plots on these nine islands ranged between 300 m² in SS-81 to 625 m² in Gumbo Limbo and Satinleaf (Table 1.1).

Table 1.1: Location and topographic data (mean, minimum, and maximum) of hardwood hammock plots on nine tree islands.

Tree Island	Easting NAD83 (UTM_Z17N)	Northing NAD83 (UTM_Z17N)	Plot Size (m ₂)	Mean (± 1 S.D.) Plot Elevation (m NAVD 88)	Minimum Plot Elevation (m NAVD 88)	Maximum Plot Elevation (m NAVD 88)	Island height (cm)**
Black Hammock	531295	2832630	400	2.330 ± 0.166	1.988	2.584	99.1
Chekika	534372	2847485	400	2.624 ± 0.035	2.545	2.712	113.8
Grossman	541819	2833205	400	2.042 ± 0.144	1.386	2.238	44.5
Gumbo Limbo	525999	2834793	625	2.059 ± 0.071	1.916	2.24	87.8
Irongrape	533651	2836523	400	2.240 ± 0.050	2.092	2.345	92.0
Satinleaf	524499	2838019	625	2.221 ± 0.076	2.082	2.368	89.3
Heartleaf (SS-81)	547639	2848113	300	2.168 ± 0.304	1.592	2.649	80.0
Vulture	528918	2841667	400	2.663 ± 0.191	2.338	2.977	127.7
NP-202	529785	2838885	225	-	-	-	-

Each plot is gridded into $5\times5m$ cells, whose corners and midpoint are marked by 30 cm long flags and $\frac{1}{2}$ " PVC stakes affixed to the ground, respectively. When the plots were first established on these islands, the plot and cells were set up using compass, measuring tape, sighting pole(s), and right-angle prism. In these plots, all trees (≥5 cm) are tagged with numbered aluminum tags, and the location of each tagged tree is recorded to the nearest 0.1m using the SW corner of the plot as a reference (0, 0). Furthermore, if a tree has multiple stems ≥5 cm diameter (cm) at breast height

(DBH), each stem is tagged with a unique ID that allows it to be cross-referenced back to its 'parent' stem. Status (live and dead) and DBH of each individual tree were recorded for the first time when plots were established (in Black Hammock, Gumbo Limbo and Satinleaf in 2001/2002, in SS-81, Chekika, Grossman, Irongrape and Vulture Hammock in 2007, and in NP-202 in 2022).

Within each plot, the status (live and dead) of tagged trees and the presence of any tree that had grown into the >5cm DBH class (hereafter called 'ingrowth') since the previous survey were recorded. Ingrowths were identified to species, tagged, and their DBH was measured. The density and species of all tree saplings (stems 1-5 cm in DBH) within each 5 x 5 m cell were also recorded, and the samplings were assigned to one of two DBH size classes: 1-3 cm or 3-5 cm. The density of woody seedlings (stems < 1 m) and shrubs (stems > 1 m and < 1 cm DBH) was estimated in nested circular plots of 1.0 m² and 3.14 m², respectively, centered on the midpoint of each cell. Seedlings present within the 1 m² (0.57 m radius) plots were counted and identified to species and assigned to one of three height categories (1-30, 30-60, and 60-100 cm). Shrubs rooted within the 3.14 m² (1 m radius) plots were counted and identified to species level. The total cover of each shrub species was also estimated using a modified Braun-Blanquet scale based on the following six cover categories: Cat 1: <1%; 2: 1-4%; 3: 4-16%; 4: 16-32%; 5: 32-66%; & 6: >66% (Sah, 2004). Within the 1 m radius plot, the total cover of all herbaceous macrophytes, which includes seedlings, shrubs (< 1 m tall), epiphytes, vines, and lianas, was also estimated by species, using the same cover scale.

Canopy closure was estimated by taking two densiometer readings, one facing north and one facing south, at the midpoint of each cell (Lemmon, 1956). The densiometer estimates of forest canopy closure were supplemented with hemispherical canopy photographs. At the midpoint of each cell, a hemispherical photo of the canopy directly overhead was taken using a Nikon 950 digital camera with a Nikon FC-E8 fisheye lens adapter (NIKON Inc., Melville, NY), placed and leveled 1.0 m above the ground. Leaf area index (LAI) was calculated by processing hemispherical canopy photos with the Gap Light Analyzer program, GLA 2.0 (Frazer et al., 1999). For each hemispherical image, we calculated the percent canopy openness and the 4-ring LAI – the ratio of the total one-sided leaf area to the projected ground area (Parker, 1995).

1.2.2.2 *Hydrology*

For hardwood hammock plots in each of the study islands, ground elevation data were available from detailed topographic survey conducted using an auto-level from either a 1st order vertical control monument (benchmark) or from a reference benchmark established in the marsh, followed by an estimate of benchmark elevation by differential GPS; in some cases, benchmark elevation was calculated by relating water depth at the benchmark to the estimate of water surface elevation at that location and time from EDEN (Everglades Depth Estimation Network) (Ruiz et al., 2011). In conjunction with the daily EDEN water surface elevation data (http://sofia.usgs.gov/eden), elevation of the ground surface within the plots was then calculated.

1.2.3 Data Analysis

1.2.3.1 Hydrologic conditions

Mean annual and seasonal water depths (hereafter called relative water level (RWL), and discontinuous hydroperiod (the number of days in a year when water is above the ground surface) were estimated based on ground elevation and the time series data of water surface elevation (WSE) extracted from the EDEN database. Previous studies have found that prairie and marsh vegetation composition are well predicted by the previous 3-5 years of hydrologic conditions (Armentano et al., 2006; Zweig and Kitchens, 2009), whereas tree island vegetation was found strongly correlated with 7-year average hydroperiod and water depth (Espinar et al., 2011; Sah, 2004; Sah et al., 2018). Thus, in this study, we averaged hydroperiod and mean annual RWL for 7 water years (May 1st – April 30th) prior to each sampling event to examine the relationships between hydrologic parameters and change in vegetation characteristics. In addition, we also calculated long-term (33 years; WY 1991/92-2022/24 [the entire period for which EDEN data are available]) average of mean annual water level to examine the annual deviation of RWL from the long-term average.

Additionally, we calculated mean monthly relative water level (RWL) and assessed the trend over time by fitting a polynomial model of two degrees. Other models including cubic spline and natural spline models were also fitted to the data, although we chose the polynomial model since it had the lowest AIC score.

1.2.3.2 Tree-layer vegetation dynamics

Tree census data were summarized by two important indicators of woody vegetation dynamics: annual mean tree mortality and annual ingrowth. In addition, tree density and basal area for each species were calculated and summed to produce totals for each island.

Differential mortality and/or ingrowth among species over time can result in changes in species composition. These changes were analyzed using non-metric multidimensional scaling (NMDS) ordination. Species importance value (IV) was used as abundance data in the ordination. Tree density and basal area for each species were summed for each plot, relativized as a proportion of the plot total, and used to calculate Importance Value (IV) of species using the following equation: $IV = 100 \cdot ((R_{den} + R_{ba})/2)$, where R_{den} is the species relative density and R_{ba} is the species relative basal area. Importance value (IV) data of each species were standardized to species-maxima, and the Bray-Curtis (B-C) dissimilarity index was used as a measure of dissimilarity in the ordination. Relationships between species composition and environmental vectors representing topography and hydro-edaphic characteristics (relative water level, TI_Ht, soil depth, soil phosphorus and total organic carbon) were examined.

1.2.3.3 Herb/Shrub layer vegetation dynamics

We characterized changes in shrub and herb species composition and examined vegetationenvironment relationships using NMDS ordination. Species' mean percentage cover was used as abundance data in the ordination, and species present in only one plot were discarded. The cover values for each species were relativized to plot total cover and the Bray-Curtis (B-C) dissimilarity index was used as a measure of dissimilarity in the ordination. Relationships between species composition and environmental vectors representing topography, hydro-edaphic characteristics (relative water depth, TI_Ht and soil depth) and tree canopy cover were examined using a vector-fitting procedure incorporated in the computer R package VEGAN (Oksanen et al., 2022; R Core Team 2024). Ordination axes were rotated so that Axis 1 was aligned with the relative water depth (RWL).

1.2.3.4 Species Rhichness, Evenness and Diversity

For both tree/sapling and herb/shrub layer vegetation in the hardwood hammock plots on the study islands, plot-level species richness (α-diversity), Shannon's species diversity index, and evenness were calculated and summarized by island and sampling year. The calculations were done using PC-ORD software V.6 (McCune and Mefford 2011).

1.3 Results

1.3.1 Hydrologic conditions

Hydrologic condition in tree island hammocks varies depending on the location of tree islands within the R&S landscape and tree island height above the surrounding marshes. On the eight tree islands, the annual mean (\pm SD) relative water level (RWL) over eighteen years (WY 2006/07 to 2023/24) ranged between -89.4 \pm 12.9 cm in Chekika and -54.9 \pm 15.1 cm in SS-81 (Table 1.2). The mean RWL in Chekika, Vulture, and Black Hammock was 20.0-34.5 cm lower than that in other tree islands individually, suggesting that island height, i.e., the difference between average plot elevation and adjacent marsh ground elevation, of these three islands are higher than other islands. Also, within the hammock plot on each island, the mean annual RWL was not uniform due to microtopographic variation within the plot. Among the studied islands, average within-plot variation (Coefficient of variation, CV) in annual mean water level was the highest in SS-81 (CV = 44.8%), and the lowest in Chekika (CV = 2.9%).

Table 1.2 Annual mean (\pm SD) relative water level (RWL) averaged over 18 years (WY 2006/07 to 2023/24) in the hardwood hammock plots on eight tree islands.

	Relative water level (RWL) (cm)					
Tree Island	Annual Mean (± S.D.)	Annual Range (Min-Max)	Within plot variation (CV %)			
Black Hammock	-82.2 ± 10.2	-100.5 to -60.3	-17.8			
Chekika	-89.4 ± 12.9	-114.2 to -57.7	-2.9			
Grossman	-62.2 ± 15.7	-91.5 to -24.9	-15.4			
Gumbo Limbo	-56.6 ± 11.0	-74.0 to -31.4	-11.6			
Irongrape	-61.5 ± 10.8	-81.7 to -35.2	-6.7			
Satinleaf	-61.6 ± 11.7	-79.0 to -35.9	-12.1			
Heartleaf (SS-81)	-54.9 ± 15.1	-84.2 to -15.4	-44.8			
Vulture	-88.2 ± 13.1	-108.8 to -58.2	-19.8			

In the hammock plots of eight islands, the RWL varied annually over the last eighteen years. For instance, before the beginning of the Increment Field Test, i.e., over nine years between WY 2006/07 and WY 2014/15, the annual mean RWL in those plots was up to 29.4 cm lower than the 33-year (WY 1992-2024) average (Figure 1.3). Exceptions were WY 2012/13 and 2013/14 when some of islands had mean RWL of 1.3 cm to 9.7 cm higher than the 33-year average. The annual mean RWL did not exceed -40 cm (Figure 1.3), which is approximately the optimum water depth of major flood-intolerant hammock species in the SRS tree islands (Armentano et al. 2002). In contrast, mean annual water was above -40 cm on seven of eight islands for one or more years between WY 2015/16 to 2023/24, i.e., during the period of the Increment Field Tests followed by the full implementation of the COP. In fact, during this nine-year period, the annual mean RWL was above the 33-year average in most years, except in WY 2015/16 and 2019/20, when the mean RWL was 2.2 to 13.8 cm below the long-term average. However, in 2015/16, two islands (Grossman and Gumbo Limbo) and in 2019/20, the other two islands (Chekika and SS-81) had

mean RWL higher than the 33-year average. Likewise, in 2016/17 and 2018/19, when many of the islands had high water levels, one island (Chekika) in 2016/17 and four islands (Gumbo Limbo, Satinleaf, Irongrape and Vulture) in WY 2018/19 had lower RWL than the 33-year average.

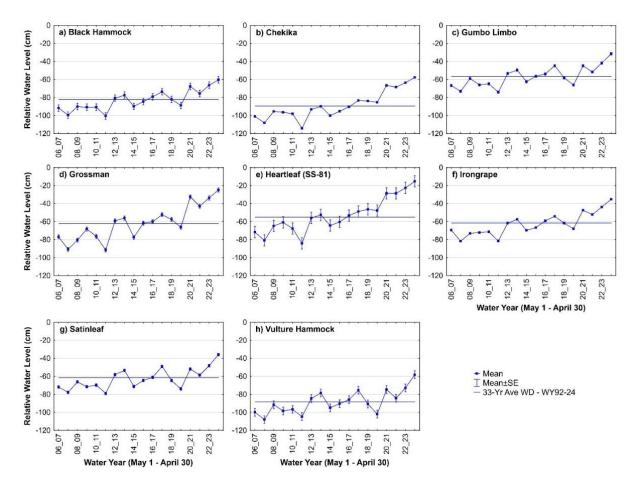


Figure 1.3: Annual mean (\pm SE) relative water level (RWL) for the period of Water Year 2006/07 – 2023/24 and long-term (WY 1991/92-2023/24) average RWL in the hardwood hammock plots on eight tree islands. For each hammock plot, RWL was averaged over 12 to 25 5x5m sub-plots. RWL for sub-plots was calculated by subtracting the mean elevation of each subplot from EDEN water surface elevation (WSE) at the hammock plot.

Over the eighteen years, i.e., since the regular monitoring of the eight islands studied began in WY 2006/07, the hydrologic condition in general showed a wetting trend (Figures 1.4, 1.5), while some years (e.g., WY 2011/12, 2014/15 and 2019/20) were much drier than others. Water levels on these islands began increasing in 2015/16, i.e., after the Increment Field Tests, however, the rate of such increase was much higher in the last four years (2020/21-2023/24) resulting from water management operational changes (e.g., full implementation of COP) as well as high rainfall. In fact, three of those four years had higher rainfall than the long-term average (see below).

Among these eighteen years, WY2023/24 was the wettest year when the annual mean RWL was 21.9 cm (in Black Hammock) to 39.5 cm (in SS-81) higher than the long-term average. Since WY

2006/07, for most years, none of the hammock plots on these eight islands, except SS-81, were inundated. However, in WY 2017/18 and 2020/21, the high-water level on many of these islands was observed. In 2017/18, characterized by the extremely high-water levels in Hurricane Irma's aftermath, plots on 7 of 8 islands (all but Chekika) were partly inundated for varying periods. One sub-plot in Black Hammock and seven sub-plots on Irongrape, i.e., 5% and 35% of study plots, were inundated for only one or two days, whereas a sub-plot (8.3% of the study plot) in SS-81 was inundated up to 184 days. In fact, seven sub-plots on Gumbo Limbo and six on Satinleaf, i.e., 28% and 24% of study plot, respectively, were also inundated for 3-47 days in the same water year. Moreover, the aforementioned sub-plot in SS-81 in NESRS was inundated for 1 to 336 days in 15 of 18 years between WY 2006/07 and 2023/24, and for more than 100 days since 2015/16, when water delivery under the Increment Field Tests began in October 2015 (USACE, 2020). On this island, a second subplot was inundated for 37-318 days during the last seven (WY 2017/18-2023/24) water years. Moreover, five out of 12 sub-plots i.e., 41.7% of the hardwood hammock plot on SS-81 was inundated for various periods during the last four (2020/21 - 2023/24) water years.

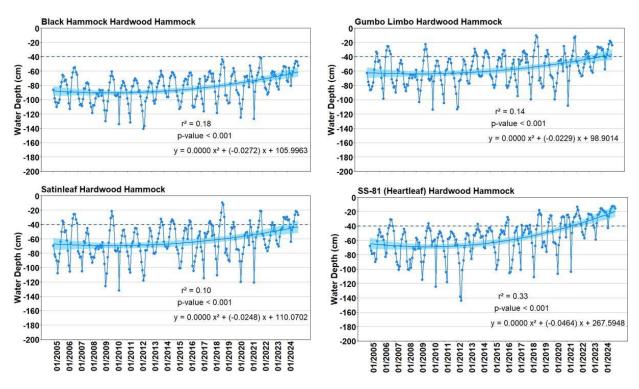


Figure 1.4: Mean monthly relative water level over eighteen years (WY 2006/07 – 2023/2024) in the hardwood hammock plots on four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled annually between 2006/07 and 2023/24. The trend line was fitted using a polynomial model.

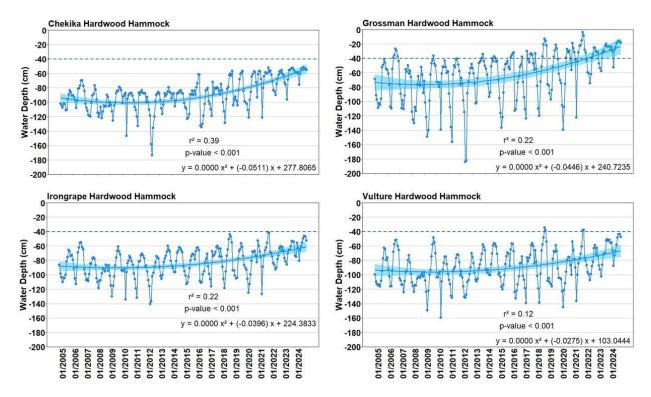


Figure 1.5: Mean monthly relative water level over eighteen years (WY 2006/07 – 2023/2024) in the hardwood hammock plots on four tree islands (Chekika, Grossman, Irongrape and Vulture Hammock) sampled between 2006/07 and 2011/12, and again for three years (2017/18, 2018/19 and 2019/20) after hurricane Irma. The trend line was fitted using a polynomial model.

In general, the annual mean water level in these hammocks followed the regular dry (low) and wet season (high) pattern. However, in some years, the water level in the hammock plots was much higher in the dry season than in the wet season due to either an anomaly in weather pattern, management-induced changes in hydrologic regime, or both. For instance, over the last 18 years, the most remarkable discrepancies between dry- and wet-season patterns were in 2011/12, 2015/16, 2020/21 and 2021/22, when the water level in the dry season was >10 cm higher than in the wet season in all eight islands (Figure 1.6). In three (2015/16, 2020/21 and 2021/22) of these four years, the RWL was much closer to the ground surface (>-40 cm) in Grossman Hammock and SS-81 than in other years. Likewise, annual mean dry- and wet- season water levels were almost the same in the other five years, 2009/10, 2014/15, 2017/18, 2022/23 and 2023/24. This pattern was possibly caused by unusually high dry season rainfall followed by the very low wet season rainfall in addition to increased water deliveries into ENP during the dry season. In those years, the discrepancies in dry and wet season water level were more distinct in NESRS and Prairie islands (Figure 1.6 b, d, e) than in SRS islands. It was also interesting to note that in both dry and wet seasons of the most recent year (2023/24), the water level was close to the ground surface (>-40) in five of eight islands (Figure 1.6), one in eastern marl prairie (Grossman), two in NESRS (Irongrape and SS-81) and two in SRS (Gumbo Limbo and Satinleaf).

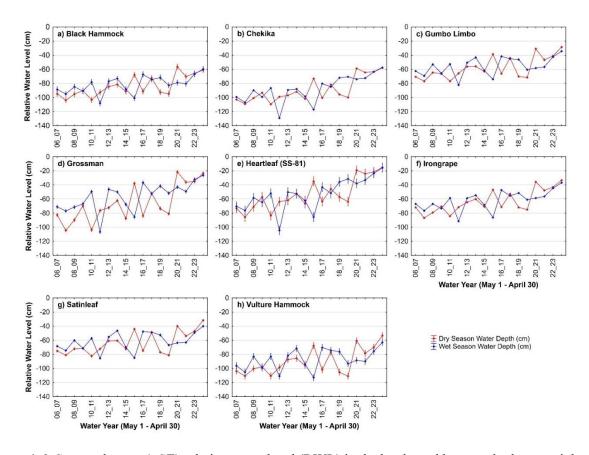


Figure 1.6: Seasonal mean (±SE) relative water level (RWL) in the hardwood hammock plots on eight tree islands. For each hammock plot, RWL was averaged over 12 to 25 5x5m sub-plots. RWL for each subplot was calculated by subtracting the mean elevation of each subplot from EDEN water surface elevation (WSE) at the hammock plot.

In South Florida, including the Everglades, winter rainfall is strongly linked to El Niño events. In WY 2015/16, WY 2020/21, WY 2022/23 and WY 2023/24, dry season rainfall was higher than the historical average (Abtew and Ciuca, 2017; Cortez et al., 2022; Cortez, 2024; Cortez and Smith, 2025), resulting in high water conditions throughout South Florida, especially the Water Conservation Areas (WCAs). That prompted emergency operations to move water to the south, i.e., into Everglades National Park (ENP). These unusual emergency deviations during the dry seasons and increased water delivery into ENP resulting from both MWD Increment Field tests followed by the full implementation of the Combined Operational Plan (COP) in August 2020 (USACE, ENP and SFWMD, 2023) have contributed to the spatial and temporal differences in water conditions within the Everglades tree island hammocks. In fact, mean annual RWL in these islands in SRS and NESRS is hardly in tandem with the total annual rainfall in that region. For this analysis, stage recorder P33 located in SRS (Figure 1.2), for which long-term rain data are available on DBHYDRO (www.sfwmd.gov/science-data/dbhydro), was used. Between 2006/07 and 2023/24, the correlation between annual total rainfall at P33 and mean RWL on each of these eight islands was not significant (Figure 1.7; p-value>0.05), because the hydrologic conditions in these islands depend in large part on the water delivery from the adjacent WCA 3A and 3B.

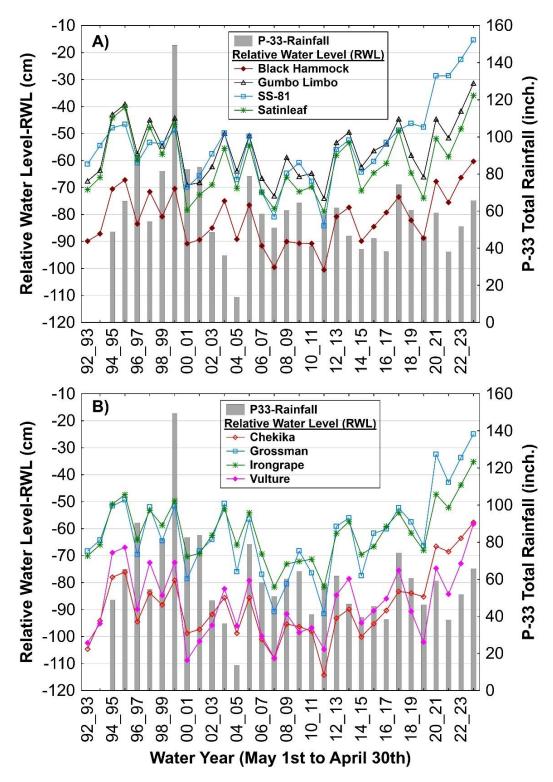


Figure 1.7: Relationship between annual total rainfall at P33 stage recorder and mean annual relative water level (RWL) in two groups of tree islands: (A) four tree islands sampled annually, and (B) four tree islands first sampled between 2006/07 and 2010/11, and then again three times between 2017/18 and 2023/24.

1.3.2 Tree mortality and ingrowth

On tree islands, tree layer vegetation dynamics are a function of tree mortality and ingrowth, two important metrics of tree-layer vegetation dynamics in forest ecosystems. Over four years, (WY 2007/08 to 2010/11), when the hardwood hammock on all 16 islands were studied, the mean annual tree mortality on those islands was 3.6%, and both NESRS and SRS islands had higher mortality than MP islands (Figure 1.8). During those years, mean tree ingrowth was significantly higher (paired t-test, P <0.001) than mean tree mortality. On average, the mean tree ingrowth was 110 trees ha⁻¹ year⁻¹ whereas tree mortality was 53 trees ha⁻¹ year⁻¹. Ingrowth on some islands was higher also because of the recovery from Hurricane Wilma in 2005.

Between WY 2011/12 and 2016/17, hardwood hammocks of only four islands (Black Hammock, Gumbo Limbo, Satinleaf, and SS-81) were studied, and on those islands, both the mean tree ingrowth and mortality showed slight variation, except on three SRS islands in 2014. In general, annual mean mortality was slightly higher than mean ingrowth. On these four islands, the mean mortality rate was significantly different between both periods, before 2011/12 (3.62%) and between 2011/12 and 2016/17 (the years when islands were sampled before Hurricane Irma) (3.13%), whereas the mean ingrowth dropped from 6.96% year-1 to 2.78% year-1.

After 2016/17, both tree ingrowth and mortality on the studied tree islands varied greatly. On some islands, tree mortality drastically increased in 2017/18, mostly caused by Hurricane Irma. After the hurricane in WY 2017/18, we sampled vegetation on four additional tree islands (Chekika, Grossman, Irongrape and Vulture), all from the same network of 16 islands within ENP (Ruiz et al., 2011). Post-hurricane surveys on these four islands continued for three years. In the first post-Irma year, the NESRS tree islands, especially Irongrape (NAD83 UTM Zone-17: 533651, 2836523) had exceptionally high (> 200%) ingrowth, mostly due to regeneration of papaya (Carica papaya) - an ephemeral semi-woody pioneer that recruits profusely from the seedbank but would disappear from the canopy within a couple of years (Sah et al., 2020).

Of the eight tree islands, tree mortality on four islands was higher in 2017/18 than in previous years (Figure 1.9). In 2017/18, i.e., within 2-4 months after Hurricane Irma, increased tree mortality was observed in Black Hammock, Grossman, Satinleaf and SS-81. Among these four islands, Black Hammock and Satinleaf were severely impacted by the hurricane (Sah et al., 2020). One year after the hurricane, i.e., in 2018/19, exceptionally high mortality (>25%) was observed on Irongrape, because not only did many Carica papaya individuals that had appeared during 2017/18 died, one fourth of the hardwood trees also died. In the following year (2019/20) two years after Hurricane Irma, while mortality was relatively high on 7 of 8 islands, an increase in mortality in comparison to previous year was observed only on 4 islands (Grossman, Gumbo Limbo, SS-81, and Vulture). In the following years (2020/21, 2021/22, 2022/23 and 2023/24) only four annually monitored islands were studied. During those years, high mortality was observed on two islands, Black Hammock, and SS-81 (Figure 1.9). The elevated rate of mortality observed on Black Hammock three years after the hurricane could be due to delayed mortality. However, on SS-81, downstream of the 1-mile Tamiami Bridge and impacted by hydrologic changes in NESRS region, tree mortality rates in each of those four years (WY 2020/21 to 2023/24) were still high, but slightly lower than in 2019/20 (Figures 1.9, 1.10).

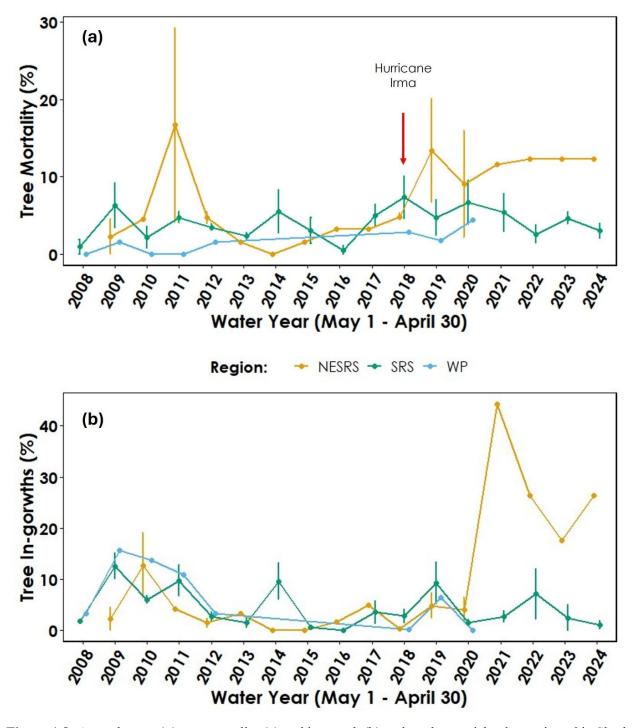


Figure 1.8: Annual mean (\pm) tree mortality (a) and ingrowth (b) and on the tree islands monitored in Shark River Slough (SRS), Northeast Shark River Slough (NESRS) and Wet Prairies (WP) within the Everglades National Park between WY 2007/08 and 2023/24. The number of tree islands studied varied among years. Between 2012/13 and 2016/17, and between 2020/21 and 2023/24, hardwood hammocks were studied on only four islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81).

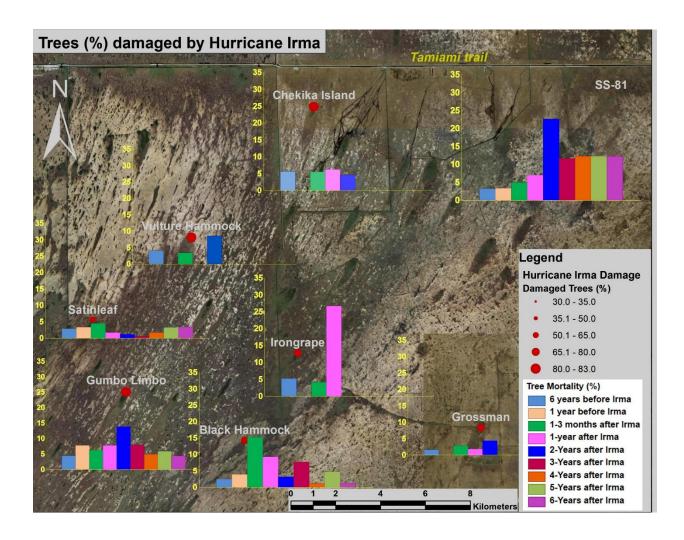


Figure 1.9: Post-Irma tree damage and annual mean tree mortality (%) on eight tree islands before and up to six years after hurricane Irma. On four islands (Chekika, Grossman, Irongrape and Vulture), pre-Irma tree mortality data were available for only 2010/11 or 2011/12, and those islands were sampled only for three years after hurricane Irma.

When the hardwood hammock on SS-81 was studied for the first time in 2007/08, Sugarberry (*Celtis laevigata*) had been a dominant species, constituting 82.7% of all tree stems (>5 cm DBH) present. Even in WY 2019/2020, the proportion of Sugarberry trees was 72.2%. However, two years later, in 2021/22, the proportion of Sugarberry was only 36.4% of all trees, and that proportion dropped further in 2022/23 to 23.5%, and then further to 16.9% the next year. This indicates high mortality of Sugarberry or ingrowths of other species. In fact, in WY 2019/20, 2020/21, 2021/22, 2022/23 and 2023/2024, the mortality rate of Sugarberry was 15.7%, 20.7%, 34.8% and 26.6%, respectively. In those years, total ingrowths of all species were 67 trees (3.7%), 633 trees (43.2%), 500 trees (26.3%), 333 trees (15.2%) and 500 trees (22.7%) ha⁻¹ year⁻¹, respectively (Figure 1.10d). It is remarkable to note that ingrowths in those five years were mostly of the exotic species, Brazilian pepper (*Schinus terebinthifolia*). An ingrowth of Brazilian pepper trees (≥40% of all ingrowths) was also observed on Gumbo Limbo in both 2021/22 and 2022/23.

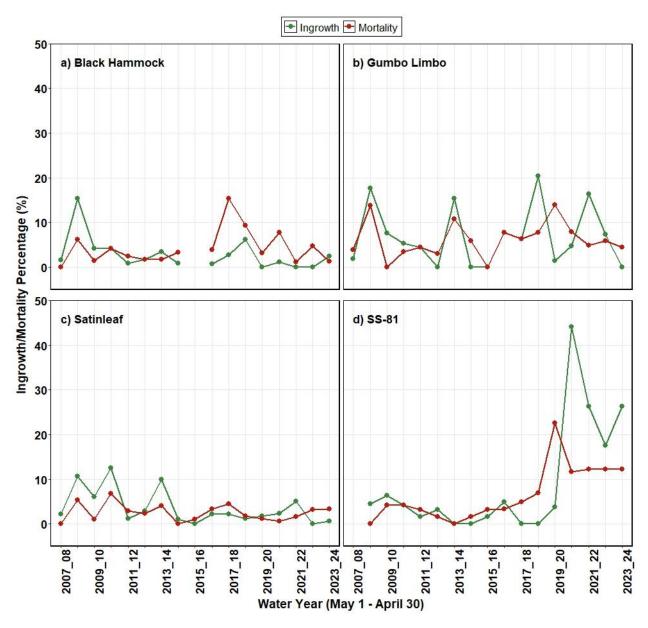


Figure 1.10: Annual mean (±) tree ingrowth and mortality on four tree islands annually monitored within the Everglades National Park between WY 2007/08 and 2023/24.

As reflected by variation in annual mean tree mortality and ingrowth, the short-term trend of tree dynamics observed in the hardwood hammocks on four islands, which were studied annually, is in accordance with variation in hydrologic conditions. Both the tree mortality and ingrowth were significantly affected by mean annual RWL annual hydrologic conditions (Figure 1.11). Mean tree mortality was relatively low ($\leq 4.0\%$) when water level was 80 cm below the surface. In contrast, the mortality was consistently high ($\geq 12\%$) when the water level was close (\geq -40 cm) to the ground surface. At intermediate water levels (between -70 cm and -40 cm), tree mortality varied greatly. Tree ingrowth showed a similar pattern. However, the high ingrowth observed on one island was mainly due to new recruitment of Brazilian pepper (*Schinus terebinthifolia*), an invasive species

on an island (SS-81). In contrast, there was high mortality of the native (once dominant) species Sugarberry (*Celtis laevigata*), on an island which had the mean water level above -40 cm for more than 180 days for four years. In fact, tree mortality was consistently high and was more severely affected when the water level was above -40 cm continuously for three years rather than an individual year (Figure 1.12).

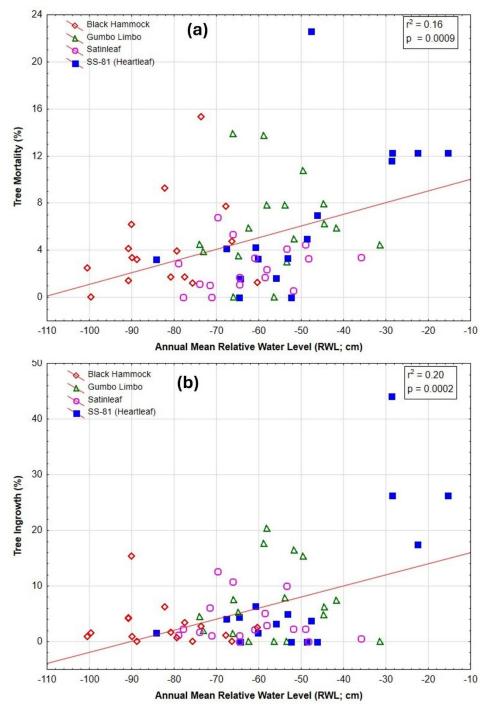


Figure 1.11: Scatterplot showing the relationship between annual mean relative water level (RWL) and tree mortality (a) and ingrowth (b) on four tree islands sampled annually between WY 2006/07 and 2023/24.

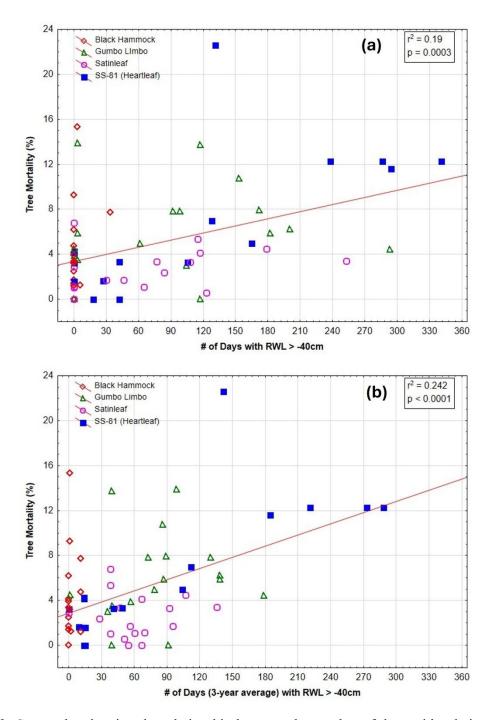


Figure 1.12: Scatterplot showing the relationship between the number of days with relative water level above -40 cm on an island and annual tree mortality on four tree islands monitored within the Everglades National Park between WY 2007/08 and 2023/24. (a) with no-lag, (b) with 3-year lag.

In concurrence with the trend in tree mortality and ingrowth on four islands that were monitored in all years, total tree basal area first increased between WY 2007/08 and 2009/10 (n = 3; r = 0.99, p = 0.058), and then significantly decreased over the next 14 years, between 2010/11 and 2023/24 (n = 13; r = -0.90, p < 0.006; Figure 1.13). The lowest value of total BA in WY 2015/16 was because only three tree islands were sampled in that year. Black Hammock, which has higher (38%)

of total) BA than the other three islands, was not sampled in 2015/16. On these islands, a sharp decrease in BA was observed after 2017/18, as the total basal areas in post-Irma years was even lower than in 2006/07 (one year after Hurricane Wilma). In fact, mean basal area was significantly lower in post-Irma years (WY 2017/18 – 2023/24) than before the hurricane (WY 2007/08 – 2016/17) on Black Hammock and Gumbo Limbo. However, basal areas have recovered in Satinleaf (Figure 1.14). On the other four islands, which were sampled for three years after the hurricane, the mean basal was higher on three of four islands in those years (2017/18 – 2019/20) than 7-10 years before Irma (i.e., 2007/08 – 2010/11) (Figure 1.13), suggesting that those islands were not affected much by the hurricane. In contrast, on Vulture tree island, where 65-80% trees were damaged, the mean basal area in post-hurricane years was lower than 7-10 years ago (Figure 1.14).

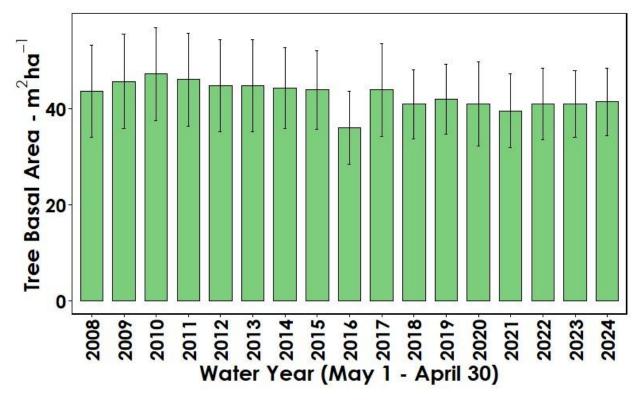


Figure 1.13: Bar diagram showing the trend in tree basal area on four tree islands monitored within the Everglades National Park between WY 2007/08 and 2022/23). In WY 2015/16, tree basal area was low, as only three tree islands were sampled.

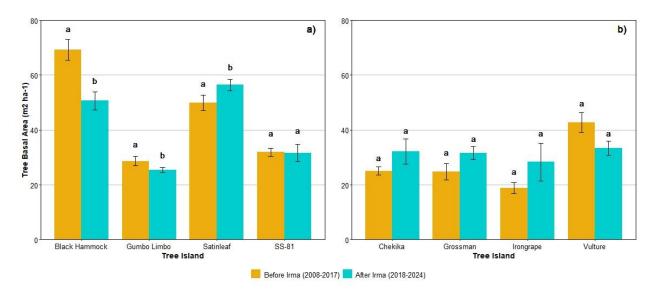


Figure 1.14: Bar diagram showing mean (\pm SD) tree basal area on eight tree islands monitored within the Everglades National Park before and after hurricane Irma. (a) Four islands were monitored annually since WY 2007/08, except in WY 2016, when only three islands were sampled. (b) Four other islands were sampled between WY 2007/08 and 2010/11 (before Irma), and then again for three years between WY 2017/18 and WY 2019/20.

A preliminary analysis of the relationship between RWL and BA revealed that across all islands and years, basal area was negatively correlated with mean annual water levels averaged over 1, 3 and 7 years prior to the sampling year (Table 1.3). However, the relationship between basal area and mean annual RWL differed among tree islands. Most islands showed significant relationships with hydrologic conditions one year prior to sampling, while only one island had a significant relationship between basal area and 7-year average RWL (Table 1.4).

Table 1.3: Relationship between relative water level (RWL) and basal area (BA) on studied islands.

Tree Island	N	RWL (1-year average)		RWL (3-year average)		RWL (7-year average)	
Tree Island		r	p-value	r	p-value	r	p-value
Black Hammock	17	-0.654	0.004	-0.702	0.002	-0.469	0.058
Chekika	9	0.856	0.003	0.641	0.063	0.224	0.562
Grossman	9	0.773	0.015	0.261	0.498	-0.016	0.968
Gumbo Limbo	18	-0.495	0.037	-0.695	0.001	-0.420	0.083
Irongrape	8	0.413	0.309	0.554	0.154	0.380	0.353
Satinleaf	18	0.566	0.014	0.193	0.444	-0.108	0.670
Heartleaf (SS-81)	16	0.154	0.569	0.070	0.797	0.015	0.955
Vulture	9	-0.411	0.271	-0.469	0.203	-0.678	0.045
All islands	104	-0.265	0.007	-0.314	0.001	-0.341	0.000

1.3.3 Tree layer vegetation dynamics

1.3.3.1 Species Composition

Among the eight islands, tree layer vegetation composition on Grossman and SS-81, located within the MP landscape and NESRS, respectively, was quite different from the SRS tree islands. A nonparametric multi-dimensional scaling (NMDS) ordination, based on tree species' importance value (IV) and B-C dissimilarity, revealed that tree species composition has changed slightly in the hammocks of these eight islands (Figure 1.15). Such changes were obvious on six islands (Black Hammock, Chekika, Gumbo Limbo, Irongrape, SS-81 and Vulture Hammock). Of these six islands, Gumbo Limbo, Chekika, Irongrape and SS-81 showed a distinct change in post-Irma years. The most dramatic change was in Irongrape, where the vegetation compositions in WY 2018/19 and 2019/20 were quite different from the vegetation in other years (Figure 1.15). Among them, SS-81 also had a noticeable change in tree layer composition in the last four years, i.e., between 2020/21 and 2023/24.

Among the four islands that were sampled annually, including 2023/24, three islands (Black Hammock, Gumbo Limbo and Satinleaf) did not show much difference in hardwood hammock tree layer vegetation from the previous three years. However, in those three years, a gradual shift in position of SS-81 in ordination space towards increasing wetness suggested noticeable changes in tree species composition driven by hydrologic changes within the area (Figure 1.15).

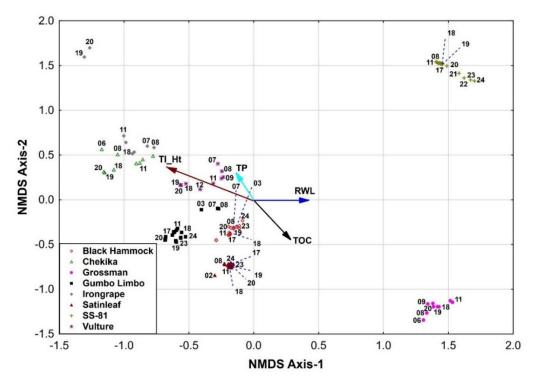


Figure 1.15: Scatterplot of NMDS ordination based on tree species IV in eight tree island hammocks sampled between Water Year (WY) 2001/02 and 2023/24. Fitted vectors are relative water level (RWL), tree island height (TI Ht), soil phosphorus (TP) and total organic carbon (TOC). The plot includes the sites'

position only in selected years, WY2002 & 2003 (when three islands were sampled for the first time), WY 2007 – 2011 (when all 8 islands were sampled, and WY 2018-2024 (all the post-Irma years).

On the tree islands, change in species composition was accompanied by changes in their relative abundance. On Black Hammock, the IV of gumbo limbo (Bursera simaruba) and sugarberry (Celtis laevigata) decreased, whereas the IV of white stopper (Eugenia axillaris) increased significantly ($r^2 = 0.92$; p-value <0.001) from 19.8% in 2002/03 to 37.6% in 2023/24 (Figure 1.16a). Likewise, the IV values of mastic (Sideroxylon foetidissimum) on Gumbo Limbo and of satinleaf (Chrysophyllum oliviforme) on Satinleaf, almost doubled in the twenty-two years since they were first sampled in 2001/2002 (from 7.3% to 13.0% and 8.9% to 13.7%) (Figure 1.16 b, c). The most noticeable change on Gumbo Limbo was the decrease in importance value (IV) of sugarberry (C. laevigata) (Figure 1.16b). Almost all individuals of this species were dead in 2019, and its IV decreased from 24.06% in WY 2007/08 to 1.02% in 2023/24. On these three islands, while there was not much shift in species composition between WY 2010/11 and 2016/17, there were some changes in composition after Hurricane Irma. After the hurricane, two species, Brazilian pepper (Schinus terebinthifolia), an invasive species, and lancewood (Nectandra coriacea), a native species, were observed for the first time on Gumbo Limbo (Figure 1.16b). In seven years (from WY2017/18 to 2023/24), their IV values increased from 1.0% to 3.5% and 2.0%, respectively.

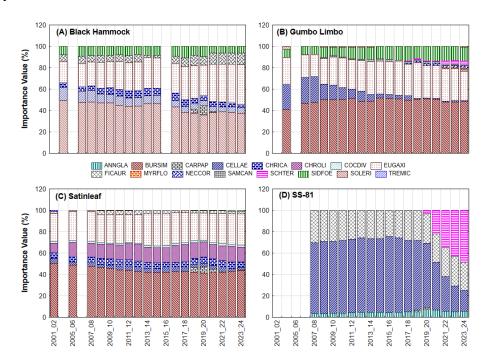


Figure 1.16: Importance value index (IV) of tree species in hardwood hammocks of four tree islands monitored annually. ANNGLA = Annona glabra; BURSIM = Bursera simaruba; CARPAP = Carica papaya; CELLAE = Celtis laevigata; CHRICA = Chrysobalanus icaco; CHROLI = Chrysophyllum oliviforme; COCDIV = Coccoloba diversifolia; EUGAXI = Eugenia axillaris; FICAUR = Ficus aurea; MYRFLO = Myrsine floridana; NECCOR = Nectandra coriacea: SAMCAN = Sambucus canadensis; SCHTER = Schinus terebinthifolius; SIDFOE = Sideroxylon foetidissimum; SOLERI = Solanum erianthum; TREMIC = Trema micranthum.

A significant shift in species composition in the tree layer was also observed in the hammock of SS-81, which has been monitored annually since WY 2007/08. On this island, the IV of sugarberry (*C. laevigata*) decreased from 66.3% in 2007/08 to 19.6% in 2023/24. A sharp decrease in its IV occurred after WY 2019/20 (Figure 1.16d). In contrast, IV of pond apple (*Annona glabra*) almost doubled in 13 years. On this island, another significant change in vegetation composition included the appearance of Brazilian pepper, which was recorded for the first time in WY 2019/20. Surprisingly, its IV values increased from 3.4% to 48.9% in five years, resulting in this species to be the most dominant species in tree-layer vegetation of this island. The distinct vegetation composition in recent years (WY 2019/20 to 2023/24) is also reflected in a shift in position of this island within the ordination space (Figure 1.15).

Hardwood hammocks on the other four islands (Chekika, Grossman, Irongrape and Vulture) were sampled annually until 2011/12, and then in 2017/18, 2018/19 and 2019/20. Among these, Grossman Hammock had relatively stable vegetation composition, whereas the other three islands showed a significant change in species abundances (Figure 1.17).

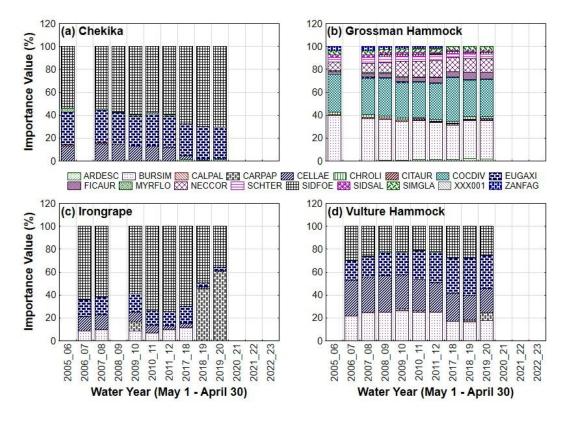


Figure 1.17: Importance value index (IV) of tree species in hardwood hammocks of four tree islands that were monitored until 2011/12, and then again in 2017/18, 2018/19, 2019/20. ARDESC = *Ardisia escallonioides*; BURSIM = *Bursera simaruba*; CALPAL = *Calyptranthes pallens*; CARPAP = *Carica papaya*; CELLAE = *Celtis laevigata*; CHROLI = *Chrysophyllum oliviforme*; CITAUR = *Citrus aurantifolia*; COCDIV = *Coccoloba diversifolia*; EUGAXI = *Eugenia axillaris*; FICAUR = *Ficus aurea*; MYRFLO = *Myrsine floridana*; NECCOR = *Nectandra coriacea*; SCHTER = *Schinus terebinthifolius*; SIDFOE = *Sideroxylon foetidissimum*; SIDSAL = *Sideroxylon salicifolium*; SIMGLA = *Simarouba glauca*; XXX001 = Unknown species; and ZANFAG = *Zanthoxylum fagara*.

One year after Hurricane Irma, the IV of sugarberry (*C. laevigata*) on Chekika was 1/10th of its IV in WY 2011/12, and the trend continued in the following two years (2018/19 and 2019/20) after the hurricane (Figure 1.17 a). Similarly, on Vulture, IV of sugarberry (*C. laevigata*) was 20% less in post-Irma years than in WY 2011/2012 (Figure 1.17 d). In contrast, mastic (*S. foetidissimum*) and white stopper (*E. axillaris*) increased on these two islands, respectively. Moreover, a major change was observed in tree layer species on Irongrape where papaya (*C. papaya*), a semi-woody ephemeral species, significantly increased after Hurricane Irma (Figure 1.17 c). In contrast, the abundance of all other major species declined in recent years. For instance, the number of trees of gumbo limbo (*B. simaruba*) and mastic (*S. foetidissimum*) sharply declined in the post-Irma period. On Vulture Hammock, while *C. papaya* was recorded for the first time in 2019/20, after 9 years, the IV of gumbo limbo (*B. simaruba*) and sugarberry (*C. laevigata*) declined by 33% and 40%, respectively (Figure 1.17 d). In contrast, the IV of white stopper (*E. axillaris*) has almost doubled in 14 years, from 16.5% in 2006/07 to 29.1% in 2019/20.

1.3.3.2 Species Richness, Evenness and Diversity

In the hardwood hammocks, tree and sapling species richness and diversity varied over the study period and among islands. The mean species diversity was relatively high and stable until 2006/07 (Figure 1.18). However, during that period, species richness showed great annual variation. After 2015/16, both the tree and sapling richness and diversity showed an increasing trend. However, in the last 5 years (2019/20 - 2023/24), the diversity did not show much variation.

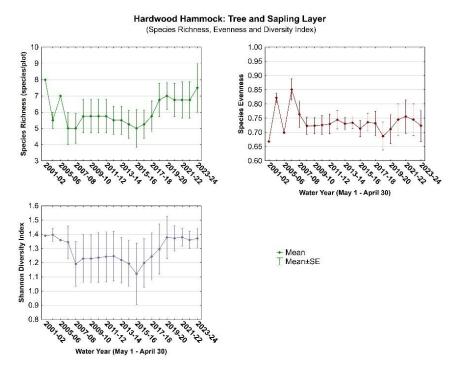


Figure 1.18: Species richness (species/plot), evenness, and Shannon species diversity in the tree and sapling (T&S) layer vegetation in the hardwood hammock averaged over four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81). sampled over 25 years (WY 2001/02 – 2023/24). In SS-81, sampling began in 2006/07, and Black Hammock was sampled in WY 2015/16.

Among the study islands, species richness and diversity were the highest in Grossman, located in the eastern prairies, and lowest in SS-81 which is in the NESRS. In Black Hammock, both the richness and diversity index were very stable over the study period (Figure 1.19a), while in Gumbo Limbo and SS-81, their values slightly increased overtime, especially after 2017/18, mainly due to invasion by and growth of exotic species like Brazilian pepper (*Schinus terebinthifolia*). In contrast, species diversity declined in Chekika and Irongrape (Figure 1.20e, g).

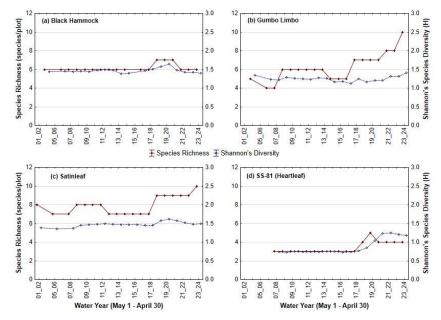


Figure 1.19: Tree and sapling species richness (species/plot) and Shannon species diversity in the hardwood hammock of four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81), sampled first in 2021/02 (or 2002/03) and then annually since 2005/06. The sampling on SS-81 began in WY 2007/08.

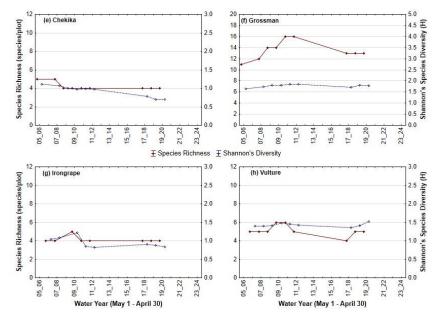


Figure 1.20: Tree and sapling species richness (species/plot) and Shannon species diversity in the hardwood hammock of four tree islands (Chekika, Grossman, Irongrape and Vulutre), sampled between WY 2005/06 (or 2006/07) and 2011/12, and then between 2017/18 and 2019/20.

1.3.4 Herb and shrub layer vegetation dynamics

1.3.4.1 Species composition

Like the tree layer, understory species composition on Grossman and SS-81 tree islands was also somewhat different from the understory vegetation on other islands (Figure 1.21). Moreover, the results of the NMDS ordination revealed that variation in understory species composition within an island over time was more divergent (Figure 1.21) than the tree layer species composition on the same island (Figure 1.15). As expected, such a shift in understory composition on most islands was noticeable in 2006/07 and/or between 2017/18 and 2023/24, i.e., after hurricane Wilma and Irma, respectively. This is possibly due to hurricane-induced changes in canopy cover and light availability in the understory.

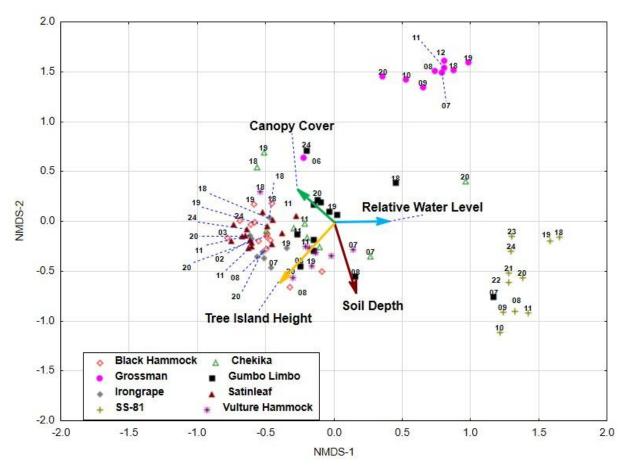


Figure 1.21: Scatterplot of NMDS ordination based on the herb and shrub species cover value for eight tree island hammocks sampled between Water Year (WY) 2001/02 and 2023/24. Fitted vectors are relative water level, canopy cover, tree island height and soil depth.

On the islands studied, total understory plant cover increased until 2-3 years after Hurricane Wilma primarily due to an increase in cover of tree seedlings together with the increase in canopy openness and then started to decrease. In the understory of SRS islands, the tree seedlings of white stopper (*Eugenia axillaris*) reached high densities (Figure 1.22). In contrast, the understory on

Grossman, an island within the marl prairie landscape, had a high cover of lancewood (*Nectandra coriacea*) seedlings (Figure 1.22). In fact, the relationship between canopy cover with the ordination configuration was highly significant (r = 0.16' p< 0.001), reiterating that canopy cover affected understory composition in the hardwood hammocks of those islands over time (Table 1.4). In addition, the environmental vectors representing relative water level (RWL) and soil depth were also significantly correlated with the ordination configuration.

Table 1.4 Correlation (r) and statistical significance of fitted environmental vectors with species coverbased 3-dimensional non-metric multi-dimensional scaling (NMDS) ordination configuration.

Vectors	r	p-value
Relative water level	0.16	< 0.01
Soil depth	0.55	< 0.001
Canopy cover	0.16	< 0.01
Tree island height	0.52	< 0.001

Total understory cover varied greatly over the years, mainly in response to changes in canopy cover resulting from tropical storms or tree/vine growth. For instance, out of three islands (Black Hammock, Gumbo Limbo and Satinleaf) that were sampled before and after Hurricane Wilma, understory cover significantly increased in two of the three post-hurricane years. Likewise, on some islands, the understory cover was low before Hurricane Irma. After two post-Irma years, the understory decreased in four islands (Satinleaf, SS-81, Irongrape and Vulture Hammock).

A noticeable increase in understory cover in 2019/20 was also observed on Chekika, mostly due to a 6-fold increase in fern (*Blechnum serrulatum*, *Nephrolepis biserrata*, and others) cover (Figure 1.23a). Fern percent cover significantly increased also on two other islands, Gumbo Limbo and SS-81. In contrast, on Gumbo Limbo, the cover of *Rivina humilis*, the most dominant species in the understory during post-Wilma years on that island, has significantly decreased in recent years. Mean cover of *R. humilis* was 67.8% in 2007/08, but <1% in 2023/24. The drastic drop in its IVI occurred between WY 2007/08 and 2008/09, i.e., 2-3 years after hurricane Wilma (Figure 1.22 b). In fact, this species was almost absent just before and after hurricane Irma. Thereafter, its IV greatly varied over the next six years.

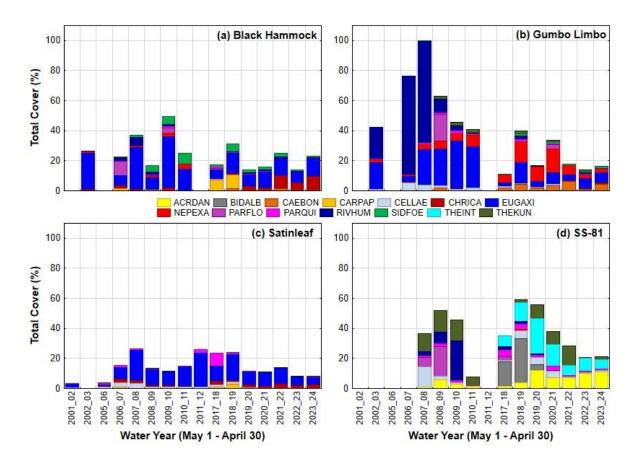


Figure 1.22: Percent cover of herb and shrub species in hardwood hammocks of four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled in WY2001/02 or 2002/03 for the first time, then annually between 2005/06 and 2011/12 and between 2017/18 and 2023/24. ACRDAN = *Acrostichum danaeifolium*; BIDALB = *Bidens alba*; CAEBON = *Caesalpinia bonduc*; CARPAP = *Carica papaya*; CELLAE = *Celtis laevigata*; CHRICA= *Chrysobalanus icaco*; EUGAXI = *Eugenia axillaris*; NEPEXA= *Nephrolepis exaltata*; PARFLO= *Parietaria floridana*; PARQUI= *Parthenocissus quinquefolia*; RIVHUM= *Rivina humilis*; SIDFOE = *Sideroxylon foetidissimum*; THEINT = *Thelypteris interrupta*; THEKUN= *Thelypteris kunthii*.

The effects of canopy cover on the understory layer were much more distinct on Irongrape, which was relatively open 13 years ago. On this island, the total cover of all species in the understory was >100 %, mostly due to the number of white stopper seedlings (Figure 1.23 c). But it now has a dense canopy (canopy cover 96.2%) due to both an increase in tree basal area (from 19.5 m² ha⁻¹ in 2007 to 36.2 m² ha⁻¹ in 2020) as well as an extensive growth of woody climber yellow nicker bean (*Caesalpinia bonduc*).

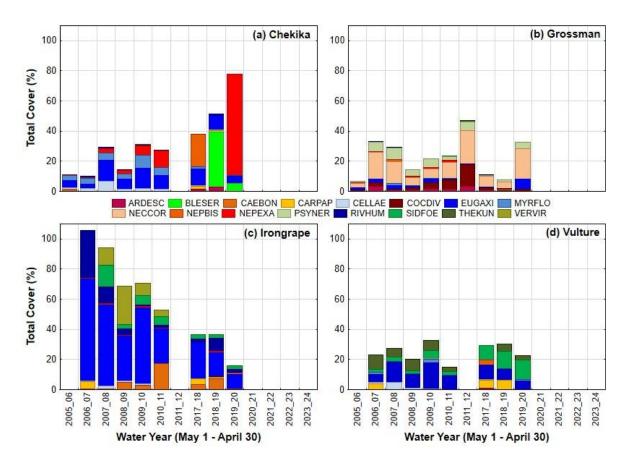


Figure 1.23: Percent cover of herbs and shrub species in hardwood hammocks of four tree islands (Chekika, Grossman, Irongrape and Vulture Hammock) sampled annually between WY 2005/26 and 2011/12 and then for three years after Hurricane Irma, between 2017/18 and 2019/20. ARDESC= *Ardisia escallonioides*; BLESER = *Blechnum serrulatum*; CAEBON= *Caesalpinia bonduc*; CARPAP= *Carica papaya*; CELLAE= *Celtis laevigata*; COCDIV= *Coccoloba diversifolia*; EUGAXI = *Eugenia axillaris*; MYRFLO = *Myrsine floridana*; NECCOR = *Nectandra coriacea*; NEPBIS = *Nephrolepis biserrata*; NEPEXA= *Nephrolepis exaltata*; PSYNER= *Psychotria nervosa*; RIVHUM= *Rivina humilis*; SIDFOE = *Sideroxylon foetidissimum*; THEKUN= *Thelypteris kunthii*; VERVIR= *Verbesina virginica*.

1.3.4.2 Species Richness, Evenness and Diversity

In the hardwood hammocks of four tree islands, the herb and shrub layer (H&S) vegetation were also sampled until WY 2011/12 along with tree layer vegetation sampling. In these plots, H&S vegetation was not sampled between 2012/13 and 2016/17. The sampling resumed in 2017/18, 3 months after Hurricane Irma. The H&S species richness, evenness, and diversity varied greatly over the sampling period (Figure 1.24). In concurrence with H&S layer species composition, both the species' richness and diversity showed response to the changes in canopy cover, possibly due to impact of two hurricanes (Wilma and Irma). The mean species richness first increased for three years after Hurricane Wilma, then began to decrease. The mean H&S species richness was relatively high during the past seven years (2017/18 – 2023/24) when the islands have experienced

relatively wetter conditions. Although mean species richness fluctuated annually, both the mean species evenness and diversity were relatively stable (Figure 1.24).

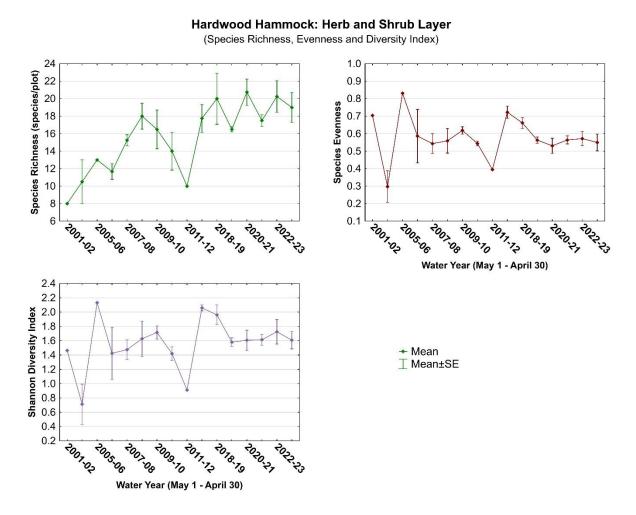


Figure 1.24: Species richness (species/plot), evenness, and Shannon species diversity in the herb and shrub (H&S) layer vegetation in the hardwood hammock averaged over four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled over 25 years. During WY 2001/02 (or 2002/03) sampling, only the first three islands were sampled. Likewise, during 2015/16, Black Hammock was not sampled.

1.4 Discussion

In the hardwood hammock portions of the Everglades tree islands that we studied, plant communities respond to changes in hydrologic conditions and periodic disturbances such as tropical storms. Our results show that rising water level and periodic fluxes in the hydrologic regime and tropical storms affect tree demography, tree layer composition, and understory (herb and shrub) composition. However, their effects vary among islands depending on the position of the islands within the landscape and existing hydrologic conditions.

Hydrologic conditions at the studied tree islands were wetter during this 5-year study period (2019-2024) than previous study years on all islands, and among those five years, WY 2023/24 was the wettest year. In fact, annual mean water levels in these tree islands in WY 2023/24 were 21.9 to 39.5 cm above the 33-year (WY 1991/92 - 2023/24) average (Figure 1.3). What's more, one island in the NESRS region, which is experiencing increasing wetness due to increased water delivery into ENP, had the highest RWL in the last 18 years. On this island, the mean water level in 2023/24 was within 15.4 ± 21.6 cm below the ground surface; 33% of the vegetation monitoring plot (300 m²) was flooded for >150 days, and 25% of the plot was flooded for >210 days.

During the last five years (2019 – 2024), high water levels in the studied islands were mostly due to both high rainfall in the SFWMD regions and increased inflow into ENP in three (WY2020/21, 2022/23 and 2023/24) of those five water years (Qiu and Ciuca, 2021; Cortez et al. 2022; Cortez 2023, 2024; Cortez and Smith 2025). For instance, total annual rainfalls were 1,532 mm (60.3 inches), 1,405 mm (55.3 inches) and 1,407 mm (55.4 inches), i.e., 185 mm (7.3 inches), 54 mm (2.11 inches) and 49 mm (1.92 inches) more rain than the historical 30-year average, respectively (Cortez et al. 2022; Cortez 2024; Cortez and Smith 2025). Likewise, the total inflow into ENP was 225%, 162% and 192% of the historical flow averaged over approximately 50 years. Within the SRS, the average stage at P-33 was 221.6 cm (7.27 ft), 211.8 cm (6.95 ft) and 210.6 cm (6.91 ft), which was 35.7 cm (1.17 ft), 26.5 cm (0.87 ft) and 25.9 cm (0.85 ft) higher than long-term (70 years: 1952-2022) average stage, respectively. By comparison, total inflow into ENP in WY2019/20 was 20% less than the long-term average, while in 2021/22, it was only 3% less than the long-term average inflow (Qiu and Ciuca, 2021; Cortez 2023).

The hydrologic condition in tree island hammocks varies depending on the location of tree islands within the R&S landscape and tree island height above the surrounding marshes. Based on their locations, islands in the NESRS area were drier than the western and central SRS islands, primarily because the area has been deprived of water for a long time due to very limited water delivery into this region. Thus, the islands in this region might be expected to have the lowest water level below the ground. However, while our results showed that Chekika had the lowest RWL, not all islands in NESRS had low RWL compared to islands in other regions. For instance, SS-81, located downstream of the 1-mile Tamiami Bridge, had relatively low water level until 2015, but thereafter RWL on that island has been consistently high (Figure 1.3, 1.4). On that island, the relatively highwater level in recent years is primarily because of water deliveries into ENP under the Increment Field Tests associated with the Combined Operational Plan (COP) that took place between 2015 and 2019, followed by its implementation thereafter (*see the next paragraph*). Due to an increase in water deliveries into ENP in recent years, water levels even in Chekika island, also within the

NESRS region, were higher than the long-term average in every single year since WY 2017/18 (Figure 1.3), and it was more than 20 cm higher than the long-term average since WY 2020/21, i.e., the year when operations under the COP were fully implemented. Moreover, hydrologic conditions on tree islands are not simply the function of regional marsh hydrology. They could also be a function of the geomorphological characteristics of tree islands, such as the tree island height (the difference in elevation between the surface of the tree island and the surrounding marsh). In a study of 76 slough and prairie tree islands within ENP and WCA3B, RWL was negatively correlated with tree island height (Ross and Sah, 2011). Among the eight islands studied, Chekika and Vulture had the lowest water level and had the greatest tree island height (Table 1.1).

Water conditions throughout the Everglades, including ENP, depend on the gradual implementation of restoration plan components. Under the preferred plan (ALTQ+) identified in the COP, water delivery into ENP (both northeast and western SRS combined) was projected to increase by 25%, resulting in an increase in water delivery into NESRS by approximately 162,000 acre-feet per year on average (USACE, 2020). Similarly, during the process of revisions to the 2005 Interim Goals and Targets for CERP, out of four simulations, the 2032PACR simulation projected the flow into NESRS to increase by a total of 528,000 acre-feet per year (RECOVER, 2020). In fact, the water level in NESRS has already been relatively high because of the increased water delivery due to the Increment Field Tests (October 2015-2019) (USACE, 2020), followed by the implementation of the COP in August 2020. In comparison to the WY 2015/16, when the Increment Field Tests began, the mean annual water levels in 2023/24 are already 37.6 cm and 45.0 cm higher on Chekika island and SS-81, respectively.

During the evaluation of the Interim Goals scenarios (RECOVER, 2020; USACE, 2020), an analysis of possible inundation of 36 tree islands, for which elevation data were available, concluded that none of those islands would be inundated more than 10% of the modeled time period, and thus may not have a drastic change in vegetation composition. In another study, that used modeled water surface elevations for different scenarios described in CEPP, results showed that relative water level on tree islands in Western/Central SRS and NESRS would increase by 5-10 cm and 15-20 cm, respectively (Wetzel et al., 2017). However, in the same study, vegetation succession models using the Everglades Landscape Vegetation Succession (ELVeS) showed minimal or no change in plant community types on those islands (Wetzel et al., 2017). In general, while prolonged flooding can devastate hardwood hammocks or even destroy whole islands (Patterson & Finck, 1999; Brandt et al., 2000; Hofmockel et al., 2008), an incremental upward shift in the RWL over time could also cause a shift in species composition and productivity of plant communities on tree islands. However, such a gradual shift in vegetation in response to hydrologic change commonly occurs in wetter communities (bayhead and bayhead swamp) (Sah et al., 2018). A sharp decrease in tree density and basal area of flood-intolerant species sugarberry (Celtis laevigata) between WY 2014/15 and 2023/24 (density and basal area by decreased by 75% and 63%, respectively) and an increase in abundance of flood-tolerant pond apple (Annona glabra) observed in the hardwood hammock of the SS-81 island during the same period was mostly due to increased wetness in NESRS. Moreover, there was a dramatic increase in the number of Brazilian pepper (*Schinus terebinthifolia*), which was recorded on this island in WY 2019/20 for the first time. This also increased the species diversity in the hardwood hammock of the island.

For flood-intolerant trees, root-zone flooding causes deleterious oxygen depletion in soils, leading to root damage, reduced nutrient uptake, stomatal closure, and decreased photosynthesis (Kozlowski 1997; Jackson & Colmer 2005; Voesenek & Bailey-Serres 2015). In the hardwood hammock of Everglades tree islands, water level higher than the optimal -40 cm for several days may adversely impact trees on these islands (Armentano et al. 2002). In six of eight studied hardwood hammocks, the annual mean RWL remained below -40 cm in most years, suggesting that limited increase in marsh hydroperiod or water depth in ENP are unlikely to have an immediate significant adverse impact on the hardwood hammock communities on these islands. However, while on five of eight islands the mean annual RWL was above -40 for >180 days only in WY2023/24, in the hammock plots of two islands (Grossman and SS-81), the mean RWL was above -40 cm for more than 180 days consistently for the last four years (2020/21-2023/24). The island SS-81 is in NESRS, and its hardwood hammock community was once dominated by the shallow-rooted, moderately flood tolerant sugarberry (Celtis laevigata) (Kennedy 1990) (Hook 1994). Consistently high annual mortality (≥12%) of this species when the mean annual water level and three-year average annual water levels were above -40 cm for more than 180 days (Figure 1.12) warrants special attention. This is important, especially when, as outlined in the Central Everglades Planning Project (CEPP) and Combined Operational Plan (COP), restoration activities are expected to further increase water deliveries from WCA 3A into ENP through NESRS (USACE, 2014, 2020). After the implementation of COP in August 2020, the volume of water delivered to NESRS across Tamiami Trail in WY2021 and 2022 was 71.0% and 84.6% higher than the volume delivered in WY2020 (USACE, ENP and SFWMD 2023), and such water deliveries are expected to increase for some years. These changes in water deliveries are likely to affect vegetation composition on most of the islands in ENP, especially when approximately 50% of 58 tree islands in SRS experienced water levels above -40 cm for >180 days for the first time in the last five years (Pablo Ruiz – personnel communication).

In general, hydrology is the major driver of differences in species composition among various plant communities arranged along topographic gradients within a tree island (Armentano et al., 2002; Wetzel, 2002; Ross & Jones, 2004; Sah et al., 2018). However, tree island hardwood hammocks rarely get flooded, and the mean annual water table is often 40 cm or more below the ground surface (Table 2; Figure 1.5). Here, tree species composition dynamics is probably more the legacy of long-term interactions between hydrology and other physical processes, including recurrent disturbances. On some of these islands, high tree mortality was observed for 3-4 years after Hurricane Wilma in 2005, and the delayed tree mortality in post-Wilma years was attributed to the interaction of multiple disturbances, e.g., hurricane and drought (Ruiz et al., 2011). Immediately after Hurricane Irma, we also observed severe damage to the tree layer vegetation on some of the islands for which we had pre-Irma data. Tree mortality after the hurricane was higher than the background mortality, i.e., mortality before the hurricane (Sah et al., 2020, 2021, 2022). In addition, like the trend observed after Hurricane Wilma (Ruiz et al., 2011), delayed mortality was observed on four of eight islands (Grossman, Gumbo Limbo, SS-81, and Vulture). On SS-81,

tree mortality was four times higher in the two years after the hurricane compared to immediately afterwards, and more than five times higher than the background mortality. However, while post-Irma mortality stabilized in other islands, tree mortality on SS-81 remained high, though lower than two years post-Irma. As a result of tree mortality caused by the hurricane, as well as an unusual increase in ingrowth, a shift in vegetation composition was noticed on some of the studied islands (Figure 1.15).

In post-Irma years, an obvious change in species composition was observed on Gumbo Limbo, Irongrape and SS-81. On Gumbo Limbo, most of the sugarberry (*Celtis laevigata*) trees died, while on Irongrape and SS-81, the combination of an increase in mortality of existing trees and an ingrowth of other species caused the composition change. On Irongrape, where the hardwood hammock was relatively open and very few hardwood trees were present up to 2010 (Ruiz et al., 2011), there was an increase in abundance of a naturalized form of a cultivated species, *Carica papaya*. The change in *C. papaya* itself may not indicate much about the health of the island, but how the increased abundance of *C. papaya* affected the germination and growth of hardwood seedings needs detailed analysis. On SS-81, a drastic change in vegetation composition since WY 2019/20 was primarily due to a decrease in IV of the moderately flood-intolerant species, sugarberry (*C. laevigata*), and an increase in IV of pond apple (*A. glabra*) and Brazilian pepper (*S. terebinthifolia*), possibly due to increased water levels in NESRS or a combination of post-hurricane mortality and an increase in water levels.

Trees on hardwood hammocks are primarily flood-intolerant species. Water level above or near the ground surface for longer periods, especially during the dry season, adversely impacts the survival and growth of those tree species (Stoffella et al., 2010). During the 2016 dry season, the RWL on the SRS tree islands was higher than that in the wet season and was very close, i.e., in the root sensitive zone to the ground surface on two islands, for a longer period than during other years, which might have affected tree growth and increased mortality in subsequent years. The discrepancies in long-term dry and wet season trends in water level were prominent in recent years. For instance, in all eight islands, the mean dry season RWL was either higher or close to wet season mean RWL in all four years since 2020/21 (Figure 1.6). In the hammock plots of Grossman and SS-81, the mean dry season RWL was even above -40 cm in those years, while that condition persisted on Gumbo Limbo in 2020/21 and 2023/24, and on Satinleaf only during 2023/24. In this study, the RWL estimates are based on a flat-water table at the same elevation as in the marsh from which the EDEN estimates are derived. However, studies have suggested that the water table under the tree island can be drawn down further during the dry season and mounded during the wet season (Sullivan et al., 2011). Thus, the water level may not be flat throughout the year as assumed, but this assumption is useful to have an approximate estimate.

Brazilian pepper (*Schinus terebinthifolia*), an exotic invasive tree species in the Everglades, has been present in Grossman Hammock since we first studied the island in 2005/06. The presence of Brazilian pepper in this location is unsurprising, as the island is in a region of wildland-urban interface (WUI) in proximity to the eastern boundary of ENP. However, the species was recorded on Gumbo Limbo and SS-81 for the first time in 2017/18 and 2019/20, respectively. While Brazilian Pepper's IV in Gumbo Limbo was approximately 3.5% in WY2023/24 (three and a half

times higher than its IV in 2017/18) the most remarkable change in abundance occurred in SS-81, where its IV was only 3.4% in 2019/20 but increased to more than fourteen-fold this amount by 2023/24, when its IV was 48.9%. The increase in Brazilian pepper abundance on SS-81 within such a short period is alarming. In fact, different aspects of the recent appearance and expansion of this species on ENP tree islands need to be carefully and regularly monitored. Animals, including mammals, are the species' main dispersers (Ewel et al., 1982). However, Brazilian pepper seeds can be dispersed as far as 10-15 km in fresh or brackish water (Tassin et al., 2007; Donnelly and Walters 2008). Thus, the water flowing from the north into NESRS may have contributed to the dispersal of Brazilian pepper into this island. The timely eradication of this exotic species is desirable.

Other study islands also experienced relatively high mortality in post-Irma years (Figure 1.9). However, those islands together with thirty other SRS islands are not expected to experience flooding more than 10% of the year in the preferred scenario of the Combined Operational Plan (USACE 2020). Nonetheless, since some islands, especially Black Hammock, Chekika, and Irongrape, are in the path of water flow through NESRS, the increase in their water levels is expected to be steeper than in other parts of SRS. The response of NESRS islands therefore requires care and regular monitoring to establish an effective link between science and management.

Beside water level and windstorms, fire is another stressor that affects tree island vegetation, especially when it consumes peat soils and lowers surface elevation (Wetzel et al., 2008). On our study islands, hardwood hammocks had not burned between 2001 and 2024. However, a fire in 2008 burned close to the hardwood hammock on Black Hammock, affecting the boundary between the tree islands and the surrounding marsh (Sah et al., 2018). Thus, the observed dynamics of plant communities in the hardwood hammocks were primarily the result of hydrologic changes and impact of tropical storms, not fire.

In summary, the hardwood hammock portions of our study islands were rarely flooded and have not burned for decades. Tree species dynamics of these hammocks are primarily the legacy of the long-term interaction between hydrology and tropical storms, although short-term responses in tree demography or understory species composition may result from flooding events and/or tropical storms. In addition, the recent records of high mortality of moderately flood-tolerant and flood-intolerant species due to increasing water level and the possible expansion of an invasive species in ENP on two islands, need additional attention. The islands (such as SS-81 in NESRS) which are being impacted by increasing water levels due to incremental water delivery into ENP need special care, including early eradication of exotic species.

2. Hydrologically driven vegetation dynamics in bayhead and bayhead swamp portions of tree islands

2.1 Introduction

In the Everglades, where the slough-ridge-tree island mosaic forms a relatively slight topographic gradient, plant communities are very sensitive to hydrologic change. This is especially true in tree islands within the ridge and slough (R&S) landscape. The R&S tree islands are complex and have different plant communities arranged along topographic, hydrologic and soil nutrient gradients (Armentano et al., 2002; Ross & Jones, 2004; Espinar et al., 2011; Sah et al., 2018). In these landscapes, alterations to hydrologic regimes, together with periodic disturbances (hurricane, fire), result in changes in species composition that ultimately influence the vegetation successional processes. For instance, prolonged dry conditions precipitate the expansion of sawgrass into sloughs. This is usually followed by the establishment and growth of trees in the peat environment which drives successional processes towards dominance of woody plants, often in patches (i.e., tree islands) (Johnson, 1958; Kolipinski & Higer, 1969; Willard et al., 2006). Paleoecological evidence also suggests that establishment and proliferation of woody vegetation in sawgrass marshes or on ridges occurred during periods of sustained drought (Willard et al., 2002, 2006; Bernhardt, 2011). Likewise, the location of boundaries between tree island communities and surrounding low-stature marsh vegetation also shifted in the past, depending on hydrology, climate, or fire-induced changes in surface elevation (Stone & Chimura, 2004), or, since the 20th century, as a result of water management (Willard et al., 2006; Bernhardt & Willard, 2009).

Substantial changes in hydrologic conditions, whether natural or management-induced, are likely to cause quantitative and qualitative changes in tree island plant community structure and composition. With extreme and prolonged changes, this could even lead to complete degradation of forest structure and extensive change in ecosystem function. For instance, management-related extreme and prolonged high water level caused loss of tree island number and coverage in Water Conservation Areas (Patterson & Finck, 1999; Brandt et al., 2000; Sklar & van der Valk, 2002; Hofmockel et al., 2008). In contrast, shorter hydroperiods than during the pre-drainage era have resulted in the continued rapid development and succession of tree islands into well-developed forested communities in other regions, such as Shark River Slough (SRS) (Johnson, 1958; Kolipinski & Higer, 1969; Willard et al., 2006). However, the number of tree islands > 1 ha within SRS has decreased by 48.4% and their areal extent has decreased by 54.5%. This has partially been attributed to fires (Sklar and Dreschel 2013) which were possibly more frequent and intense during the drier conditions present in 1960s, 70s and 80s compared to the pre-drainage era.

The climatological records and hydrologic data from the SRS region suggest that the water level during most of the last decade of the 20th century was well above the 33-year average. In contrast, after 2000, both the mean annual rainfall and water level were relatively low for some years (e.g., WY2003/04, 2006/07, 2007/08, 2011/12 and 2014/15). A comprehensive analysis of vegetation data collected in 2001/2002, and again in 2011/2012 on three SRS tree islands suggested that there was little change in vegetation composition in the head portion of the tree islands whereas in the tail portion of the islands the relative abundance of flood-tolerant species declined, while that of moderately flood-tolerant species increased over the study period (Sah et al., 2018). In contrast to

the hydrological conditions observed during the 2001-2012 period, the conditions have been wetter than normal during recent years, especially after WY 2014/15. For instance, between 2015/16 and 2023/24, the annual mean water level was higher than the 33-year average in seven of nine years on most islands (Section 1; Figure 1.3), Moreover, the water level in the past four years (2020/21 – 2023/24) was either as high as or even higher than in the mid to late 1990s. Such a sequential change in water conditions (wet-dry-wet) over two and half decades has provided an opportunity to assess the response of SRS tree island vegetation, including those in hydric portions of an island, to shifts in hydrological regime. The question is- how resilient are bayhead and bayhead swamp vegetation communities in tree islands in response to those short-term changes in hydrologic regime.

This study examines vegetation dynamics over a 23-year period between 2001 and 2024 within hydric portions (bayhead [BH] and bayhead swamp [BS]) of SRS tree islands by i) assessing the response of species composition and life forms to changes in hydrologic regime over time, and ii) quantifying changes in relative importance of woody species. We expected that in response to hydrologic variation from wet to dry and then to wet conditions, both bayhead and bayhead swamp communities would show characteristics of low resistance but high resiliency. Relative abundance of flood-intolerant or moderately flood-tolerant woody species increased during the 15 years after 2001 when the system was relatively dry, while both communities would shift towards a more hydric type during the most recent years when water level in the region showed an increasing trend.

2.2 Methods

2.2.1 Study Area

Tree islands on which bayhead and bayhead swamp communities were periodically sampled included three islands (Black Hammock, Gumbo Limbo, and Satinleaf) in the Shark River Slough, and one island (SS-81) in Northeast Shark River Slough (Figure 2.1). SS-81 is located immediately downstream from the 1-mile (eastern) bridge on Tamiami Trail and thus is more likely to be impacted by increased flow from WCAs into ENP. This island, however, does not have distinct bayhead community, and thus only the bayhead swamp community was sampled. On the three islands within SRS, the bayhead and bayhead swamp plots were sampled first in WY 2001/02 or 2002/03 (Table 2.1), and then in 2011/12 or 2012/13, and again in 2018/19 (Table 2.2). Recently, only bayhead communities on those islands were sampled in WY 2023/24. In the tail (tall sawgrass) region of Gumbo Limbo, an additional plot was also established and sampled in WY 2002/03, and then was sampled in WY 2003/04, 2012/13 and 2018/19. On SS-81, a bayhead swamp plot was established and sampled for the first time in WY 2012/13. Thereafter, this plot was sampled two times, in WY 2018/19 and WY 2023/24.

During this 5-year period (WY 2018/19 to 2023/24) of the project, bayhead swamp plots were established and sampled for the first time in 2021/22 on an additional four islands; Chekika, Irongrape, Vulture, and NP-202 (Table 2.1). While repeated samplings of bayhead and/or bayhead swamp plots on the first four islands help assess the vegetation dynamics over two and a half decades, recently established bayhead swamp plots on the other four islands serve as a baseline for

assessing the vegetation dynamics in response to potential hydrologic changes. Specifically, the potential changes from operational shifts in water management, associated with restoration efforts.

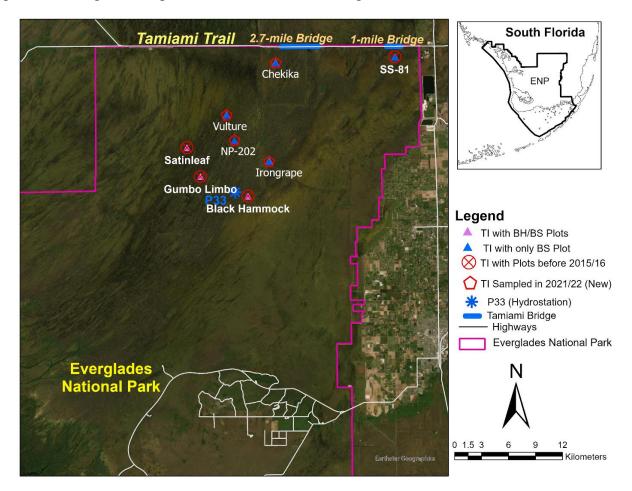


Figure 2.1: Location map of tree islands that have permanent plots in bayhead (BH) and/or bayhead swamp (BS) plots. The plots have been sampled in varying periods between 2001/02 and 2023/24.

2.2.2 Data Collection

2.2.2.1 Vegetation sampling

The vegetation sampling in the bayhead and bayhead swamp plots employed a nested sampling design that accounts for all the major vegetation strata (trees & saplings, shrubs, seedlings, and herbaceous macrophytes) present within the plots. The sampling protocol followed the methodology described by Sah (2004) and Ruiz et al. (2013a). The size of bayhead and bayhead swamp plots are 400 m² and 225 m², respectively (Table 2.1). The size of the sawgrass tail plot in Gumbo Limbo is the same as that of a bayhead swamp plot.

Each plot is gridded into $5\times5m$ cells, whose corners are marked by 30 cm long flags and whose midpoint have a ½" PVC stakes affixed to the ground. In these plots, all trees (≥5 cm) are tagged with numbered aluminum tags, and the location of each tagged tree relative to the SW corner of the plot is recorded to the nearest 0.1m. Furthermore, if a tree has multiple stems ≥5 cm diameter

(cm) at breast height (DBH), each stem is tagged with a unique ID that allows it to be cross-referenced back to its 'parent'. DBH of each individual living tree was first recorded when plots were established. In the BH and BS plots of three islands (Black Hammock, Gumbo Limbo and Satinleaf) and BS plot of SS-81, vegetation was re-surveyed in 2011/12 or 2012/13, and again in 2018/19 and 2023/24 (Table 2.2). During subsequent samplings on those islands, the tree census included the mortality status (live and dead) and DBH of tagged trees, and the DBH and mortality status of any tree that had grown into the >5cm DBH class since the previous survey (i.e., ingrowths). In-growths were identified to species and tagged.

Table 2.1: Location and topographic data (mean, minimum, and maximum) of bayhead (BH), bayhead swamp (BS) and sawgrass tail plots on eight tree islands.

Tree Island	Plot	Established Year (WYr)	Easting NAD83 (UTM_Z17N)	Northing NAD83 (UTM_Z17N)	Plot Size (m ₂)	Mean (± 1 S.D.) Plot Elevation (m NAVD 88)	Minimum Plot Elevation (m NAVD 88)	Maximum Plot Elevation (m NAVD 88)
Black Hammock	ВН	2002/03	531246	2832598	400	1.572 ± 0.062	1.435	1.729
Біаск пашшоск	BS	2002/03	531053	2832372	225	1.450 ± 0.088	1.354	1.828
	ВН	2002/03	525986	2834724	400	1.499 ± 0.084	1.336	1.701
Gumbo Limbo	BS	2002/03	525741	2834101	225	1.244 ± 0.034	1.186	1.302
	Tail	2002/03	525319	2833597	225	na	na	na
C-4:-16	ВН	2001/02	524454	2837943	400	1.564 ± 0.109	1.444	1.827
Satinleaf	BS	2001/02	524421	2837834	225	1.456 ± 0.074	1.383	1.640
SS-81	BS	2012/13	547596	2847668	225	1.600 ± 0.029	1.570	1.660
Chekika	BS	2021/22	534270	2846908	225	1.56 ± 0.039	1.510	1.630
Irongrape	BS	2021/22	533167	2836035	225	1.392 ± 0.057	1.310	1.500
Vulture	BS	2021/22	528798	2841434	225	1.631 ± 0.046	1.560	1.700
NP-202	BS	2021/22	529714	2838546	225	1.527 ± 0.024	1.490	1.560

Within each 5 x 5 m cell of BH and BS plots, the density and species of all tree saplings (stems 1-5 cm in DBH) was also recorded, and assigned to one of two DBH size classes: 1-3 cm or 3-5 cm. At the midpoint of each cell, the density of woody seedlings (stems < 1 m height) and shrubs (stems > 1 m and < 1 cm DBH) was estimated using nested circular plots of 1.0 m² and 3.14 m², respectively. Seedlings present within the 1 m² (0.57 m radius) plots were counted and identified to species and assigned to one of three height categories (1-30, 30-60, & 60-100 cm). All shrubs rooted within the 3.14 m² (1 m radius) plots were counted and identified to species. The total cover of each shrub species was also estimated using a modified Braun-Blanquet scale based on the following six cover categories: Cat 1: <1%; 2: 1-4%; 3: 4-16%; 4: 16-32%; 5: 32-66%; & 6: >66% (Sah, 2004). The total cover of all herbaceous macrophytes, which includes seedlings, shrubs (< 1 m tall), epiphytes, vines and lianas, within the 1 m radius plot was similarly estimated by species, using the same cover scale.

Table 2.2: Frequency of vegetation sampling in bayhead (BH), bayhead swamp (BS) and/or sawgrass tail plots on eight tree islands.

Tree Island	Plot	Ye	Burned Years			
i i ee isianu	1 101	Sampevent-1 Sampevent-2 Sampevent-3 Sampe		Sampevent-4	(2001-2024))	
DI 1 II 1	ВН	2002/03	2012/13	2018/19	2023/24	2006, 2008
Black Hammock	BS	2002/03	2011/12	2018/19		2006, 2009
	ВН	2002/03	2011/12	2018/19	2023/24	2017
Gumbo Limbo	BS	2002/03	2012/13	2018/19		2017
	Tail	2002/03; 2003/04	2012/13	2018/19		2017
S-4:-1£	ВН	2001/02	2011/12	2018/19	2023/24	2017
Satinleaf	BS	2001/02	2011/12	2018/19		2017
SS-81	BS		2012/13	2018/19	2023/24	2018
Chekika	BS				2021/22	
Irongrape	BS				2021/22	
Vulture	BS				2021/22	
NP-202	BS				2021/22	

2.2.2.2 *Hydrology*

For bayhead and bayhead swamp plots on three SRS tree islands, ground elevation data were available from a detailed topographic survey conducted using either an auto-level from a 1st order vertical control monument (benchmark), or a reference benchmark established in marsh followed by their elevation estimation by differential GPS or calculating from the EDEN (Everglades Depth Estimation Network) water surface elevation for that particular location (Ruiz et al., 2011).

For the bayhead swamp plot in the other five islands (SS-81, Chekika, Irongrape, NP-202 and Vulture), ground elevation was calculated using field-based water depth, measured in each 5x5m sub-plot, and water surface elevations provided by USGS's Everglades Depth Estimation Network (EDEN)) for the specific date when water depths were measured. In the BS plot on SS-81, water depths were measured in WY 2018/19, while in the BS plots on the other four islands, water depths were measured in WY 2021/22. Ground elevation for each sub-plot was then estimated by subtracting the mean water depth from the EDEN water surface elevation on the day it was sampled. Later, in conjunction with the daily EDEN water surface elevation data (http://sofia.usgs.gov/eden), those elevation data were used to calculate monthly, seasonal and annual mean water depths, and discontinuous hydroperiod (i.e., the discontinuous number of days in a water year (WY: May 1 - April 30) when water level was above the ground surface).

2.2.3 Data Analysis

2.2.3.1 Hydrologic conditions

Mean monthly, seasonal and annual water depths and discontinuous hydroperiod were calculated using ground elevation and the time series data of water surface elevation extracted from EDEN database. Previous studies have found that prairie and marsh vegetation composition are well predicted by the previous 3-5 years of hydrologic conditions (Armentano et al., 2006; Ross et al.,

2006; Zweig & Kitchens, 2009), whereas tree island vegetation was found strongly correlated with 7-year average hydroperiod and water depth (Espinar et al., 2011; Sah, 2004; Sah et al., 2018). Thus, in this study, we averaged hydroperiod and mean annual water depth for 4-7 water years (May 1st – April 30th) prior to each sampling event to examine the relationships between hydrologic parameters and change in vegetation characteristics.

Additionally, we used mean monthly relative water level (RWL) and assessed the trend over time by fitting a polynomial model of two degrees. Other models including cubic spline and natural spline models were also fitted to the data, although we chose the polynomial model since it had the lowest AIC score, for models fitted to Black Hammock Bayhead RWL).

2.2.3.2 Tree and Sapling-layer vegetation dynamics

Tree census data were summarized by calculating tree density and basal area. Changes in tree density and basal area together with differential mortality and/or in-growth among species over time usually results in a shift in species composition and species' relative abundance. Changes in tree species composition were analyzed using non-metric multidimensional scaling (NMDS) ordination. The abundance data used in the ordination was species' importance value standardized by species maximum. Bray-Curtis (B-C) dissimilarity index was used as a measure of dissimilarity in the ordination. Species' importance value (IV) was calculated using the equation: IV = $100 \cdot ((R_d + R_{ba})/2)$, where R_d is the species relative density and R_{ba} is the species relative basal area.

2.2.3.3 Shrub and herb-layer vegetation dynamics

Shrub and herb layer vegetation data were summarized by calculating annual mean percentage cover of all herb layer species including seedlings, shrubs (< 1 m tall), epiphytes, vines and lianas. We characterized changes in shrub and herb species composition and examined vegetation-environment relationships using NMDS ordination. Abundance data used in the herb layer ordination was species' mean percentage cover. The cover values for each species were standardized to plot total cover and the Bray-Curtis (B-C) dissimilarity index was used as a measure of dissimilarity in the ordination. Species present in less than 5% of sites were excluded from analysis. Relationships between species composition and environmental vectors representing hydro-edaphic characteristics (water depth and soil depth) were examined using a vector-fitting procedure incorporated in the computer R package VEGAN (Oksanen et al., 2022). Vector fitting is a form of multiple linear regression that finds the direction along which sample coordinates have maximum correlation with the fitted vector within the ordination space. Ordination axes were rotated so that Axis 1 was aligned with the water depth.

1.2.3.4 Species Rhichness, Evenness and Diversity

For both tree/sapling and herb/shrub layer vegetation in the hardwood hammock plots on the study islands, plot-level species richness (α-diversity), Shannon's species diversity index, and evenness were calculated and summarized by island and sampling year. The calculations were done using PCOrd software V.6 (McCune and Mefford 2011).

2.3 Results

2.3.1 Hydrologic conditions

Hydrologic conditions in the hydric portions of tree islands varied among islands and within an island over the years. Among the three tree islands on which BH plots were surveyed four times between WY 2001/02 and WY 2023/24, the BH plot on Black Hammock was drier than the BH plots on the other two islands, Gumbo Limbo and Satinleaf which had similar hydrologic conditions. In the BH plots of these three islands (Black Hammock, Gumbo Limbo and Satinleaf), the mean hydroperiods averaged over the 33 years for which EDEN data are available (1991/92 to 2023/24), were 151, 180 and 182 days, respectively. Likewise, the annual mean (\pm SD) relative water levels (RWL) were -6.0 \pm 2.6 cm, -0.6 \pm 5.2 cm and -0.2 \pm 5.4, respectively (Figure 2.2).

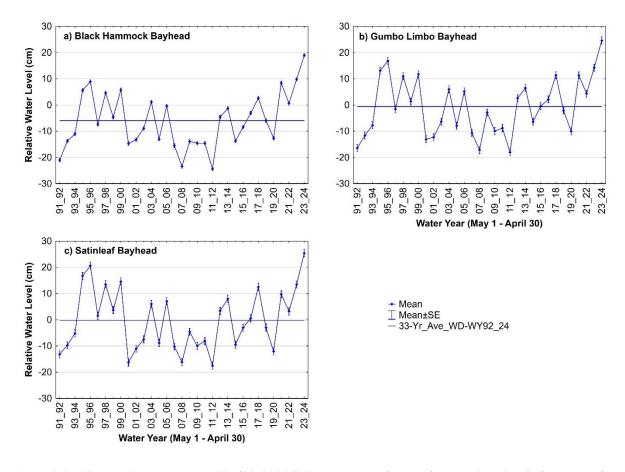


Figure 2.2: 33-year (Water Year 1991/92-2023/24) average and annual mean (±SE) relative water level (RWL) in bayhead forests on three tree islands (a) Black Hammock, (b) Gumbo Limbo, and (c) Satinleaf.

The BS plots were surveyed on eight islands: multiple times on four islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) while only one time (WY 2021/22) on the other four islands (Chekika, Irongrape, NP-202 and Vulture). The long-term hydrological data revealed that among

those eight islands, the BS plot was the wettest on Vulture Hammock. In BS plots on Black Hammock, SS-81, Satinleaf. Gumbo Limbo, Chekika, Irongrape, NP-202 and Vulture, the 33-year average hydroperiods were 223, 263, 265 and 320 days, and annual mean (\pm SD) RWL were 4.7 \pm 3.8 cm, 7.4 \pm 2.9 cm, 13.3 \pm 4.3 and 24.1 \pm 1.4, 16.93 \pm 3.9, 22.6 \pm 5.7, 8.4 \pm 4.6 and 25.2 \pm 2.4, respectively (Figure 2.3).

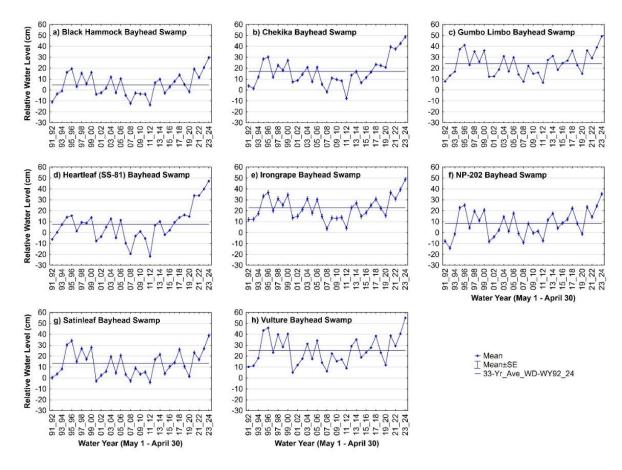


Figure 2.3: 33-year (Water Year 1991/92-2023/24) average and annual mean (±SE) relative water level (RWL) in bayhead swamp (BS) plots on four tree islands (a) Black Hammock, (b) Chekika, (c) Gumbo Limbo, (d) Heartleaf (SS-81), (e) Irongrape, (f) NP-202, (g) Satinleaf, and (h) Vulture.

Over the last three and a half decades, the hydrologic conditions in both BH and BS plots also showed a sequential periodic change from wet to dry to wet period. For instance, the hydrologic condition was much wetter in the mid-90s, prior to the first sampling in 2001/02, compared to the following decade, especially between WY 2000/01 and WY 2011/12, when the annual mean RWL was lower than the 33-year average in all years except WY 2003/04 and 2005/06 (Figures 2.2, 2.3). In contrast, during the past 7-year period (WY 2017/18 - 2023/24), the mean annual RWL was again above the 33-year average in most years in both BH and BS plots on these islands. However, like in other periods, variation in annual pattern in mean RWL during this period also differed among islands. For instance, after a surge in water levels during 2017/18, primarily due to hurricane Irma, the mean RWL decreased in the following year (2018/19) in the BS plots on

seven of the eight islands (Figure 2.3). But SS-81, located in NESRS, experienced an increase in RWL mainly due to an increase in amount of water delivery into the Park resulting from a series of Modified Water Deliveries (MWD) Incremental Field Tests (USACE, 2020) followed by the full implementation of Combined Operational Plan (COP) in 2020 (USACE/SEFMD/ENP 2023). In fact, among the eight islands on which bayhead swamp plots were studied, the overall wetting trend in recent years was much stepper in both islands within NESRS, Chekika and SS-81 (Figures 2.5, 2.6).

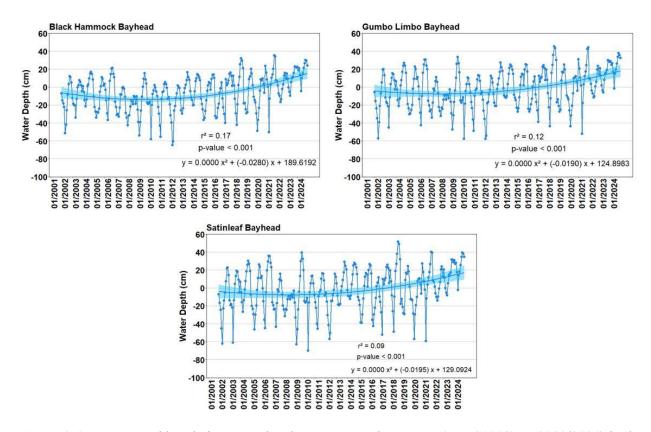


Figure 2.4: Mean monthly relative water level over twenty-three years (WY 2000/01 - 2023/2024) in the bayhead plots on three tree islands (Black Hammock, Gumbo Limbo and Satinleaf) sampled four times (2001/02, 2011/2012, 2018/19 and 2023/24) between 2001/02 and 2023/24. The trend line was fitted using a polynomial model.

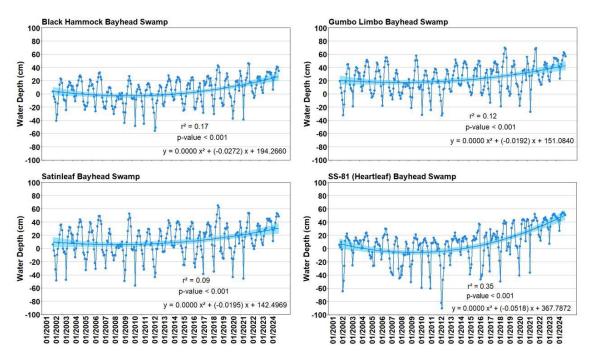


Figure 2.5: Mean monthly relative water level over twenty-three years (WY 2000/01 – 2023/2024) in the bayhead swamp plots on three tree islands (Black Hammock, Gumbo Limbo, Satinleaf) sampled three times between 2001/02 and 2023/24 (2001/02, 2011/2012 or 2012/13, and 2018/19), and SS-81, which was sampled three times between 2001/02 and 2023/24 (2013/13, 2018/19, and 2023/24). The trend line was fitted using a polynomial model.

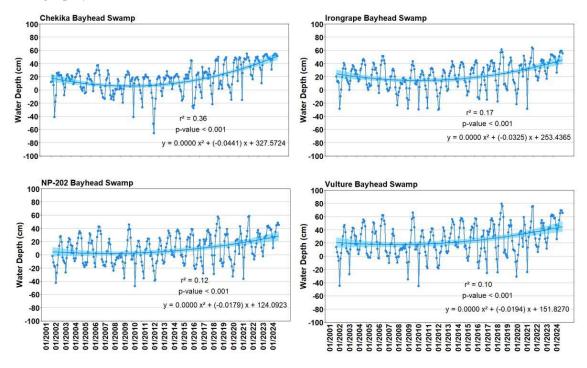


Figure 2.6: Mean monthly relative water level over twenty-three years (WY 2000/01 – 2023/2024) in the bayhead swamp plots on four tree islands (Chekika, Irongrape, NP-202 and Vulture) sampled once in 2021/22. The trend line was fitted using a polynomial model.

In general, as in the hard wood hammock plots, the annual mean water level in the hydric portions of tree islands also followed the regular dry (low) and wet season (high) pattern. However, in some years, the water levels in both the BH and BS plots were much higher in the dry season than in the wet season due to either an anomaly in weather pattern, management-induced changes in hydrologic regime, or both. For instance, since these plots were sampled for the first time during the 2001-2003 study, the most remarkable discrepancies between dry- and wet-season patterns were in 2001/02, 2009/10, 2011/12, 2015/16, 2017/18, and all four years since 2021/22. During these years, the water level in the dry season was either equal to or higher than in the wet season in all eight islands (Figure 2.7, 2.8). In four years (2015/16, 2020/21, 2021/22, and 2023/2024), this pattern was possibly caused by unusually high dry season rainfall followed by very low wet season rainfall in addition to increased dry season water deliveries into ENP. Because of management effects, the discrepancies in dry and wet season water level in those years were more distinct in NESRS than in SRS islands.

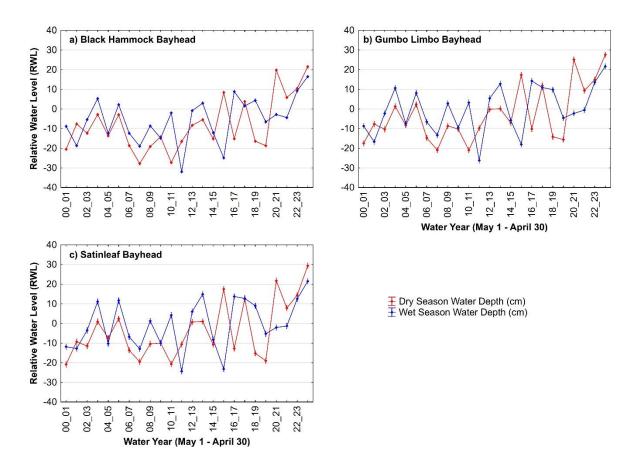


Figure 2.7: Seasonal-mean relative water level (RWL) between Water Year 2000/01-2023/24 and in bayhead forests on three tree islands (a) Black Hammock, (b) Gumbo Limbo, and (c) Satinleaf.

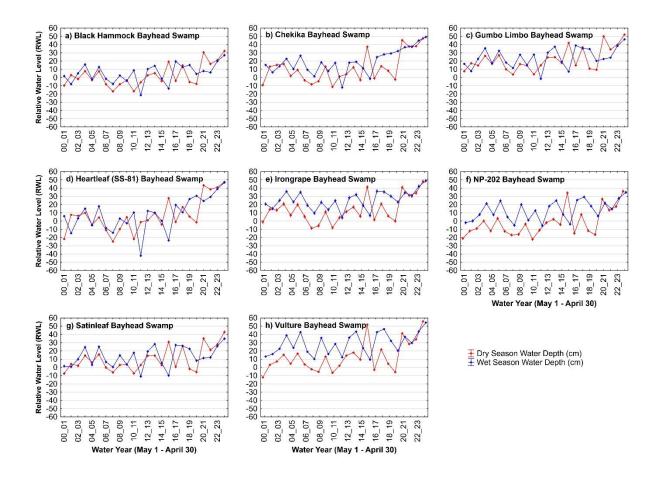


Figure 2.8: Seasonal mean (±SE) relative water level (RWL) in the bayhead swamp plots on eight tree islands. For each bayhead swamp plot, RWL was averaged over 12 to 25 5x5m sub-plots. RWL for each sub-plot was calculated by subtracting the mean elevation of each subplot from EDEN water surface elevation (WSE) at the hammock plot.

There is a time lag between changes in hydrologic conditions and their effects on vegetation composition. Researchers have shown that tree island vegetation is strongly correlated with 7-year average hydroperiod and water depth (Sah, 2004; Espinar et al., 2011; Sah et al., 2018). The periodic fluctuations in hydrologic conditions observed over 33 years were also manifested in hydroperiod and annual mean RWL averaged over seven years before each sampling event. While the number of islands sampled in the bayhead swamp plots varies among sampling events, the 7-year average hydroperiod and water depth were calculated across four islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) for each sampling event to report on hydrologic conditions. In both BH and BS plots, 7-year average hydroperiod and RWL were significantly (Wilxocon matched pairs test; p < 0.05) lower before the 2011/12 sampling event than before the 2001/02, 2018/19 and 2023/24 sampling events. Typically, the average 7-year hydroperiod was 40-90 days shorter and RWL was 9-12 cm lower during the 2011/12 sampling than during the other two samplings, 2001/02 and 2018/19 (Figures 2.9, 2.10). Over the study period of 25 years of bayhead

and bayhead swamp plots, the past 7-year period was the wettest. For instance, during the 2023/24 sampling in bayheads, the 7-year average hydroperiod was 85-173 days longer and RWL was 5.0-16.8 cm higher than during the three previous samplings (Figure 2.9). Likewise, during the same sampling in the bayhead swamps, the 7-year average hydroperiod was 19-86 days longer and RWL was 9.7-23.4 cm higher than during the three previous samplings (Figure 2.10).

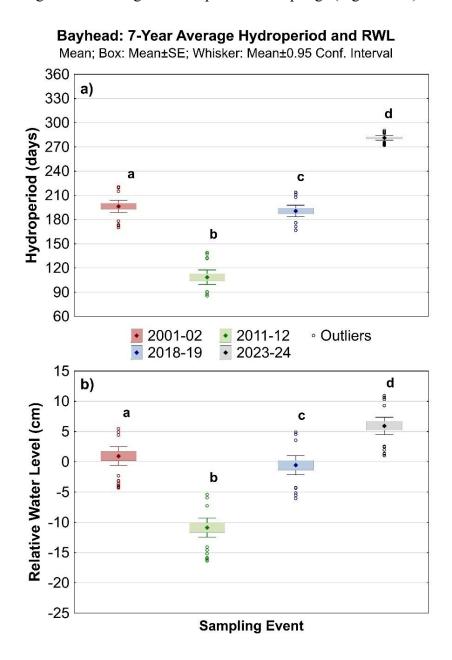


Figure 2.9: Box Plots showing a) hydroperiod and b) relative water level (RWL) averaged over seven years prior to water years 2001/02, 2011/12, 2018/19 and 2023/24, further averaged over bayhead plots in three Shark River Slough tree islands (Black Hammock (BL), Gumbo Limbo (GL) and Satinleaf (S)). Different letters represent significant (Wilcoxon matched pair test: P < 0.05) difference in 7-year average hydroperiod or RWL among water years.

Bayhead Swamp: 7-Year Average Hydroperiod and RWL

Mean; Box: Mean±SE; Whisker: Mean±0.95 Conf. Interval

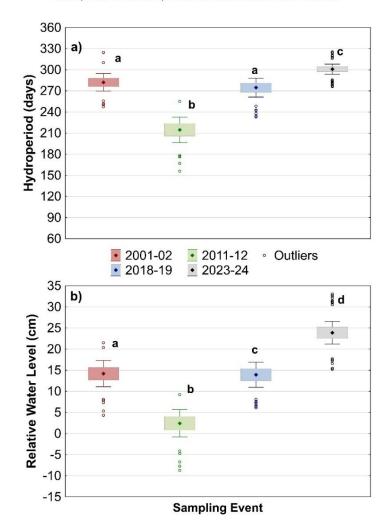


Figure 2.10: Box Plots showing a) hydroperiod and b) relative water level (RWL) averaged over seven years prior to water years 2001/02, 2011/12, 2018/19 and 2023/24, and further averaged over bayhead swamp plots on three Shark River Slough tree islands (Black Hammock (BL), Gumbo Limbo (GL) and Satinleaf (SL)) and one Northeast Shark River Slough tree island (SS-81 (HL)). While not all bayhead swamp (BS) plots were sampled in each of the four years (SS-81 BS was not sampled in 2001/02 and SRS island BS were not sampled in 2023/24), 7-year average hydroperiod and RWL were calculated for all four islands across all four years. Different letters represent significant (Wilcoxon matched pairs test: P < 0.05) difference in 7-year average hydroperiod or RWL among water years.

2.3.2 Tree/Sapling-layer vegetation dynamics

2.3.2.1 Species composition

Variation in the tree and sapling layer vegetation in the hydric (bayhead and bayhead swamp) portion of tree islands are well illustrated by NMDS ordination (stress = 0.139). The tree and

sapling layer woody vegetation in BS plots on SS-81 and Gumbo Limbo were different from the vegetation in the BH and BS plots on other islands and were indicative of a much wetter type (Figure 2.11). In contrast, woody vegetation in BS plots of Black Hammock and Satinleaf islands were to some extent similar in species composition to BH plots on those islands.

The NMDS ordination also revealed changes in vegetation composition over time. However, the pattern varied among islands. For instance, a shift in the position of Gumbo Limbo BH and BS plots first towards the drier end of the hydrologic vector (Figure 2.11), and then in the opposite direction was in concurrence with changes in hydrologic pattern over the study period (Figure 2.2, 2.3), but a shift in the position of BH or BS plots of the other islands along the gradient in the ordination space was not so distinct. Nonetheless, the BH plot of Black Hammock has shifted towards increasing wetness and BS plot of SS-81 had woody vegetation (saplings, *see below*) during the 2012/13 and 2018/19 samplings, but not during the 2023/24 sampling.

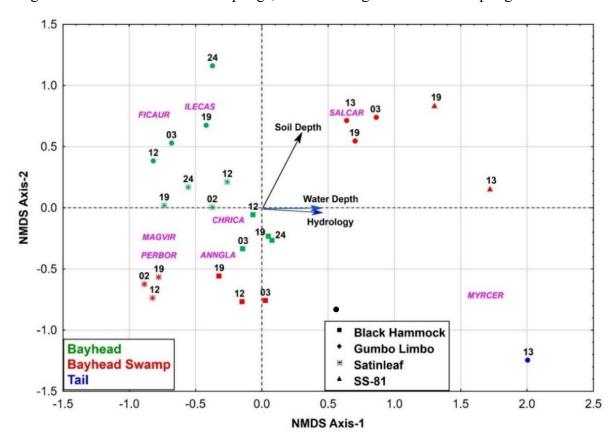


Figure 2.11: Scatterplot of NMDS ordination based on tree species basal area in bayhead and bayhead swamp plots on four islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled three or four times between Water Year (WY) 2001/2022 and 2023/24. Fitted environmental vectors represent the direction of maximum correlation between the variable and ordination configuration.

The importance value (IV) of species in both tree and sapling layers showed a great variability between plots and census periods. Across all BH plots, the average IV of several tree species declined between 2001/02 and 2011/12 (Table 2.2). However, the IV of three tree species, dahoon holly (*Ilex cassine*), coastal plain willow (*Salix caroliniana*), and cocoplum (*Chrysobalanus*)

icaco), increased during this period. The most notable increase was in the IV value of *C. icaco*. Its IV increased across all BH plots. In the BH plots of Black Hammock and Satinleaf, the IV of this species increased further in subsequent samplings (2018/19 and 2023/24) (Figure 2.12), when the region became relatively wet.

Table 2.2 Mean (±1 S.E.) tree and sapling importance value (IV) in bayhead and bayhead swamp plots of four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled during 2001/02 (or 2002/03), 2011/12 (or 2012/13), 2018/19 and 2023/24 samplings. The IV values for bayhead plots were averaged over three islands (Black Hammock, Gumbo Limbo and Satinleaf), and for bayhead swamp plots over the same three islands for the first sampling event, over all four islands for the second and third sampling events, and over one island (SS-81) for the fourth sampling event. * No woody species was recorded in bayhead swamp plot of SS-81 that was sampled in 2023/24. Mean total IVI for bayhead swamp plots were 33.3 50.0 for the 2001/02 (or (200203) and next two sampling events, as woody species were present only in one and two islands, respectively.

		Bayhead				Bayhead swamp			
Species	Species	2001/02	2011/12			2001/02	2011/12		
Species	Code	or	or	2018/19	2023/24	or	or	2018/19	2023/24*
		2002/03	2012/13			2002/03	2012/13		
	Trees								
Annona glabra	ANNGLA	44.6 ± 24.5	35.5 ± 7.4	42.2 ± 4.2	30.1 ± 16.9	14.3 ± 24.7	37.2 ± 47.8	35.9 ± 47.4	
Chrysobalanus icaco	CHRICA	4.4 ± 7.6	18.4 ± 17.4	25.9 ± 19.6	27.3 ± 18.6		1.6 ± 3.3	2.2 ± 4.5	
Ficus aurea	FICAUR	12.7 ± 22.0	9.9 ± 16.3	0.7 ± 1.2	3.3 ± 3.6				
	ILECAS	2.9 ± 3.0	3.3 ± 3.4	5.8 ± 8.5	3.3 ± 4.1		3.4 ± 6.8	6.0 ± 12.0	
Magnolia virginiana	MAGVIR	15.4 ± 17.2	10.6 ± 9.9	11.6 ± 10.0	12.1 ± 10.5		4.9 ± 9.8	5.9 ± 11.7	
Morella cerifera	MORCER	2.9 ± 2.8	2.1 ± 1.0	1.6 ± 1.4		4.2 ± 7.2	2.8 ± 5.7		
Persea borbonia	PERBOR	0.8 ± 1.4							
Salix caroliniana	SALCAR	14.7 ± 4.9	19.8 ± 0.7	12.3 ± 5.6	22.9 ± 18.5	14.9 ± 25.8			
Sambucus canadensis	SAMCAN	1.5 ± 1.5	0.4 ± 0.7		0.9 ± 1.6				
Mean total (IVI		100.0	100.0	100.0	100.0	33.3	50.0	50.0	
			S	Saplings/Woo	ody vines				
Annona glabra	ANNGLA	23.5 ± 18.7	10.7 ± 5	6.6 ± 6	1.4 ± 2.4	49.6 ± 32.6	38.8 ± 36.3	42.8 ± 35.3	
Cephalanthus occidentalis	CEPOCC	0.2 ± 0.3						1.0 ± 2.1	
Chrysobalanus icaco	CHRICA	37.2 ± 45.4	50.7 ± 41	48.8 ± 39.1	69.4 ± 32.9	0.2 ± 0.4	0.6 ± 1.2	1.3 ± 2.7	
Dalbergia ecastaphyllum	DALECA			1.0 ± 1.7					
	FICAUR	0.2 ± 0.3	14.4 ± 24.9		2.2 ± 3.8	0.1 ± 0.1	0.1 ± 0.1		
Ilex cassine	ILECAS	3.3 ± 4.9	2.6 ± 3.4	6.0 ± 8.5	8.6 ± 11.5		0.4 ± 0.8	1.4 ± 1.5	
virginiana	MAGVIR	8.0 ± 13.8	9.4 ± 11.1	8.5 ± 8		14.9 ± 24	8.8 ± 16	8.5 ± 16	
Morella cerifera		21.3 ± 21.9	3.1 ± 3.3	0.5 ± 0.8		6.1 ± 7.3	23.7 ± 32.6	10.0 ± 12.4	
	PERBOR		4.0 ± 7.0			0.2 ± 0.3	0.3 ± 0.4		
Salix caroliniana	SALCAR	6.2 ± 3.2		19.3 ± 18.6	17.0 ± 18.0	28.8 ± 48.1	27.4 ± 38.3	34.8 ± 40.9	
Sambucus canadensis	SAMCAN	0.2 ± 0.3	5.1 ± 6.3						
Vitis sp.	VITSPP			0.7 ± 1.3					
Mean total (IVI		100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Between the 2001/02 and 2011/12 sampling events, the IV of flood-tolerant pond apple (*Annona glabra*) decreased in the BH plot on Black Hammock but remained relatively unchanged on Gumbo Limbo and Satinleaf (Figure 2.12). This contrasts with increase in the IV of *C. iacoco* (also flood tolerant). On Satinleaf, the IV of sweetbay magnolia (*Magnolia virginiana*) significantly decreased and has remained unchanged since then. On this island, *C. iacoco* saplings have become much more dominant in recent years than before. In Gumbo Limbo, a significant decrease in IV of *A. glabra* was observed between 2018/19 and 2023/24 during which the plot became much wetter. In this plot, however, IV of willow (*S. caroliniana*) trees and saplings (another flood-tolerant species) increased significantly during the same period.

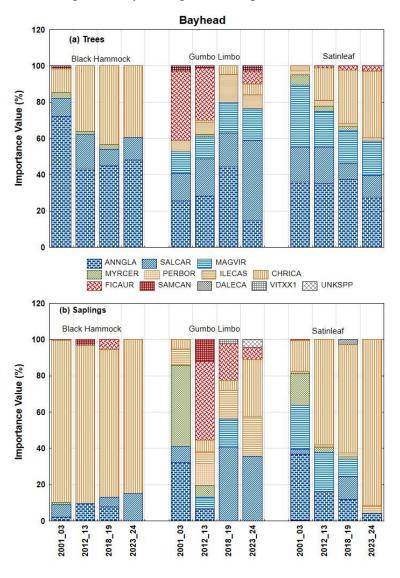


Figure 2.12: Importance value index (IVI) of tree and sapling species in Bayhead plots on three tree islands. ANNGLA= Annona glabra; CEPOCC= Cephalanthus occidentalis; CHRICA= Chrysobalanus icaco; DALECA= Dalbergia ecastaphyllum; FICAUR= Ficus aurea; ILECAS= Ilex cassine; MAGVIR= Magnolia virginiana; MORCER= Morella cerifera; PERBOR= Persea borbonia; SALCAR= Salix caroliniana; SAMCAN= Sambucus canadensis; VITSPP= Vitis spp.

In BS plots, there were no trees on Gumbo Limbo and SS-81 (Figure 2.13). However, there were woody saplings of several species in these plots. Between 2001/02 and 2011/12, the IV of the two dominant sapling species, *A. glabra* and *M. virginiana* increased in tree layer, but significantly decreased in sapling layers (Table 2.2). In the sapling layer, however, an increase in IV of wax myrtle (*Morella cerifera*) was noticeable, while IV of *S. caroliniana* species remained almost unchanged between these two surveys, as did most of the other sapling species.

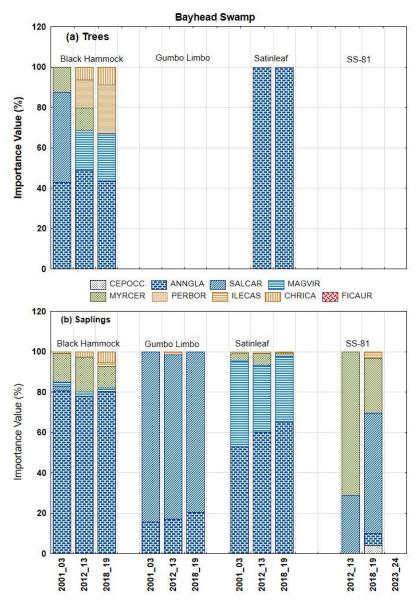


Figure 2.13: Importance value index (IVI) of tree and sapling species in bayhead Swamp on four tree islands. ANNGLA= *Annona glabra*; CEPOCC= *Cephalanthus occidentalis*; CHRICA= *Chrysobalanus icaco*; ILECAS= *Ilex cassine*; MAGVIR= *Magnolia virginiana*; MORCER= *Morella cerifera*; PERBOR= *Persea borbonia*; SALCAR= *Salix caroliniana*.

Between 2011/12 and 2018/19, the change pattern observed in IV of several species was opposite of what was observed between the first two samplings. For instance, across all bayhead plots, the

IV of *A. glabra* trees increased by 20% from 35.5% to 42.2%. In contrast, the IV of *S. caroliniana* decreased by 35%. An opposite trend was observed in the IV of these two species in the sapling layer. Surprisingly, the IV of two major species, *C. icaco* and *I. cassine* continued to increase during this period also. In BS plots, while the IV of *I. cassine* doubled on Black Hammock, the IV of other species did not change much during this period, except in sapling layer on SS-81. On this island, the IV of *M. cerifera* decreased by 50% while the IV of *S. caroliniana*, a species with relatively high flood tolerance, significantly increased.

2.3.3.1 Species' Richness, Evenness and Diversity

In both BH and BS plots, woody (trees and sampling) species richness, evenness and diversity did not differ much among the sampling years (Figure 14). In the BH plots of three tree islands (Black Hammock, Gumbo Limbo and Satinleaf), the mean species richness was the highest $(7.3 \pm 2.1 \text{ species/plot})$ during the 2001-2003 sampling (Event 1), while the diversity was the highest during 2011-2013 sampling (Event 2), when 7-year average hydroperiod and RWL were relatively low. As per expectations, both the species' richness and diversity were lowest during the most recent sampling, 2023/24 (Event 4), when the 7-year average hydroperiod and RWL were higher than previous three samplings.

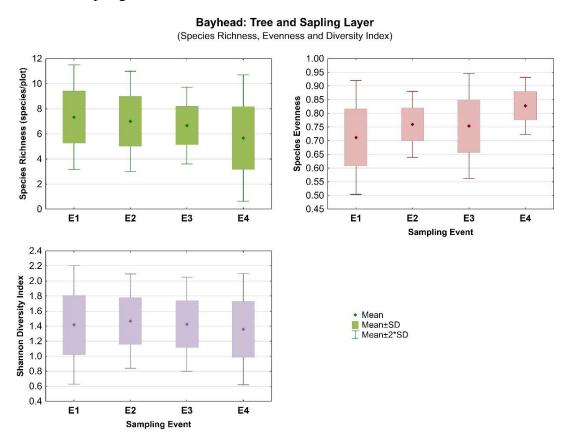


Figure 2.14: Species richness (species/plot), evenness, and Shannon species diversity in the tree and sampling (T&S) layer vegetation in the bayhead plots averaged over three tree islands (Black Hammock, Gumbo Limbo and Satinleaf) sampled over 25 years.

Like bayheads, species richness, evenness and diversity in bayhead swamps also did not show much variation over sampling period. However, in contrast to the trend observed in BH plots, the tree and sapling (T&S) species richness and diversity in BS plots was the highest during the third sampling event (2018/19) (Figure 2.15). In bayhead swamps, the mean T&S species richness was 4.0 species/plot during both the first and second sampling events, (2001-2003 and 2011-2013), while it increased to 4.3 species/plot during the third sampling event (2018/19). Shannon diversity index for bayhead swamps was 0.684, 0.705 and 0.797 during first, second, and third sampling events respectively.

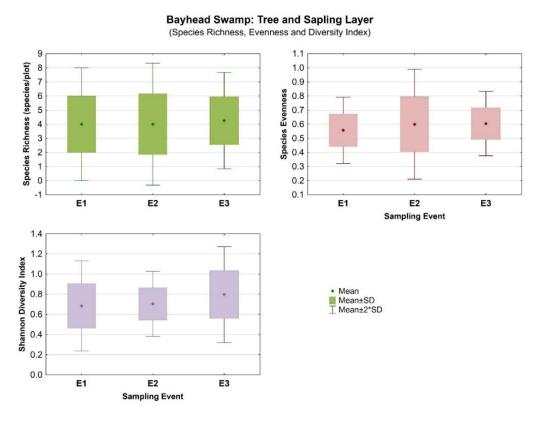


Figure 2.15: Species richness (species/plot), evenness, and Shannon species diversity in the three and sampling (T&S) layer vegetation in the bayhead plots averaged over four tree islands (Black Hammock, Gumbo Limbo, Satinleaf and SS-81) sampled over 25 years. During WY 2001/02 (or 2002/03) sampling, only the first three islands were sampled. During WY 2023/24, only SS-81 was sampled, but the plot did not have any individual in tree/sapling layer.

2.3.3 Shrub and herb layer vegetation dynamics

2.3.3.1 Species composition

Variation in shrub and herbaceous species composition in tree island plots was well summarized by the NMDS ordination (stress = 0.113), which revealed that bayhead, bayhead swamp and marsh vegetation were different in shrub and herb composition (Figure 2.16). Bayhead and bayhead swamp plots separate along the first NMDS axis which was strongly associated with hydrology

(7Yrs RWL, r = 0.71, p-value<0.001) (Figure 2.16). Soil depth is aligned orthogonally to the primary axis and correlates negatively with axis two.

Bayhead swamp plots, graminoids, and forbs, all clustered to the positive side of axis one. This was also in the direction of water depth and hydroperiod, indicating that BS plots have higher water levels and longer hydroperiods than BH plots and are characterized by graminoids and forbs vegetation. As is expected, also clustered on this side of the ordination were seedlings of two flood-tolerant tree species- pond apple (*Annona glabra*) and coastal plain willow (*Salix caroliniana*) (Figure 2.16). The BH plots clustered to the negative side of axis 1, associated with lower water levels and shorter hydroperiods. Here, seedlings of moderate flood-tolerant tree species cocoplum (*Chrysobalanus icaco*) and redbay (*Persea borbonia*) and flood tolerant species sweet bay magnolia (*Magnolia virginiana*) and dahoon holly (*Ilex cassine*) also clustered. Additionally, three ferns (giant leather fern, *Acrostichum danaeifolium*, swamp fern, *Blechnum serrulatum* and hottentot fern, *Thelypteris interrupta*) were common in bayhead portion of islands (Figure 2.16).

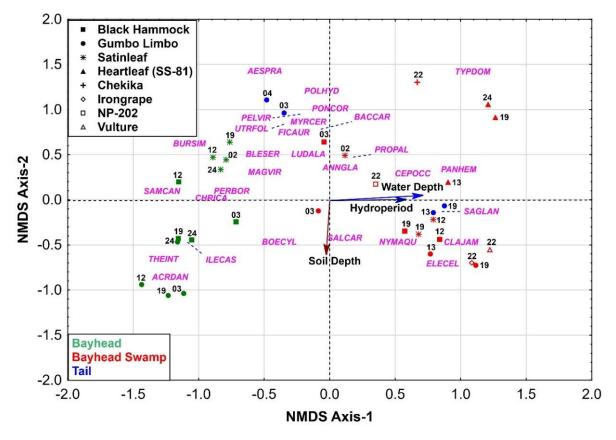


Figure 2.16: Plots of axis scores derived from shrub and herbs cover—based non-metric multidimensional ordination (NMDS) of bayhead and bayhead swamp plots sampled in 8 tree islands. Fitted environmental vectors represent the direction of maximum correlation between the fitted variable and ordination configuration. Bayhead plots were sampled four times (WY 2001/02 or 2002/03, 2011/12 or 2012/13, 2018/19, and 2023/24) on three islands (Black Hammock, Gumbo Limbo and Satinleaf). Bayhead swamp plots were sampled three times on four islands ((Black Hammock, Gumbo Limbo, Satinleaf and SS-81), between 2001/02 and 2023/24, whereas only one time (WY 2021/22) on the other four islands (Chekika, Irongrape, NP-202 and Vulture).

In herb and shrub layer vegetation, changes in species composition over time (2001/02-2023/24) varied among islands, and among the plot types within an island. Between the first two sampling events (i.e., between 2001/02 or 2002/03 and 2011/12 or 2012/13) in the BH plots of Black Hammock and Gumbo Limbo, there was a significant shift in species composition towards the drier end of the ordination, which aligns with the observed hydrologic trend during that period (Figure 2.16). A reverse trend was observed between 2011/12 (or 2012/13) and 2023/24. However, in the BH plots of Satinleaf, the change in herb and shrub layer species composition over time was not so distinct.

Bayhead swamp plots showed more temporal variation in herb and shrub layer vegetation composition than BH plots (Figure 2.16). On three tree islands (Black Hammock, Gumbo Limbo and Satinleaf) the shift in herb/shrub layer vegetation was not quite aligned with hydrologic trends between the first two sampling events (Figure 2.16), during which sites had experienced relatively dry conditions (Figures 2.2, 2.9). During that period, bayhead swamp herbs/shrubs layer vegetation showed a shift towards a wetter type, suggesting that factors other than hydrology might also have affected the composition during that period. On the other hand, after 2012/13, herb/shrub vegetation in BS plots on Gumbo Limbo and SS-81 shifted toward wetter type (Figure 2.16). Particularly, the BS plot on SS-81 had very high cover of cattail (*Typha domingensis*) during the most recent two sampling events. In fact, cover of cattail in this plot increased from just 1.5% in 2011/12 to over 40% in 2017/18 and over 70% in 2023/24. Likewise, the sawgrass tail sampled in Gumbo Limbo had shown a significant shift in composition. In this plot, sawgrass cover in 2011/12 and 2018/19 was much higher than in 2001/02. This might have created a competitive environment for other hygrophilous species like swamp smartweed (Polygonum hydropiperoides), pickerelweed (Pontederia cordata), green arrow arum (Peltandra virginica) and leafy bladderwort (*Utricularia foliosa*), resulting in reduction in their abundance.

2.3.3.1 Species' Richness, Evenness and Diversity

In both bayhead and bayhead swamp plots, species richness, evenness and diversity in herb/shrub layer (understory) vegetation varied over the sampling period. In BH plots, the mean understory species richness was the highest $(21.7 \pm 4.9 \text{ species/plot})$ during the first sampling event (2001-2003). The richness value was consistently low during the subsequent three sampling events (Figure 2.17). However, the understory species diversity was the highest (1.430 ± 0.046) during the 2011-2012 sampling event and was relatively low during the third and fourth sampling events (2018/19 and 2023/24).

In BS plots, the mean species richness, evenness, and diversity were the highest during the first sampling event (2001-2003) and decreased consistently during the subsequent three sampling events (Figure 2.18). During the 2001-2003 sampling event, the mean richness and diversity were 24.7 (\pm 4.2) species/plot and 2.164 (\pm 0.394), respectively. Species richness was 20.5 (\pm 5.4), 15.3 (\pm 3.1), 20.5 (\pm 5.4), and 10.0 species/plot whereas species diversity was 1.479 (\pm 0.307), 0.883 (\pm 0.387) and 0.800 during the second, third, and fourth sampling events respectively (2012/13, 2018/19, and 2023/24). It is important to note that sampling was done on three islands (Black Hammock, Gumbo Limbo and Satinleaf) during the first sampling event (2001-2003), but only on

one island (SS-81) during the most recent sampling event (2023/24). The four islands on which bayhead plots were sampled for the first time in 2021/2022 have not been considered for calculating mean species richness and diversity values.

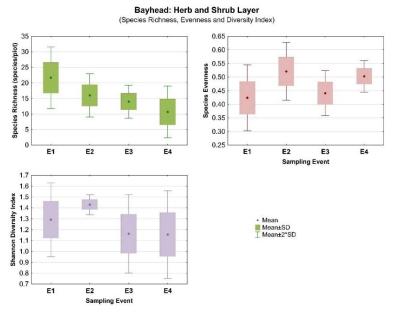


Figure 2.17: Species richness (species/plot), evenness, and Shannon diversity in the tree and sapling (T&S) layer vegetation in the bayhead plots averaged over three tree islands (Black Hammock, Gumbo Limbo and Satinleaf) which were sampled four times (E1: 2001-2003, E2: 2011-203913, E3: 2018/19 and E4: 2023/24) over the past 25 years. SS-81 (Heartleaf Island) does not have a bayhead plot.

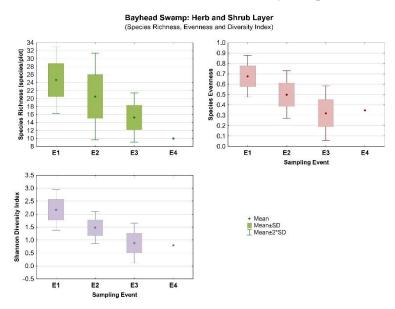


Figure 2.18: Species richness (species/plot), evenness, and Shannon species diversity in the tree and sapling (T&S) layer vegetation in the bayhead swamp plots averaged over three/four tree islands (Black Hammock, Gumbo Limbo, Satinleaf, and SS-81) sampled over the past 25 years. During the WY 2001/02 or 2002/03) sampling (E1), only the first three islands were sampled. Likewise, during the 2023/24 sampling (E4), bayhead swamp plots were only sampled in SS-81 (Heartleaf).

2.4 Discussion

Tree island plant communities, especially those in hydric areas, are dynamic, and respond rapidly to changes in hydrologic conditions. Our results show that below average water levels and shorter hydroperiods over a period as short as a decade can promote the establishment and growth of woody plants within tree islands. In contrast, an increase in water depth over the same timeframe promotes the growth of hydric herbaceous and fern species over woody species or shifts the relative proportion of woody species towards more flood-tolerant species.

In tree islands within the R&S landscape, bayhead, bayhead swamp, and sawgrass marsh are commonly considered as phases of a chronosequence of vegetation succession. Along this sequence, the proportion of woody plants and herbaceous species varies, and woody composition in bayhead and bayhead swamp also differs (Armentano et al., 2002; Sah et al., 2018). Bayhead forest typically has a mix of flood-tolerant and flood-intolerant tree species. Several flood-tolerant tree species e.g., pond apple (Annona glabra), wax myrtle (Morella cerifera), sweet bay magnolia (Magnolia virginiana), and coastal plain willow (Salix caroliniana) that occur in bayhead also occur in bayhead swamp portions of tree islands. However, their growth remains stunted in the latter. Because of relatively dry conditions during 2001/02-2011/12, our expectation was that woody plant abundance would increase in cover in both bayhead and bayhead plots. During that period, we saw an increase in tree density and basal area in both bayhead and bayhead swamp plots. In bayhead plots, flood-tolerant species like pond apple (Annona glabra) and coastal plain willow (Salix caroliniana) saw their IV decline while moderately flood-tolerant species like cocoplum (Chrysobalanus icaco) and dahoon holly (Ilex cassine) increased. The increase in abundance of woody plants (especially flood-intolerant species) in hydric portions of these tree islands during a relatively dry period, supports the concept that tree island communities are much more dynamic than previously thought. Such changes in community composition in response to hydrologic fluxes may result in successional changes in plant communities (Stone & Chimura, 2004). In these plots, an increase in the number of trees and a new cohort of saplings indicate a slow but steady progression in the succession of the bayhead swamp into a bayhead community as conditions stay relatively dry.

With an increase in wetness in tree islands, one would expect a decline in abundance of woody plants or at least an increase in relative proportion of flood-tolerant species over moderately flood-tolerant and flood-intolerant species. The periods between 2011/12 and 2018/19, and between 2018/19 and 2023/24 were wetter than the 7-year period before 2011/12. In 2018/19, we observed an increase in IV of some flood-tolerant species, like *A. glabra* in the tree layer of bayhead plots. However, in contrast to our expectations, the IV of moderately flood-tolerant species like *C. icaco* and *I. cassine* also increased and the IV of a flood-tolerant species, *S. caroliniana* decreased. While on average, the 7-year period between 2011/12 and 2018/19 was relatively wet, in fact, South Florida did experience a severe drought in 2014/2015, that might have countered the effects of increasing wetness. After 2015/16, water level in the study area was higher than the 33-year average for three years, but the RWL decreased again in 2018/19 and 2019/202. Since then, however, water levels in bayheads and bayhead swamps have remained above the long-term average (Figures 2.2, 2.3). While mixed results in woody plant abundance were observed between

2011/12 and 2018/19 (mainly due to inter-annual variability in water level) the wetting trend after 2018/19 has resulted in an increase in the relative portion of the very flood tolerant willow (*S. caroliniana*) in both trees and saplings (Table 2.2).

In contrast to the three SRS islands, SS-81 in NESRS has experienced increasing wetness after 2015 (Figure 2.3). High water levels observed in NESRS were mainly due to the Increment Field Tests (October 2015-2019), followed by the implementation of the COP in August 2020 (USACE, 2020). Furthermore, in comparison to WY 2015/16, when the Increment Field Tests began, the mean annual water level in 2023/24 was already 45.0 cm higher on SS-81. The effects of such a sharp increase in water levels in the NESRS were observed on the vegetation in the bayhead swamp plots on SS-81. Between 2011/12 and 2018/19, the IV of sapling of the flood tolerant coastal plain willow (Salix caroliniana) increased by more than 100% while the IV of the moderately floodtolerant wax myrtle (Morella cerifera) significantly decreased (Figure 2.11). During the most recent (2023/24) sampling event, there were no woody trees or saplings in the plot at all. Instead, it was mostly covered with the aggressive cattail (Typha domingensis). While in response to increasing wetness the increase in relative portion of flood-tolerant species, or reduction in woody plants in the hydric portions of tree islands supports the expectation, the increase in dominance of cattail in the bayhead swamps is alarming. The reason for an increase in abundance of cattail in the region could be due to the increased P concentration in marsh water resulting from the redistribution of legacy phosphorus in water inflows (Sarker et al. 2020).

In coming years, water delivery into ENP (both northeast and western SRS combined) will continue to increase. If the trend in wetness observed on SS-81 since 2015/16 and its effects on bayhead swamp vegetation is an indication, we can expect similar changes in the hydric portions of tree islands in both NESRS and SRS. Since this is the part of the R&S mosaic, where tree island expansion and contraction of islands in response to hydrologic changes commonly occur (Stone and Chmura 2004), restoration activities under the Comprehensive Everglades Restoration Plan (CERP) which increase the water delivery to ENP are likely to affect tree island extent and dynamics. Depending on the magnitude of increase in water delivery into ENP, the balance between flood-tolerant and flood-intolerant woody species and herbaceous vegetation on these tree islands will change, and that may result in a shift in boundary between tree islands and marshes in this part of ENP.

While the distribution of tree species in tree islands has normally been viewed in relation to prolonged low or high-water conditions, tree island plant communities are also susceptible to the direct and indirect effects of disturbances like fire, particularly during drought conditions like those observed in 2007-2008, 2011-2012 and 2014-2015. Fires not only kill trees, but also consume rich organic soils on tree islands, thereby lowering the surface elevation and altering the water regime (Wetzel et al., 2008). Under these circumstances, immediate post-fire flooding can be detrimental to tree island recovery and may lead to their recession or elimination (Ruiz et al., 2013b). Furthermore, fire is known to sharpen the edges of both ridges and tree islands (Givnish et al., 2008; Wetzel et al., 2008). Between our sampling in 2001/02 and 2011/12, three fires burned the marshes close to Black Hammock (Table 2.1). However, these fires did not burn any part of our study plots, though both bayhead and bayhead swamp plots were within the fire boundary. Thus,

vegetation within the bayhead and bayhead swamp portion of Black Hammock was not affected. Between sampling events in 2011/12 and 2018/19, a fire in 2017 burned portions of Satinleaf and Gumbo Limbo, and a fire in 2018 partially burned the bayhead swamp plot on SS-81 (Table 2.1). Changes in abundance of woody plant species in the bayhead swamp portion of those three islands and in the sawgrass tail of the Gumbo Limbo were probably also affected by these fires and their interactions with hydrology. A more detailed analysis of the effects of those fires and their interaction with hydrology on vegetation in tree islands will help to better understand the plant community dynamics in the hydric portion of tree islands.

In summary, the hydric portions of our study islands (i.e., bayhead and bayhead swamp), experienced both natural and management-induced hydrologic variation. These hydrologic changes were significant enough to drive succession first towards less flood tolerant, and then towards more flood tolerant plant communities. These shifts were especially apparent in the understory layer and on those islands closest to water deliveries into ENP mandated by the Comprehensive Everglades Restoration Plan (CERP). As restoration continues, monitoring changes in these life stages on the islands in the affected areas will help achieve ideal habitat distributions.

3. Spatial Distribution of Plant Communities Mapped from Multispectral Satellite and Airborne LiDAR Data and their Realized Hydrological Niche Spaces across Tree Islands in Northern ENP (Ximena Mesa and Daniel Gann)

3.1 Introduction

Tree island monitoring is an essential aspect of the implementation of the Comprehensive Everglades Restoration Plan (CERP) to assess the impact of hydrological regime shifts on tree island vegetation composition, structure, and island configuration. To understand how the structure and composition of plant communities in tree islands are correlated and respond to hydrologic regimes and their change, we developed a mapping method that allows us to detect and model structural vegetation community classes from very high-resolution multi-spectral satellite data in combination with Light Detection and Ranging (LiDAR) derived canopy height and canopy structure metrics. Accurate detection of plant communities at a resolution that represents the scales at which change is expected to occur along hydrologic and nutrient gradients had previously been demonstrated for five tree islands located in the Shark River Slough (SRS) in Everglades National Park (ENP) and three tree islands in Water Conservation Area A (Sah et al., 2019). During the current phase of the project (2020–2025), the fully implemented and refined detection method and algorithms were applied to map community classes in areas with different hydrological management legacies.

We mapped vegetation of eleven tree islands to gain a better understanding of the relative elevation differences of communities across these islands and to evaluate the difference of hydrological conditions that these plant communities experienced before and after the beginning of the hydrological restoration of the Northeastern Everglades National Park in 2015. One tree island was in the marl prairie, east of Shark River Slough and the other ten islands were in the broader marsh wetland of Shark River Slough. We generated absolute and relative elevation distributions for all eleven islands and calculated pre- and post-restoration start hydrological variables per island and vegetation type. We then analyzed the woody community distribution across all islands and modeled the correlation of percent cover of each woody class with the size of the total woody core area of an island.

Finally, vegetation detection methods and LiDAR data algorithms were combined with Aerial Stereo Photography (ASP) derived point clouds to generate Digital Surface Models (DSMs) to evaluate their comparability when delineating forest structure (height) change. This is work in progress as the quality of historic aerial photography varies and even though validation procedures presented in this report are promising, we still need to develop a streamlining process that includes rigorous evaluation procedures.

The main objective of this report is to describe and summarize the findings of the work accomplished between 2020 and 2025.

3.2 Methods

3.2.1 Study Area

The eleven islands we focused on for this study are Black Hammock, Gumbo Limbo, Satinleaf, Vulture, NP202 and Irongrape, six islands located within Shark River Slough; four islands, Chekika, SS-93, SS-94 and SS-81 were situated in Northeast Shark River Slough; and one island, Grossman Hammock, a marl prairie island at the eastern border of ENP (Fig. 3.1 and Table 3.1). For each island type, we defined a classification schema that best represented the woody vegetation and the adjacent marsh or prairie communities (Table 3.2).

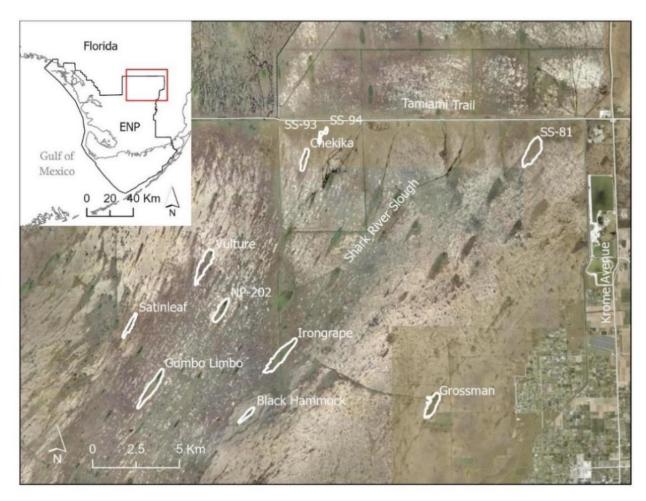


Figure 3.1 Locations of the eleven tree islands of interest. Black Hammock, Gumbo Limbo, Satinleaf, Vulture, NP202 and Irongrape are located in the central Shark River Slough; Chekika, SS-93, SS-94 and SS-81 in Northeast Shark River Slough; and Grossman Hammock in the marl prairie along the eastern border of ENP.

Table 3.1 Approximate location of the highest location of the woody vegetation of each island.

Tree Island	Easting (UTM 17N)	Northing (UTM 17N)
NP-202	529789	2838868
SS-93	535509	2848796
SS-94	533508	2848749
Black Hammock	531295	2832631
Chekika	534372	2847486
Grossman	541819	2833206
Gumbo Limbo	525999	2834794
Irongrape	533651	2836524
Satinleaf	524499	2838020
Heartleaf (SS-81)	547639	2848114
Vulture	528918	2841668

3.2.2 Plant Community Classification Schemes

The plant community classification scheme we used for the mapping of the tree island vegetation is presented in Table 3.2. Tree island woody vegetation classes included Hardwood hammock (tH) with trees and shrub species with growth heights greater than 5 m that are not typically found in standing water, Bayhead forest (tB) with trees and other woody species that are more tolerant to wet conditions, and Bayhead swamp representing shrubs and woody species with heights less than 5 m tall (sB). A mixed herbaceous vegetation with shrubs (hV_s) class is a broadleaved emergent class that is commonly interspersed with low shrubs. This class is typically found in tree island tails and edges frequently including *Cephalanthus occidentalis* (buttonbush) and/or fern species and broadleaved emergent species with strong graminoid presence (typically *Cladium* or *Typha*).

Table 3.2 Vegetation class code and corresponding class descriptions

Class Code	Class Name (Description)			
oM	Open marsh (mixed species of floating and submerged			
gM	Graminoid Marsh (mixed species of dense graminoid species			
gMT	Graminoid Marsh Tall (mix of Cladium / Typha)			
gMCl	Graminoid Marsh dominated by Cladium jamaicense			
gMTy	Graminoid Marsh dominated by Typha			
gP	Graminoid Prairie dominated by herbaceous vegetation			
gPCl	Graminoid Prairie dominated by Cladium			
hV_s	Mixed shrub, graminoid, and emergent broadleaf, including ferns			
sB	Bayhead Shrubs dominated by woody species with heights less than 4 m			
tB	Bayhead Trees dominated by woody species at least 4 m tall			
tH	Hardwood Hammock			
Wtr	Open Water			

Marsh classes were divided into classes dominated by a single species or a mix of species. The dominant monotypic marsh classes included regular to dense graminoid *Cladium jamaicense* (gMCl), or *Typha domingensis* (gMTy) marsh. When *Cladium* and *Typha* were mixed we called the class tall graminoid marsh (gMT). Two other mixed classes included a graminoid class of dense to very dense short growth graminoid species (gM) that include *Eleocharis spp.*, *Panicum spp.*, or *Rhynchospora spp.* A generic open marsh (oM) class with a mixture of sparse to very sparse graminoid marsh of the same short growth species together with dense submerged and floating vegetation including periphyton, typically found in deeper and longer hydroperiod marshes or sloughs. A graminoid prairie class (gP) and a *Cladium* dominated prairie class (gPCl) were included for Grossman Hammock, the only marl prairie island (Table 3.2).

3.2.3 Data Selection and Processing

We chose WorldView (WV) 2 and 3 data to map the tree island plant communities because WV sensors have a very high 2 m spatial and eight spectral bands that were previously successfully used to detect wetland plant communities including woody vegetation (Gann, 2018; Gann & Richards, 2023; Hochmair et al., 2022; Sah et al., 2019; Wendelberger et al., 2018). Gann (2018) and Wendelberger et al. (2018) showed that bi-season data increased mapping accuracy significantly. The main criterium for WV data scene selection was the ENP LiDAR acquisition date of spring 2017. Our WV data scenes were optimally selected within less than five years of the spectral data acquisition. Images with minimal cloud cover were obtained for wet and dry conditions during the dry season, ranging from October to February and March to April, respectively. Optimally the two dates were far enough apart to capture the highest variability of phenologies of the vegetation while cloud cover was minimal during the dry season (late-October to mid-May). We mapped Black Hammock, Irongrape, NP202, Vulture, Chekika, SS-93 and SS-94 from two images containing the seven islands that were obtained for the wet condition in 2018 (2018-02-16) and dry season in 2020 (2020-03-28). Islands Gumbo Limbo, Satinleaf and Vulture were mapped from two images obtained on the wet condition of 2018 (2018-02-16) and dry condition of 2018 (2018-04-17). Islands Heartleaf (SS-81) and Grossman Hammock were mapped from two images obtained in the wet condition of 2018 (2018-02-16) and on the dry condition of 2017 (2017-05-07). Vegetation in the last two islands was mapped independently from one another but still used the same images because of difference in vegetation communities between both tree islands.

The WV images were geometrically and radiometrically calibrated and atmospherically corrected in ENVI (*Exelis Visual Information Solutions*, 2013). Atmospheric correction of images was completed using the Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) module in ENVI (ENVI, 2009). Selection of the atmospheric model used in FLAASH was based on local air temperature at the time of image acquisition while the aerosol model chosen was based on wind direction (coastal vs. inland) and time of year. In addition to the eight original spectral bands, we generated eight vegetation indices (VI) derived from WV2 spectral bands (Table 3.3).

Table 3.3 List of the eight vegetation indices (VIs) derived from WV imagery. Band wavelengths of WV-2: B1: Coastal Blue (400-450 nm), B2: Blue (450-510 nm), B3: Green (510-580 nm), B4: Yellow (585-625 nm), B5: Red (630-690 nm), B6: Red-edge (RE) (705-745 nm), B7: Near-infrared1 (NIR1) (770-895 nm), B8: NIR2 (860-1040 nm).

Vegetation Index	Acrony m	Equation with Spectrum Name	References
Normalized Difference Vegetation Index	NDVI	(NIR1 - Red) / (NIR1 + Red)	(Rouse et al., 1974)
Normalized Difference Red-Edge Index	NDRE	(NIR1 - RE) / (NIR1 + RE)	(Barnes et al., 2000)
Normalized Difference Water Index	NDWI	(Green - NIR2) / (Green +NIR2)	(McFeeters, 1996)
Green Normalized Difference Vegetation Index	GNDVI	(NIR1 - Green) / (NIR1 + Green)	(Gitelson et al., 1996)
Enhanced Vegetation Index-2	EVI-2	2.5(NIR - Red) / (NIR1 + 2.4 Red +1)	(Jiang et al., 2008)
Normalized Difference Index using Red and Red-Edge	NDI45	(RE - Red) / (RE + Red)	(Delegido et al., 2011)
Modified Chlorophyll Absorption in Reflectance Index	MCARI	1.2[2.5(NIR1 - Red) - 1.3(NIR1 - Green)]	(Daughtry et al., 2000)
Soil Adjusted Vegetation Index	SAVI	(1+L) (NIR1 - Red) / (NIR1 + Red + L); L = 0.5	(Huete, 1988)

Since the inclusion of airborne LiDAR data products further improved the detection accuracy of woody vegetation (Sah et al., 2019; Wendelberger et al., 2018), we included vegetation height and canopy structure information. We generated seven LiDAR-derived metrics for each WV pixel from the 2017 ENP LiDAR data point clouds (Gann et al. in review). The LiDAR derived metrics included canopy pseudo-height (full range maximum – minimum of LiDAR returns), lower and upper 25th and 50th percentile ranges, and their ratios.

In a final step of data cube preparation, we masked previously digitized man-made structures on the islands and clipped the extent of the study area defined by a 200 m buffer of the approximate boundaries of each tree island that were manually digitized from high-resolution aerial photography in ArcGIS. The buffer of 200 m was generated to include the ecotone between the tree island and surrounding marsh communities and to allow for analysis of expansion and contraction of the tree islands over time.

3.2.4 Spectral Signature Evaluation

We evaluated the spectral signatures for each plant community of interest using a supervised classification algorithm. Training points were digitized across all islands representing all vegetation classes. Training samples for each vegetation class were digitized in ArcGIS using a combination of field surveys (2009) and high-resolution CIR aerial photography as reference. For all training samples, spectral signatures and LiDAR metrics were extracted from the 24-layer data

cube. A random forest classifier (Breiman, 2001) as implemented in the unifying modeling framework of the 'caret' package (Kuhn, 2015) was trained. We determined from test runs that 500 decision trees were sufficient to maximize model-based classification accuracy, beyond which no significant increase in accuracy was observed ($\alpha = 0.05$) (Kuhn et al., 2015). The parameter for the optimal number of random variables selected at each split ("mtry") was established for each random forest model through built-in tuning routines. Finally, the random forest classifier model was applied to all pixels of the study area to generate the vegetation class map.

3.2.5 Morphological Filtering of Vegetation Maps

A minimal mapping unit (MMU) of 80 m² was enforced for the Hammock tree community class and an MMU of 12 m² was enforced for all other classes by assigning a unique number to each connected region evaluating connectivity for the four nearest neighbors of each pixel and grouping pixels with the same value. Regions with an area equal to or below 12 m² were set to null and used as a mask to replace values with the values of the nearest neighbor from the original vegetation map.

3.2.6 User-Based Accuracy Assessment

We assessed the accuracy of the final plant community maps by image (wet/dry: 2018/2018, 2018/2020, 2018/2017) and separately for Heartleaf and Grossman because of their different classification schemes. The number of samples required for each class was calculated assuming a multinomial distribution of error for a desired map accuracy confidence of 95% with a 5% precision of the accuracy estimate (Congalton & Green, 1998). Samples were sampled using a stratified random sample method with equally distributed samples across all classes. Pixel centroids that were selected for accuracy assessment were greater than 1 m away from training pixels to avoid training sample inclusion in the accuracy assessment sample sets. We evaluated each sample visually from aerial photography and assigned a class label. Confusion matrices were constructed from predicted and reference class labels for all islands. Overall and class-specific user's and producer's accuracy were calculated and adjusted for inclusion probabilities associated with the stratified random sample design. Finally, bias adjusted areas were calculated for each class (Olofsson et al., 2014, 2013). All sampling, and bias adjusted accuracy assessment and area calculations were coded in R (R Development Core Team & R Core Team, 2013).

3.2.7 Woody Community Class Distribution

We were interested in the distribution of woody plant communities on tree islands and how the proportion of class distributions vary with total tree island woody core area size. For analytical purposes to standardize percent cover calculation of the class distribution of each tree island we generated a woody core area that included (1) Bayhead shrub, Bayhead tree and hammock tree (Woody Core 3). For each tree island, woody vegetation classes in the plant community maps were reclassified into a single class, converted from raster to polygon. A 100 m buffer was applied to the woody core areas to crop the plant community maps and class area and percent cover were calculated for each island. We finally analyzed the relationship between tree island woody core area size and the percentage of the three woody classes.

3.2.8 Absolute and Relative Elevation by Island and Vegetation Class

We were interested in the relative elevation of plant communities for each island to assess the effects of changed hydrological regimes on the woody communities of each island. Relative elevation was calculated in reference to absolute elevations. The absolute elevation digital terrain model (DTM) we used was a bias-adjusted LiDAR derived DTM (Gann et al. in review). Relative elevation for each pixel was generated for a 100 m radius around each pixel. Elevations were then aggregated and summarized by vegetation class.

3.2.9 Hydrology by Island and Vegetation Class

Since we were interested in the effects of hydrological restoration on tree island woody plant communities, we specified 7-year pre- and post-restoration periods with a restoration modeling start date set to 2015-01-01. EDEN surface layers were stacked and subset to buffered island outlines. EDEN stacks were then resampled to the 2 m vegetation map resolution using bilinear interpolation. Water depths were calculated by subtracting the bias adjusted DTM from the resampled EDEN surface using EDEN daily water surface estimates. From the daily water depth time-series we calculated water depth and hydroperiod variables for the pre- and post-restoration start periods. The variables of interest we are reporting here include Percent Wet (PW), Minimum Water Depth when Dry (WDDMin), Maximum Water Depth (WDMx), and Maximum Wet Event Length (WELMx).

3.2.10 Canopy Height Model from Historic Stereophotography

To evaluate the effect of hydrology on structural changes of woody communities on tree islands, we evaluated the use of historic stereoscopic aerial photography to establish location-specific canopy height. We processed ten stereoscopic near-infrared digital aerial photographs from 2012 (Miami-Dade County - 2012 Digital Aerial Photography) using the OrthoMapping workflow in ArcGIS Pro. Camera and frame tables were generated using the camera calibration report associated with the imagery. The camera table included interior orientation parameters focal length, pixel size, principal point, and lens distortion. The frames table consisted of exterior orientation parameters including the perspective center coordinates (x, y, z), and rotation angles Omega, Phi, and Kappa. Ground Control Points (GCP) were digitized from ArcGIS basemap aerial photography and used to geo-reference each historic photo. Both artificial and pseudo-invariant natural features were used to digitize the GCPs.

Block adjustment was performed by calculating tie points from the overlapping portion of images using frame triangulation (ArcGIS Pro). Image location accuracy was set to medium and tie point similarity, density and distribution were set to high, medium and random, respectively. The images were visually inspected for accuracy and more GCPs were added in low accuracy regions before block adjustment was reapplied. Stereo models were generated, and stereo pairs were defined by setting the minimum overlap area to 40% and selecting stereo pairs across flight lines. Finally, point clouds were computed by selecting stereo pairs using a multi-view image matching method developed by Hirschmuller (2008). This algorithm determines the difference by approximating a computation cost calculating the dissimilarity between corresponding pixels, to produce a dense

point cloud within reasonable run times on large images (Haala & Rothermel, 2012). The data were referenced to the horizontal datum NAD 83 (2011) and the vertical datum NAVD 88.

To evaluate bias and accuracy of DSMs derived from ASP generated point clouds for Chekika, we generated reference DSMs at different spatial resolutions from the Miami-Dade County 2015 LiDAR point clouds (https://coast.noaa.gov/htdata/lidar2_z/geoid18/data/5038/). The geographic coordinates in North American Datum of 1983 and orthometric heights in reference to the North American Vertical Datum (NAVD) of 1988, geoid 18, were converted to the horizontal and vertical projection and datum of the ASP point cloud, before the data were interpolated to surface models.

Since ASP and LiDAR point clouds were not perfectly vertically aligned and registered to each other, we calculated bias of point clouds in reference to points that coincided with man-made features like roofs and roads. As reference data for the bias assessment, we used 2017 LiDAR data derived DSM (Everglades National Park, 2017 Green and Infrared LiDAR Data), the most accurate elevation estimates available for those features. The calculated bias in the ASP point cloud was subsequently subtracted from the Z values of the ASP point cloud before DSMs were generated.

The algorithm we selected to convert point clouds to DSMs was the 'point2raster' (p2r) conversion method as implemented in the R package 'lidR' (Roussel et al., 2020). The algorithm we used implements a points-to-raster method where each pixel of the output raster is represented by the height of the highest points encountered within a search radius. The subcircle parameter allows for the replacement of each point with 8 points around the original one to more realistically represent the cloud points as discs. Data were processed and analyzed in R version 4.2.1 (R Core Team, 2022). We used the modeling framework of the 'lidR' package (Roussel et al., 2020), using its 'rasterize_canopy' function applying the 'p2r' function. DSMs were generated for the LiDAR point cloud and the ASP point cloud at 3-, 6-, 9-, and 12-feet resolution with a consistent sub-circle parameter set to 3 feet for all iterations.

We used the Root Mean Square Error (RMSE), a commonly used statistical measure of the difference between estimated and known values, to evaluate the accuracy of each ASP derived DSM, comparing the interpolated model values to the LiDAR derived DSMs.

3.3 Results and Discussion

3.3.1 Map Accuracy Assessment

Overall accuracy for the four maps ranged from 92.0 ± 1.4 % to 96.5 ± 1.2 % (Table 3.4). Highest accuracy was achieved for the Hammock and Bayhead tree classes ranging from 95.1 ± 2.4 to 100.0 ± 0.0 (Tables 3.5 - 3.8). The inclusion of LiDAR-derived vegetation height metrics has important implications in overall and class-specific accuracy and for the mapping of these communities, hence the high accuracy. The woody class with the lowest accuracy was the mixed woody class with accuracy ranging from 89.2 ± 3.2 to 97.6 ± 1.7 .

Table 3.4 Overall accuracy of classes by image.

Island Name	Bi-Season Data Images (wet/dry)	Overall Accuracy
Vulture, Satinleaf, Gumbo Limbo	2018-02-16/2018-04-17	96.5 ± 1.2 %
NP202, Irongrape, Black Hammock, Chekika, SS-93, SS-94	2018-02-16/2020-03-28	92.0 ± 1.4 %
SS-81	2018-02-16/2017-05-07	$96.5 \pm 0.7 \%$
Grossman Hammock	2018-02-16/2017-05-07	$95.0 \pm 0.9 \%$

Table 3.5 Design-based class-specific accuracy for Vulture, Satinleaf and Gumbo Limbo (wet/dry WV images: 2018-02-16/2018-04-17).

Class Name	User's Accuracy	Producer's Accuracy
Graminoid Marsh	94.6 ± 2.4	93.2 ± 3.1
Graminoid Cladium	95.7 ± 2.1	97.0 ± 1.1
Graminoid Typha	91.4 ± 2.9	100.0 ± 0
Herbaceous & Shrub	91.4 ± 2.9	88.0 ± 7.8
Open Marsh	97.8 ± 1.5	97.5 ± 2.3
Bayhead Shrub	100.0 ± 0.0	100.0 ± 0.0
Bayhead Tree	100.0 ± 0.0	100.0 ± 0.0
Hammock Tree	100.0 ± 0.0	100.0 ± 0.0

Table 3.6 Design-based class-specific accuracy for Black Hammock, Irongrape, NP202, Chekika, SS-93, and SS-94 (wet/dry WV images: 2018-02-16/2020-03-28).

Class Name	User's Accuracy	Producer's Accuracy
Graminoid Marsh	88.2 ± 3.4	96.0 ± 1.2
Graminoid Cladium	94.6 ± 2.4	93.3 ± 1.4
Graminoid Typha	84.9 ± 3.7	76.2 ± 15.8
Herbaceous & Shrub	89.2 ± 3.2	71.6 ± 7.7
Open Marsh	90.3 ± 3.1	99.7 ± 0.3
Bayhead Shrub	90.3 ± 3.1	98.9 ± 0.6
Bayhead Tree	97.8 ± 1.5	93.2 ± 4.4
Hammock Tree	100.0 ± 0.0	100.0 ± 0.0

Table 3.7 Design-based class-specific accuracy for Heartleaf (SS-81) (wet/dry WV images: 2018-02-16/2017-05-7).

Class Name	User's Accuracy	Producer's Accuracy
Graminoid Marsh	96.3 ± 2.1	99.4 ± 0.4
Graminoid Cladium	100.0 ± 0.0	95.9 ± 1.4
Graminoid Typha	96.3 ± 2.1	95.3 ± 4.5
Herbaceous & Shrub	93.9 ± 2.7	91.1 ± 3.6
Open Marsh	86.6 ± 3.8	97.8 ± 2.1
Bayhead Shrub	91.5 ± 3.1	96.4 ± 2.1
Bayhead Tree	95.1 ± 2.4	93.4 ± 6.0
Hammock Tree	97.6 ± 1.7	100.0 ± 0.0
Open Water	96.3 ± 2.1	100.0 ± 0.0

Table 3.8 Design-based class-specific accuracy for Grossman Hammock (wet/dry WV images: 2018-02-16/2017-05-07).

Class Name	User's Accuracy	Producer's Accuracy
Graminoid Marsh	94.0 ± 2.6	93.7 ± 3.4
Graminoid Marsh Tall	81.0 ± 4.3	76.9 ± 9.5
Graminoid Prairie	98.8 ± 1.2	97.2 ± 1.1
Graminoid Prairie Cladium	89.3 ± 3.4	96.5 ± 2.7
Herbaceous & Shrub	97.6 ± 1.7	73.3 ± 7.4
Bayhead Shrub	91.7 ± 3	96.7 ± 1.5
Bayhead Tree	96.4 ± 2	94.2 ± 3.9
Hammock Tree	97.6 ± 1.7	96.7 ± 2.4
Open Water	100.0 ± 0.0	92.1 ± 7.3

The similarity in spectral signatures of Bayhead trees and shrubs explains the low accuracy in this class. All other classes reached accuracy of 91% or greater. High overall accuracy verifies that WV satellite images provide data with characteristics suitable for detecting and mapping tree islands plant communities and their adjacent marshes. Random forest classifiers applied to the biseasonal and textural data were able to classify plant communities at high class-specific accuracy. Woody tree and shrub classes were rarely confused with graminoid and broadleaved vegetation in the tails and surrounding marshes. These results indicate that the differentiation between tree islands and their tails and marsh communities is very reliable and that, given the high spatial resolution of the WV data, expansion or contraction of tree islands can be detected as they occur.

3.3.2 Class Distribution, Relative Elevation and Hydrology by Island

The eleven tree islands varied considerably in both total area and vegetation composition. Total island area ranged from 62.25 ha at Grossman, the largest island, down to the smallest 5.47 ha large Satinleaf Island. Heartleaf (38.68 ha), Irongrape (29.84 ha), and Gumbo Limbo (27.98 ha)

were other relatively large islands. Hardwood hammock communities occupied relatively small areas across all islands, with Grossman containing the most extensive coverage at 3.7 ha, while most other islands contained less than 0.6 ha and SS94 lacked this community entirely. Of the marsh islands, Vulture Island, had the largest hardwood hammock (0.43ha). Bayhead tree communities displayed a more even distribution, with Gumbo Limbo (7.07 ha) and Chekika (6.73 ha) containing the largest areas, while most other islands ranged from 0.87 to 3.96 ha. Bayhead shrub represented the most extensive woody community type, with Heartleaf containing the most extensive coverage at 15.69 ha, followed by substantial coverage on Irongrape (13.63 ha) and Grossman (13.14 ha), while smaller islands like Satinleaf, SS93, and SS94 contained less than 1.5 ha of this community type.

Black Hammock had the highest relative elevation for Hardwood hammock at nearly 0.8 m. Most islands (Chekika, Irongrape, Vulture, NP202, Satinleaf and Gumbo Limbo) had Hardwood hammock communities at relative elevations between 0.63-0.71 m. Grossman, SS93, and Heartleaf represented islands where Hardwood hammock occurred at notably lower relative elevations (0.20, 0.21 and 0.08 m, respectively). Black Hammock had the highest relative elevation for Bayhead tree at 0.09 m followed by Heartleaf and SS94 at 0.04 and 0.06 m. Most islands (8 out of 11) had Bayhead tree communities with approximately 0.0 m median relative elevation. NP202 was unique in having Bayhead shrub at a higher elevation than Bayhead trees. The lowest Bayhead shrub elevations were found at Grossman and SS94 at approximately a median relative elevation of -0.10 m.

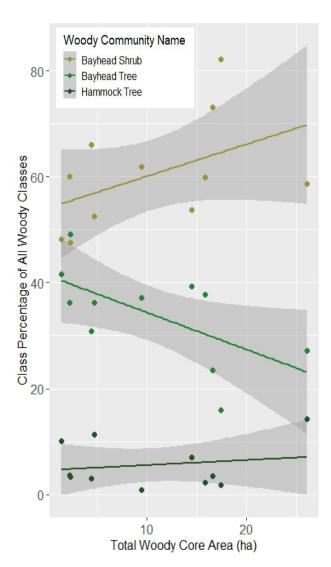
Based on the percent wet days data, during the pre-restoration period (2008-2015), Hardwood hammock remained completely dry (0% wet days) across most islands where it occurred, except for Heartleaf (75% wet days) and SS93 (27.6% wet days). For Bayhead communities, Heartleaf exhibited the wettest woody vegetation with 50% of the Bayhead trees experiencing 79.5% and Bayhead shrub 87.4% wet days. Grossman displayed the driest conditions with Bayhead tree at only 26.9% median wet days and Bayhead shrub at 62.2%. The remaining tree islands had average median percent wet days on Bayhead tree communities of approximately 75%. Following restoration, woody communities showed an increase in percent median wet days. Hardwood hammock began experiencing occasional wet conditions, with SS93 increasing by 38.8% wet days while Hardwood Hammock communities on Black Hammock, Chekika, Gumbo Limbo Irongrape and Vulture remained dry. Heartleaf remained the wettest for woody vegetation with Bayhead tree at 89.5% and Bayhead shrub at 94.7%. SS94 and Satinleaf showed an increase in Bayhead tree (87.3% and 87.2%, respectively), while Vulture, NP202, and Chekika maintained high Bayhead shrub wet days above 90%. Grossman continued as the driest island, with Bayhead tree reaching 56.6% and Bayhead shrub 75.7% median wet days.

Median values for pre- and post-restoration (Post-7) maximum water depth when wet across the eleven tree islands increased for all classes. The Hardwood hammock on Heartleaf experienced the highest maximum water depths with medians of 38 cm pre-restoration and 69 cm post-restoration. Grossman Island followed with 69 cm pre-restoration and 106 cm post-restoration. Other islands showed lower median maximum water depths on Hardwood hammock areas: Irongrape, NP-202, Satinleaf, SS93 and SS94 increased by 11, 13, 11, 24 and 24 cm, respectively.

Four islands (Black Hammock, Chekika, Gumbo Limbo and Vulture) recorded 0 cm median values in both periods. Bayhead tree communities displayed more consistent water depths across islands. Satinleaf and NP-202 both increased from 58 cm pre-restoration to 71 cm post-restoration, and Gumbo Limbo (46 cm pre, 60 cm post). SS94 and Heartleaf showed similar patterns with 47 cm and 46 cm pre-restoration, increasing to 72 cm and 77 cm post-restoration respectively. The highest change in median maximum water depths occurred at Grossman (18 cm pre, 54 cm post) and S993 and SS94 (38 cm pre, 62 cm post). Grossman, the only island in this analysis located in the marl prairie and with the largest area of woody vegetation, experienced relatively the highest change in medians maximum water depths.

Hardwood Hammocks on Grossman exhibited the longest wet events with 598 days pre-restoration and 738 days post-restoration, followed by Heartleaf with 580 and 736 days pre- and post-restoration, respectively. Wet events on hardwood Hammock communities on Black Hammock, Chekika, Gumbo Limbo and Vulture remained at 0 days pre- and post-restoration, while Irongrape, NP-202 and Satinleaf increased by 3, 61 and 53 days, respectively. Bayhead tree communities saw a higher increase in median wet event lengths with Irongrape leading with 394 days while the other islands increased by 100-200 days.

<u>Woody Core Class Distribution:</u> We modeled the relationship between community core class contribution to the woody core and the size of the woody core area of an island. As core area increases in size, the proportion of Bayhead shrubs and Hardwood Hammock increased while the



proportion of Bayhead trees decreased (Fig. 3.15). This relationship is likely to change as increasing deeper water depths and extended wet event periods. Overall, most likely a reduction in the woody core will occur and it might affect smaller islands more rapidly and more severely. Smaller islands will be pushed toward a wetter, even more shrub dominated core, because of anticipated increase in Bayhead tree mortality and contraction or complete loss of Hardwood hammocks. Some Bayhead tree expansion into Hammock is expected so that overall Bayhead tree cover might be stable, taking up the Hardwood hammock areas. For larger islands the difference in percent cover is expected to become even more drastic. The proportional occupation of Bayhead trees might be reduced, but if Hammocks are high enough and are therefore expected to potentially persist while Bayhead trees will survive in higher elevations, but Bayhead shrubs will infringe on lower areas and expand along the ecotones of the two communities.

Figure 3.3 Class percentage of the three woody core classes as a function of total core area.

3.3.2.1 Black Hammock

<u>Community Area and Percent Cover:</u> Bayhead shrub covered the largest area of Black Hammock at 3.0 hectares, accounting for 28.1% of the total, with a high woody core percentage of 68.8% (Table BH.1). Cladium followed with 2.9 hectares, making up 26.7% and the highest non-woody percentage at 45.1%. Graminoid marsh occupied 1.8 hectares (16.8% of the area) and had a significant non-woody percentage at 28.3%. The herbaceous-shrub mix covered 1.4 hectares (13.2%), while Bayhead trees occupied 1.3 hectares (11.8%) with a 29.0% woody core. Hardwood hammock tree occupied a small area of 0.10 ha (0.9%) (Fig. BH.1 and Table BH.1).

<u>Relative Elevation</u>: Relative elevation of woody and herbaceous plant communities within a 100 m radius shows that the herbaceous classes had a median elevation just below 0 m indicating no gradient and no specific difference between classes at that scale (Fig. BH.2). For the herbaceous with shrub class, the interquartile range (IQR) ranged from -0.1 to 0.4 m. Relative elevation IQR increased for the woody classes with Bayhead shrub and Bayhead tree classes, ranging between 0.2 to 1.0 m and for Hardwood hammock from 0.15 to 1.0 m (Fig. BH.2). These data support the gradient of increasing elevation from the marshes to Hardwood hammock but there was a large overlap between adjacent classes.

<u>Percent Wet:</u> During the 7 years prior to restoration start, open and graminoid marsh (short) experienced a median wet condition for around 81% of the time, with ranges extending from roughly 70% to nearly 96%. For Cladium and herbaceous with shrub communities 85% of the days were wet for 50% of these communities. For Bayhead shrub and Bayhead tree medians were lower at around 80% and 57%, respectively. Hardwood hammock had the lowest median wet day percentage near 0% with no change in the median for the post-restoration period. After restoration started, herbaceous plant communities experienced a 5% median increase with ranges narrowing slightly. For Bayhead shrubs and Bayhead trees the percentage of median wet days increased by 5.5% and 14.1% to 87% and 70%, respectively. (Figure BH.3, Table BH.2).

Minimum Water Depth when Dry: Before restoration, herbaceous including shrubby herbaceous communities and Bayhead shrubs on Black Hammock showed very little variability in minimum water depths when dry (median ~ -50 cm) (Figure BH.4, Table BH.3). For Bayhead trees that value was close to -70 cm with a higher variability, while Hardwood hammock, as expected, had the lowest median at about -130 cm, along with a wide IQR. After restoration started, all classes experienced an 8 to 9 cm increase in water depth when dry (Figure BH.4, Table BH.3).

<u>Maximum Water Depth:</u> Maximum water depth before restoration for herbaceous communities had medians around 50-55 cm (Figure BH.5, Table BH.4). After restoration started, these medians increased by approximately 28 cm for all classes (Figure BH.5, Table BH.4). Bayhead trees had a median around 34 cm before restoration, increasing to 60 cm after restoration maintaining its range. In contrast, Hardwood hammock, which had the lowest median around 0 cm, showed an increase in the range of the depths during wet periods with an increase of the 75th percentile from 2 cm to 30 cm.

<u>Maximum Wet Event Length:</u> Wet event maximum length before and after the 2015 restoration show that herbaceous plant communities saw an increase in medians from ~600 days to over 700 days (Figure BH.6, Table BH.5). For Bayhead trees that metric increased from 267 days to 466 days, while for Hardwood hammocks the median was maintained at 0 days, but about 25% of the Hardwood trees experienced an increase of wet event length from 0 to about 100 days for the 7-year post-restoration start date (Figure BH.6, Table BH.5).

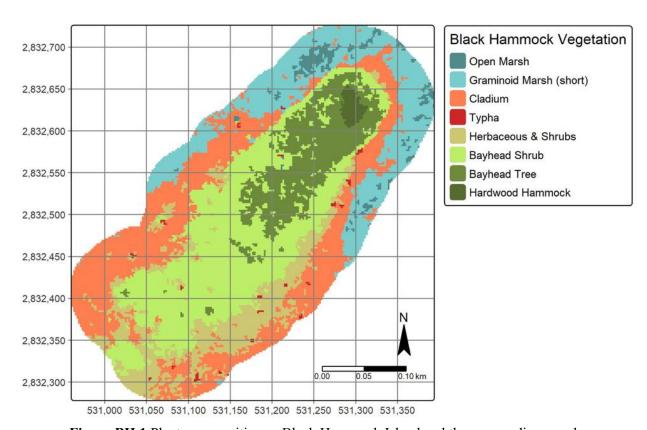


Figure BH.1 Plant communities on Black Hammock Island and the surrounding marsh.

Table BH.1 Class distribution on Black Hammock Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes; Non-Woody (%) = class percentages considering only non-woody classes.

Black Hammock Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.23	2.1	-	3.5
Graminoid Marsh	1.81	16.8	-	28.3
Cladium	2.88	26.7	-	45.1
Typha	0.04	0.4	-	0.7
Herbaceous - Shrub Mix	1.42	13.2	-	22.3
Bayhead Shrub	3.03	28.1	68.8	-
Bayhead Tree	1.28	11.8	29.0	-
Hardwood Hammock Tree	0.10	0.9	2.2	

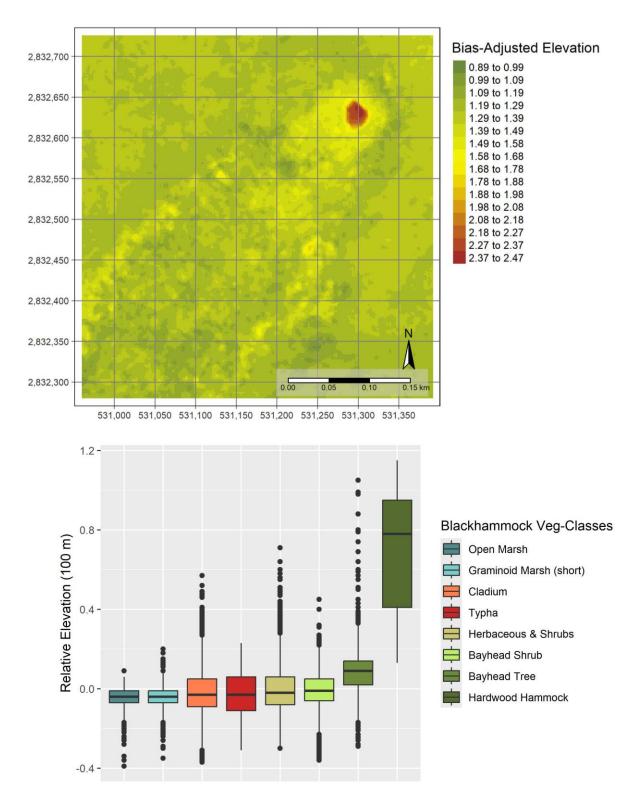


Figure BH.2 Bias-adjusted elevation in meters for Black Hammock Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Black Hammock Island and the surrounding marsh (bottom).

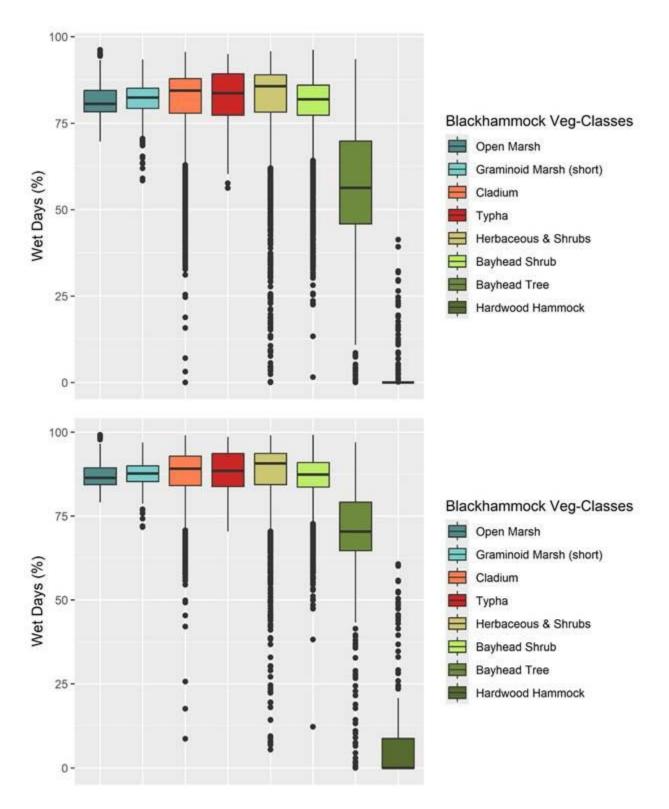


Figure BH.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Black Hammock Island.

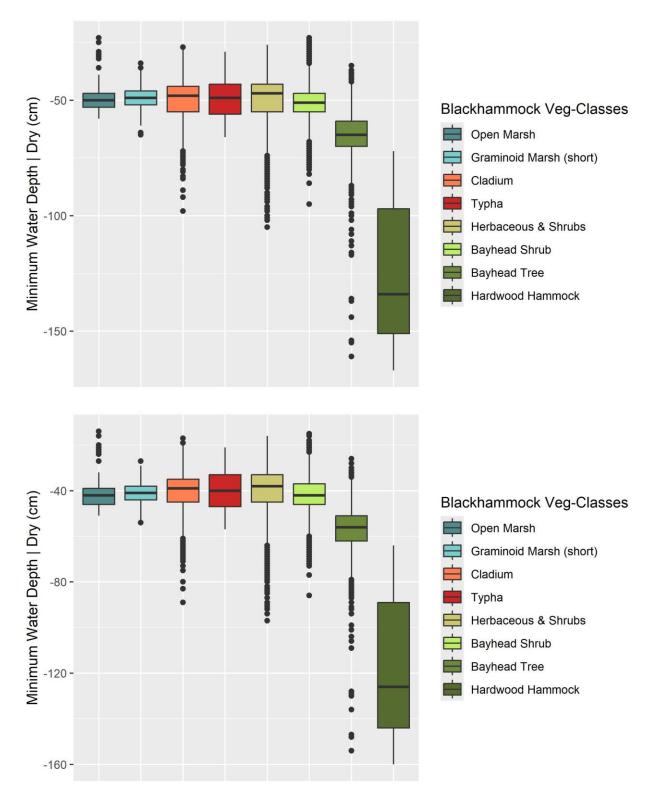


Figure BH.4 Boxplots for minimum water depth when dry (cm) by plant community for 7-year (top) preand (bottom) post-restoration periods for Black Hammock Island.

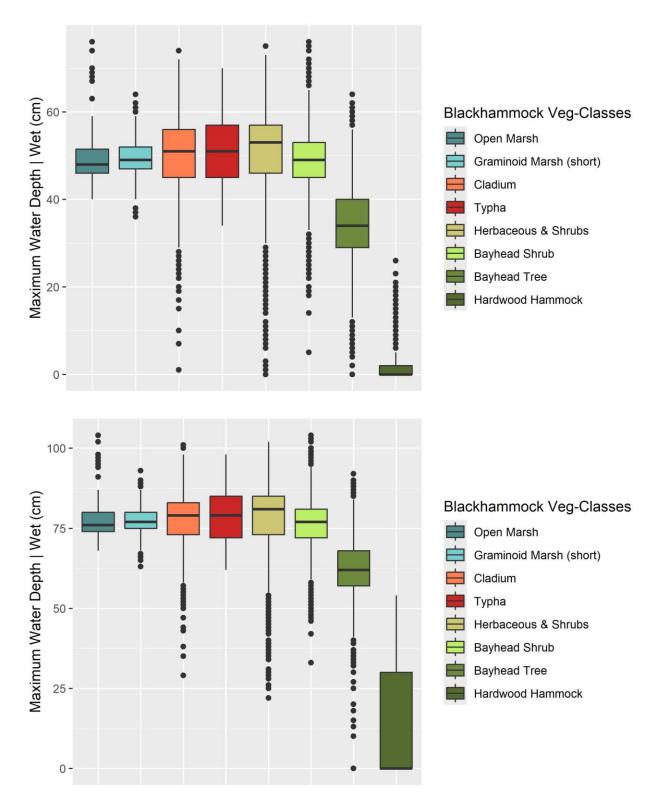


Figure BH.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Black Hammock Island.

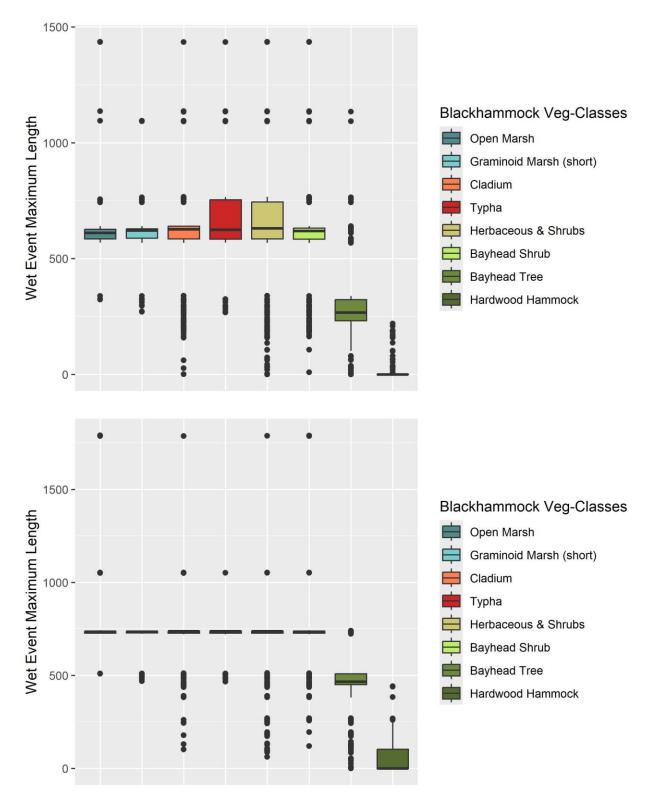


Figure BH.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Black Hammock Island.

Table BH.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Black Hammock Island.

	Pre-7						Post-7			
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	69.7	78.3	80.6	84.5	96.2	79.1	84.4	86.4	89.4	99.2
Gram. Marsh (short)	58.4	79.3	82.4	85.1	93.4	71.7	85.3	87.7	90	96.9
Cladium	0	77.9	84.4	87.9	95.6	8.6	84.07	89.1	92.9	99.1
Typha	56.2	77.3	83.7	89.3	95	70.4	83.8	88.5	93.7	98.6
Herbaceous & Shrubs	0	78.2	85.7	89	95.8	5.4	84.4	90.7	93.7	99.1
Bayhead Shrub	1.5	77.3	81.9	86	96.2	12.2	83.7	87.4	91	99.2
Bayhead Tree	0	45.88	56.3	69.8	93.5	0	64.7	70.4	79.2	97
Hardwood Hammock	0	0	0	0	41.3	0	0	0	8.8	60.7

Table BH.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Black Hammock Island.

		1	Pre-7			P	ost-7	
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-58	-53	-50	-47	-51	-46	-42	-39
Gram. Marsh (short)	-65	-52	-49	-46	-54	-44	-41	-38
Cladium	-98	-55	-48	-44	-89	-45	-39	-35
Typha	-66	-56	-49	-43	-57	-47	-40	-33
Herbaceous & Shrubs	-105	-55	-47	-43	-97	-45	-38	-33
Bayhead Shrub	-95	-55	-51	-47	-86	-46	-42	-37
Bayhead Tree	-161	-70	-65	-59	-154	-62	-56	-51
Hardwood Hammock	-167	-151	-134	-97	-160	-144	-126	-89

Table BH.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Black Hammock Island.

		Pr			Po	st-7		
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	46	48	51.5	76	74	76	80	104
Gram. Marsh (short)	47	49	52	64	75	77	80	93
Cladium	45	51	56	74	73	79	83	101
Typha	45	51	57	70	72	79	85	98
Herbaceous & Shrubs	46	53	57	75	73	81	85	102
Bayhead Shrub	45	49	53	76	72	77	81	104
Bayhead Tree	29	34	40	64	57	62	68	92
Hardwood Hammock	0	0	2	26	0	0	30	54

Table BH.5 Maximum wet event length for 7-year pre- and post-restoration periods Black Hammock

	Pre-7				Post- 7			
Class	Q1	Median	Q3	Q1	Median	Q3		
Open Marsh	585	611	627	727	735	737		
Gram. Marsh (short)	588	621	629	728	735	737		
Cladium	585	627	640	727	737	737		
Typha	584	625	754	727	737	737		
Herbaceous & Shrubs	585	631	745	727	737	737		
Bayhead Shrub	584	619	632	727	735	737		
Bayhead Tree	232	267	323	451	466	508		
Hardwood Hammock	0	0	1	0	0	103		

3.3.2.2 Chekika

<u>Community Area and Percent Cover:</u> Bayhead shrub covered the largest area of Chekika at 7.2 hectares (27.6%), with a high woody core percentage at 50.1% (Table C.1). *Cladium* occupied 6.9 hectares, or 26.5% of the area and had the highest non-woody percentage at 59%. The herbaceous-shrub mix covered 3.1 hectares (11.8%) and had a non-woody class percentage of 26.2%. *Typha* occupied 1.2 hectares (4.5%) and graminoid marsh 0.48 hectares (1.8%), with non-woody percentages of 10.1% and 4.1%, respectively. Bayhead trees also covered a significant area of 6.7 hectares (25.9%) with a woody core contribution of 47%. Hardwood Hammock tree occupied a small area of 0.40 ha (1.6%) (Fig. C.1, Table C.1).

<u>Relative Elevation:</u> Figure C.2 shows the relative elevation for various plant communities on Chekika and the surrounding marsh. Hardwood hammock had the highest elevation, with a median around 0.70 m with an Interquartile Range (IQR) ranging from 0.40 to 0.80 m. Bayhead tree and Bayhead shrub exhibited medians around -0.05 m. Herbaceous classes like *Cladium, Typha*, and herbaceous and shrubs presented medians near zero. Open marsh and graminoid marsh (short) exhibited the lowest medians, below zero.

<u>Percent Wet:</u> Before restoration, open marsh and graminoid marsh (short) had wet conditions around 85% of the time (Figure C.3, Table C.2). Herbaceous and shrubs and Bayhead shrubs exhibited wet conditions around 80% of the time, while Bayhead tree had a median of around 75%. After restoration started, median wet days increased by 15% for Bayhead tree. Hardwood hammock, which was dry pre-restoration, saw an increase of 8% for about 25% of trees for the 7-year post-restoration start date.

Minimum Water Depth when Dry: The median of the minimum water depth when dry during a seven-year pre-restoration period for herbaceous plant communities was approximately -70 cm (Figure C.4, Table C.3). Herbaceous and shrubs and Bayhead shrubs exhibited medians near -66 cm. Bayhead tree had a median of -75 cm while Hardwood hammock had the lowest median water depth at -162 cm. After restoration, median minimum water depth for all classes increased by approximately 34 cm, Hardwood hammock continued to have the deepest median depth at -128 cm (Figure C.4, Table C.3).

<u>Maximum Water Depth:</u> Maximum water depth when wet, during a seven-year pre-restoration period, for herbaceous plant communities on Chekika presented medians from approximately 35 – 46 cm, with *Cladium* having a broader IQR and *Typha* having the highest variability. Herbaceous and shrubs and Bayhead shrubs exhibited medians at 42 and 45 cm, respectively. Hardwood hammock had the lowest median at 0 cm. Seven years post-restoration, median maximum water depths for all classes increased by 25 cm, while Hardwood hammock had an increase in the range of water depths with an increase of the 75th percentile from 0 cm to 5 cm (Figure C.5, Table C.4).

<u>Maximum Wet Event Length</u>: The length of maximum wet events for herbaceous plant communities had medians that ranged from 581 to 642 days, during a seven-year pre-restoration period. Herbaceous with shrub and Bayhead shrub exhibited medians of 629 and 636 days, respectively, while Bayhead tree showed a median of 586 days. Most of the Hardwood hammock plant community didn't experience wet events seven years pre-restoration. Wet event lengths

increased by 385 days during the seven years post-restoration for open marsh and *Typha*; and approximately 100 days for the other herbaceous communities. Bayhead shrub and Bayhead tree increased by 102 and 151 days, respectively. Median wet event length remained the same for most areas of the Hardwood hammock community, but about 25% of the trees saw an increase from 0 to 18 days (Figure C.6, Table C.5).

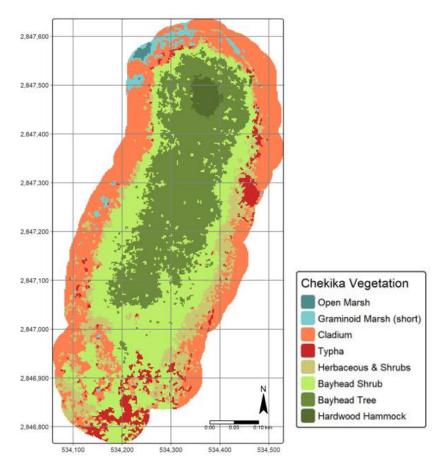


Figure C.1 Plant communities on Chekika Island and the surrounding marsh

Table C.1 Class distribution on Chekika Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes; Non-Woody (%) = class percentages considering only non-woody classes.

Chekika Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.07	0.3	-	0.6
Graminoid Marsh	0.48	1.8	-	4.1
Cladium	6.86	26.5	-	59
Typha	1.18	4.5	-	10.1
Herbaceous - Shrub Mix	3.05	11.8	-	26.2
Bayhead Shrub	7.17	27.6	50.1	-
Bayhead Tree	6.73	25.9	47	-
Hardwood Hammock Tree	0.40	1.6	2.8	-

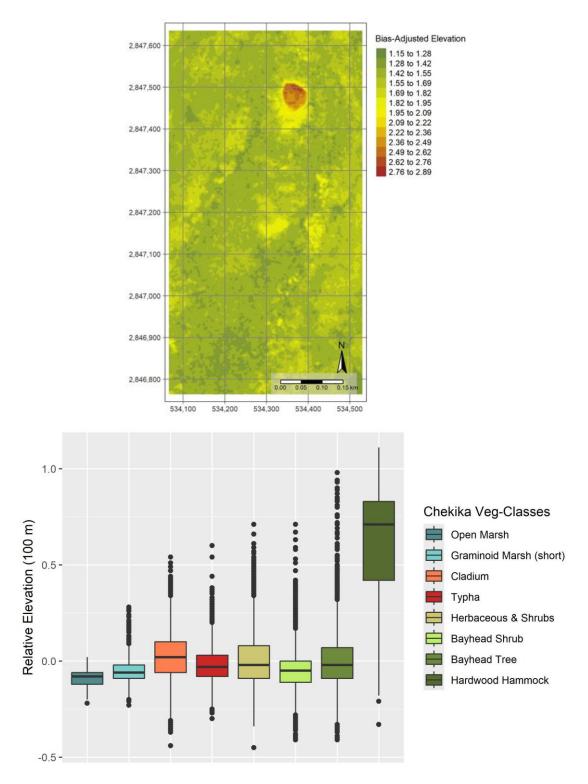


Figure C.2 Bias-adjusted elevation in meters for Chekika Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Chekika Island and the surrounding marsh (bottom).

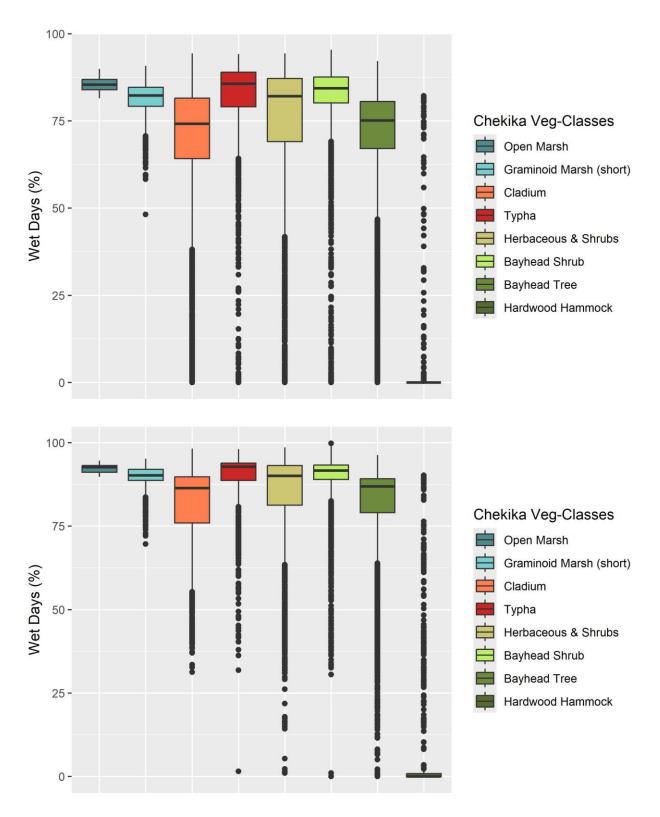


Figure C.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Chekika Island.

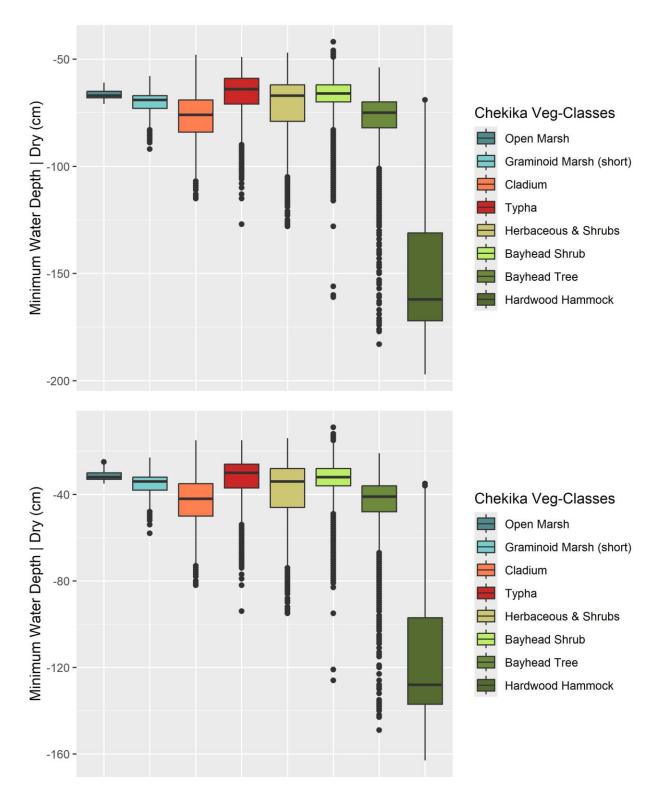


Figure C.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Chekika Island.

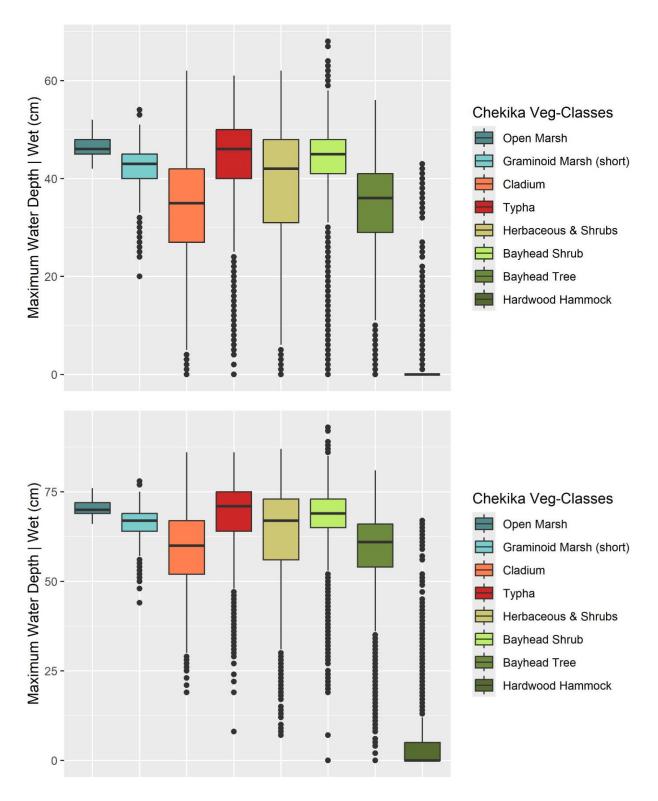


Figure C.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Chekika Island.

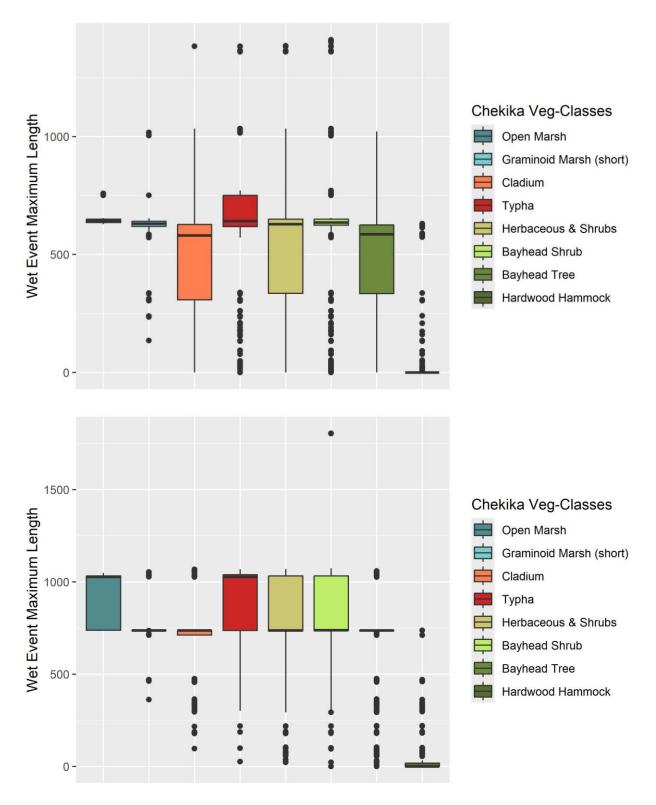


Figure C.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Chekika Island.

Table C.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Chekika Island.

	Pre-7					Post-7				
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	81.5	84	85.4	86.95	89.9	89.7	91.2	92.7	93.18	94.6
Gram Marsh (short)	48.2	79.2	82.35	84.7	90.8	69.6	88.7	90.2	92	95.2
Cladium	0	64.2	74.2	81.6	94.4	31.2	76	86.4	89.8	98.2
Typha	0	79.1	85.7	89	94.2	1.5	88.7	92.8	93.9	98.1
Herbaceous & Shrubs	0	69.1	82.1	87.2	94.4	1	81.3	90.1	93.2	98.6
Bayhead Shrub	0	80.2	84.4	87.6	95.4	0	89	91.7	93.3	99.8
Bayhead Tree	0	67.1	75.2	80.6	92.2	0	79.1	86.9	89.2	96.3
Hardwood Hammock	0	0	0	0	82.2	0	0	0	0.8	90.2

Table C.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Chekika Island.

		P	re-7		Post-7			
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-65	-68	-67	-65	-35	-33	-32	-30
Gram Marsh (short)	-67	-73	-69	-67	-58	-38	-34	-32
Cladium	-69	-84	-76	-69	-82	-50	-42	-35
Typha	-59	-71	-64	-59	-94	-37	-30	-26
Herbaceous & Shrubs	-62	-79	-67	-62	-95	-46	-34	-28
Bayhead Shrub	-62	-70	-66	-62	-126	-36	-32	-28
Bayhead Tree	-70	-82	-75	-70	-149	-48	-41	-36
Hardwood Hammock	-131	-172	-162	-131	-163	-137	-128	-97

Table C.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Chekika.

		Pre	-7		Post-7			
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	45	46	48	52	69	70	72	76
Gram Marsh (short)	40	43	45	54	64	67	69	78
Cladium	27	35	42	62	52	60	67	86
Typha	40	46	50	61	64	71	75	86
Herbaceous & Shrubs	31	42	48	62	56	67	73	87
Bayhead Shrub	41	45	48	68	65	69	73	93
Bayhead Tree	29	36	41	56	54	61	66	81
Hardwood Hammock	0	0	0	43	0	0	5	67

Table C.5 Maximum wet event length for 7-year pre- and post-restoration periods Chekika Island.

	Pre-7				Post-7			
Class	Q1	Median	Q3	Q1	Median	Q3		
Open Marsh	636	642	649.75	738	1027	1032		
Gram. Marsh (short)	619	631	641	737	737	738		
Cladium	308	581	628	712	737	737		
Typha	618.5	642	751	737	1027	1038		
Herbaceous & Shrubs	335	629	650	735	737	1032		
Bayhead Shrub	624	636	650	737	738	1032		
Bayhead Tree	334	586	626	735	737	737		
Hardwood Hammock	0	0	0	0	0	18		

3.3.2.3 Gumbo Limbo

<u>Community Area and Percent Cover:</u> The vegetation mapping for Gumbo Limbo (Fig. GL.1 and Table GL.1) covered 27.98 hectares, with non-woody vegetation occupying the majority at 53.9% of the total area (15.1 ha), dominated by herbaceous with shrub mix which accounted for 23.6% of the total area and represented 54.5% of all non-woody vegetation. Within the non-woody classes, *Cladium* covered 12% of the total area, followed by graminoid marsh at 6.4%, while open marsh and *Typha* each comprised less than 1%. Woody vegetation, representing 46.1% of the total area (13.88 ha), was predominantly composed of Bayhead shrub, which covered 30.2% of the total area and made up 53.2% of the woody core. Bayhead tree vegetation occupied 25.3% of the total area, while Hardwood hammock formed a minor component at just 1.3%.

<u>Relative Elevation:</u> Open marsh occupied the lowest elevations on Gumbo Limbo (Fig. GL.2), with a median near -0.1 m. Graminoid marsh, *Cladium* and *Typha* occurred at slightly higher elevations with a median around 0.0 m. The herbaceous and shrubs, Bayhead shrub, and Bayhead tree communities occupied similar median relative elevations around 0.0 m and moderate variability. Hardwood hammock represented the highest elevation community on the island, with a median approaching 0.6 m and the highest upper quartile among all vegetation types.

<u>Percent Wet:</u> Open marsh on Gumbo Limbo maintained consistently 95% wet days during the seven-year period before and after restoration periods. Graminoid marsh, Cladium, and Typha showed an increase of 2-3% following restoration. Herbaceous and shrubs increased from 85% to 88% wet days, Bayhead shrub from 76% to 81%, and Bayhead tree from 58% to 70%. Hardwood hammock shifted from being predominantly dry (no wet days) to experiencing intermittent flooding, with an increase of the 75th percentile to 5% wet days (Fig. GL.3 and Table GL.2).

<u>Minimum Water Depth when Dry</u>: Median minimum depths when dry increased by approximately 9 cm for *Cladium* and *Typha* herbaceous plant communities on Gumbo Limbo from pre- to post-restoration periods. Woody communities had a similar change, with depths for Bayhead shrub and Bayhead tree increasing by 8 cm. Hardwood hammock, despite maintaining the deepest minimum water levels, increased by 9 cm, from -131 cm to -122 cm (Fig. GL.4 and Table GL.3).

<u>Maximum Water Depth:</u> From all the herbaceous plant communities, open marsh had the deepest maximum water depths during wet periods (Fig. GL.5 and Table GL.4) – 77 cm pre- and 91 cm post-restoration. The other herbaceous plant communities exhibited maximum water depths ranging from 57 to 63 cm, pre-restoration. Water depths increased by 14 cm for herbaceous classes post-restoration. Woody communities also saw an increase on their median maximum water depths when wet of 14 cm post-restoration, except for Hardwood hammock which remained at 0 cm but the 75th percentile increased to 14 cm.

<u>Maximum Wet Event Length:</u> Before restoration, open marsh had a median wet event maximum length over 1000 days and a wide interquartile range. Other classes, such as graminoid marsh (short) and *Cladium*, had lower medians between 400 and 600 days. After restoration, open marsh experienced a lower median, under 1000 days. Median wet event lengths for Bayhead shrub and Bayhead tree increased by 348 and 213 days, respectively. Hardwood hammock remained at 0

days for most of the area, but about 25% of the trees saw an increase from 0 to 62 days (Fig. GL.6 and Table GL.5).

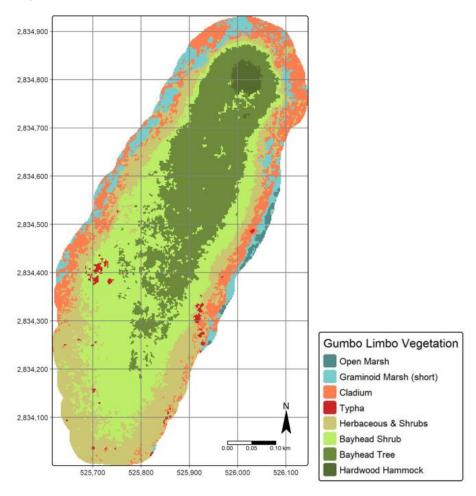


Figure GL.1 Plant communities on Gumbo Limbo Island and the surrounding marsh.

Table GL.1 Class distribution on Gumbo Limbo Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes; Non-Woody (%) = class percentages considering only non-woody classes.

Gumbo Limbo Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.18	0.6	-	1.5
Graminoid Marsh	1.79	6.4	-	14.8
Cladium	3.35	12	-	27.6
Typha	0.18	0.7	-	1.5
Herbaceous - Shrub Mix	6.60	23.6	-	54.5
Bayhead Shrub	8.45	30.2	53.2	-
Bayhead Tree	7.07	25.3	44.6	-
Hardwood Hammock Tree	0.36	1.3	2.2	-

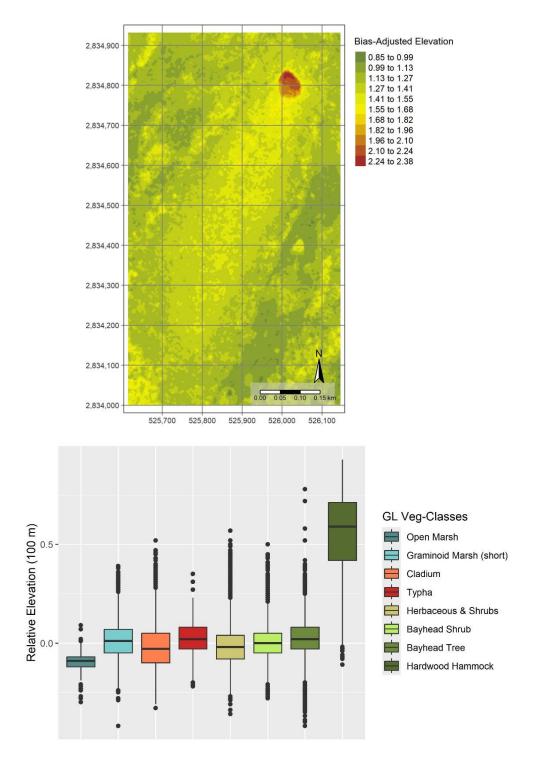


Figure GL.2 Bias-adjusted elevation in meters for Gumbo Limbo Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Gumbo Limbo Island and the surrounding marsh (bottom).

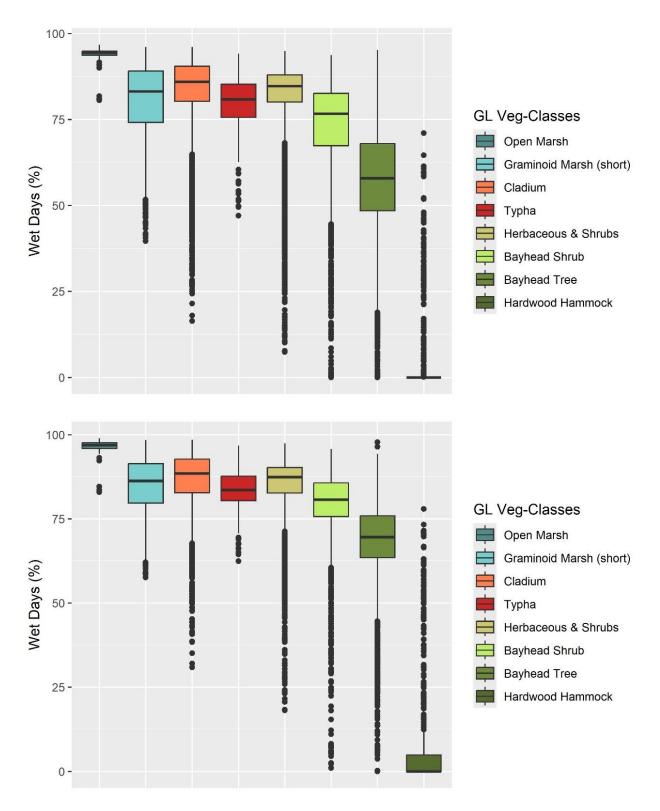


Figure GL.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Gumbo Limbo Island.

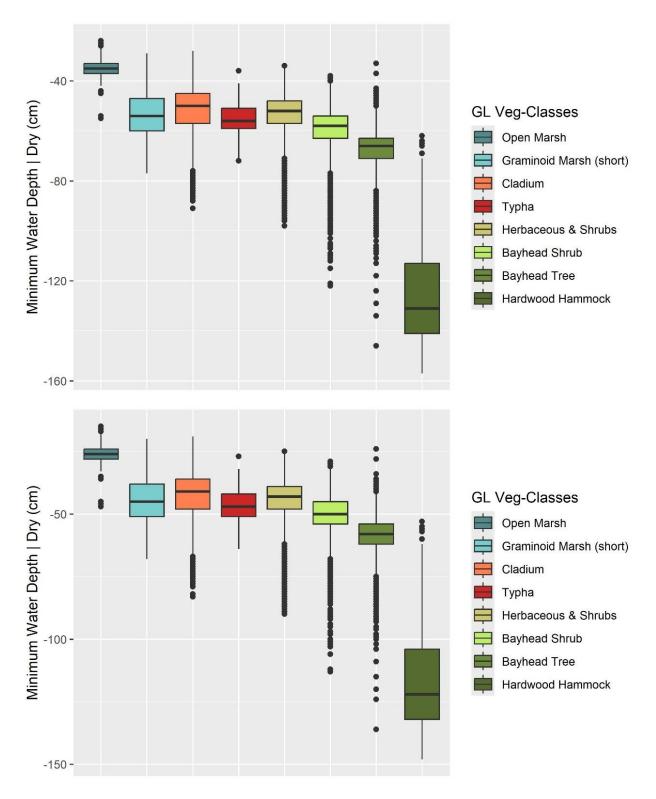


Figure GL.4 Boxplots for minimum water depth when dry (cm) by plant community for 7-year (top) preand (bottom) post-restoration periods for Gumbo Limbo Island.

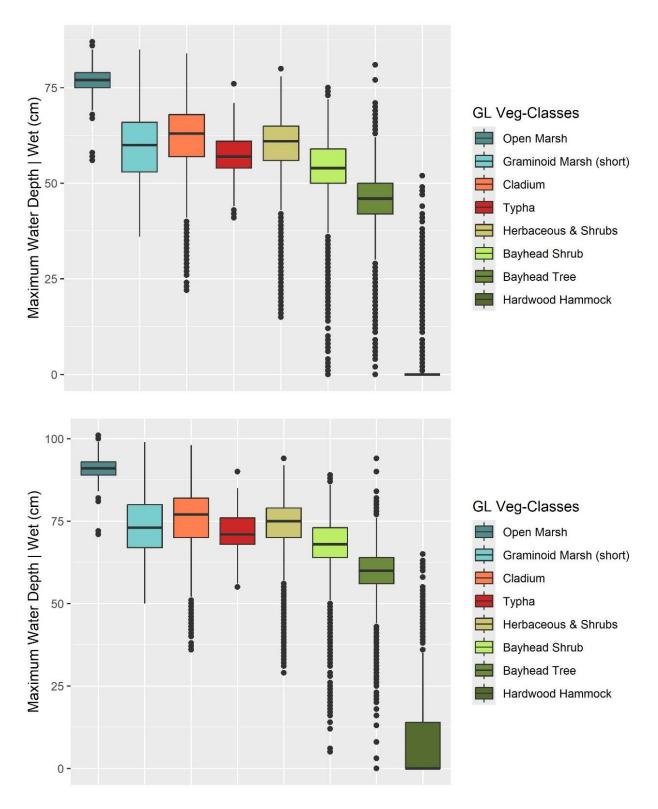


Figure GL.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Gumbo Limbo Island.

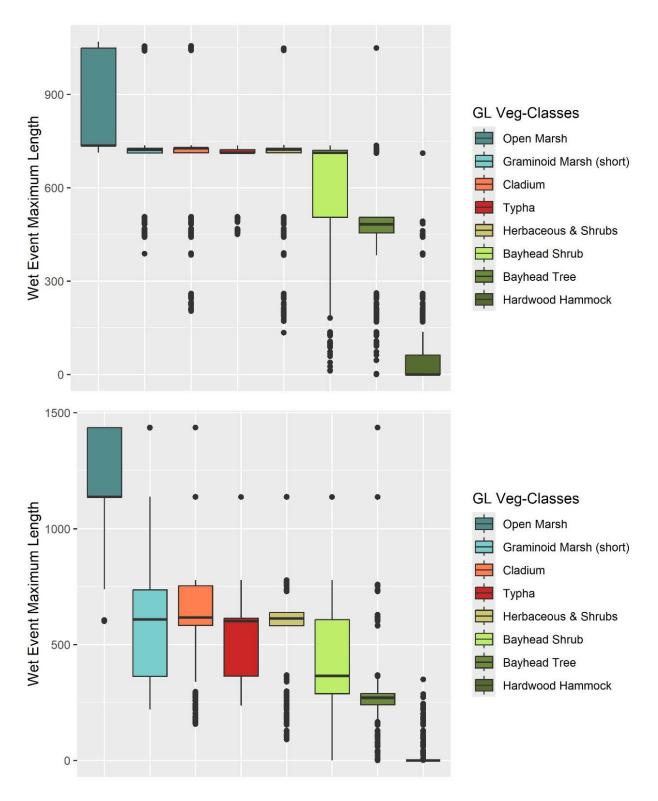


Figure GL.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Gumbo Limbo Island.

Table GL.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Gumbo Limbo Island.

	Pre-7						Post-7			
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	80.6	93.7	94.4	94.9	96.7	82.9	95.9	96.9	97.6	98.9
Graminoid Marsh (short)	39.6	74.2	83.2	89.1	96.1	57.6	79.7	86.3	91.4	98.4
Cladium	16.4	80.3	86	90.5	96.1	30.9	82.8	88.5	92.8	98.5
Typha	47	75.6	80.9	85.3	94.1	62.4	80.4	83.6	87.7	96.8
Herbaceous & Shrubs	7.4	80.1	84.7	88	94.9	18.1	82.7	87.4	90.3	97.4
Bayhead Shrub	0	67.4	76.7	82.6	93.7	1	75.7	80.7	85.7	95.8
Bayhead Tree	0	48.5	57.9	68	95.2	0	63.5	69.6	75.9	97.8
Hardwood Hammock	0	0	0	0	71	0	0	0	4.93	77.9

Table GL.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Gumbo Limbo Island.

	Pre-7				Post-7			
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-55	-37	-35	-33	-47	-28	-26	-24
Graminoid Marsh (short)	-77	-60	-54	-47	-68	-51	-45	-38
Cladium	-91	-57	-50	-45	-83	-48	-41	-36
Typha	-72	-59	-56	-51	-64	-51	-47	-42
Herbaceous & Shrubs	-98	-57	-52	-48	-90	-48	-43	-39
Bayhead Shrub	-122	-63	-58	-54	-113	-54	-50	-45
Bayhead Tree	-146	-71	-66	-63	-136	-62	-58	-54
Hardwood Hammock	-157	-141	-131	-113	-148	-132	-122	-104

Table GL.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Gumbo Limbo Island.

		Pre-	Post-7					
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	75	77	79	87	89	91	93	101
Gram. Marsh (short)	53	60	66	85	67	73	80	99
Cladium	57	63	68	84	70	77	82	98
Typha	54	57	61	76	68	71	76	90
Herbaceous & Shrubs	56	61	65	80	70	75	79	94
Bayhead Shrub	50	54	59	75	64	68	73	89
Bayhead Tree	42	46	50	81	56	60	64	94
Hardwood Hammock	0	0	0	52	0	0	14	65

Table GL.5 Maximum wet event length for 7-year pre- and post-restoration periods Gumbo Limbo Island.

	Pre-7				Post-7			
Class	Q1	Median	Q3	Q1	Median	Q3		
Open Marsh	1136	1137	1436	736	736	1049		
Graminoid Marsh (short)	363	608	736	712	722	727		
Cladium	582	617	754	713	727	727		
Typha	364	601	614	713	713	723		
Herbaceous & Shrubs	581	613	638	713	723	727		
Bayhead Shrub	288	365	607	505	713	720		
Bayhead Tree	240	270	289	455	483	505		
Hardwood Hammock	0	0	0	0	0	62		

3.3.2.4 Grossman

<u>Community Area and Percent Cover:</u> Grossman hammock and the surrounding marsh covered 62.25 hectares, divided between non-woody vegetation (32.09 ha, 51.6%) and woody vegetation (26.06 ha, 41.9%), with minimal open water (0.1 ha, 0.2%) (Fig. G.1, Table G.1). Within the non-woody classes, graminoid prairie Cladium dominated at 29.0% of non-woody vegetation, followed by herbaceous-shrub mix at 25.3% and graminoid marsh at 20.8%. The woody vegetation was primarily composed of Bayhead shrub, which covered 24.6% of the total area and represented 58.7% of all woody vegetation. Bayhead tree accounted for 11.3% of the total area (27.1% of woody vegetation), while Hardwood hammock trees comprised 5.9% of the total area (14.2% of woody vegetation).

<u>Relative Elevation</u>: The relative elevation data of Grossman show graminoid marsh tall and short at -0.15m and 0.0 m, respectively. Prairie communities (graminoid prairie and prairie *Cladium*) and herbaceous and shrubs occupied elevations around 0.0 m, all displaying variability between -0.5 m and 0.5 m. Woody communities occupied the highest elevations, with Bayhead tree showing medians near 0.05 m and extensive ranges extending up to 1.0 m. Hardwood hammock represented the highest community with a median around 0.2 m (Fig. G.2).

<u>Percent Wet:</u> The comparison of median wet conditions from 7 years pre- to post- restoration on plant communities show graminoid marsh short and graminoid marsh tall increasing by14.6% and 8.8%, respectively. Graminoid prairie median wet conditions increased by 18% and prairie Cladium by 14%. The biggest changes occurred in woody communities: Bayhead shrub increased from 62% to 78% median percent wet days, Bayhead tree from 27% to 57%, and Hardwood hammock shifted from near 0% to 0.2% with an increase of the 75th percentile from 0% to 18%.

<u>Minimum Water Depth when Dry</u>: The minimum water depth during dry conditions for graminoid marsh short and graminoid marsh tall increased by 36 cm. (Fig. G.4, Table G.3). Prairie communities also reflected an increase of 35 cm. Bayhead tree and Bayhead shrub experienced a 35 cm increase in median minimum water depths and Hardwood hammock a 37 cm increase.

<u>Maximum Water Depth:</u> Following the 2015 restoration, median maximum water depth during wet conditions increased by an average of 36 cm for all herbaceous communities (Fig. G.5, Table G.4). Bayhead tree and Bayhead shrub also showed a 36 cm increase in median maximum water depths despite higher elevations. For Hardwood hammock maximum water depth increased by 37 cm, for 25% of the community.

<u>Maximum Wet Event Length</u>: Median maximum wet event lengths increased by an average of 212 days for most herbaceous communities, except for graminoid marsh (tall) which saw a decrease of 23 days. Bayhead shrub increased by 211 days, Bayhead tree by 190 days, and Hardwood hammock saw 6 days of continuous flooding with about 25% of the Hardwood trees experiencing an increase of wet event length from 0 to about 150 days for the 7-year post-restoration start date (Fig. G.6, Table G.5).

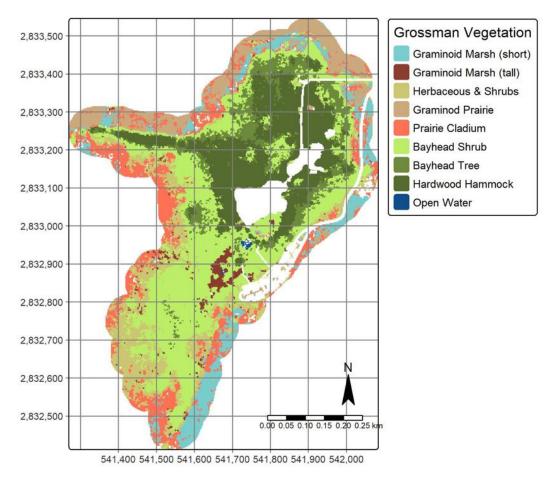


Figure G.1 Plant communities on Grossman Island and the surrounding marsh.

Table G.1 Class distribution on Grossman Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

Grossman Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Graminoid Marsh	6.68	10.7	-	20.8
Graminoid Marsh Tall	2.01	3.2	-	6.3
Herbaceous - Shrub Mix	4.14	6.6	-	25.3
Graminoid Prairie	9.89	15.9	-	18.3
Graminoid Prairie Cladium	13.37	21.5	-	29.0
Bayhead Shrub	15.3	24.6	58.7	-
Bayhead Tree	7.06	11.3	27.1	-
Hardwood Hammock Tree	3.7	5.9	14.2	-
Open Water	0.1	0.2	-	0.3

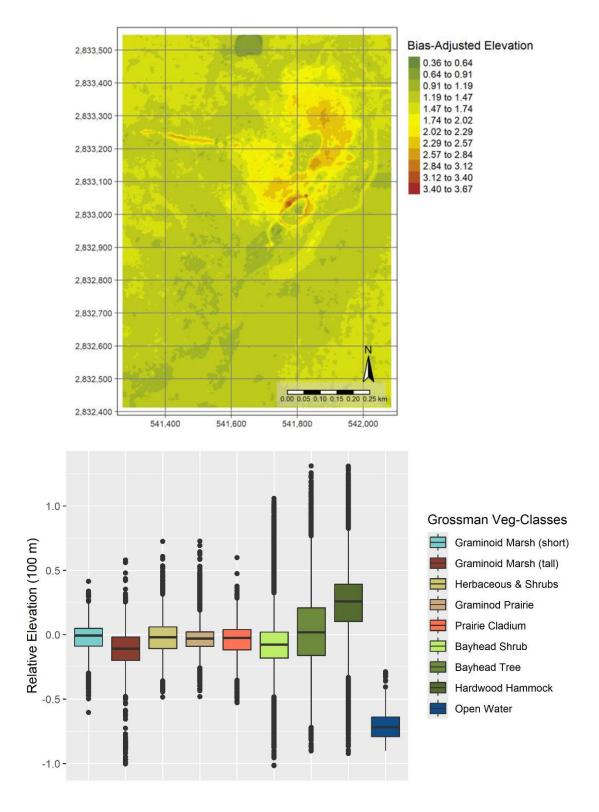


Figure G.2 Bias-adjusted elevation in meters for Grossman Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Grossman Island and the surrounding marsh (bottom).

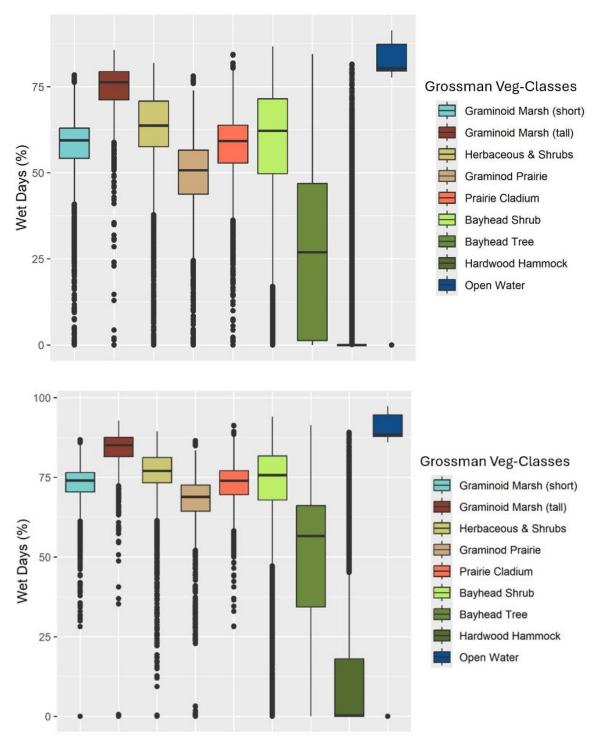


Figure G.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Grossman Island.

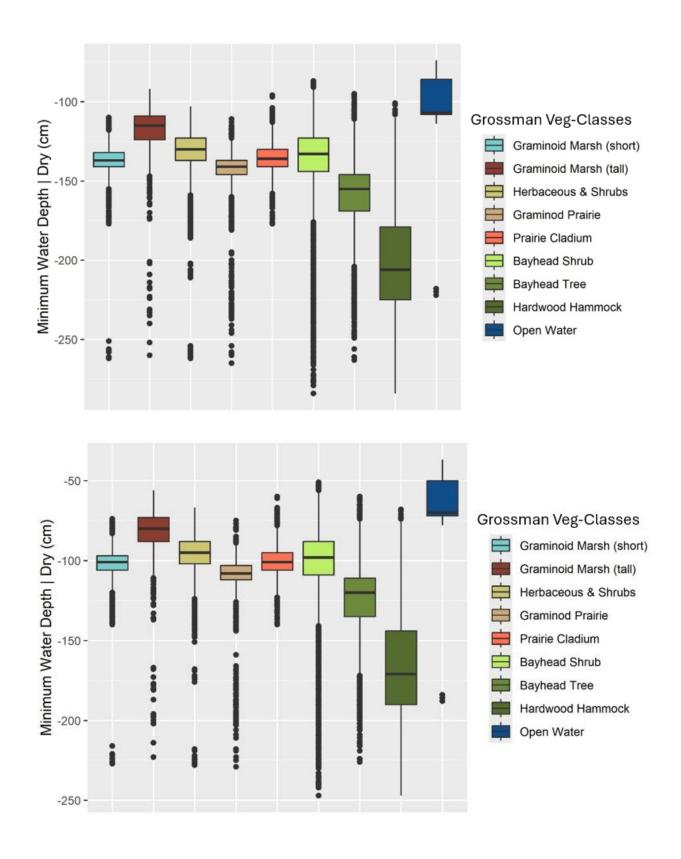


Figure G.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Grossman Island.

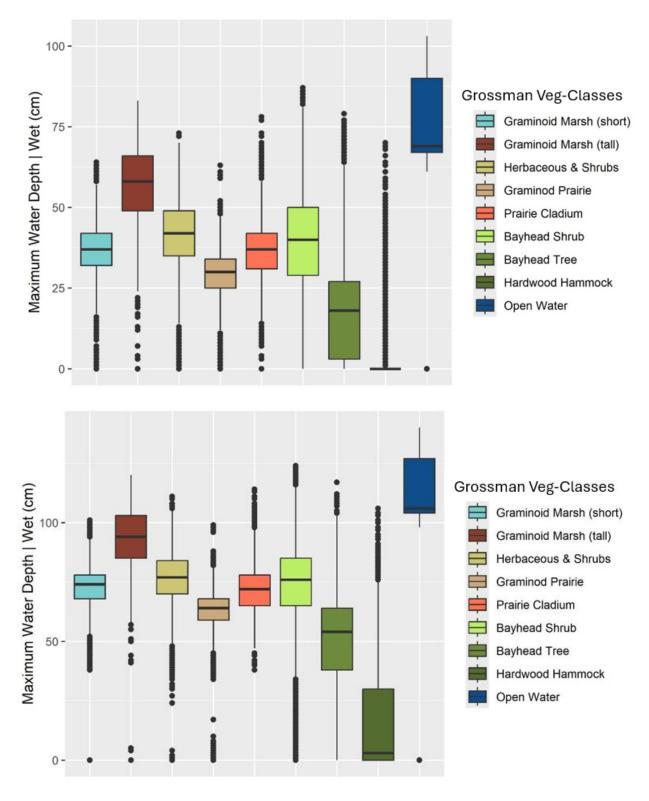


Figure G.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Grossman Island.

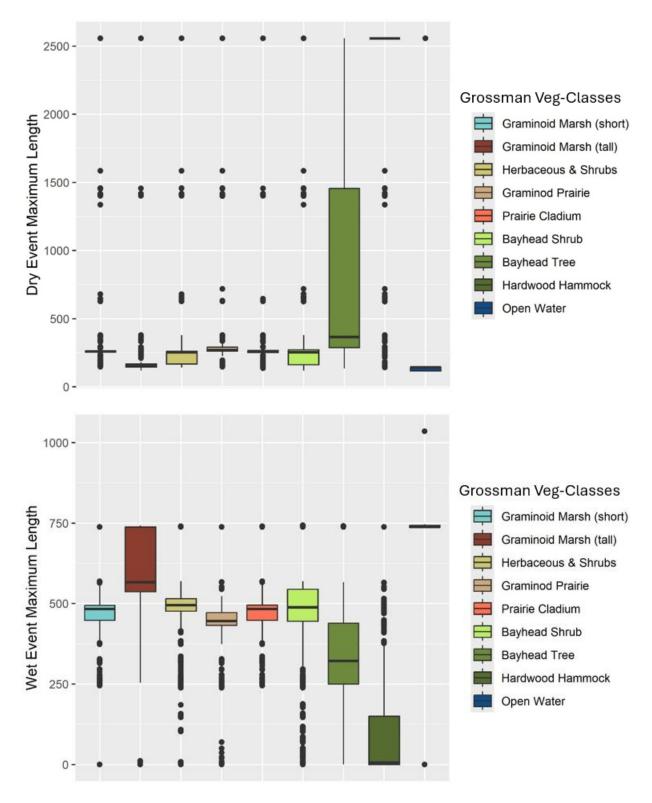


Figure G.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Grossman Island.

Table G.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Grossman Island.

			Pre-7					Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Graminoid Marsh (short)	0	54.2	59.4	63	78.4	0	70.4	74	76.5	86.8
Graminoid Marsh (tall)	0	71.2	76.3	79.4	85.6	0	81.5	85.1	87.53	92.8
Herbaceous & Shrubs	0	57.6	63.7	70.8	81.8	0	73.3	77	81.2	89.4
Graminod Prairie	0	43.8	50.7	56.6	78.1	0	64.4	68.9	72.6	86.5
Prairie Cladium	0	52.8	59.2	63.8	84.3	28.1	69.6	73.9	77.1	91.3
Bayhead Shrub	0	49.7	62.2	71.5	86.7	0	67.9	75.7	81.7	94.1
Bayhead Tree	0	1.3	26.9	46.9	84.4	0	34.3	56.6	66.1	91.4
Hardwood Hammock	0	0	0	0	81.5	0	0	0.2	18	89.1
Open Water	0	79.6	80.3	87.3	91.3	0	87.82	88.3	94.6	97.3

Table G.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration

periods for Grossman Island.

			Pre-7			F	Post-7	
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Graminoid Marsh (short)	-262	-141	-137	-132	-227	-106	-101	-97
Graminoid Marsh (tall)	-260	-124	-115	-109	-223	-88	-80	-73
Herbaceous & Shrubs	-262	-137	-130	-123	-228	-102	-95	-88
Graminod Prairie	-265	-146	-141	-137	-229	-112	-108	-103
Prairie Cladium	-177	-141	-136	-130	-140	-106	-101	-95
Bayhead Shrub	-284	-144	-133	-123	-247	-109	-98	-88
Bayhead Tree	-263	-169	-155	-146	-226	-135	-120	-111
Hardwood Hammock	-284	-225	-206	-179	-247	-190	-171	-144
Open Water	-222	-108	-107	-86	-188	-72	-70	-50

Table G.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Grossman

		Pre	e-7			Pos	st-7	
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Graminoid Marsh (short)	32	37	42	64	68	74	78	101
Graminoid Marsh (tall)	49	58	66	83	85	94	103	120
Herbaceous & Shrubs	35	42	49	73	70	77	84	111
Graminod Prairie	25	30	34	63	59	64	68	99
Prairie Cladium	31	37	42	78	65	72	78	114
Bayhead Shrub	29	40	50	87	65	76	85	124
Bayhead Tree	3	18	27	79	38	54	64	117
Hardwood Hammock	0	0	0	70	0	3	30	106
Open Water	67	69	90	103	104	106	127	140

Table G.5 Maximum water depth when wet (cm) for 7-year pre- a& post-restoration periods for Grossman

		Pre-7	•	•	Post-7	
Class	Q1	Median	Q3	Q1	Median	Q3
Graminoid Marsh (short)	248	271	278	448	483	494
Graminoid Marsh (tall)	297	589	596	536.75	566	738
Herbaceous & Shrubs	268	279	297	476	495	515
Graminod Prairie	231	239	267	432	446	472
Prairie Cladium	245	271	280	448	483	495
Bayhead Shrub	236	277	304	445	488	544
Bayhead Tree	14	132	233	250	322	439
Hardwood Hammock	0	0	0	0	6	150
Open Water	596	598	640	738	738	743

3.3.2.5 *Heartleaf (SS-81)*

Community Area and Percent Cover: The area encompassed by Heartleaf and its surrounding marsh was 38.68 hectares, with herbaceous-shrub mix dominating the landscape at 36.4% of the total area. Non-woody vegetation covered 8.03 ha (20.7%) and the woody core area covered 16.58 ha (42.8%). Within non-woody vegetation, Cladium dominated at 70.5%, followed by Typha at 11.9%, open marsh at 10.1%, and graminoid marsh at 7.4%. Among woody vegetation, Bayhead shrub was predominant, covering 31.3% of the total area and representing 73.1% of all woody vegetation. Bayhead tree accounted for 10% of the total area (23.4% of woody vegetation), while Hardwood hammock tree comprised only 1.5% of the total area (3.5% of woody vegetation) (Fig. HL.1, Table HL.1).

<u>Relative Elevation</u>: As in other islands, the relative elevation data from Heartleaf showed a clear gradient among plant communities. Open marsh and Typha occupied the lowest elevations at approximately -0.05 m. The other non-woody communities - graminoid marsh, Cladium, and herbaceous and shrubs, had median elevations near zero meters. Bayhead tree and Hardwood hammock occupied relative elevations at around 0.05 and 1.0 m, respectively, with Hardwood hammock showing the widest Interquartile range (0.02 - 0.15 m) (Fig. HL.2).

<u>Percent Wet:</u> The percent wet days data showed an increase across all plant communities of approximately 5.8%, after the 2015 restoration, except for open marsh which increased by 3.9% (Fig. HL.3, Table HL.2). Woody communities (Bayhead tree and Hardwood hammock) showed the greatest increases, rising from 75-80% to 88-90% wet days.

<u>Minimum Water Depth when Dry</u>: Overall, minimum water depths during dry periods increased from the 7 year pre- to post-restoration periods for plant communities on Heartleaf. Herbaceous communities saw an average increase of 38 cm. Hardwood hammock increased from –92 cm to –54 cm. (Fig. HL.4, Table HL.3).

<u>Maximum Water Depth:</u> Figure HL.5 and Table HL.4 show that maximum water depths during wet periods presented an increase of 30 cm across all plant communities following the 2015 restoration. Before the restoration, there was a distinct water depth gradient, with open marsh experiencing the deepest depths (85 cm) and Hardwood hammock experiencing the shallowest (38 cm). For the 7-year post-restoration period, the median maximum depths in Hardwood hammock increased from 38 cm to 69 cm, with an increase of the 75th percentile from 42 to 73 cm.

<u>Maximum Wet Event Length</u>: Median wet event lengths for most herbaceous communities were 1,000 and 1,400 days, pre-restoration (Fig. HL.5, Table HL.4). Bayhead shrub, Bayhead tree, and Hardwood hammock were characterized by significantly shorter wet events, with median lengths around 580 to 643 days. For the seven-year post-restoration period, this pattern changed. The median maximum wet event length for graminoid marsh, *Cladium*, *Typha*, Bayhead shrub, Bayhead tree, and Hardwood hammock all increased and clustered between roughly 736 and 1,050 days, with their interquartile ranges shrinking dramatically to became narrow lines.

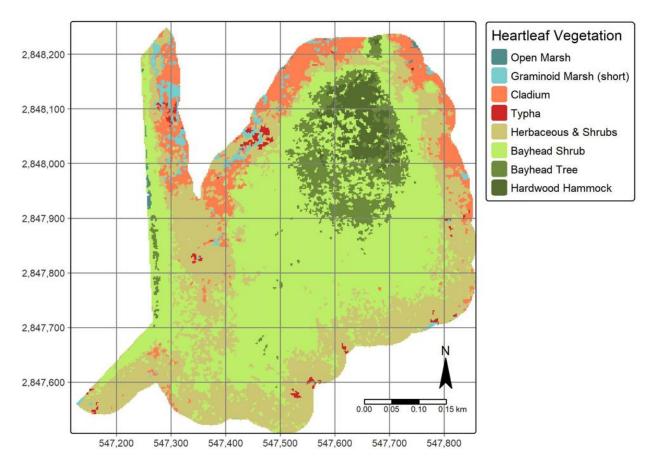


Figure HL.1 Plant communities on Heartleaf (SS-81) Island and the surrounding marsh.

Table HL.1 Class distribution on Heartleaf (SS-81) Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

Heartleaf Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.81	2.1	-	10.1
Graminoid Marsh	0.6	1.5	-	7.4
Cladium	5.66	14.6	-	70.5
Typha	0.96	2.5	-	11.9
Herbaceous - Shrub Mix	14.07	36.4	-	-
Bayhead Shrub	12.12	31.3	73.1	-
Bayhead Tree	3.88	10	23.4	-
Hardwood Hammock Tree	0.58	1.5	3.5	-

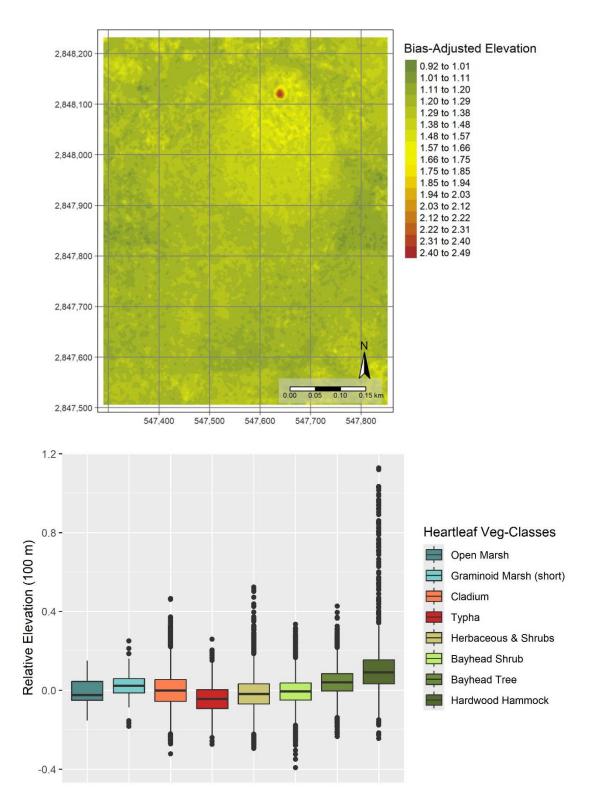


Figure HL.2 Bias-adjusted elevation in meters for Heartleaf (SS-81) Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Heartleaf Island and the surrounding marsh (bottom).

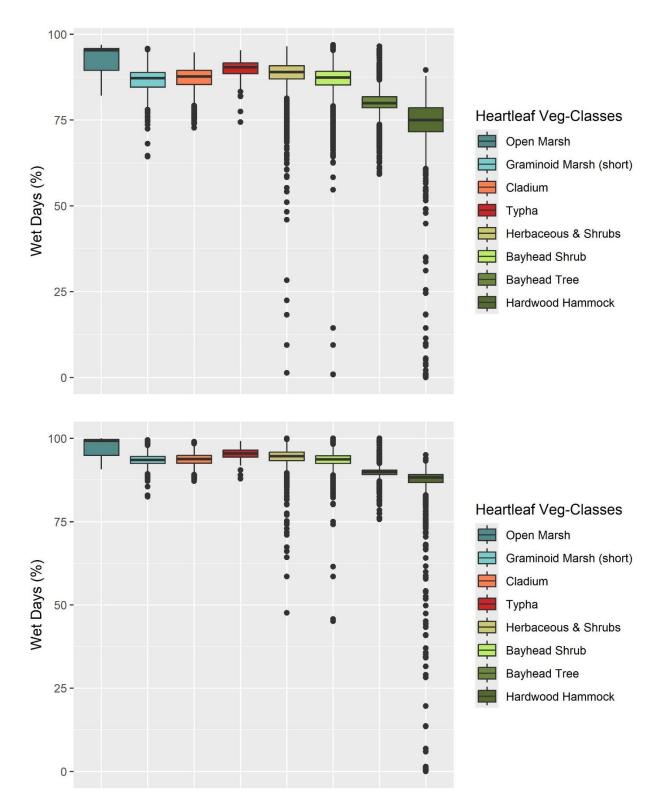


Figure HL.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Heartleaf Island.

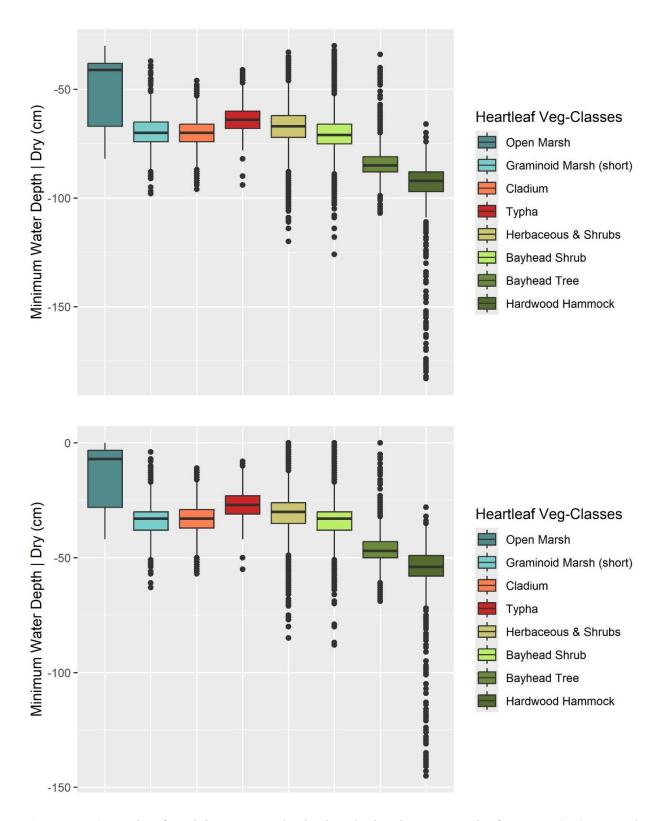


Figure HL.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Heartleaf Island.

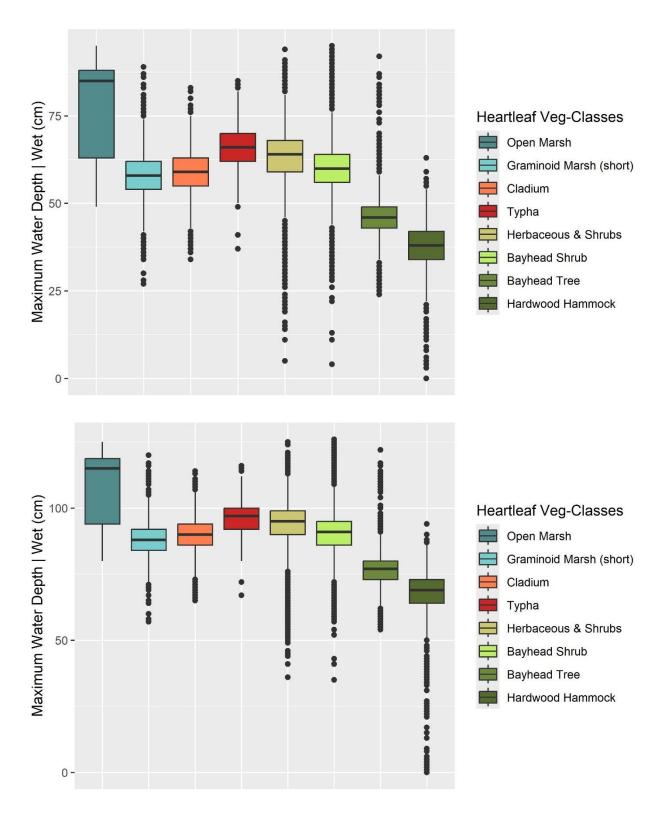


Figure HL.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Heartleaf Island.

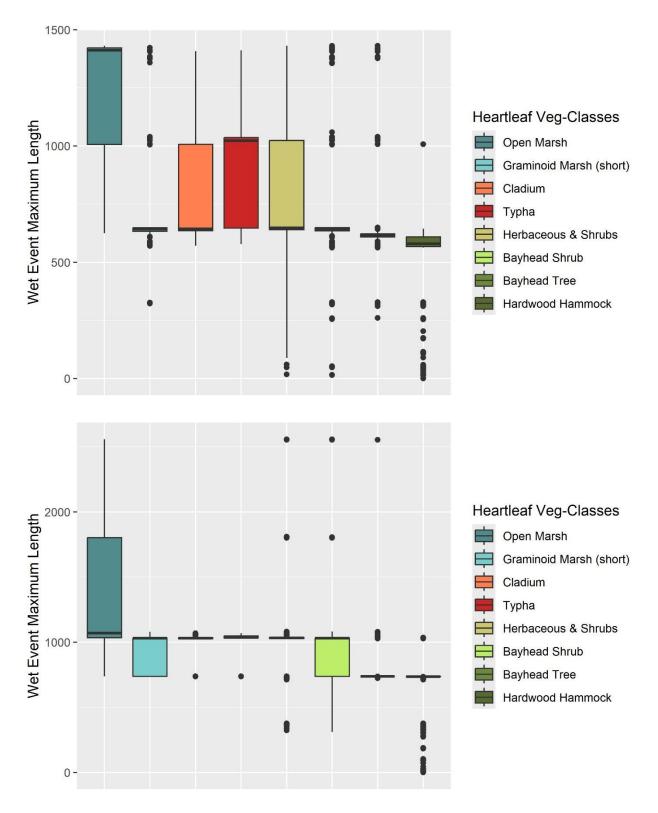


Figure HL.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Heartleaf Island.

Table HL.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Heartleaf Island.

			Pre-7					Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	82.1	89.5	95.4	95.9	96.9	90.7	94.9	99.3	99.7	100
Graminoid Marsh (short)	64.3	84.6	87.2	88.9	95.8	82.5	92.5	93.5	94.6	99.5
Cladium	72.7	85.4	87.7	89.5	94.7	87.2	92.6	93.8	94.9	99
Typha	74.4	88.5	90.4	91.68	95.3	87.9	94.4	95.5	96.5	99.2
Herbaceous & Shrubs	1.3	87	89	90.8	96.5	47.6	93.4	94.7	95.9	100
Bayhead Shrub	0.8	85.2	87.4	89.2	96.9	45.1	92.5	93.7	94.8	100
Bayhead Tree	59.2	78.6	79.9	81.8	96.5	75.7	89.2	89.9	90.5	100
Hardwood Hammock	0	71.6	75	78.6	89.6	0	86.8	88.3	89.2	95

Table HL.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Heartleaf Island.

		P	re-7		Post-7				
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3	
Open Marsh	-82	-67	-41	-38	-42	-28	-7	-3.25	
Graminoid Marsh (short)	-98	-74	-70	-65	-63	-38	-33	-30	
Cladium	-96	-74	-70	-66	-57	-37	-33	-29	
Typha	-94	-68	-64	-60	-55	-31	-27	-23	
Herbaceous & Shrubs	-120	-72	-67	-62	-85	-35	-30	-26	
Bayhead Shrub	-126	-75	-71	-66	-88	-38	-33	-30	
Bayhead Tree	-107	-88	-85	-81	-69	-50	-47	-43	
Hardwood Hammock	-183	-97	-92	-88	-145	-58	-54	-49	

Table HL.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Heartleaf

		Pre-	-7			Po	st-7	
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	63	85	88	95	94	115	118.75	125
Gram. Marsh (short)	54	58	62	89	84	88	92	120
Cladium	55	59	63	83	86	90	94	114
Typha	62	66	70	85	92	97	100	116
Herbaceous & Shrubs	59	64	68	94	90	95	99	125
Bayhead Shrub	56	60	64	95	86	91	95	126
Bayhead Tree	43	46	49	92	73	77	80	122
Hardwood Hammock	34	38	42	63	64	69	73	94

Table HL.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Heartleaf Island.

		Pre-7			Post-7	
Class	Q1	Median	Q3	Q1	Median	Q3
Open Marsh	1007	1413	1423	1035	1070	1802
Gram. Marsh (short)	633	642	648	738	1031	1033
Cladium	636	644	1008	1027	1031	1035
Typha	647	1023	1037	1032	1036	1047
Herbaceous & Shrubs	640	648	1024	1030	1033	1037
Bayhead Shrub	635	643	649	738	1031	1033
Bayhead Tree	609	616	622	737	737	738
Hardwood Hammock	568	580	609	736	736	737

3.3.2.6 *Irongrape*

Community Area and Percent Cover: Irongrape island and its surrounding marsh encompassed approximately 29.84 ha, split between woody vegetation (57.3%) and non-woody vegetation (42.7%) (Fig. IG.1, Table IG.1). Bayhead shrub was the dominant vegetation class, covering 13.63 ha or 45.7% of the total area and representing 79.7% of all woody core vegetation. The second largest class was herbaceous-shrub mix at 6.21 ha (20.8% of total area), which accounted for nearly half of all non-woody vegetation. Cladium marsh followed with 4.97 hectares (16.6% of total area), making up 39% of non-woody areas. Bayhead tree vegetation covered 3.12 hectares (10.5% of total area), while smaller areas were occupied by Typha (0.81 ha), graminoid marsh (0.63 ha), Hardwood hammock tree (0.35 ha), and open marsh (0.12 ha).

<u>Relative Elevation:</u> The relative elevation data on Irongrape showed that open marsh and graminoid marsh occupied the lowest elevations with medians around -0.1 m, followed by *Cladium*, *Typha*, and herbaceous and shrubs at 0 m (Fig. IG.2,). Median elevation for Bayhead shrub spanned from -0.4 to 0.5 m, while Bayhead tree occupied slightly higher ground with medians around 0.1 m. Hardwood hammock dominated the highest elevations, with median values around 0.6 m and an interquartile range (IQR) from 0.30 to 0.75 m.

<u>Percent Wet:</u> Percent wet days seven-year pre- and post- restoration periods showed an overall increase across plant communities. Open marsh and herbaceous communities increased from median values of 85-90% to 90-95% wet days, while Bayhead shrub rose from 79% to 87% and Bayhead tree from 71% to 80%. Hardwood hammock increased from no wet days to a median of 0.1% wet days, and the range of percent wet days saw an increase of the 75th percentile from 7% to 38%. (Fig. IG.3, Table IG.2).

<u>Minimum Water Depth when Dry</u>: Median minimum water depths when dry increased on Irongrape island from pre- to post- restoration periods by approximately 36% for herbaceous communities (Fig. IG.4, Table IG.3). For woody communities it increased by about 38 cm (Fig. IG.4, Table IG.3).

<u>Maximum Water Depth:</u> Median maximum water depths when wet increased by approximately 36 cm in all communities, except for Hardwood hammock that presented an increase of 11 cm. Before restoration, Bayhead shrub and Bayhead tree had median depths at 45 cm and 39 cm, respectively, which increased to 80 cm and 75 cm. Hardwood hammock was the driest plant community with an IQR of 0 to -9 cm increasing to 3 - 46 cm (Fig. IG.5, Table IG.4).

<u>Maximum Wet Event Length</u>: The maximum length of wet events on Irongrape, unlike other tree islands, saw a decrease in most herbaceous communities. For the seven-year period pre-restoration, median maximum wet events ranged from 630 to 762 days for herbaceous plant communities. Bayhead shrub and Bayhead tree showed shorter median durations of 616 and 335 days, respectively. Hardwood hammock experienced no measurable wet events, with all quartiles at 0 days. Post-restoration, all plant communities except Hardwood hammock converged to nearly identical values, with medians between 733-737 days and minimal variation across quartiles. Hardwood hammock showed an increase from 0 to a median of 3 days, with the third

quartile reaching 198 days, though it remained substantially drier than all other communities (Fig. IG.6, Table IG.5).

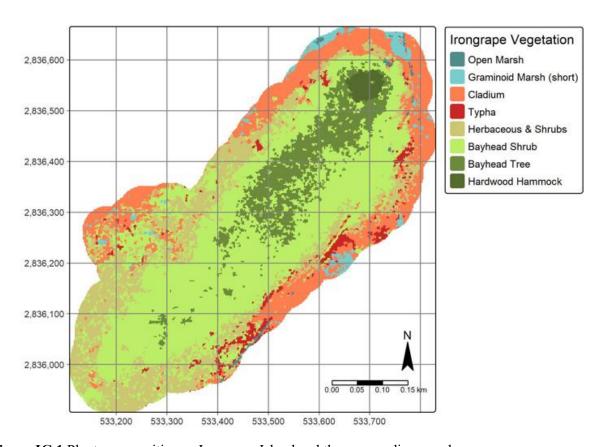
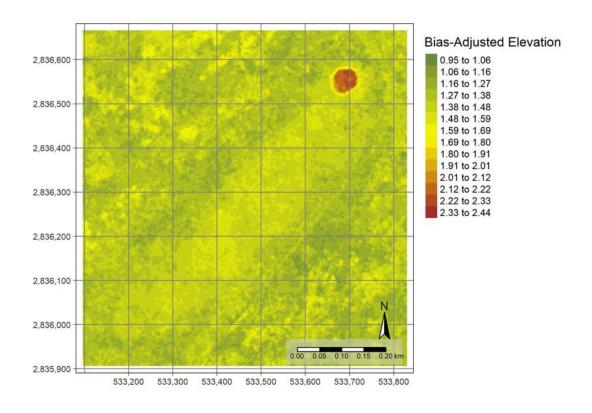
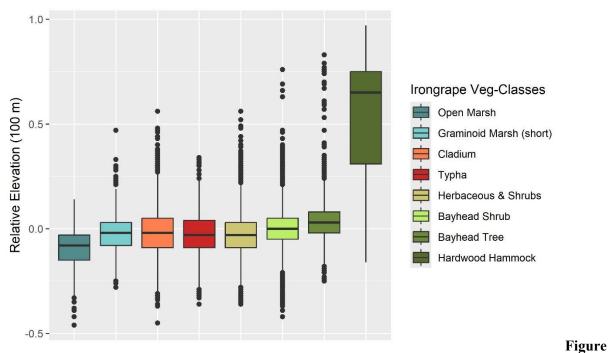


Figure IG.1 Plant communities on Irongrape Island and the surrounding marsh.

Table IG.1 Class distribution on Irongrape Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

Irongrape Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.12	0.4	-	0.9
Graminoid Marsh	0.63	2.1	-	4.9
Cladium	4.97	16.6	-	39
Typha	0.81	2.7	-	6.4
Herbaceous - Shrub Mix	6.21	20.8	-	48.8
Bayhead Shrub	13.63	45.7	79.7	-
Bayhead Tree	3.12	10.5	18.3	-
Hardwood Hammock Tree	0.35	1.2	2	-





IG.2 Bias-adjusted elevation in meters for Irongrape Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Irongrape Island and the surrounding marsh (bottom).

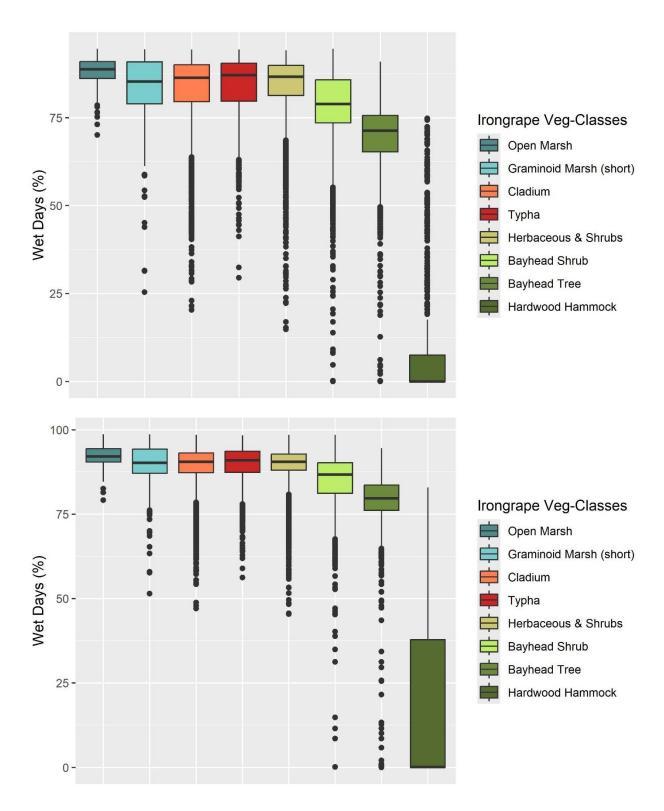


Figure IG.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Irongrape Island.

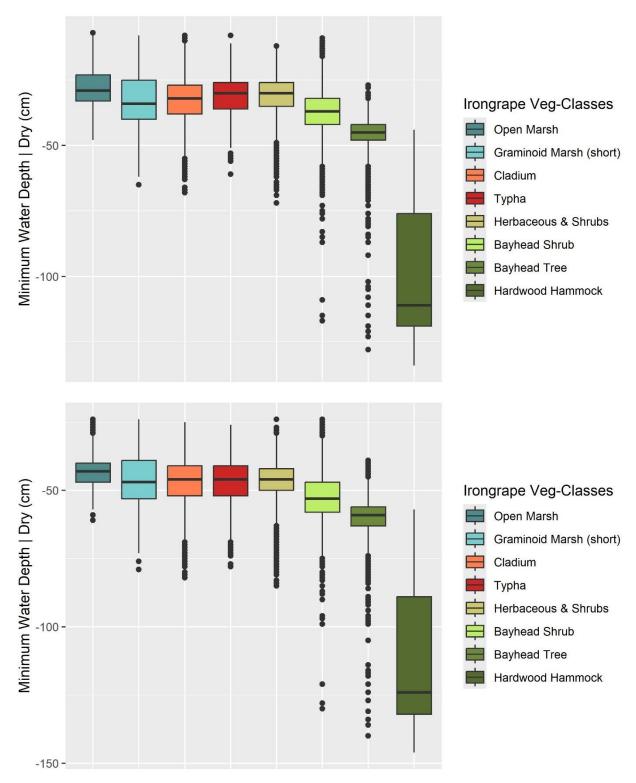


Figure IG.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Irongrape Island.

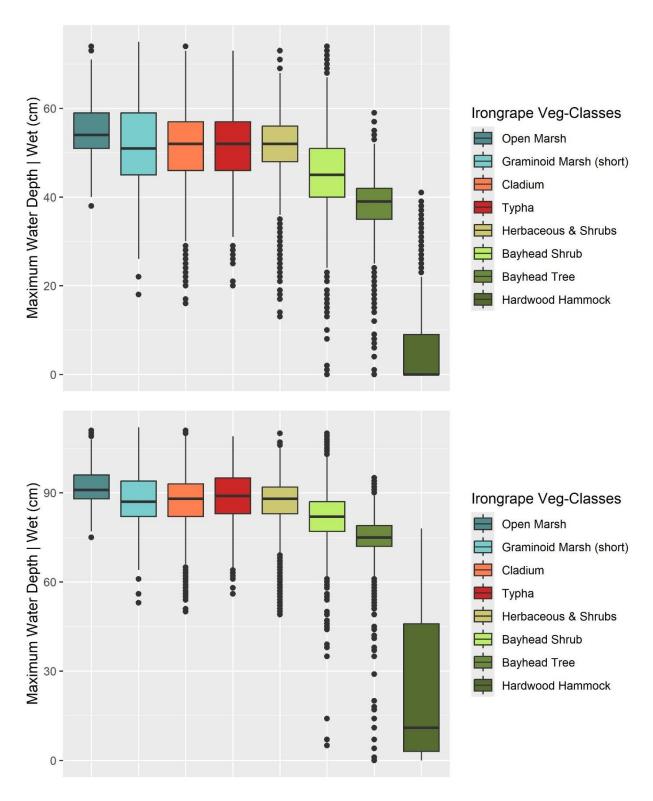


Figure IG.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Irongrape Island.

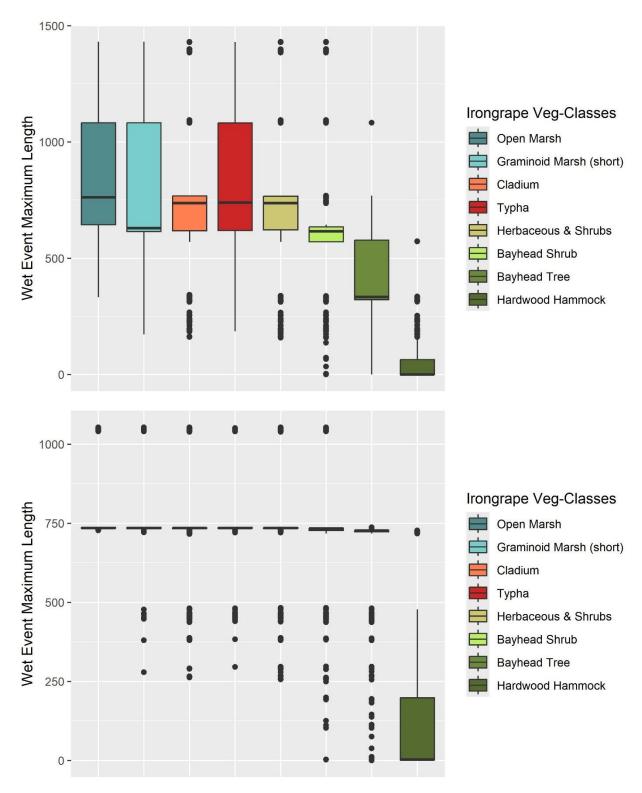


Figure IG.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for Irongrape Island.

Table IG.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Irongrape Island.

		•	Pre-7	•	•			Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	70.1	86.2	88.8	91	94.6	79.1	90.4	92.1	94.4	98.6
Graminoid Marsh (short)	25.4	79	85.3	90.9	94.5	51.4	87.1	90.2	94.3	98.6
Cladium	20.3	79.6	86.4	90.1	94.4	47	87.3	90.5	93.1	98.5
Typha	29.5	79.7	87.2	90.5	94.4	56.2	87.4	90.9	93.6	98.3
Herbaceous & Shrubs	14.8	81.4	86.7	89.9	94.2	45.4	88	90.5	92.8	98.5
Bayhead Shrub	0	73.6	78.9	85.8	94.6	0.1	81.2	86.7	90.2	98.5
Bayhead Tree	0	65.3	71.3	75.7	90.9	0	76.1	79.7	83.6	94.5
Hardwood Hammock	0	0	0	7.5	74.8	0	0	0.1	37.8	82.9

Table IG.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration

periods for Irongrape Island.

		P	re-7		Post-7					
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3		
Open Marsh	-48	-33	-29	-23	-61	-47	-43	-40		
Gram Marsh (short)	-65	-40	-34	-25	-79	-53	-47	-39		
Cladium	-68	-38	-32	-27	-82	-52	-46	-41		
Typha	-61	-36	-30	-26	-78	-52	-46	-41		
Herbaceous & Shrubs	-72	-35	-30	-26	-85	-50	-46	-42		
Bayhead Shrub	-117	-42	-37	-32	-130	-58	-53	-47		
Bayhead Tree	-128	-48	-45	-42	-140	-63	-59	-56		
Hardwood Hammock	-134	-119	-111	-76	-146	-132	-124	-89		

Table IG.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Irongrape Island.

		Pre-7				Post-	7	
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	51	54	59	74	88	91	96	111
Gram. Marsh (short)	45	51	59	75	82	87	94	112
Cladium	46	52	57	74	82	88	93	111
Typha	46	52	57	73	83	89	95	109
Herbaceous & Shrubs	48	52	56	73	83	88	92	110
Bayhead Shrub	40	45	51	74	77	82	87	110
Bayhead Tree	35	39	42	59	72	75	79	95
Hardwood Hammock	0	0	9	41	3	11	46	78

Table IG.5 Max water depth when wet (cm) for 7-year pre- and post-restoration periods for Irongrape Island.

	Pre-7			Post-7		
Class	Q1	Median	Q3	Q1	Median	Q3
Open Marsh	644	762	1083	735	735	737
Graminoid Marsh (short)	615	630	1083	733	735	737
Cladium	618	737	768	733	735	736
Typha	619	739	1082	734	735	737
Herbaceous & Shrubs	622	737	767	734	735	736
Bayhead Shrub	571	616	635	727	733	735
Bayhead Tree	322	333	578	723	727	727
Hardwood Hammock	0	0	64	1	3	198

3.3.2.7 NP-202

Community Area and Percent Cover: NP202 and the surrounding marsh covered approximately 18.81 hectares. The area was nearly evenly split between non-woody vegetation (51.6%) and woody vegetation (48.4%). Bayhead shrub represented the largest vegetation class at 5.58 hectares (29.6% of total area), comprising 61.2% of the woody core. Herbaceous-shrub mix was the second largest class at 4.37 hectares (23.2% of total area), accounting for 45% of all non-woody vegetation. Bayhead tree covered 3.46 hectares (18.4% of total area) and represented 38% of woody vegetation, while Cladium occupied 3.27 hectares (17.4% of total area) and made up 33.7% of non-woody areas. Smaller areas were occupied by graminoid marsh (1.41 ha, 7.5%), Typha (0.50 ha, 2.7%), open marsh (0.15 ha, 0.8%), and Hardwood hammock tree (0.07 ha, 0.3%) (Fig. NP-202.1, Table NP-202.1).

<u>Relative Elevation</u>: On NP-202, open marsh and graminoid marsh occupied the lowest elevations with medians around -0.1 to -0.05 m. Herbaceous and shrubs, Cladium, and Typha had a median elevation of approximately 0.0 m. Bayhead shrub and Bayhead tree occurred at slightly higher elevations with medians around 0.05 meters. Hardwood hammock dominated the highest elevation with a median of 0.6 m and the narrowest range (Fig. NP-202.2).

<u>Percent Wet:</u> Percent wet days on NP202 increased from seven-year pre- to post-restoration periods. Wet conditions on open marsh, graminoid marsh, *Cladium, Typha* and herbaceous and shrubs increased by 2.7, 2.7, 1.7, 0.9 and 1.4%, respectively. Bayhead shrub median values reached 83.9%, and Bayhead tree rose to 78.4% wet conditions. Hardwood hammock showed a change from 0% to 4.8% median wet days, with the 75th percentile increasing from 1.2 to 7% (Fig. NP-202.3, Table NP-202.2).

<u>Minimum Water Depth when Dry</u>: Minimum water depth when dry for NP202 increased across all plant communities following the 2015 restoration by approximately 6-7 cm. Open marsh increased from -22 cm to -16 cm; graminoid marsh, Cladium, Typha, and herbaceous and shrubs from around -28 to -38 cm pre-restoration to -22 to -32 cm post-restoration, and woody communities presented similar shifts. Hardwood hammock maintained the deepest water depths, increasing from -108 cm to -101 cm. All quartile and minimum values showed an increase (Fig. NP-202.4, Table NP-202.3).

Maximum Water Depth: The comparison of median maximum water depth when wet for NP202 showed an increase of 13-16 cm across all plant communities following the 2015 restoration. Marsh communities rose from 70-85 cm to 83-99 cm, and woody communities from 55-63 cm to 71-77 cm. Hardwood hammock presented the biggest change, shifting from no flooding (median 0 cm) to 13 cm median depths, with the 75th percentile increasing from 7 to 20 cm (Fig. NP-202.5, Table NP-202.4).

<u>Maximum Wet Event Length</u>: Open marsh and graminoid marsh on NP-202 experienced increases from approximately 1435 days to 1790 days. In contrast, *Cladium* and *Typha* showed significant decreases from around 1135 days to 735-755 days. All woody communities experienced longer flooding durations, with Bayhead tree doubling from 352 to 727 days and Hardwood hammock

tripling from 30.5 to 93 days. Post-restoration, many communities converged around wet event lengths lasting 730-760 (Fig. NP-202.6, Table NP-202.5).

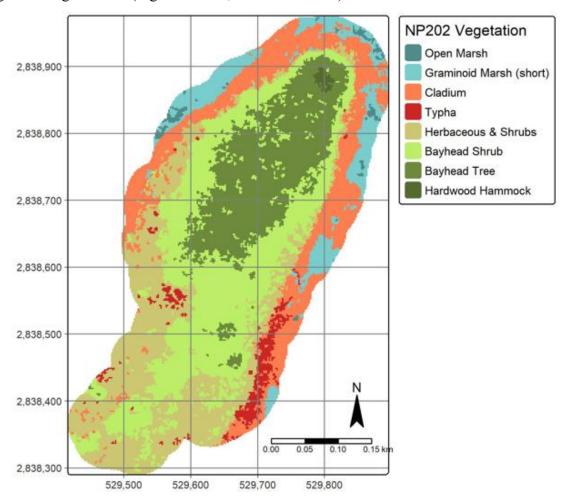


Figure NP-202.1 Tree Island plant communities on NP-202 Island and the surrounding marsh.

Table NP-202.1 Class distribution on NP202 Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes; Non-Woody (%) = class percentages considering only non-woody classes.

NP202 Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.15	0.8	-	1.6
Graminoid Marsh	1.41	7.5	-	14.5
Cladium	3.27	17.4	-	33.7
Typha	0.50	2.7	-	5.2
Herbaceous - Shrub Mix	4.37	23.2	-	45
Bayhead Shrub	5.58	29.6	61.2	-
Bayhead Tree	3.46	18.4	38	-
Hardwood Hammock Tree	0.07	0.3	0.7	-

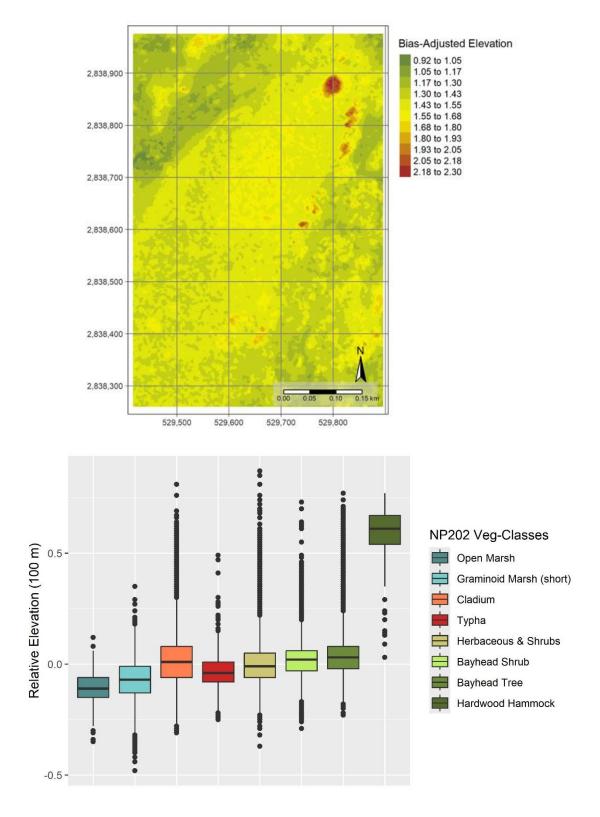


Figure NP-202.2 Bias-adjusted elevation in meters for NP-202 Island and the surrounding marsh (top). Boxplot of plant community relative elevation for NP-202 Island and the surrounding marsh (bottom).

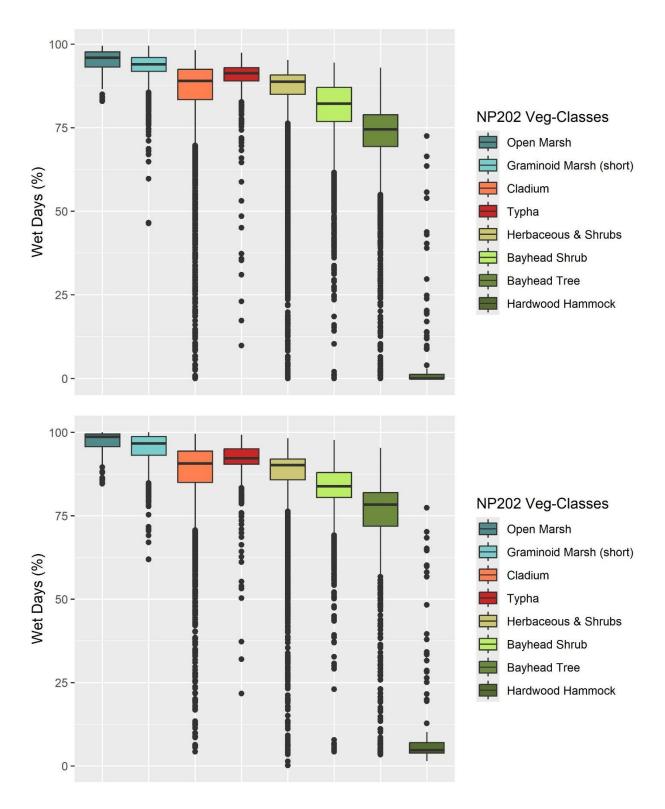


Figure NP-202. Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for NP-202 Island.

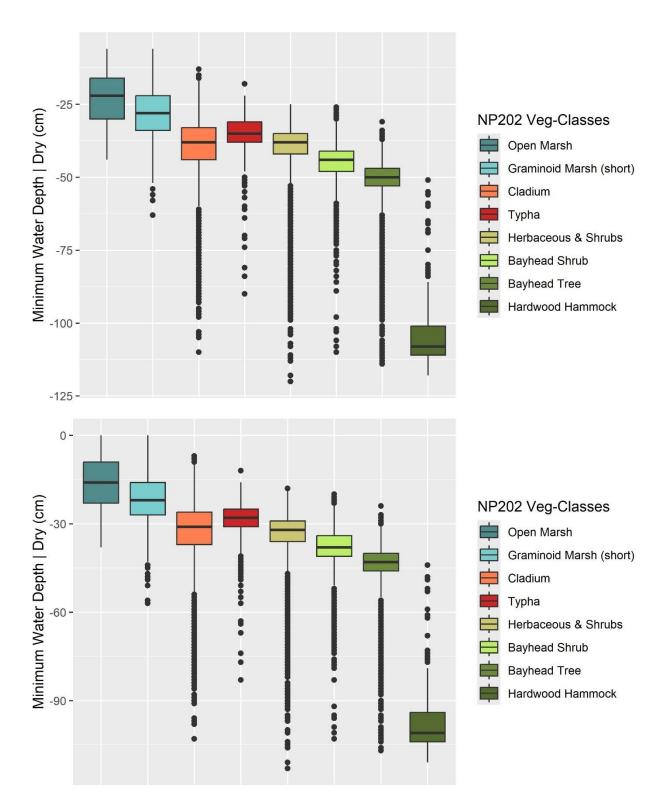


Figure NP-202.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) preand (bottom) post-restoration periods for NP-202 Island.

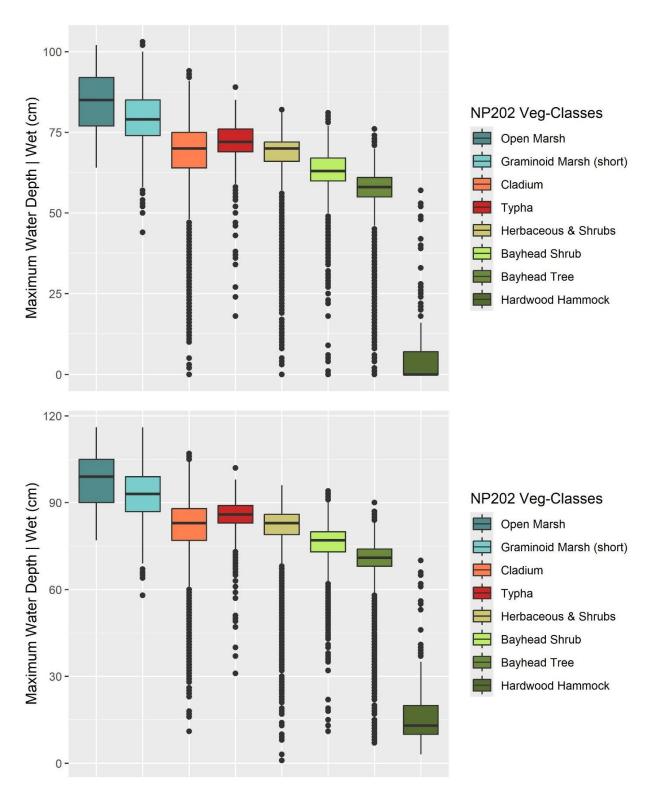


Figure NP-202.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for NP-202 Island.

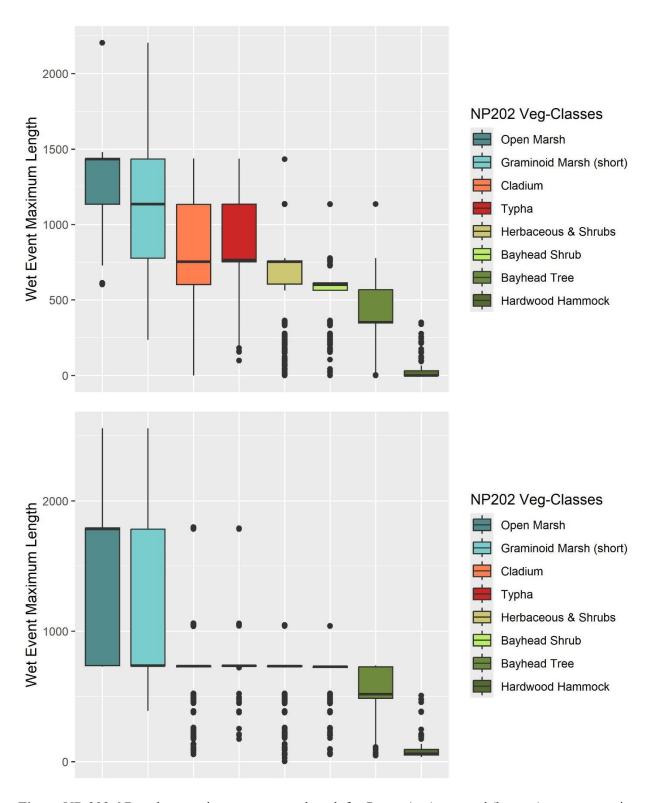


Figure NP-202.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods for NP-202 Island.

Table NP202.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for NP-202 Island.

		Pre-7				Post-7				
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	82.9	93.2	96	97.7	99.5	84.6	95.8	98.7	99.5	100
Graminoid Marsh (short)	46.4	91.9	94	96.1	99.5	61.9	93.2	96.7	98.8	100
Cladium	0	83.4	89	92.5	98.2	4.3	85	90.7	94.4	99.6
Typha	9.8	89	91.3	93	97.4	21.7	90.5	92.2	95.1	99.3
Herbaceous & Shrubs	0	85	88.8	90.8	95.3	0.2	85.8	90.2	92	98.2
Bayhead Shrub	0	76.9	82.2	87.1	94.5	4.3	80.5	83.9	88	97.7
Bayhead Tree	0	69.4	74.5	78.9	93	3.4	71.9	78.4	82	95.3
Hardwood Hammock	0	0	0	1.2	72.5	1.5	3.9	4.8	7	77.4

Table NP202.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for NP-202 Island.

			Pre-7		Post-7			
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-44	-30	-22	-16	-38	-23	-16	-9
Graminoid Marsh (short)	-63	-34	-28	-22	-57	-27	-22	-16
Cladium	-110	-44	-38	-33	-103	-37	-31	-26
Typha	-90	-38	-35	-31	-83	-31	-28	-25
Herbaceous & Shrubs	-120	-42	-38	-35	-113	-36	-32	-29
Bayhead Shrub	-110	-48	-44	-41	-103	-41	-38	-34
Bayhead Tree	-114	-53	-50	-47	-107	-46	-43	-40
Hardwood Hammock	-118	-111	-108	-101	-111	-104	-101	-94

Table NP202.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for NP-202 Island.

		Pre-		Post	-7	•		
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	77	85	92	102	90	99	105	116
Graminoid Marsh (short)	74	79	85	103	87	93	99	116
Cladium	64	70	75	94	77	83	88	107
Typha	69	72	76	89	83	86	89	102
Herbaceous & Shrubs	66	70	72	82	79	83	86	96
Bayhead Shrub	60	63	67	81	73	77	80	94
Bayhead Tree	55	58	61	76	68	71	74	90
Hardwood Hammock	0	0	7	57	10	13	20	70

Table NP202.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for NP-202 Island.

		Pre-7		Post-7			
Class	Q1	Median	Q3	Q1	Median	Q3	
Open Marsh	1136	1434	1437	737	1786	1794	
Graminoid Marsh (short)	777	1136	1434	736	737	1785.5	
Cladium	603	754	1133	727	734	736	
Typha	754	765	1136	733	735	737	
Herbaceous & Shrubs	606	754	760	729	733	735	
Bayhead Shrub	564	600	613	723	727	732	
Bayhead Tree	347	352	569	487	518	727	
Hardwood Hammock	0	0	30.5	51	61	93	

3.3.2.8 *Satinleaf*

<u>Community Area and Percent Cover:</u> The area encompassed by plant communities on Satinleaf and the surrounding marsh was approximately 5.47 hectares (Fig. SL.1, Table. SL.1), dominated by 73.5% non-woody vegetation and woody vegetation comprising only 26.5%. Among woody vegetation, Bayhead tree was the dominant type at 0.70 hectares (12.8% of total area), representing 48.2% of the woody core. Bayhead shrub covered 0.54 hectares (9.9% of total area) and comprised 37.4% of woody vegetation, while Hardwood hammock occupied 0.21 hectares (3.8% of total area). *Cladium* represented the largest vegetation class at 1.56 hectares (28.5% of total area), accounting for 38.8% of all non-woody vegetation. Graminoid marsh was the second largest class at 1.19 hectares (21.7% of total area), making up 29.5% of non-woody areas. Herbaceous-shrub mix covered 0.91 hectares (16.7% of total area), while open marsh occupied 0.34 hectares (6.2% of total area). *Typha* had minimal presence at only 0.02 hectares (0.4% of total area).

<u>Relative Elevation</u>: Open marsh occupied the lowest positions with median elevations around -0.1 m. Graminoid marsh occurred at slightly higher elevations with medians near -0.05 m. *Cladium* displayed median elevations around 0.05 m, while *Typha* showed slightly higher median values near 0.1 m. Herbaceous and shrubs and Bayhead shrub communities both had median elevations close to 0 m. Bayhead tree occupied median elevations around 0.05 m but exhibited extensive vertical distribution from approximately -0.3 to 0.6 m. Hardwood hammock was found in the highest elevations with median values around 0.65 m and the most restricted IQR, extending from approximately 0.5 to 0.9 meters.

<u>Percent Wet:</u> Median percent wet days for Satinleaf showed a 3.8 average increase in wet conditions across herbaceous plant communities following the 2015 restoration (Fig. SL.3, Table. SL.2). Bayhead tree displayed one of the larger increases from 72.7% to 78.3% and Hardwood hammock shifted from completely dry conditions (0% median) to 2.2% median wet days, with the 75th percentile increasing from 3% to 7% wet days.

<u>Minimum Water Depth when Dry</u>: Minimum water depth when dry on Satinleaf showed an overall increase across all plant communities following the 2015 restoration. This increase was approximately 12-13 cm, Bayhead tree and Bayhead shrub increased from a median minimum water depth of -80 and -70 cm to approximately -67 and -58 cm, respectively. Hardwood hammock maintained the lowest median minimum water depths when dry, increasing from -139 cm to -127 cm (Fig. SL.4, Table. SL.3).

<u>Maximum Water Depth:</u> Maximum water depth when wet for Satinleaf increased across all plant communities following the 2015 restoration. All vegetation types experienced consistent increases of 11-14 cm in median maximum flooding depths, with marsh and herbaceous communities rising from 60-72 cm to 74-86 cm, and woody communities from 58-67 cm to 71-80 cm. Hardwood hammock shifted from completely dry conditions (0 cm median) to 11 cm median depths, with the 75th percentile increasing from 11.5 to 25 cm. (Fig. SL.5, Table. SL.4).

<u>Maximum Wet Event Length:</u> Median wet event maximum lengths showed substantial increases following the 2015 restoration. Most communities converged from varied pre-restoration median values (335-642 days) to nearly uniform durations around 730-736 days post-restoration. Notable

changes included *Typha* increasing from 376 to 728 days, Bayhead tree doubling from 335 to 733 days, and Hardwood hammock shifting from completely dry conditions to 53-day median wet events.

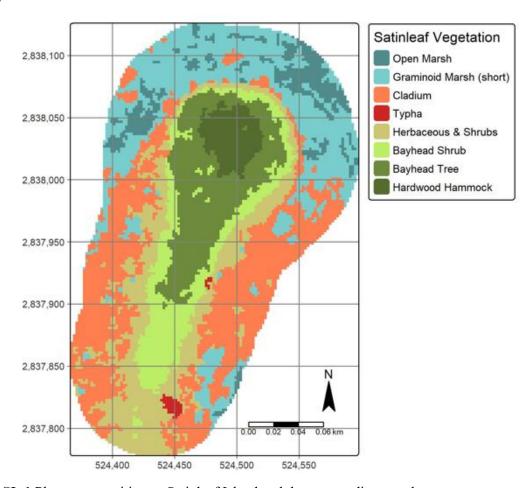


Figure SL.1 Plant communities on Satinleaf Island and the surrounding marsh.

Table SL.1 Class distribution on Satinleaf Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

Satinleaf Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.34	6.2	-	8.4
Graminoid Marsh	1.19	21.7	-	29.5
Cladium	1.56	28.5	-	38.8
Typha	0.02	0.4	-	0.6
Herbaceous - Shrub Mix	0.91	16.7	-	22.7
Bayhead Shrub	0.54	9.9	37.4	-
Bayhead Tree	0.70	12.8	48.2	-
Hardwood Hammock Tree	0.21	3.8	14.4	-

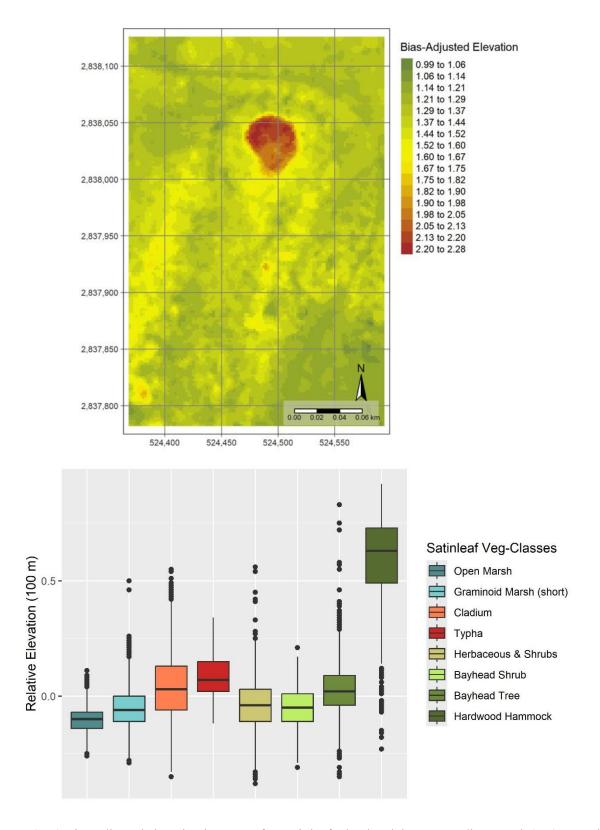


Figure SL.2 Bias-adjusted elevation in meters for Satinleaf Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Satinleaf Island and the surrounding marsh (bottom).

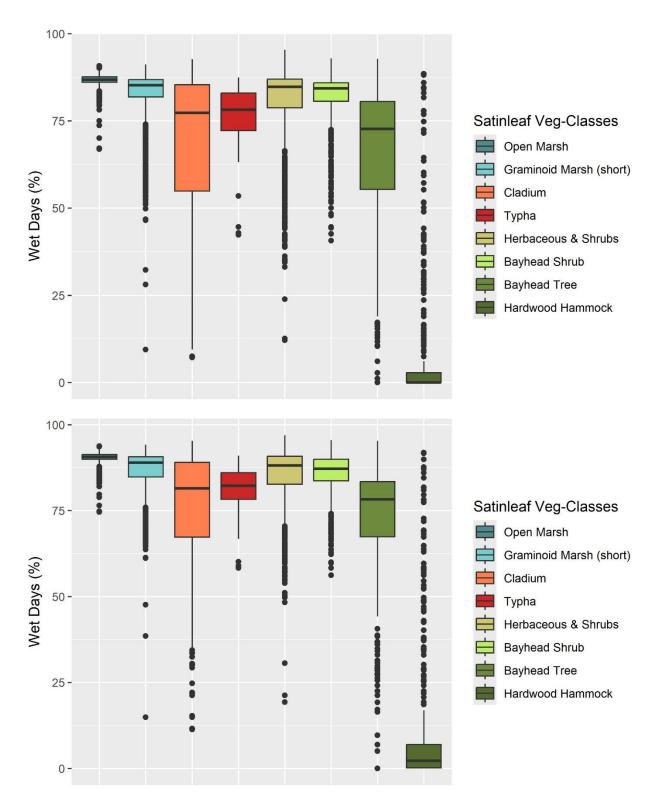


Figure SL.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Satinleaf Island.

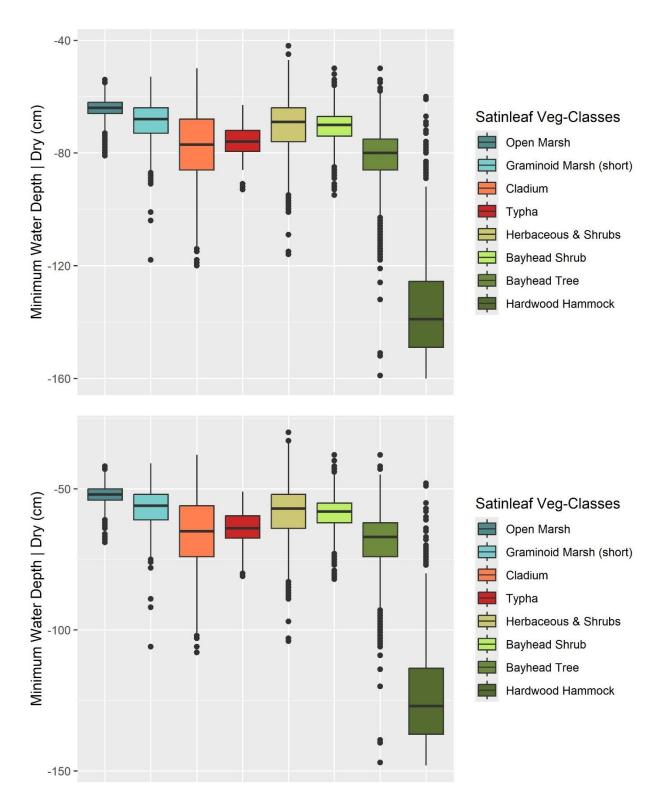


Figure SL.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Satinleaf Island.

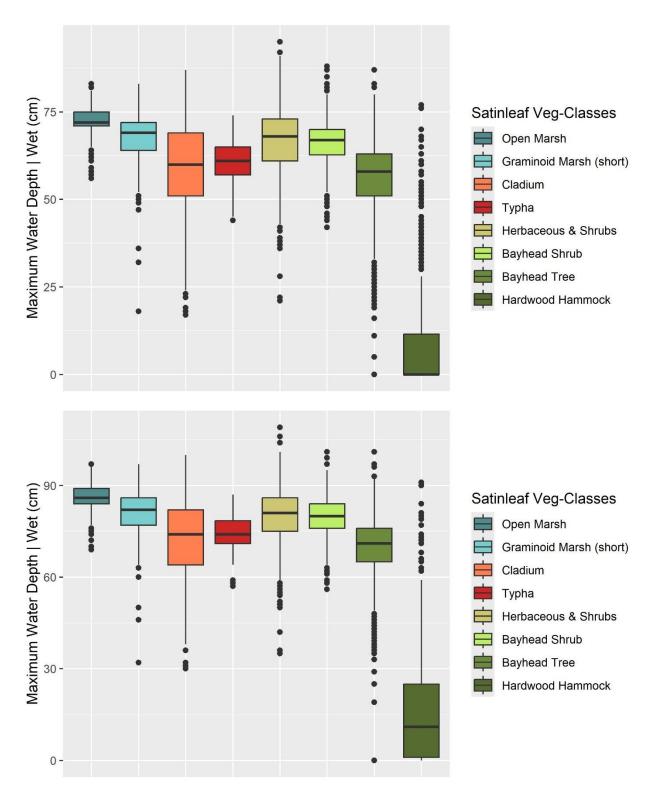


Figure SL.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Satinleaf Island.

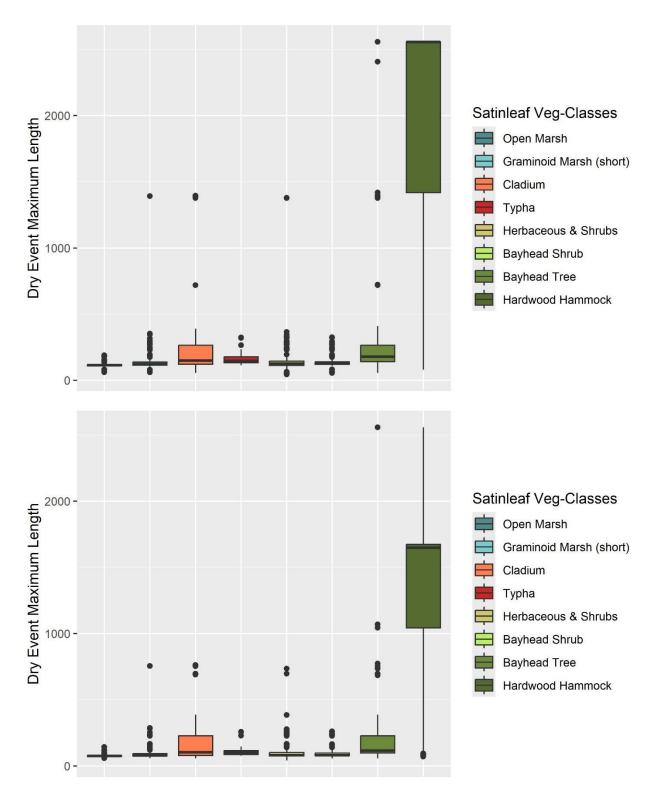


Figure SL.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods Satinleaf Island.

Table SL.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Satinleaf Island.

			Pre-7					Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	66.9	86.1	86.9	87.7	90.8	74.6	90	90.7	91.4	93.8
Graminoid Marsh (short)	9.4	81.9	85.3	86.9	91.2	14.9	84.8	89	90.7	94.2
Cladium	7.1	54.9	77.4	85.4	92.7	11.3	67.3	81.5	89.1	95.3
Typha	42.3	72.3	78.3	83.05	87.4	58.3	78.3	82.3	86.1	91
Herbaceous & Shrubs	12.1	78.8	84.8	87	95.4	19.3	82.7	88.2	90.8	96.9
Bayhead Shrub	40.7	80.7	84.4	86	93	56.2	83.68	87.2	90	95.5
Bayhead Tree	0	55.4	72.75	80.6	92.8	0	67.4	78.3	83.5	95.3
Hardwood Hammock	0	0	0	2.8	88.5	0	0.2	2.2	6.95	91.9

Table SL.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Satinleaf Island.

			Pre-7				Post-7	
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-81	-66	-64	-62	-69	-54	-52	-50
Graminoid Marsh (short)	-118	-73	-68	-64	-106	-61	-56	-52
Cladium	-120	-86	-77	-68	-108	-74	-65	-56
Typha	-93	-79.5	-76	-72	-81	-67.5	-64	-59.5
Herbaceous & Shrubs	-116	-76	-69	-64	-104	-64	-57	-52
Bayhead Shrub	-95	-74	-70	-67	-82	-62	-58	-55
Bayhead Tree	-159	-86	-80	-75	-147	-74	-67	-62
Hardwood Hammock	-160	-149	-139	-125.5	-148	-137	-127	-113.5

Table SL.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Satinleaf Island.

		Pre-7				Post-7					
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max			
Open Marsh	71	72	75	83	84	86	89	97			
Graminoid Marsh (short)	64	69	72	83	77	82	86	97			
Cladium	51	60	69	87	64	74	82	100			
Typha	57	61	65	74	71	74	78.5	87			
Herbaceous & Shrubs	61	68	73	95	75	81	86	109			
Bayhead Shrub	62.75	67	70	88	76	80	84	101			
Bayhead Tree	51	58	63	87	65	71	76	101			
Hardwood Hammock	0	0	11.5	77	1	11	25	91			

Table SL.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Satinleaf Island.

		Pre-7			Post-7	
Class	Q1	Median	Q3	Q1	Median	Q3
Open Marsh	638	642	646	736	736	736
Graminoid Marsh (short)	609	633	642	732	735	736
Cladium	257	375	634	481	532	735
Typha	357.5	376	621	523	728	733
Herbaceous & Shrubs	376	631	643	728	735	736
Bayhead Shrub	605	628	637	730	735	736
Bayhead Tree	258	358	604	481	523	730
Hardwood Hammock	0	0	63.5	2	53	99

3.3.2.9 SS93

Community Area and Percent Cover: The area encompassed by plant communities on SS93 and the surrounding marsh occupied 6.79 hectares (Fig, SS93.1, Tbl. SS93.1). The area was dominated by non-woody vegetation (65.4%) and woody vegetation (34.6%). Cladium was by far the largest vegetation class at 3.40 ha (50.1% of total area), representing 76.5% of all non-woody vegetation. The remaining non-woody communities were much smaller, with herbaceous-shrub mix covering 0.76 ha (11.1% of total area), Typha at 0.15 ha (2.2%), and graminoid marsh at 0.14 ha (2.0%). Among woody vegetation, Bayhead tree was the dominant type at 1.25 ha (18.5% of total area), comprising 53.5% of the woody core. Bayhead shrub covered 0.99 ha (14.6% of total area) and represented 42.4% of woody vegetation, while Hardwood hammock tree had a minimal presence at only 0.10 hectares (1.4% of total area).

<u>Relative Elevation:</u> Graminoid marsh and *Typha*, presented median elevations around -0.05 m (Fig, SS93.2). Cladium exhibited median elevations around 0 m with considerable variability. Herbaceous with shrubs and Bayhead shrub both showed median elevations close to 0 m, with herbaceous and shrubs displaying a wider range extending up to 0.7 m. Bayhead tree had median values near 0 m extending from approximately -0.25 to 0.9 m. Hardwood hammock occupied the highest elevations with median values around 0.25 m and a relatively narrow range from 0.1 to 0.45 m.

<u>Percent Wet:</u> Figure SS93.3 and Table SS93.2 show that graminoid marsh (short), *Cladium*, *Typha*, herbaceous and shrubs, and Bayhead shrub communities all experienced an increase in percent wet days after restoration. Bayhead shrub increased from 84.5% to 91.8% and Bayhead tree also saw an increase in median percent wet days, from 77.7% to 88.1%. In contrast, the Hardwood hammock community exhibited a relatively large range of percent wet days both before and after the restoration - median percent wet days increased from 27.6% to 66.4%.

<u>Minimum Water Depth when Dry</u>: Figure SS93.4 and Table SS93.3 show the median minimum water depth when dry for all plant communities increasing by 32 – 33 cm after the restoration. Bayhead shrub increased from -67 cm to -34 cm, Bayhead tree from -74 cm to -42 cm, and Hardwood hammock from -96 cm to -63 cm. The interquartile ranges also shifted upwards for all communities, indicating a reduction in the variability of minimum water depths when dry.

<u>Maximum Water Depth:</u> Median maximum water depths for herbaceous and woody communities on SS93, increased after the restoration, with median values rising by 24 cm. Woody plant communities, including Bayhead tree and Hardwood hammock, experienced increases in median maximum water depth, from 38 cm to 62 cm and 16 cm to 41 cm, respectively (Fig, SS93.5, Tbl. SS93.4)

<u>Maximum Wet Event Length:</u> Median maximum length of wet events increased for most communities on SS93 after restoration (Fig, SS93.6, Tbl. SS93.5). Herbaceous communities increased by an average of 248 days. Bayhead shrub, Bayhead tree and Hardwood hammock saw an increase on median maximum wet event of 97, 122 and 284 days, respectively. Hardwood hammock's 75th percentile increased from 64 to 348 days. (Fig, SS93.6, Tbl. SS93.5)

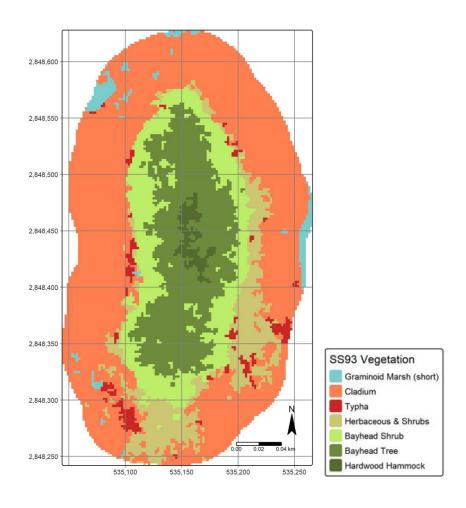


Figure \$\$93.1 Plant communities on \$\$593 Island and the surrounding marsh.

Table SS93.1 Class distribution on SS93 Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

SS93 Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0	0	-	0
Graminoid Marsh	0.14	2	-	3.1
Cladium	3.40	50.1	-	76.5
Typha	0.15	2.2	-	3.4
Herbaceous - Shrub Mix	0.76	11.1	-	17
Bayhead Shrub	0.99	14.6	42.4	-
Bayhead Tree	1.25	18.5	53.5	-
Hardwood Hammock Tree	0.10	1.4	4.1	-

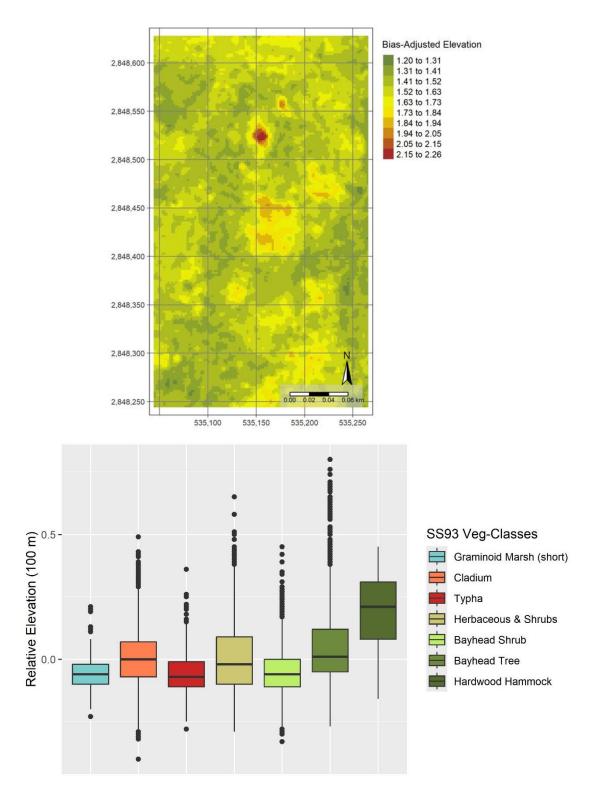


Figure SS93.2 Bias-adjusted elevation in meters for SS93 Island and the surrounding marsh (top). Boxplot of plant community relative elevation for SS93 Island and the surrounding marsh (bottom).

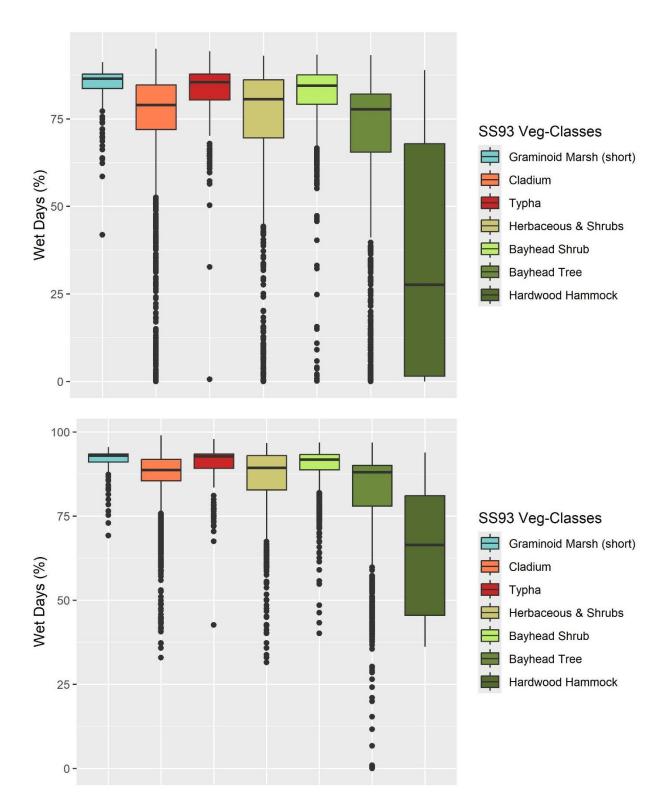


Figure SS93.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for SS93 Island.

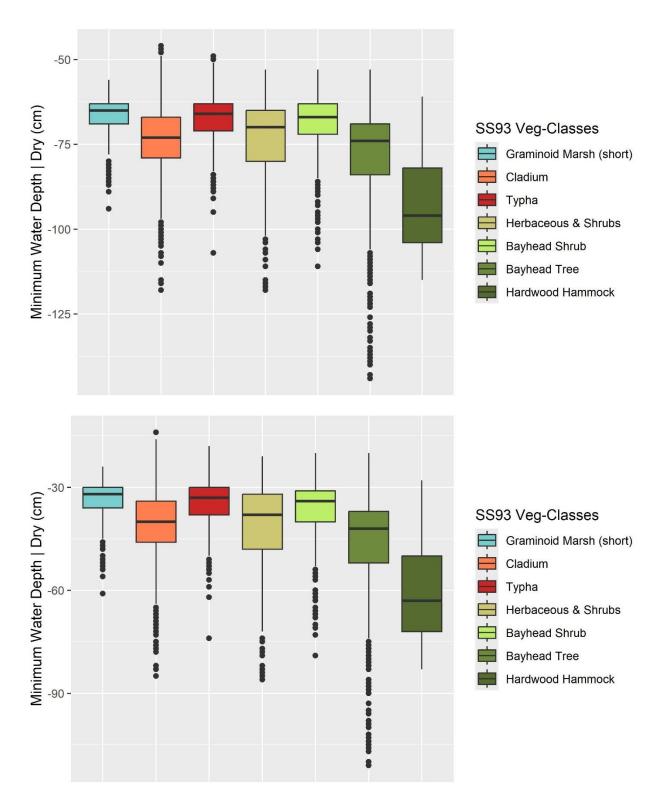


Figure SS93.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) preand (bottom) post-restoration periods for SS93 Island.

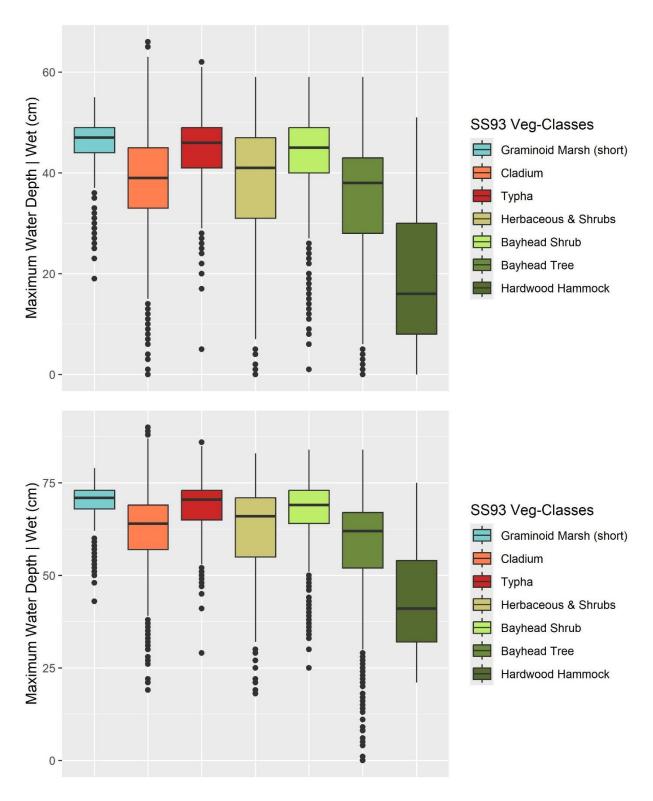


Figure SS93.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for SS93 Island.

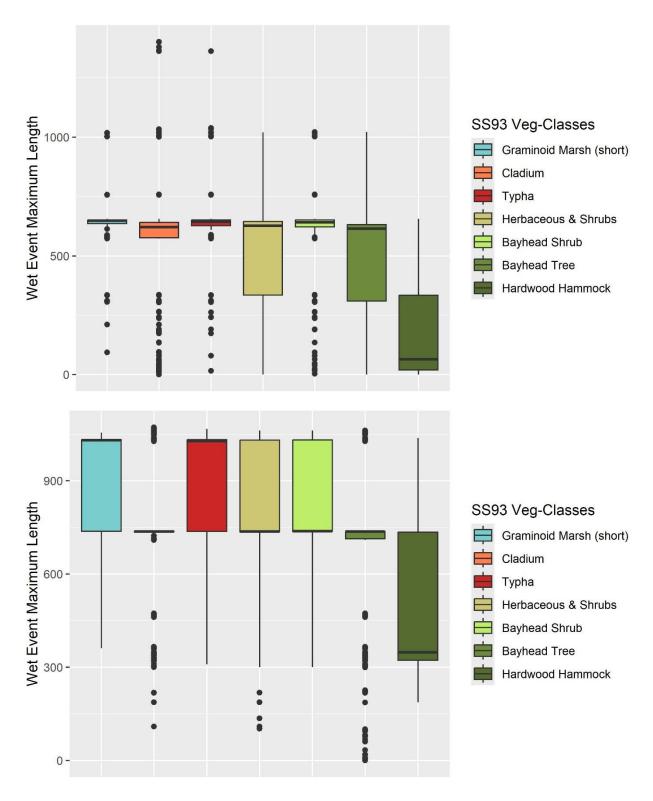


Figure SS93.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods SS93 Island.

Table SS93.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for SS93 Island.

			Pre-7					Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Graminoid Marsh (short)	41.9	83.7	86.5	87.8	91.2	69.2	91.1	93	93.5	95.5
Cladium	0	72	79	84.7	95	32.9	85.5	88.7	91.9	99
Typha	0.6	80.4	85.45	87.8	94.3	42.6	89.2	92.8	93.5	97.9
Herbaceous & Shrubs	0	69.6	80.6	86.2	93	31.5	82.8	89.4	93	96.7
Bayhead Shrub	0.1	79.2	84.5	87.6	93.3	40.1	88.8	91.8	93.35	96.9
Bayhead Tree	0	65.5	77.7	82.1	93.2	0	78	88.1	90.1	96.9
Hardwood Hammock	0	1.5	27.6	67.95	88.9	36.1	45.5	66.4	81.1	93.9

Table SS93.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for SS93 Island.

		P	re-7		Post-7				
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3	
Graminoid Marsh (short)	-94	-69	-65	-63	-61	-36	-32	-30	
Cladium	-118	-79	-73	-67	-85	-46	-40	-34	
Typha	-107	-71	-66	-63	-74	-38	-33	-30	
Herbaceous & Shrubs	-118	-80	-70	-65	-86	-48	-38	-32	
Bayhead Shrub	-111	-72	-67	-63	-79	-40	-34	-31	
Bayhead Tree	-144	-84	-74	-69	-111	-52	-42	-37	
Hardwood Hammock	-115	-104	-96	-82	-83	-72	-63	-50	

Table SS93.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for SS93 Island.

		Pre-	7			Post-	7	
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Graminoid Marsh (short)	44	47	49	55	68	71	73	79
Cladium	33	39	45	66	57	64	69	90
Typha	41	46	49	62	65	70.5	73	86
Herbaceous & Shrubs	31	41	47	59	55	66	71	83
Bayhead Shrub	40	45	49	59	64	69	73	84
Bayhead Tree	28	38	43	59	52	62	67	84
Hardwood Hammock	8	16	30	51	32	41	54	75

Table SS93.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for SS93 Island.

		Pre-7			Post-7	
Class	Q1	Median	Q3	Q1	Median	Q3
Graminoid Marsh (short)	636	648	651	738	1031	1033
Cladium	576	621	641	736	737	738
Typha	627	643	651	737	1028	1033
Herbaceous & Shrubs	335	627	645	736	737	1031
Bayhead Shrub	622	641	651	737	738	1032
Bayhead Tree	309	615	632	714	737	737
Hardwood Hammock	19	64	334	322	348	735

3.3.2.10 SS94

<u>Community Area and Percent Cover:</u> Plant communities on SS94 and surrounding marsh covered approximately 6.96 hectares. The dominant vegetation community was *Cladium*, which occupied 3.67 hectares (52.7%) of the total area and represented 90.5% of the non-woody vegetation. Bayhead shrub covered 1.42 hectares (20.5%) and had a woody core percentage of 60.1%. Bayhead tree vegetation occupied 0.87 hectares (12.5%) with a woody core percentage of 36.2%. The herbaceous-shrub mix accounted for 0.67 hectares (9.6%). Smaller areas included graminoid marsh at 0.20 hectares (2.8%), which comprised 7.6% of the non-woody vegetation, and *Typha* at 0.13 hectares (1.9%), representing 1.8% of the non-woody vegetation. Hardwood hammock was not present on SS94 (Fig. SS94.1, Table SS94.1).

<u>Relative Elevation:</u> Figure SS94.2 shows bias-adjusted relative elevation in meters for SS94. Bayhead tree occurred at the highest elevations, with a median around 0.08 m. Open marsh displayed the most restricted elevation range, centered around 0.00 m with minimal variation. Graminoid marsh (short) occupied slightly lower elevations with a median around -0.05, *Cladium* exhibited a median near -0.05 m, and *Typha* occurred at relatively low elevations at -0.10 m. Herbaceous and shrubs showed a median relative elevation near -0.03 m. Bayhead shrub was found at around -0.10 m and displayed substantial variation.

<u>Percent Wet:</u> Wet conditions on SS94 increased following the 2015 restoration. Open marsh, graminoid marsh, *Cladium*, and *Typha* increased in wet conditions by 13%, 8%, 9% and 6 %, respectively. Bayhead tree increased to 87.3% median wet days and retained the highest variability (IQR: 70.3-91.6%). Most communities displayed compressed IQRs post-restoration (Fig. SS94.3, Table SS94.2).

<u>Minimum Water Depth when Dry</u>: Minimum water depth during dry periods increased on SS94 across all vegetation communities, following the 2015 restoration, by approximately 33cm (Fig. SS94.4, Table SS94). After restoration, all communities maintained higher water depths: Bayhead shrub reached -32 cm (from -65 cm) and Bayhead tree -44 cm (from -76 cm). Post-restoration conditions showed reduced variability with compressed IQRs across most communities.

<u>Maximum Water Depth:</u> Maximum water depths increased on SS94 by approximately 25 cm on all plant communities following the 2015 restoration (Fig. SS94.5, Table SS94.4). Before restoration, median maximum depths ranged from 35 cm (open marsh) to 50 cm (*Typha*), with Bayhead tree showing the greatest variability (median 36 cm, IQR: 20-45 cm). After restoration, Bayhead shrub reached median maximum depths of 72 cm and Bayhead tree increased to 60 cm median depth. Post-restoration conditions displayed wider IQRs across most communities, indicating more variability.

<u>Maximum Wet Event Length:</u> Median wet event maximum lengths increased on SS94 across all vegetation communities following the 2015 restoration. Before restoration, median wet event lengths ranged from 584 days (open marsh) to 652 days (*Typha*), with Bayhead tree displaying extreme variability (median 587 days, IQR: 173-640 days). After restoration, wet event durations increased by 150-400 days across all communities and became more uniform. Bayhead tree

continued to show high variability (median 737 days, IQR: 363-738 days) (Fig. SS94.6, Table SS94.5).

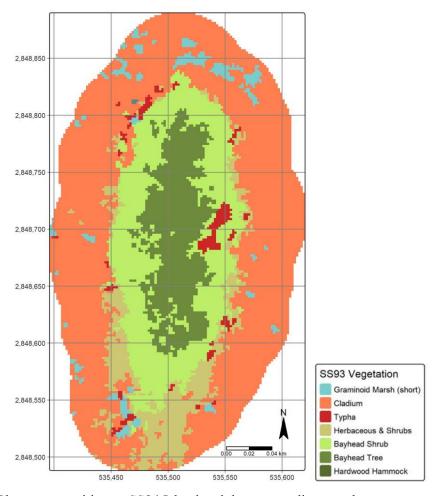


Figure SS94.1 Plant communities on SS94 Island and the surrounding marsh.

Table SS94.1Class distribution on SS94 Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

SS94 Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.00	0	-	0
Graminoid Marsh	0.20	2.8	-	7.6
Cladium	3.67	52.7	-	90.5
Typha	0.13	1.9	-	1.8
Herbaceous - Shrub Mix	0.67	9.6	-	-
Bayhead Shrub	1.42	20.5	60.1	-
Bayhead Tree	0.87	12.5	36.2	-

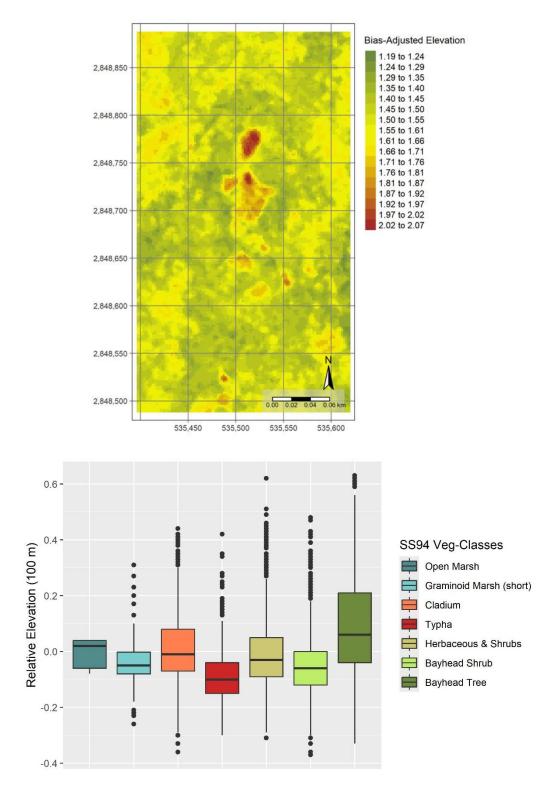


Figure SS94.2 Bias-adjusted elevation in meters for SS94 Island and the surrounding marsh (top). Boxplot of plant community relative elevation for SS94 Island and the surrounding marsh (bottom).

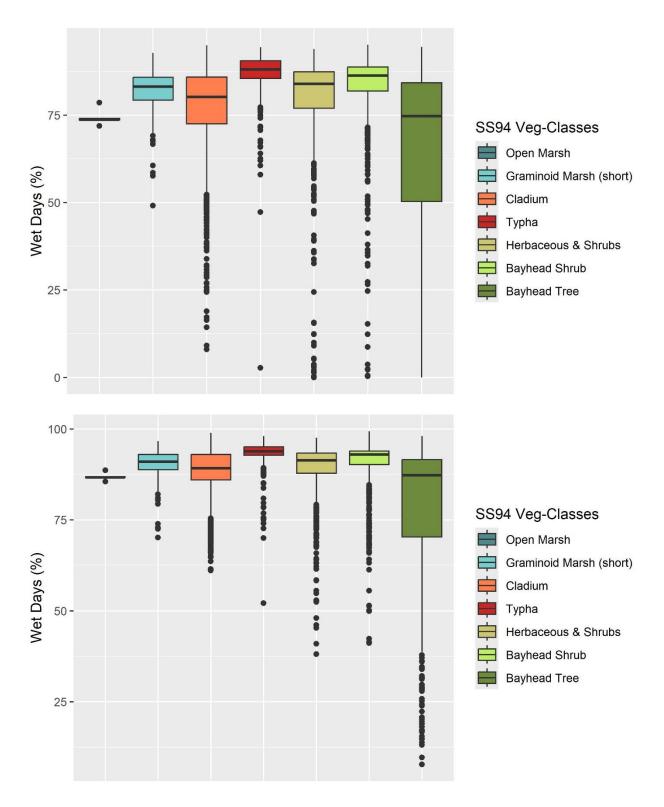


Figure SS94.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for SS94 Island.

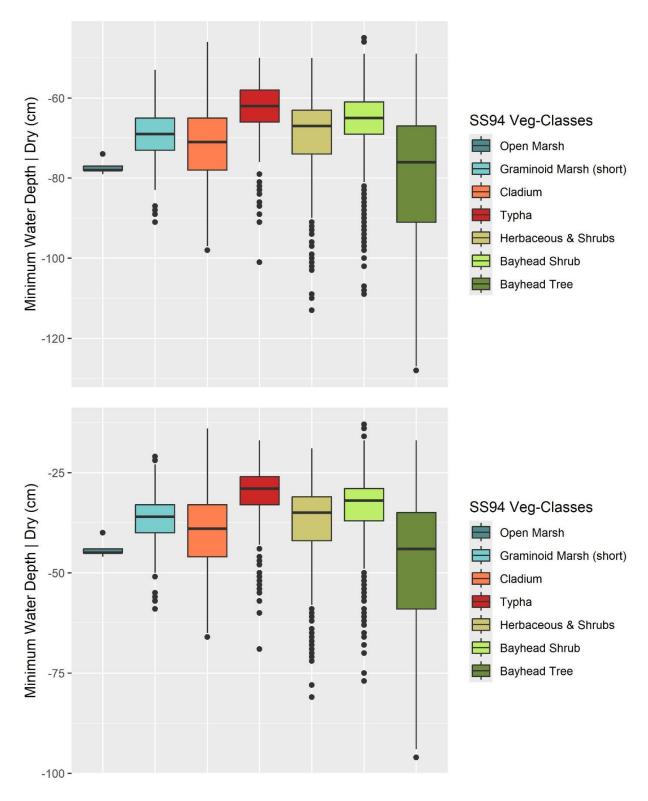


Figure SS94.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) preand (bottom) post-restoration periods for SS94 Island.

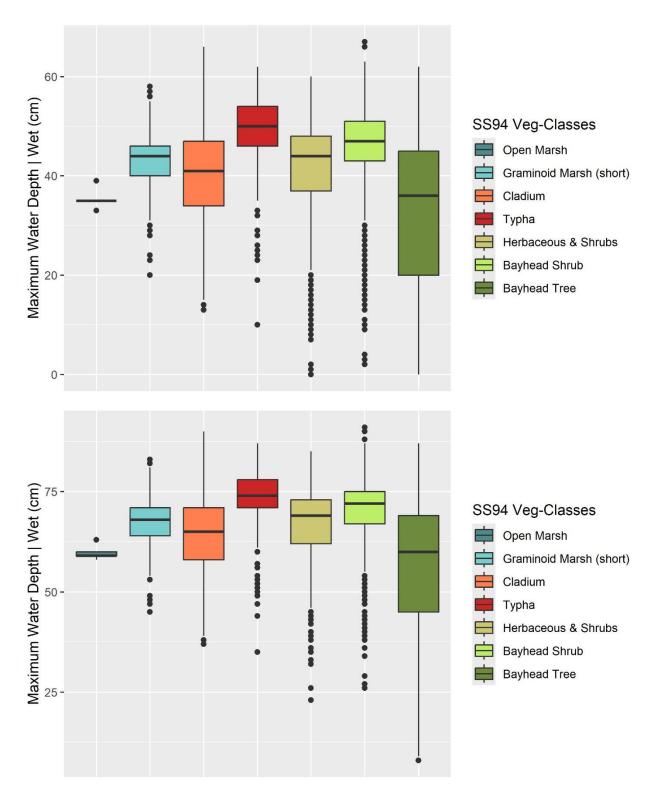


Figure SS94.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for SS94 Island.

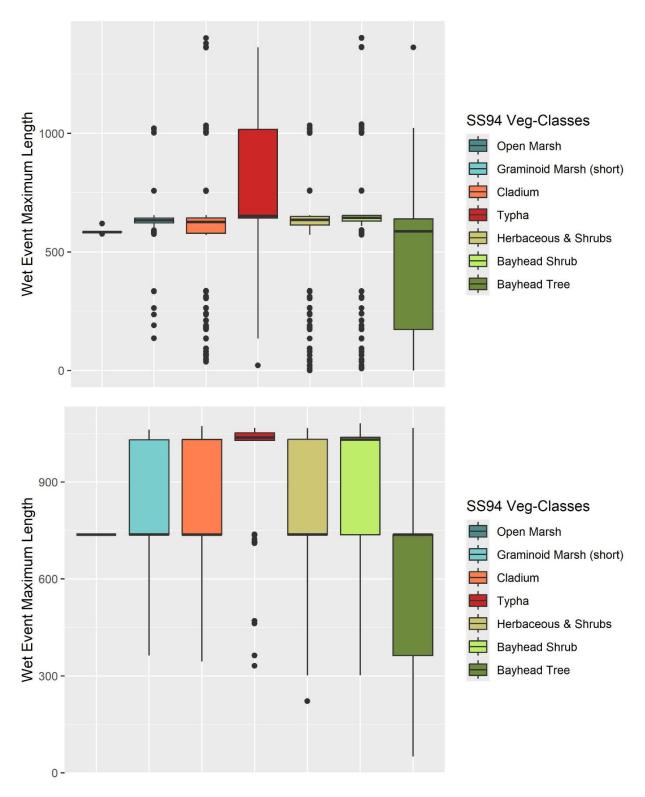


Figure SS94.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods SS94 Island.

Table SS94.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for SS94 Island.

			Pre-7					Post-7		
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	71.9	73.7	73.7	74.1	78.6	85.5	86.7	86.7	86.9	88.6
Graminoid Marsh (short)	49.1	79.3	83.2	85.88	92.8	70.1	88.8	91	93	96.6
Cladium	8	72.5	80.2	85.9	95	61.1	86	89.2	93	98.9
Typha	2.7	85.5	88.1	90.6	94.4	52.1	92.8	93.8	95.1	98
Herbaceous & Shrubs	0	77.03	84	87.4	93.9	38.1	87.8	91.4	93.4	97.5
Bayhead Shrub	0.3	81.9	86.3	88.8	95.1	41.1	90.2	93	93.9	99.3
Bayhead Tree	0	50.3	74.7	84.3	94.5	7.8	70.3	87.3	91.6	98

Table SS94.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for SS94 Island.

	Pre-7					Post-7				
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3		
Open Marsh	-79	-78	-78	-77	-46	-45	-45	-44		
Graminoid Marsh (short)	-91	-73	-69	-65	-59	-40	-36	-33		
Cladium	-98	-78	-71	-65	-66	-46	-39	-33		
Typha	-101	-66	-62	-58	-69	-33	-29	-26		
Herbaceous & Shrubs	-113	-74	-67	-63	-81	-42	-35	-31		
Bayhead Shrub	-109	-69	-65	-61	-77	-37	-32	-29		
Bayhead Tree	-128	-91	-76	-67	-96	-59	-44	-35		

Table SS94.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for SS94 Island.

	Pre-7				Post-7			
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max
Open Marsh	35	35	35	39	59	59	60	63
Graminoid Marsh (short)	40	44	46	58	64	68	71	83
Cladium	34	41	47	66	58	65	71	90
Typha	46	50	54	62	71	74	78	87
Herbaceous & Shrubs	37	44	48	60	62	69	73	85
Bayhead Shrub	43	47	51	67	67	72	75	91
Bayhead Tree	20	36	45	62	45	60	69	87

Table SS94.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for SS94 Island.

	Pre-7			Post-7			
Class	Q1	Median	Q3	Q1	Median	Q3	
Open Marsh	584	584	585	737	737	737	
Graminoid Marsh (short)	622.5	634	643	737	738	1030.75	
Cladium	579	626	644	737	737	1031	
Typha	643	652	1017	1028	1037	1052	
Herbaceous & Shrubs	613	636	650	737	738	1032	
Bayhead Shrub	631	644	654	737	1031	1038	
Bayhead Tree	173	587	640	363	737	738	

3.3.2.11 Vulture

<u>Community Area and Percent Cover:</u> Vegetation class distribution on Vulture Island covered approximately 11.53 hectares. The vegetation was dominated by *Cladium*, which occupied 3.09 hectares (26.8%) of the total area and comprised 47.9% of the non-woody vegetation. Bayhead shrub was the second most extensive community, covering 2.98 hectares (25.8%) with a woody core percentage of 58.6%. Bayhead tree occupied 1.67 hectares (14.5%) with a woody core percentage of 32.9%. The herbaceous-shrub mix covered 1.53 hectares (13.3%) and represented 23.8% of the non-woody vegetation. Hardwood hammock tree was the least extensive community, covering 0.43 hectares (3.8%) with a woody core percentage of 8.5% (Fig. V.1, Tbl. V.1).

<u>Relative Elevation:</u> Figure V.2 shows Hardwood hammock occupying the highest elevations on Vulture with a median around 0.70 m. Open marsh and graminoid marsh (short) occurred at the lowest elevations, both centered around -0.05 to 0.00 m with very narrow elevation ranges. *Typha* displayed the lowest median elevation at approximately -0.15 m. *Cladium* showed a median near 0.00 m and herbaceous and shrubs occupied slightly higher elevations with a median around 0.05 m. Bayhead shrub had a median near -0.05 m, Bayhead tree exhibited the greatest elevation range among all communities, with a median around 0.00 m (Fig. V.2)

<u>Percent Wet:</u> Wet conditions on plant communities on Vulture increased slightly (1 - 2%) following the 2015 restoration. The most notable increase occurred in Bayhead tree, which increased to 75% median wet days from 72.8 %. Hardwood hammock remained predominantly dry but showed an increase in its 75th percentile from 0% to 2.2%. (Fig. V.3, Table V.2)

<u>Minimum Water Depth when Dry</u>: Median minimum water depth during dry periods increased on Vulture by approximately 10-11 cm across all vegetation communities following the 2015 restoration. Before restoration, Hardwood hammock experienced the deepest minimum water depths at -141 cm median depth. After restoration, Bayhead shrub increased from -46 cm to -36 cm, Bayhead tree from -64 cm to -53 cm and Hardwood hammock from -141 to -131 cm (Fig. V.4, Table V.3).

<u>Maximum Water Depth:</u> Median maximum water depths for Vulture increased by approximately 14 cm for most plant communities, except for Hardwood hammock which increased by 5 cm. Prerestoration median depths ranged from 60 cm in Bayhead tree to 80 cm in *Typha*, with most plant communities experiencing depths between 66-77 cm. Hardwood hammock areas remained dry with no measurable median value. Post-restoration, medians ranged from 74 cm in Bayhead tree to 94 cm in *Typha*. Hardwood hammock's 75th percentile increased from 0 to 5 cm (Fig. V.5, Table V.4).

<u>Maximum Wet Event Length:</u> Median wet event maximum lengths for Vulture island converged following the 2015 restoration. Pre-restoration median durations varied from 349 days in Bayhead tree communities to 761.5 days in Typha communities, with most marsh and transitional communities ranging between 604-752 days. Hardwood hammock areas remained completely dry. Post-restoration, nearly all vegetation communities converged to a uniform median of 737 days, except Bayhead tree at 499 days and Hardwood hammock at 27 days (Fig. V.6, Table V.5).

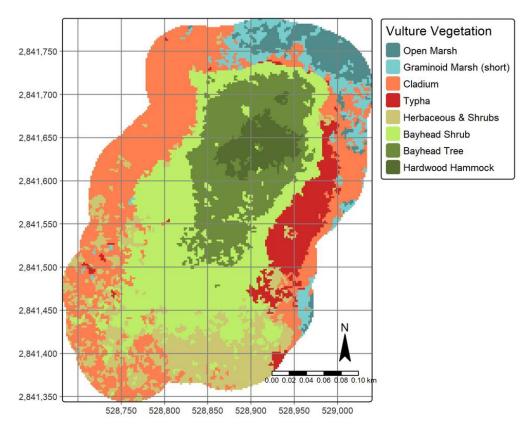


Figure V.1 Plant communities on Vulture Island and the surrounding marsh.

Table V.1 Class distribution on Vulture Island. Area in hectares (ha), and percent for the entire 100 m buffered three-class woody core area. Woody Core 3 (%) = class percentages considering only the three woody classes, Non-Woody (%) = class percentages considering only non-woody classes.

Vulture Classes	Area (ha)	Percent	Woody Core 3 (%)	Non-Woody (%)
Open Marsh	0.51	4.4	-	7.9
Graminoid Marsh	0.57	5	-	8.9
Cladium	3.09	26.8	-	47.9
Typha	0.75	6.5	-	11.6
Herbaceous - Shrub Mix	1.53	13.3	-	23.8
Bayhead Shrub	2.98	25.8	58.6	-
Bayhead Tree	1.67	14.5	32.9	-
Hardwood Hammock Tree	0.43	3.8	8.5	-

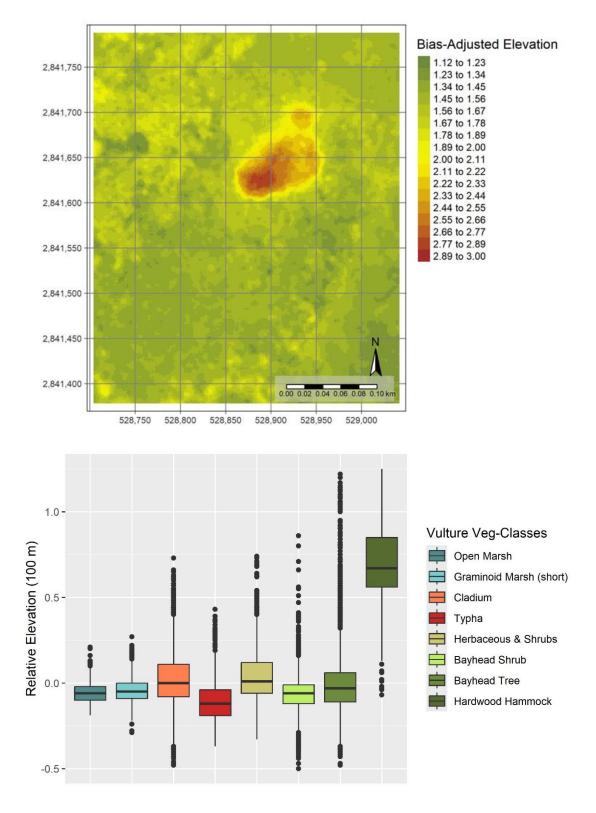


Figure V.2 Bias-adjusted elevation in meters for Vulture Island and the surrounding marsh (top). Boxplot of plant community relative elevation for Vulture Island and the surrounding marsh (bottom).

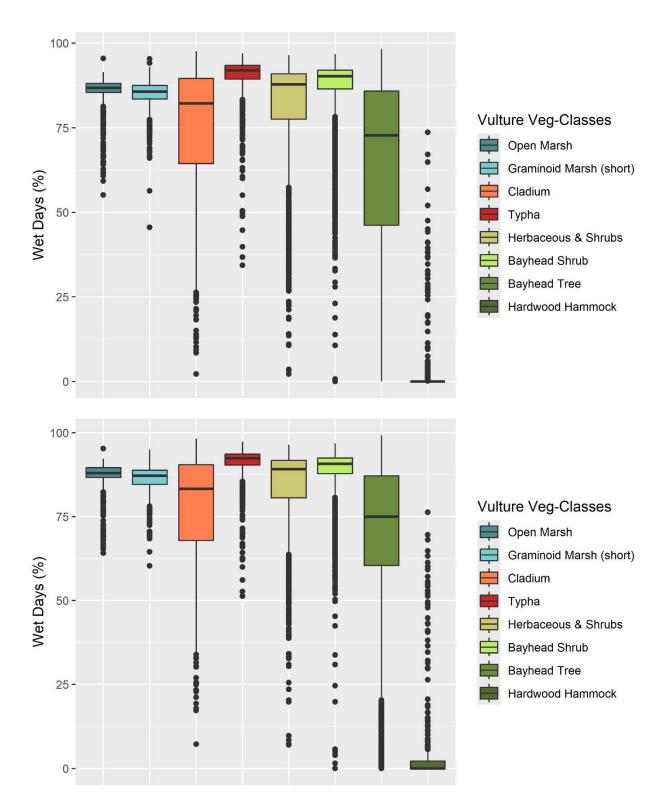


Figure V.3 Boxplots for percent wet days by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Vulture Island.

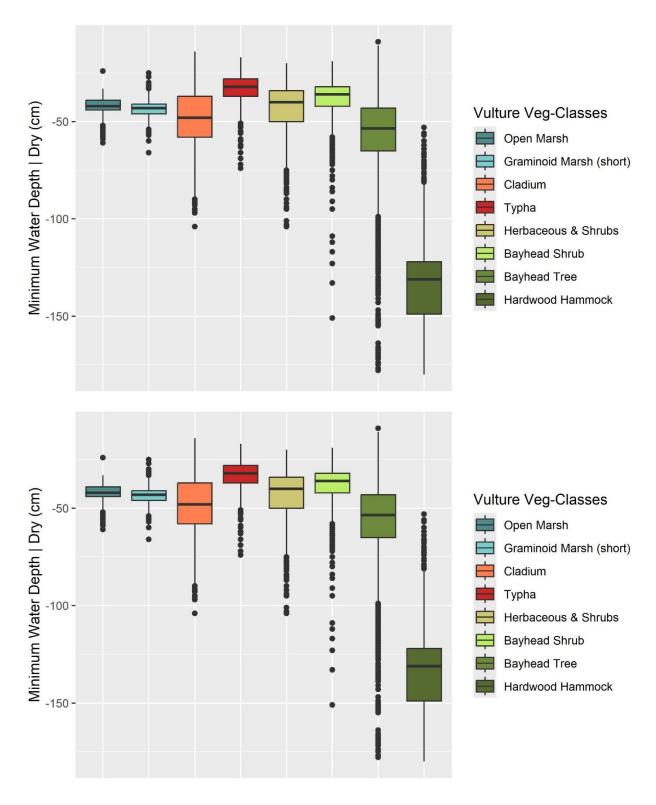


Figure V.4 Boxplots for minimum water depth when dry by plant community for 7-year (top) pre- and (bottom) post-restoration periods for Vulture Island.

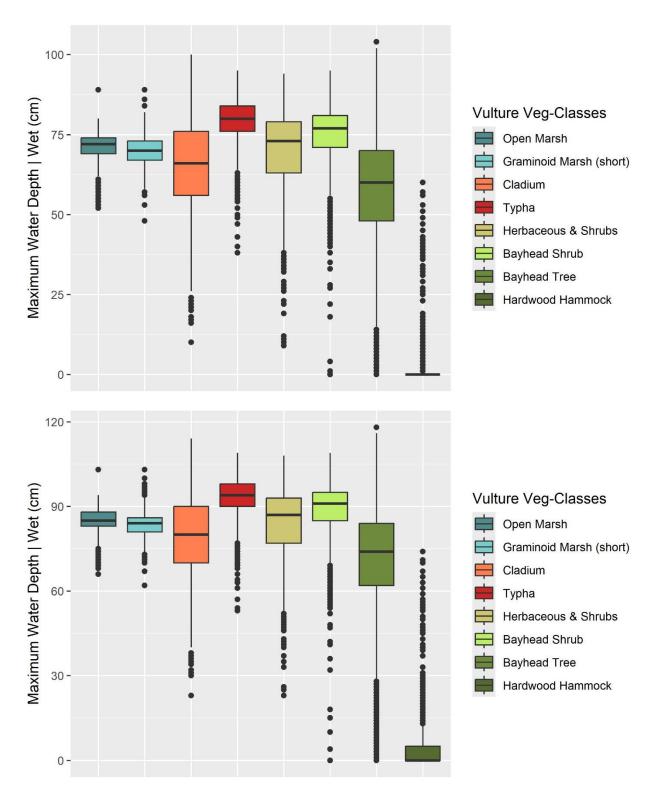


Figure V.5 Boxplots of maximum water depth when wet (cm) for 7-year (top) pre- and (bottom) post-restoration periods for Vulture Island.

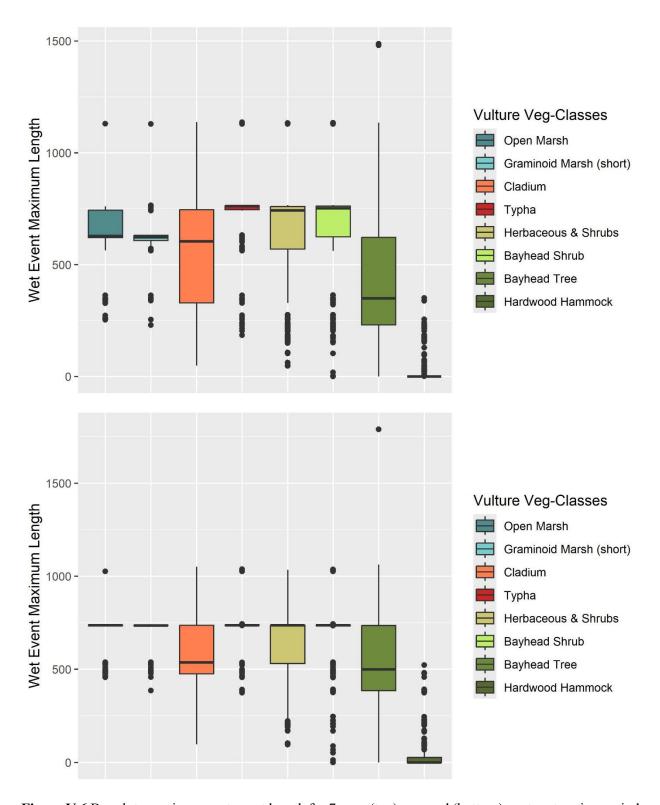


Figure V.6 Boxplots maximum wet event length for 7-year (top) pre- and (bottom) post-restoration periods Vulture Island.

Table V.2 Class percent wet days by plant community for 7-year pre- and post-restoration periods for Vulture Island.

	Pre-7				Post-7					
Class	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
Open Marsh	55.1	85.4	86.85	88.1	95.5	64.1	86.7	88	89.6	95.3
Graminoid Marsh (short)	45.5	83.5	85.7	87.5	95.3	60.3	84.6	87.2	88.8	95
Cladium	2.2	64.4	82.2	89.6	97.6	7.2	67.9	83.3	90.5	98.2
Typha	34.3	89.4	91.9	93.43	97	51.3	90.38	92.4	93.6	97.3
Herbaceous & Shrubs	2.2	77.5	87.8	90.9	96.5	7	80.6	89.2	91.8	96.4
Bayhead Shrub	0	86.5	90.2	92	96.8	0	87.8	90.8	92.5	96.8
Bayhead Tree	0	46.18	72.8	85.8	98.3	0	60.5	75	87.2	99.2
Hardwood Hammock	0	0	0	0	73.6	0	0	0	2.2	76.3

Table V.3 Minimum water depth when dry (cm) by plant community for 7-year pre- and post-restoration periods for Vulture Island.

		Pre-7			Post-7			
Class	Min	Q1	Median	Q3	Min	Q1	Median	Q3
Open Marsh	-71	-54	-52	-49	-61	-44	-42	-39
Graminoid Marsh (short)	-76	-56	-54	-51	-66	-46	-43	-41
Cladium	-113	-68	-58	-47	-104	-58	-48	-37
Typha	-84	-47	-42	-38.75	-74	-37	-32	-28
Herbaceous & Shrubs	-114	-60	-50	-44	-104	-50	-40	-34
Bayhead Shrub	-161	-52	-46	-42	-151	-42	-36	-32
Bayhead Tree	-188	-75	-64	-53	-178	-65	-53.5	-43
Hardwood Hammock	-190	-159	-141	-132	-180	-149	-131	-122

Table V.4 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Vulture Island.

		Pre-7				Post-7			
Class	Q1	Median	Q3	Max	Q1	Median	Q3	Max	
Open Marsh	69	72	74	89	83	85	88	103	
Graminoid Marsh (short)	67	70	73	89	81	84	86	103	
Cladium	56	66	76	100	70	80	90	114	
Typha	76	80	84	95	90	94	98	109	
Herbaceous & Shrubs	63	73	79	94	77	87	93	108	
Bayhead Shrub	71	77	81	95	85	91	95	109	
Bayhead Tree	48	60	70	104	62	74	84	118	
Hardwood Hammock	0	0	0	60	0	0	5	74	

Table V.5 Maximum water depth when wet (cm) for 7-year pre- and post-restoration periods for Vulture Island.

Didirai						
		Pre-7			Post-7	•
Class	Q1	Median	Q3	Q1	Median	Q3
Open Marsh	621	627	743	736	737	737
Graminoid Marsh (short)	608	622	631	736	736	737
Cladium	329	604	745	476	537	737
Typha	745	761.5	764	737	737	738
Herbaceous & Shrubs	569	742	760	531	737	737
Bayhead Shrub	624	752	762	736	737	737
Bayhead Tree	230	349	622	386	499	736
Hardwood Hammock	0	0	0	0	0	27

3.3.3 Accuracy of ASP Point Cloud DSM

The estimated bias for the ASP point cloud in reference to the 2017 DSM was 9.93 ft. This bias was subtracted from each Z value of the ASP point cloud before ASP point clouds were converted to DSMs. Interpolation of the LiDAR and ASP point clouds produced continuous surface models that represented the top layer (or DSMs) of the vegetation in reference to NAVD 88 (ft). The RMSE for the point to raster algorithm was lowest at a resolution of 9 ft (Table 3.9). Discrepancies between the predicted and reference data were 3.41 ft at the highest spatial resolution of 3 ft and lowest at 3.19 ft at 9 ft resolution (Table 3.9). The most accurate surface model at 9 ft resolution is presented in Figure 3.3.

Table 3.9 The RMSE values of the 'point2raster' (p2r) interpolation algorithms for spatial resolutions ranging from 3 ft to 12 ft. Subcircle parameter was set to 3 ft for all iterations. RMSE are reported in survey feet.

Spatial Resolution	3 ft	6 ft	9 ft	12 ft
Point to Raster RMSE (ft)	3.41	3.27	3.19	3.24

The vertical bias of the ASP derived DSM when compared to the 2015 LiDAR data DSM at 9 ft resolution displays a bi-modal error distribution with a peak at less than -1 foot and one at \sim -7 feet (Figure 3.2 (f)). Most of the island surrounding marsh vegetation was overestimated for the ASP derived DSM (tan shades in Figure 3.3). Contrary, surface elevation of the woody vegetation canopy on the island, including Hardwood hammock and Bayhead forest in the tree island head, and the adjacent swamp areas in the southern tail of the island of Chekika was generally underestimated by the ASP DSM (green shades in Figure 3.3).

When focusing only on the positive and negative bias estimates for the higher elevations of the island that contain the taller trees of Hardwood hammock and Bayhead forest areas (Figure 3.3 (b) to (e)), the area with under- and overestimation of canopy elevation is evenly distributed indicating no general bias in that part of the island. The largest errors are also encountered in this region with high underestimations juxtaposed to very high overestimation, suggesting that the horizontal alignment of the two-point clouds might need adjustment or that the shadows captured by the aerial photography interfere with the accurate tie point generation that are still relevant at the lower spatial resolution of DSMs.

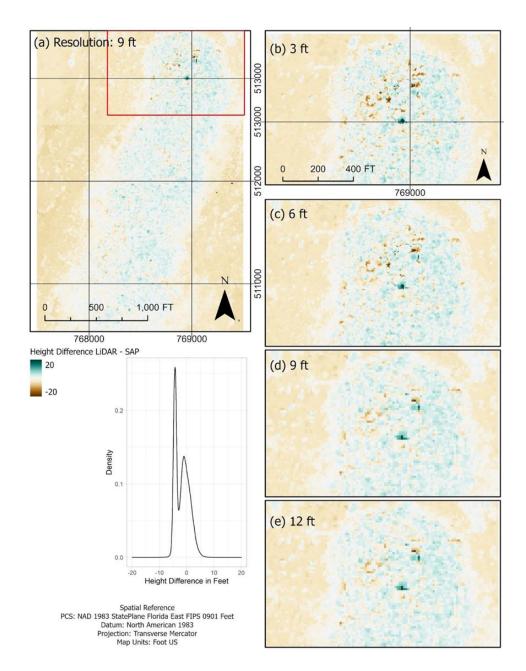


Figure 3.3 Plots of height differences between LiDAR point cloud data and ASP derived Digital Surface Models generated at (a) 9 ft for the whole study area. In (b) - (e) the high canopy area of the Hardwood hammock and Bayhead forest area is featured at resolutions of (b) 3 ft, (c) 6 ft, (d) 9ft and (e) 12 ft resolution. The density plot (f) indicates bias and height difference distribution across the area in (a).

Aerial photography can provide a reliable source of height information for detection of historical vegetation height (Eitzel et al., 2016). Our results show that the bias removal and estimating elevation for larger ground units (decreasing spatial resolution) lead to a 3.2 ft RMSE between LiDAR derived reference DSM and ASP point cloud derived DSM. The issues that will be explored further reduce bias and error, and to further investigate their spatial patterns and

correlation with plant communities and to expand the method to other aerial photography of earlier years include the following:

- 1. Vertical alignment of point cloud tiles in the point cloud generation process is currently not very effective. Figure 3.4 (left panel) demonstrates some of the vertical alignment problems between ASP point cloud tiles that lead to abrupt bias reduction or increase along tile boundaries. Aligning the tiles vertically, by modeling the differences between tiles from overlap areas will be used to model and reduce local bias and to adjust all tiles to a common vertical (between tile) and aligned reference frame. Global bias reduction that is delineated from invariant features such as man-made structures can then lead to a global reduction in bias across the tile mosaic, and very likely result in a more random residual error distribution across the study area.
- 2. In some areas, points were generated in groups of three with each point having a different value, but the pattern of value differences being systematic (Figure 3.4 (b-e)). It is uncertain at the moment why points were generated in groups of three at such a close distance and why the pattern is systematic. Once we determine the reason, we will attempt to systematically remove the error sources that contribute to that high local variability in Z values.

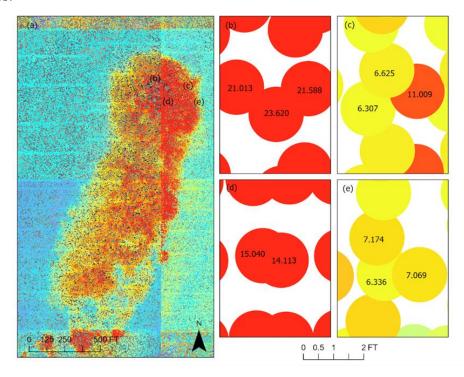


Figure 3.4 Point cloud data generated using 2012 digital aerial photography (a). Strong contrast of point heights along tile boundaries indicates vertical alignment and registration errors. Groups of systematic point triplets and pairs generated in the Hardwood hammock and Bayhead area (b-e) (point z-value in NAVD 88 feet).

3. To better understand the vegetation introduced or specific source of error and ultimately reduce it, we will explore the error distribution across tree island and surrounding marsh

- communities, and attempt to develop point cloud inherent metrics to identify and reduce erroneous points.
- 4. As expected, RMSE decreased with a decrease in spatial resolutions since the number of points considered for each pixel estimation increases and the local heterogeneity in differences, caused by minor mis-registration of point clouds, gets smoothed over. The large data gaps that exist in tall tree areas and result from not finding tie-points need to be filled in. The algorithm we use to generate DSMs has several interpolation methods that can be applied to fill those gaps. We are in the process of testing different algorithms and their effects on errors for the data gap regions. The methods and their characteristics are listed in Table 3.10. Most likely, algorithms like MBA will have a higher accuracy because non-convex interpolators can predict values below or above the range of the input values and can make up for missing high values when other interpolators underestimate the surface elevation. Ridges in the Hardwood hammock areas of tree islands would be predicted even if these extremes are not included in the input data (Watson & Philip, 1985). Aguilar et al. (2005) tested the effects of IDW, thin plate and natural cubic spline interpolation algorithms on the accuracy of height values in DTMs. The IDW algorithm performed worse in rugged areas than the others because of its inability to model local maxima and minima. Erdogan (2009) found that the IDW interpolator produced higher errors closer to the top of the hill. Spline interpolators create a surface that minimizes the curvature generating a smoother surface, making them ideal for creating surface models in areas with slight variation in the terrain. Further research is required to understand if the accuracy varies depending on the vegetation community.
- 5. We also attempted to generate point cloud data from 1973 scanned ASP to estimate vegetation height for Chekika island (Figure 3.5). Point clouds, when compared to the 2012 digital aerial photography derived point cloud shows the strong contrast in point cloud density and its patchiness. The reason for the gaps is most likely image quality that affects automated tie-point detection. To be able to extend the DSM generation method to delineate vegetation height from older stereo aerial photography, we need to explore contrast enhancement methods that allow for detection of more reliable tie points between photo pairs to extract dense point clouds.

Table 3.10 General characteristics of future interpolation methods for filling no data gaps of large point cloud gaps.

	Acronym	Scale of Analysis	Smoothing	Shape
Inverse-distance weighting	IDW	Local	Exact	Convex
Multilevel B-Spline	MBA	Global	Approximate	Non-convex
Ordinary Kriging	OK	Global	Approximate	Convex

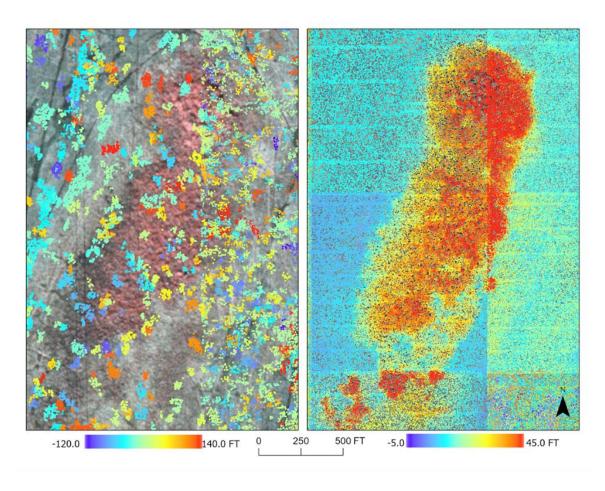


Figure 3.5 Point cloud raw data generated from 1973 scanned aerial photography (left) and 2012 digital aerial photography (right).

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