Final Report

Surface-groundwater interactions in Everglades tree islands

MAP Number: 3.1.3.6.
Agency: Florida International University
Principal Investigator: Tiffany Troxler, 305-348-1453, troxlert@fiu.edu
Point of Contact: Al Cofrancesco; al.f.cofrancesco@usace.army.mil
Agreement: Cooperative Agreement #W912HZ-10-2-004

February 29, 2012

Principal Investigator: Tiffany Troxler
Southeast Environmental Research Center
University Park, OE 148
Florida International University
Miami, FL 33199 USA
Tel: 305-348-1576
Fax: 305-348-4096
troxlert@fiu.edu

Collaborator: Leonel Sternberg
Department of Biology
University of Miami
Coral Gables, FL 3312, USA
Tel: 305-284-6436,
Fax: 305-284-3039,
l.sternberg@miami.edu

Co-Principal Investigator: Jennifer Richards
Southeast Environmental Research Center
University Park, OE 148
Florida International University
Miami, FL 33199 USA
Tel: 305-348-3102
Fax: 305-348-4096
richards@fiu.edu

Collaborator: Paul Wetzel
Department of Biological Sciences
Clark Science Center
Smith College
Northampton, Massachusetts 01063 USA
Tel: 413-268-3115
Fax: 413-585-3786
pwetzel@smith.edu

Collaborator: Vic Engel
South Florida Natural Resources Center
Everglades National Park
Homestead, FL. 33030
Tel: 305-224-4237
Fax: 305-224-4147
vic_engel@nps.gov

Collaborator: Carlos Coronado
South Florida Water Management District
Everglades Division
3301 Gun Club Road
West Palm Beach Florida, 33406, USA
Tel: 561-686-8800 ext. 4547
ccoron@sfwmd.gov

II. EXECUTIVE SUMMARY

In the Everglades, tree islands are considered characteristic of the ecological "health" of the landscape. Phosphorus (P) levels in upland tree island soils are >100 times higher than P in adjacent marsh soils. Tree islands are hypothesized to be an active sink of P in the landscape contributing to the P balance of Everglades slough wetlands. This project was developed to compare hydraulic and hydrogeochemical patterns at multiple temporal and spatial scales of four Everglades tree islands in the Water Conservation Areas (WCA) and in Everglades National Park (ENP): wet, intact (3AS3-WCA3A); wet, degraded (Ghost Island-WCA3A); dry, intact (Satin Leaf-ENP); and dry, degraded (Twin Heads-WCA3B). Of primary concern is maintaining tree island soil P to prevent P enrichment of local marsh communities. Hydraulic and geochemical properties are key to understanding how the structure and function of tree islands can be maintained and restored. In this project, we related tree island community structure, hydrology and hydrogeochemistry to identify performance measures and refine monitoring of tree island function.

A proposed model for accumulation of tree island phosphorus, the focused nutrient redistribution (FNR) hypothesis suggests that among other mechanisms, evapotranspirational pumping (ET; indicated by daytime drawdown of the tree island soil water table) and the concentration of chloride (Cl) ions (indicating plant-water interactions that build ionic strength and promote mineral soil stability) are characteristics of "healthy" tree islands. This study tested that hypothesis by monitoring the soil water table temporal pattern and major ion concentrations on two "healthy" tree islands and two degraded tree islands. In each pair, we studied tree islands that were subject to wetter and drier hydrologic conditions. In each sampling, we also monitored isotopic composition that related water sources (soil water, surface water/groundwater) to water use by tree island plants and characterized soil P concentrations in three of four the tree islands. Our results showed that the diurnal patterns of ET do not differ between "healthy" and degraded islands. However, the seasonal duration of ET was lower on a tree islands degraded by overflooding. This coincided with low Cl concentrations and stem/source water isotopic composition illustrating weak differentiation of water use among communities. High variability in ionic strength of soil water in the P-rich High Head of the overflooded island was strongly correlated with high variability in total dissolved P concentrations. On a dry degraded island (Twin Heads), the duration of ET was longer than healthy and overflooded islands but Cl concentrations were also low. Stem/source water isotopic composition indicated weak differentiation of water use among communities except for the WH. These results further indicated that: 1) higher ion accumulation associated with mineral precipitation and potential for mineral soil stability in the wet, intact island, 2) high soil water P concentrations associated with mineral dissolution in the wet, degraded island and 3) a decoupling of plant-water interactions in the dry, degraded island. Plant stem/source water isotopic composition provided corroborating evidence.

Thus, our project demonstrates that ET, soil water dissolved P and ion concentrations of plant stems and water sources are key indicators of healthy tree island function, but also provided new information on how these parameters could be applied and monitored as performance measures. Future monitoring should: 1) focus sampling on

the High Head, Wet Head and Marsh communities and 2) reconfigure the study design to span a greater range in hydrologic conditions and degradation within the Water Conservation Areas or northern Shark River Slough (i.e. footprint of Tamiami Trail rehydration).

III. TABLE OF CONTENTS

IV. LIST OF FIGURES

V. LIST OF TABLES

VI. BACKGROUND/INTRODUCTION

The Water Resources Development Act (WRDA) of 2000 authorized the Comprehensive Everglades Restoration Plan (CERP) as a framework for modifications and operational changes to the Central and Southern Florida Project needed to restore the South Florida ecosystem. Provisions within WRDA 2000 provide for specific authorization for an adaptive assessment and monitoring program. A CERP Monitoring and Assessment Plan (MAP) (RECOVER 2004, 2006) has been developed as the primary tool to assess the system-wide performance of the CERP by the Restoration Coordination and Verification (RECOVER) program. The MAP presents the monitoring and supporting research needed to measure the responses of the South Florida ecosystem to CERP implementation.

The MAP also presents system-wide performance measures representative of the natural and human systems found in South Florida that will be evaluated to help determine CERP success. These system-wide performance measures address the responses of the South Florida ecosystem that the CERP is explicitly designed to improve, correct, or otherwise directly affect. The Development and Application of Comprehensive Everglades Restoration Plan System-wide Performance Measures (RECOVER 2007) provides the scientific, technical, and legal basis for the performance measures.

Generally, the Cooperative Agreement (CA) under which this project was implemented was intended to support four broad objectives of the MAP:

- Establish pre-CERP reference conditions and variability for each performance measure
- Determine the status and trends of the performance measures

- Detect unexpected responses of the ecosystem to changes in stressors resulting from CERP activities
- Support scientific investigations designed to increase ecosystem understanding, cause-and-effect relationships, and interpret unanticipated results

This research addresses the Greater Everglades Module: MAP I, Activity 3.1.3.6 and MAP II, Section 9.2.3 Integrated Hydrology and Water Quality. This work seeks to improve our understanding of tree island formation and persistence, and builds on the results of earlier projects funded through the MAP. The previously-funded projects include “Monitoring of tree island condition in the southern Everglades” (PIs Mike Ross and Steve Oberbauer, funded through 2010), “Tree Island Function in Relation to Marsh Hydrology” (PI Leonel Sternberg, Univ. of Miami, which expired in 2009), and a project entitled “Tree island stage duration and the measurement of water depth on tree islands located in WCA 3A and 3B” (PI Carlos Coronado) jointly funded by the SFWMD Everglades Division. The ultimate goal is to link results from these previous MAP projects and the project described herein to develop a comprehensive conceptual model that will provide both evaluation and assessment tools for CERP or other system-wide programs for assessment.

Tree islands of the freshwater Everglades are rare upland habitat that support numerous species (including wading birds) and which hold tremendous cultural value for several CERP stakeholder groups. Roughly half of the original tree island areal extent in WCA 2, WCA 3, and ENP has been lost due to stressors associated with hydrologic management, including fire. The loss of islands is not equally distributed. Some areas have lost more than 90% of the original tree island aerial extent, while others areas exhibit significantly less decline. However, in all areas tree islands are subject to an ever-increasing list of stressors, including invasive exotic species such as *Lygodium*. Thus, the preservation of the remaining tree islands and the restoration of the lost acreage is a prime objective of CERP. Information on the mechanisms which cause tree islands to form and to persist is needed to guide the development of tree island performance measures and to assess the effects of CERP on these features.

Tree islands are characterized by very high soil phosphorus (P) concentrations in the otherwise oligotrophic Everglades, and this leads to several hypotheses regarding their functioning. Wetzel et al. (2010) proposed the Focused Nutrient Redistribution (FNR) model of tree island biogeochemistry, which suggests that patches of woody vegetation alter local biogeochemical cycling. According to the FNR model, tree islands concentrate resources (especially P) through a combination of evapotranspirational pumping of surface and groundwater (McCarthy and Ellery 1994; Ross et al. 2006; Rietkerk et al. 2004), dry deposition (Weathers et al. 2001; Krah et al. 2004), and deposition of animal bones and feces under trees (Burton et al. 1979, Coultas et al. 2008, Frederick and Powell 1994, Lund 1957, Tomassen et al. 2005). Yet the concentration of these resources is spatially constrained to what is typically the driest plant community.

The hypothesis of evapotranspirational pumping in the FNR model suggests that high transpiration rates of tree island communities cause them to take up water and nutrients from the surrounding marsh and groundwater, especially during the dry season, and that nutrients gradually accumulate through this process (Wetzel *et al.*, 2005). This hypothesis is supported by two previous studies (Saha 2009, Saha et al 2010, Wetzel et al. 2010) using ^{18}O data that show trees and ferns located on the dry head use P-rich soil water in the wet season. In the dry season, if the shallow soil water is not available, then the dry head island plants obtain water from the regional water sources (marsh or groundwater) that are typically phosphorus-poor. However, wetland trees in wet head or swamp forest use P-poor groundwater or marsh surface water regardless of season.

The observations of fluctuations in deep and shallow groundwater on Island 3AS3 in WCA 3A and those seen on the Satinleaf Island in ENP are also considered as support of the hypothesis of evapotranspirational pumping (Ross et al. 2006; Adamski, 2008; Troxler et al. 2009). These fluctuations are presumably caused by a daytime drawdown of soil water from transpiring vegetation that then recovers at night with recharge from deep groundwater sources or the surrounding marshes. Diurnal groundwater fluctuations are also observed on the LILA islands (Sullivan 2011). The groundwater beneath these islands also exhibits a remarkable build-up of cations such as Cl-. This increase in ionic strength is indicative of groundwater discharge beneath the islands driven by root water uptake and exclusion of dissolved salts. These results suggest diurnal groundwater fluctuations and the build-up of cations may provide a metric of “healthy” tree island function. However, it is not known if groundwater beneath degraded islands exhibits the same characteristics. More data is needed to clarify the degree of hydrologic connectivity between marsh surface water, soil water, and groundwater in both disturbed and well-preserved tree islands.

Evapotranspiration pumping is a fundamental component of the closely related chemohydrodynamic hypothesis of tree island hydrology-nutrient interactions (Wang et al. 2010; Figure 1). In this model, a distinction is made between hydrology-nutrient interactions in slough tree islands (i.e. the islands in Shark Slough or in the ridge and slough habitat of the WCAs) versus islands located in shorter-hydroperiod marl prairies. According to this model, slough tree islands can maintain high transpiration rates during the dry season using standing marsh water around the island or groundwater, while prairie tree islands will have low transpiration rate during dry season due to low water availability. Thus, the difference in hydroperiod between slough and prairie tree islands will result in differential nutrient accumulation rates and suggests that slough tree islands can accumulate more nutrients than prairie tree islands.

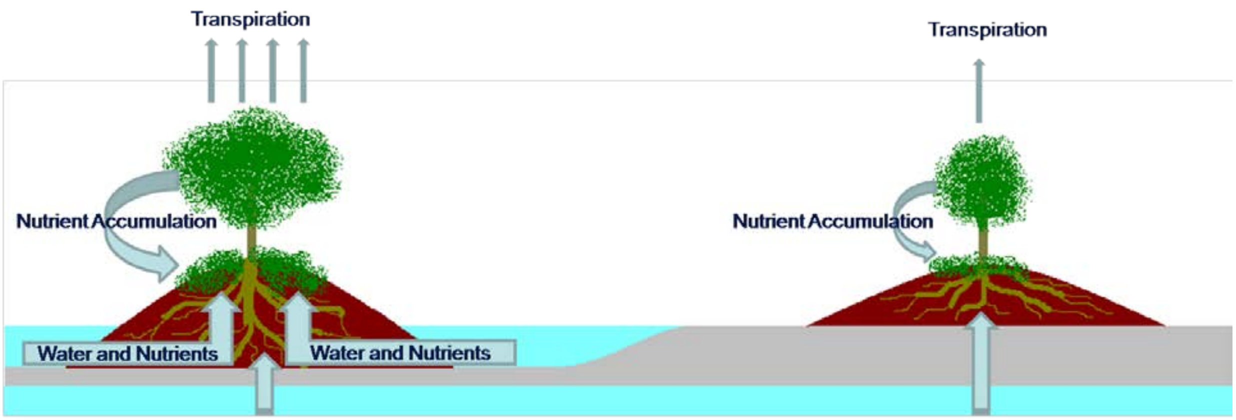


Figure 1. Chemohydrodynamic hypothesis. During the dry season, tree islands in the slough (left) transpire more than the tree islands in the prairies, and therefore accumulate more mineral nutrients. Both islands access surface water in the wet season when the surrounding marshes are flooded.

There are several predictions regarding tree island functioning which can be derived from the FNR and the chemohydrodynamic hypotheses. For example, since P uptake is transpiration driven, tree islands with low transpiration will have lower P accumulation rates than tree islands with high transpiration. Since slough islands utilize an additional water source (marsh water) that is not available to the prairie islands during much of the dry season, slough islands are expected to exhibit greater P concentrations. Furthermore, nitrogen (N) limitation becomes more pronounced with increasing P, and this suggests the ratio of stable nitrogen isotopes ($^{15}N/^{14}N$) in tree biomass should also increase with P and transpiration rate. The ratio increases because as N becomes more limiting, plants must increasingly utilize ^{15}N for growth as the availability of the preferred lighter isotope ^{14}N is diminished. In a recent paper, Wang et al. 2010 present ^{15}N and soil P data from four slough and four prairie islands which strongly support these predictions. On slough islands, both ^{15}N and soil P were significantly higher than that found on the marl prairie islands.

Recent work on Tree Island 3AS3 in the Water Conservation Area 3A provides further strong support for the FNR and chemohydrodynamic hypotheses. Using an intensive network of well clusters coupled with biogeochemical measurements, mass balance estimates of P flux of Wet Head and Near Tail communities were determined. Troxler et al. (in revision) found the Wet Head community to be a “gaining” system, receiving P from sources that could not be accounted, presumably from the upstream, P-rich soils of the High Head community. In contrast, ecosystem P mass balance suggested that the Near Tail was highly efficient in cycling P. Furthermore, comparing a dry and wet year, more P was found in subsurface soil waters of the Wet Head community in the dry year, nearly half of which was lost through infiltration. P from an upstream source that is transported to and efficiently cycled within the downstream Near Tail community characterizes the chemohydrodynamic thought to contribute to tree island functioning. Results of this work also suggest how intra-annual hydrologic variability can influence tree island functioning. Interestingly, in this tree island, preferential concentration of ions (especially Cl) are observed in shallow soils almost exclusively in the High Head community with the principle hydraulic gradient from High Head to Wet Head. Taken together, these data suggest that evapotranspirational pumping occurs in the High Head with P increasing along a lateral pathway toward the Wet Head where it is transported downstream or lost to lower depths in the soil profile via infiltration.

In order to test the validity of the chemohydrodynamic model and the hypothesis of evapotranspiration pumping across different Everglades tree islands and investigate the development of tree island performance measures and assessment tools based on groundwater dynamics, we developed a monitoring and assessment study that would achieve two goals. Our study was intended to: 1) expand upon an existing network of monitoring wells and install new wells on tree islands and 2) couple intensive measurements of hydraulic head gradients and ionic strength in surface and groundwater wells with data on soil phosphorus, stem and source water ^{18}O and ^{2}H isotopic composition and plant nitrogen and carbon isotope patterns in a larger set of tree islands that varied along hydrologic and disturbance gradients.

The objectives of this project were to: 1) install wells on Twin Heads, 3AS3, and Satin Leaf tree islands, 2) monitor water levels, 3) collect water and plant tissue for laboratory analysis, and 4) prepare report describing a) initial findings which tests the predictions of the FNR and chemohydrodynamic models, b) recommendations for continued monitoring plan design, and c) the integration of the results with evaluation tools or tree island performance measures currently under development by RECOVER.

VII. METHODS

A. Study Design. Our study was conducted in four tree islands in the southern Water Conservation Areas 3A (WCA 3A), 3-B (WCA 3B) and Everglades National Park in the Florida Everglades (Figure 2). These islands were 3AS3 (25°51'24.00"N and

80°46'10.80"W) and Ghost Island (25°54'50.10"N and 80°39'18.10"W) in WCA 3A, Twin Heads (25°49'21.40"N and 80°37'32.11"W) in WCA 3B, and Satin Leaf (25°39'35.98"N and 80°45'21.16"W) in ENP. The tree island 3AS3 is located within a relatively intact ridge-slough mosaic and considered to be a relatively intact tree island. The "Ghost Island" is located in an area of WCA 3A that is considered impounded, resulting in over-flooding on the tree island. The Twin Heads island is in an overdry basin and Satin Leaf is located in a relatively short hydroperiod rocky glade. All tree islands of our study are fixed tree islands with vegetative communities described as high head (HH), wet head (WH), and near tail (NT). Downstream of the HH, in a lateral orientation, are the WH and NT plant communities. Due to funding constraints, the sampling design selected was one that would provide the minimum level of information necessary to characterize variation in plant community hydrology and plant-water interactions.

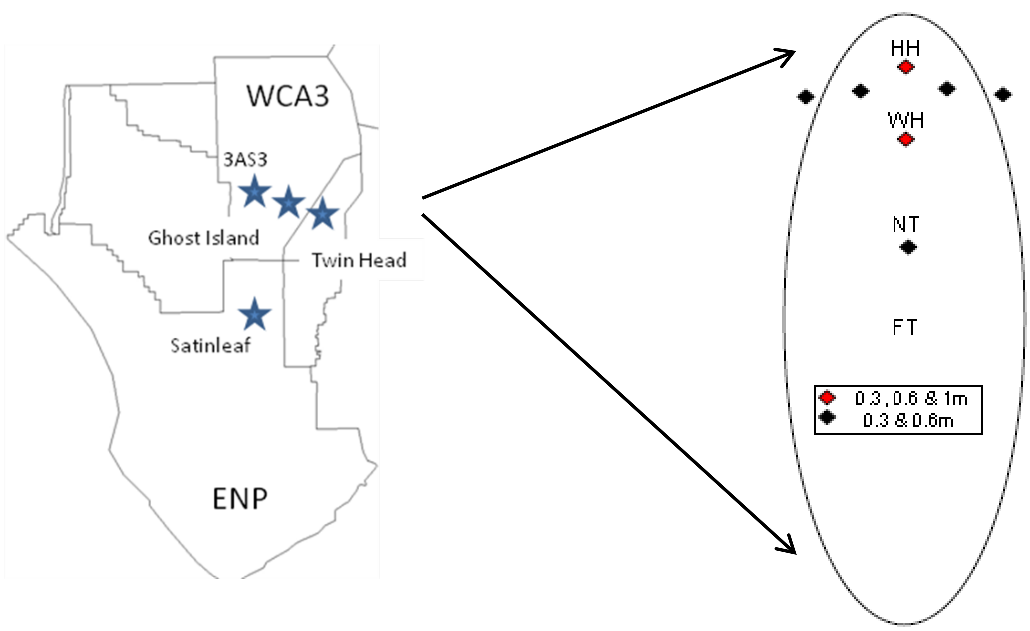


Figure 2. Landscape Study Design. The tree islands are located in WCA 3 and in ENP (left). A schematic of well locations and depths to be utilized in this study is shown on the right.

The Ghost Island served as the wet, degraded end-member along the hydrologic/disturbance gradient. 3AS3 that along with Satin Leaf island in ENP, represented the well-preserved islands in this study. The tree communities on these islands differ significantly, and the hydroperiod is shorter on Satin Leaf island due to its height above the surrounding marsh and regional hydrologic setting. Thus, two well-preserved islands are presented in this scheme with significantly different hydrologic conditions and community types; 3AS3 serves as the wet, “intact” island and Satin Leaf serves as the dry, “intact” island along the hydrologic/disturbance gradient. In WCA 3B, a full set of wells were installed on the island called Twin Head. This island served as the dry, degraded end-member along the hydrologic/disturbance gradient.

The HH in the 3AS3 tree island is dry with typically no standing water throughout the year. The WH vegetation is of shorter stature and the NT community is intermixed with shrubs and trees with open herbaceous vegetation in areas. In the Ghost Island, vegetation of the HH is more typical of a wetter environment, with pond apple (*Annona glabra*) dominating the canopy throughout the High and Wet Head communities. The NT vegetation on the Ghost Island is more typical of the “far tail” (FT) plant community on 3AS3 and comprised of relatively dense sawgrass (*C. jamaicense*) intermixed with shrub and other herbaceous vegetation. Overall, species composition of 3AS3 vegetation communities is less so whereas species composition of the Ghost Island is fairly uniform with vegetation communities apparently differentiated by their structure (i.e. density, canopy height). The Twin Heads island has vegetation characterized by ruderal species in the driest plant community surrounded by an extensive pond apple (*Annona glabra*) forest. The vegetation structure of the Satin Leaf tree island is characterized by tropical hardwood hammock species including white stopper (*Eugenia axillaris*) and satin leaf (*Chyrsophyllum oliveforme*). Hydrostratigraphic characterization of the 3AS3 tree island provides evidence that the high head coincides with a topographic high that originated with the underlying Pliocene Tamiami sand formation and Pleistocene age marine limestone (McNeill and Cunningham 2003). The hydrostratigraphy of the other three islands has not been reported to our knowledge.

B. Meteorological Data. Precipitation and potential evapotranspiration (PET) data were obtained from a weather station operated by the South Florida Water Management District (SFWMD). Precipitation data are recorded on a CR10 datalogger in the HH of the 3AS3 tree island. PET data reported here are recorded with a CR10 datalogger. As the WCA tree islands were in relative close proximity, these precipitation data were considered similar for tree islands in this area.

C. Hydraulic Characterization. Figure 2 describes the general schematic of the well installation design that was targeted for each tree island. This entailed installations of wells in each of 7 locations (well clusters), red well clusters having wells installed and cased to 3 depths (0.3m, 0.6m and 0.9m) and black well clusters with wells installed and cased to 2 depths (0.3m and 0.6m) below the soil surface. Three well depths were sampled in interior well clusters of the High Head (HH) and Wet Head (WH) locations. In the Neartail (NT) and marsh locations, wells at 2 depths were sampled.

On tree island 3AS3, well began in 2007. In 3AS3, we installed wells in the HH, along two transects across the WH (north) and NT (south) communities, and in the marsh (Figure 3). Wells on the HH were installed in four clusters, with one cluster just north of the HH [High Head (N)] on the tree island edge. Two of the interior clusters had wells installed at 60 and 90cm depth below the soil surface. The third interior cluster had wells installed at three depths, 30cm, 60cm and 90cm. In the WH and NT, wells were installed in five clusters across each transect, with two wells per cluster, installed to 30cm and 60cm below the soil surface. In the adjacent slough, two well clusters were installed on both west and east sides of the tree island near the HH. On the Ghost Island, well installation was completed in July 2010. On this island, we followed a similar design, but with two of the HH interior well clusters installed with wells at 30cm and 60cm depth and with three clusters in each of the WH and NT transects (Figure 4).

Installation of wells on the Satin Leaf tree island in ENP for WH, NT and marsh locations were completed in December 2011 (Figure 5). The Satin Leaf island in Everglades National Park posed particular challenges as ENP would not issue a permit for well installation due to the potential risk of disturbing cultural resources in High Head soils (despite ENP Wilderness committee approval in April 2011). Thus, all well installations were delayed. When the Compliance staff responded, it was determined that wells installed outside of the High Head area could be approved. Well installations in the High Head are still pending. However, we were able to salvage this aspect of the project by sampling extant wells. Although not ideal, this sampling enabled us to proceed with including the ENP tree island in the project, albeit with limited well sampling. Well installations in the Twin Heads tree island of WCA3B were completed in January 2011. Wells were installed according to the baseline design for this project (Figure 6).

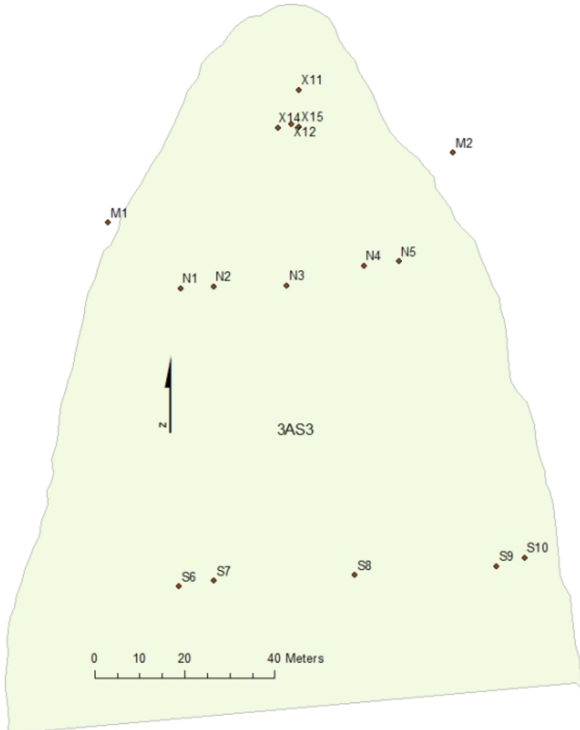


Figure 3. Schematic of tree island well locations in the wet, intact 3AS3 in WCA 3A. Map shows locations in high head (X12, X14 and X15), north high head (X11) on the North edge of the island, a transect in the wet head (N1-N5), a transect in the near tail (S6-S10), and marsh (M1 and M2) well clusters. Each cluster in the wet head, near tail and marsh has wells installed at 30cm and 60cm depth below the soil surface. In the high head and wet head central location (N3), wells are installed at 30, 60 and 90cm at X12 and at 60cm and 90cm at X14 and X15.

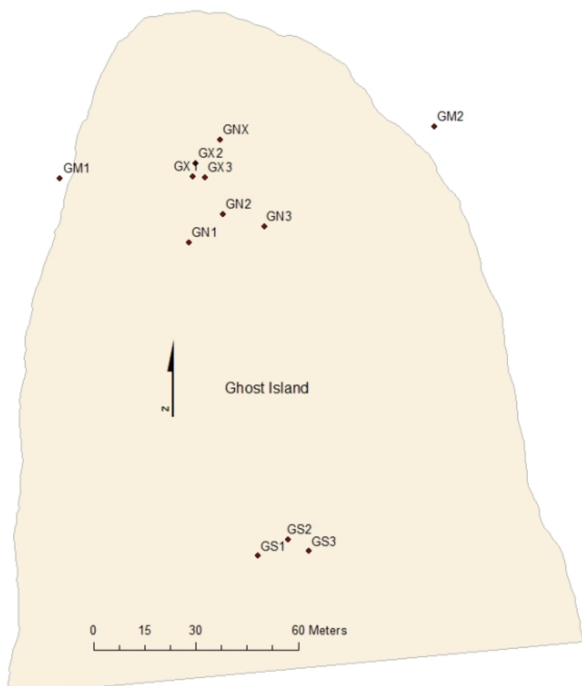


Figure 4. Schematic of tree island well locations in the wet, degraded "ghost" Island in WCA 3A. Map shows locations in high head (GX1,GX2, and GX3), north high head (GNX) on the North edge of the island, wet head (GN1-GN3), near tail (GS1-GS3), and marsh (GM1 and GM2) well clusters. Each cluster in the wet head, near tail and marsh has wells installed at 30cm and 60cm depth below the soil surface. In the high head and wet head central location (N3), wells are installed at 30, 60 and 90cm.

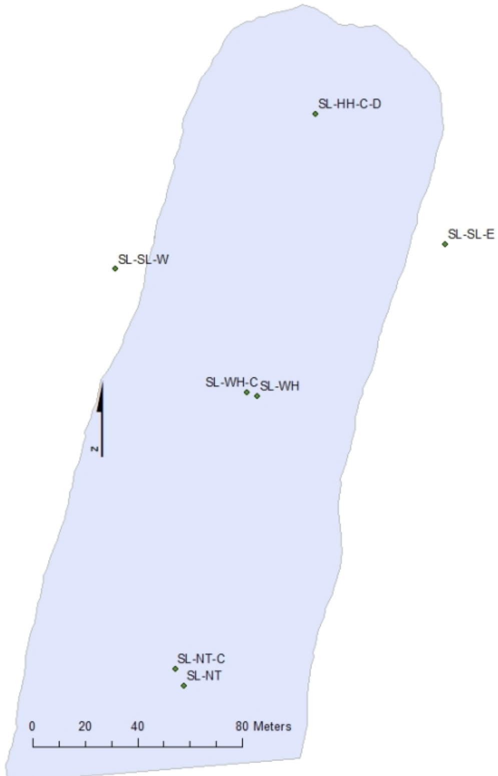


Figure 5. Schematic of tree island well locations in dry, intact Satin Leaf in Everglades National Park. Map shows locations in high head (SL-HH-C-D), wet head (SL-WH-C), near tail (SL-NT-C), and marsh (SL-SL-W and SL-SL-E) well clusters. Each cluster in the wet head, near tail and marsh has wells installed at 30cm and 60cm depth below the soil surface. In the high head, the well is installed between 60cm and 1m depth.

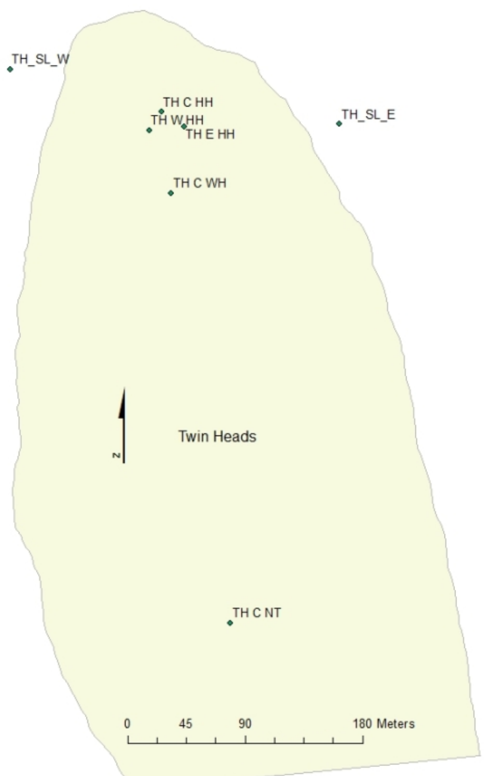


Figure 6. Schematic of tree island well locations in dry, degraded Twin Heads in WCA 3B. Map shows locations in high head (TH-C-HH, TH-W-HH, and TH-E-HH), wet head (TH-C-WH), near tail (TH-C-NT), and marsh (TH-SL-W and TH-SL-E) well clusters. Each cluster in the near tail and marsh has wells installed at 30cm and 60cm depth below the soil surface. In the high head and wet head, wells are installed at 30, 60 and 90cm.

The well design was a 2” PVC slotted along the lower 10 cm of the pipe (Figure 7). We installed each well by excavating an approximately 20cm diameter hole with a gas-powered or hand auger. To ensure that the wells did not migrate due to peat shrinkage or swelling, the pipes were installed with riser and well sections. The bore hole for each well was dug down to limestone where the riser section rested. The slotted section of the well (well screen) was 20-30cm, 50-60cm or 80-90cm below the soil surface for shallow (S), deep (D) and deep deep (DD) wells, respectively. The annular areas surrounding the wells were filled with very fine sand around the riser section with a thin layer of bentonite (ENVIROPLUG™) below the well screen and filled with 6/20 filter sand to completely cover the well screen. The annular area was then capped with bentonite above the well screen and finished with very fine sand. Each well was fit with a pressure transducer (*In-situ*®) water level recorder. These wells were surveyed with a Leica™ Total Station to the best of our ability.

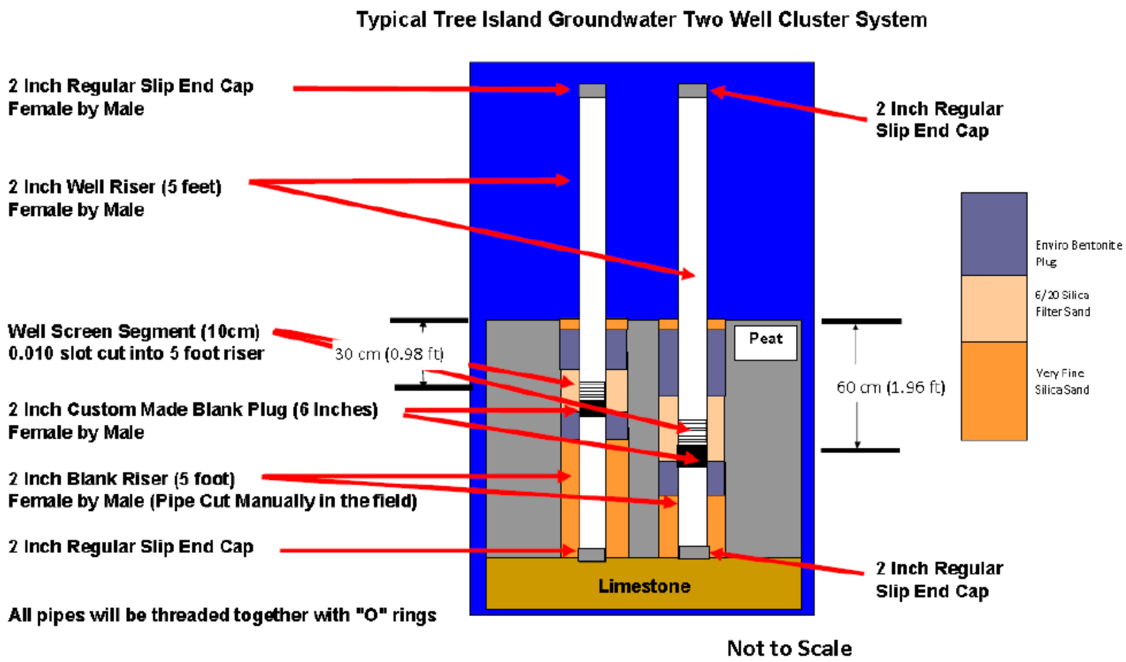


Figure 7. Schematic of two well cluster design

We report hydraulic head levels (mm) relative to the NGVD 29 datum. Water levels are reported for periods that capture the maximum variation in hydrologic conditions. These periods are: wet - a period when water levels were among the highest (October - November 2010) and dry – with the lowest water levels (April 2011). Wells at Twin Heads and Satin Leaf were installed in January 2011 and December 2011 (due to permit restrictions by ENP), respectively. Thus, period of record for Twin Heads begins after the dry season (June 2011) and water level data for Satin Leaf are not yet available. Daily hydraulic head levels are 15-minute levels averaged over a 24 hour period. Diurnal hydraulic head levels are reported as levels at 15-minute intervals.

D. Hydrogeochemical Sampling. We conducted two samplings under this project: sampling of 2 islands in the first sampling and 4 islands in a second sampling. The first sampling was conducted with duration between January – March 2011 at Twin Heads and Satin Leaf islands with a subset of wells also sampled at 3AS3 and Ghost Island. While this period was chosen to represent a wet season sampling, there was little precipitation after mid December 2010 resulting in a "dry down" period when the sampling was conducted. A second sampling took place from August 18 – October 24, 2011. This was a period when the region was experiencing a "rewetting" period, with "wet" islands targeted at the beginning of the sampling event. Although not part of this contract, we also include summary data from a comparable wet season sampling (October – November 2010) for 3AS3 and Ghost Island.

Wells were purged of three well volumes and DO, temp, pH and specific conductivity were recorded until three stable readings were obtained. Samples were run through a flow-through vessel and measurements conducted with a YSI. Wells were then purged a fourth time for sample collection and filtered through 0.45μm glass fiber filters. Surface waters were similarly sampled. Chemical analyses of Ca, Cl, Mg, K, Na, SO_4, alkalinity as $CaCO_3$, dissolved organic carbon (DOC), total Kedjhal nitrogen (TKN) and total dissolved phosphate ($TDPO_4$) were conducted by the SFWMD analytical lab following EPA protocols. Mineral saturation indices (*SI*) were determined using Aq-QA® (Rockware Inc.) where *SI* = log *Q/K* and *Q*=ion activity product and *K*=equilibrium constant. We determined the charge balance for each water sample in meq L^{-1}.

E. Isotope Characterization of Water, Stem and Leaf tissue.

Oxygen and Hydrogen in Water. Field water samples are sealed in scintillation vials capped with a Cone-Shaped liner (VWR, PA, USA). Vials are further sealed with Parafilm ® (VWR) and kept in cool place. Samples are refrigerated at 5ºC in the laboratory until analysis. Plant samples are sealed in a special distillation tube prepared in the laboratory (Vendramini & Sternberg, 2007). Soil or plant samples are held at one end of the tube with a wire mesh and the tube is sealed with a polyethylene stopper and further sealed with a Parafilm. Plant samples are kept in ice until arrival in the laboratory where they are frozen to -10ºC.

Plant samples are sealed under vacuum and placed in a special distillation apparatus designed in this laboratory (Vendramini & Sternberg, 2007). Distilled water samples are kept refrigerated until the time of analysis. Water samples (0.5ml) are placed in a 5.9 ml vials (Labco, Buckinghamshire, UK) containing a cuvette holding a small amount of platinum catalyst (Platinum Black, Sigma Aldrich) and sealed with screw caps having a pierceable rubber septum. Samples are placed in a Multiflow apparatus (Elementar, Hanau, Germany) and each vial is first flushed with a mixture containing 13% hydrogen and 87% ultra high purity helium and allowed to equilibrate for a 24 hour period at room temperature (25ºC). After the incubation period an aliquot of the equilibrated gas is collected passed through a Naflon tube and gas chromatography to separate the hydrogen from any contaminants and finally introduced to the mass spec for isotopic analysis. After equilibration, the equilibrated carbon dioxide is passed through naflon and gas chromatography to separate the carbon dioxide from other contaminants and introduced into the mass spectrometer (ISOPRIME, Elementar, Hanau, Germany). Hydrogen or oxygen isotope ratios of water according to the following equation:

$$\delta^{18}O_{WATER} \text{ or } \delta^{2}H_{WATER} = (\delta^{18}OCO_2 \text{ or } \delta^{2}HH_2 - (\alpha-1)103)/\alpha,$$

where $\delta^{18}O_{WATER}$ and $\delta^{2}H_{WATER}$ are the oxygen and hydrogen isotope ratios of water respectively. $\delta^{18}OCO_2$ and $\delta^{2}HH_2$ are the isotope ratios of the gas equilibrated with the water respectively, and α is the equilibrium fractionation factor for either hydrogen or oxygen. The internal laboratory standard is calibrated against universally accepted standards (vSMOW, vSLAP and bGISP). The precision of analyses are typically ±0.1‰ and ±3.0‰ for oxygen and hydrogen isotope ratios.

Carbon and Nitrogen in Leaf Tissue. Samples and standards were placed in the carousel of an elemental analyzer (Eurovector, Milan, Italy) connected in tandem with an Isoprime isotope ratio mass spectrometer (Elementar, Hanau, Germany). Samples were sequentially dropped via the Eurovector mechanism into an oxidizing reaction tube containing (chromium oxide, and silvered cobalt oxide, Elementar America, New Jersey, USA) held at 1050C. Isotope ratios of each sample were expressed as:

$$\delta^{13}C \text{ or } \delta^{15}N = (Rsample/Rstandard - 1) * 1000$$

Where $\delta^{13}C$ or $\delta^{15}N$ represent the isotopic abundance of carbon and nitrogen respectively, and R_{Sample} and $R_{Standard}$ represent the ratio of heavy to light isotopes from the sample and standard respectively

F. Soil Phosphorus. Soil cores were collected on 3AS3, Ghost Island and Twin Heads islands. No soil samples were collected on Satin Leaf due to a delayed permit process. Cores were extracted using a PVC pipe augmented with a serrated cutting blade. The soil corer was driven to refusal (but no less than 30cm) and extracted cores were sectioned into 10cm segments. Soil samples were dried at 60ºC, ground to a homogeneous powder (<500 mm), and analyzed for TP using the modified Solorzano and Sharp (1980) method.

VIII. RESULTS & DISCUSSION

A. Meteorological Data. The daily sum of precipitation was obtained from the DBHYDRO database managed by the SFWMD (Figure 8). Precipitation was estimated to describe the climatologic conditions of the 2009-2011 years to illustrate inter-annual variation, seasonal variation for the sampling year (2011) and prior to each seasonal diurnal signal. From Nov 2010 to February 2011, the sum of daily precipitation was 3.8 in. (half of last year this time). From March 2011 through the end of May, precipitation was 5.9 in. (also ~50% from last year at this time). Prior to the beginning of the August sampling on 3AS3 (June 1-August 18) the sum of daily precipitation was 24.5 in. (up 8 in. from last year at this time). Thus 2011 (Jan-Sept) was a in a very dry period with typical precipitation beginning in late June 2011 as compared with the protracted wet season of 2010 but was fairly similar to 2009. The precipitation total at the time of the wet season sampling in the Ghost Island was 3 in. higher than when 3AS3 was sampled and represent comparable samplings (without consideration of water management). Given its close proximity, precipitation at 3AS3 is likely comparable to local precipitation at Twin Heads. Precipitation data for Satin Leaf are not available for this report.

Sampling occurred in February 2011 when wet season rains had generally ceased to occur for approximately 3 months and was conducted at a time of regional drydown. Conversely, sampling began in mid August when wet season rains were pronounced 2-3 months prior and was conducted at a time of regional rewetting.

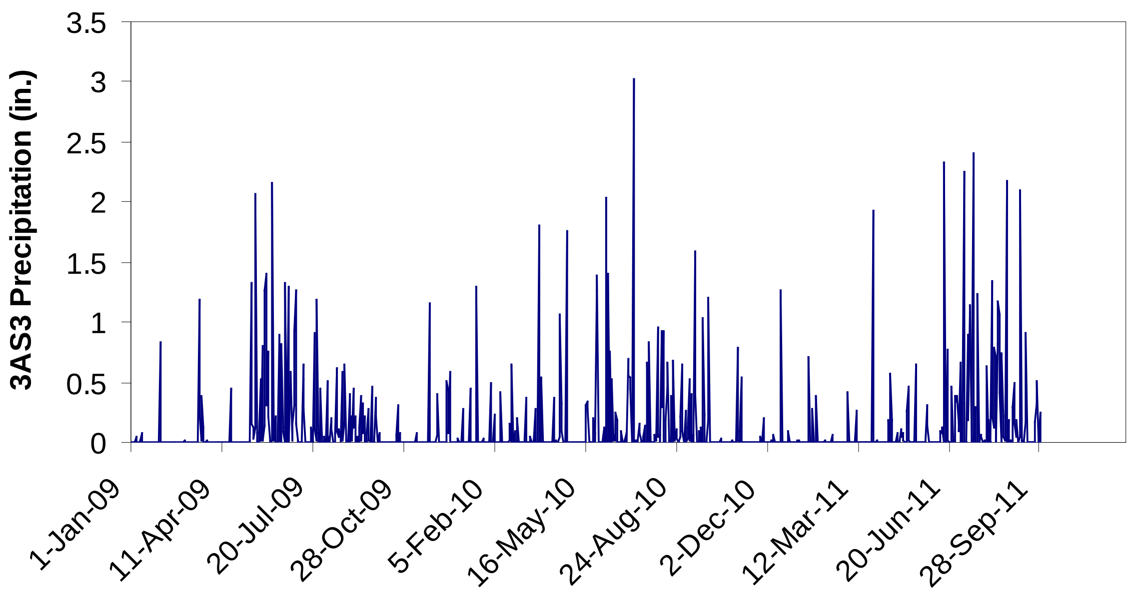


Figure 8. Precipitation from meteorological station 3AS3X at tree island 3AS3 in the WCA-3A.

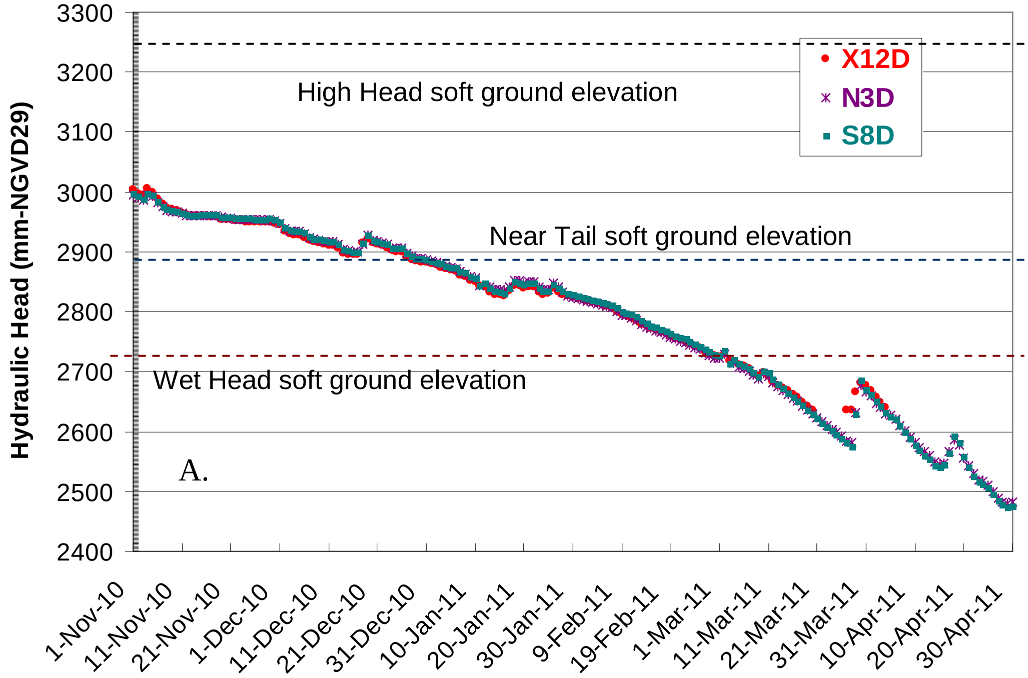
B. Plant Community Hydraulic Patterns – daily and diurnal. We used hydraulic head levels collected at 15-minute intervals to investigate seasonal and diurnal patterns.

Seasonal variation in head levels are presented for the periods November 2010 - May 2011 (Figure 9) and July 2011 – December 2011 (Figure 10A&B) for 3AS3 and Ghost Island. Twin Heads gauges were deployed in June 2011 and water level data are presented for Aug 2011-November 2011. Diurnal patterns in water levels beneath the HH, WH, NT and marsh plant communities for three periods are presented for 3AS3 and Ghost Island: wet (November 27 - December 7, 2010; Figure 10), dry (April 24 – May 4, 2011; Figure 11) and rewetting (September 15 – September 26, 2011). Water level data are presented for Twin Heads tree island for dry July 6 – July 26 2011) and rewetting (September 15 – September 26, 2011) periods. Water level data are not available for Satin Leaf tree island.

The 3AS3 tree island wells were surveyed by Keith and Schnarrs in 2007. Topographic survey data for Ghost Island and Twin Heads collected by the Troxler lab provide a preliminary comparison of hydraulic head levels for these islands. In 3AS3, hydraulic head levels in the HH were always below the soil surface during the period of record (November 2010 –December 2011) except for a one-month period in November 2011 (Figures 9A&10A). However, in 3AS3, water levels for the HH were 25cm below the soil surface for the entire year prior to this time (Figures 9A&10A). In the WH, hydraulic head levels receded below the soil surface in mid March 2011 and reinundated the soil surface in mid-August 2011 (Figures 9A&10A). In the Ghost Island, water levels in the HH did not recede to this depth (25cm below the soil surface) until mid March 2011 reflecting its wetter conditions (Figure 9B). Thus, water levels in the HH of the Ghost Island are more comparable to water levels in the WH and NT of 3AS3. In 3AS3, water levels were at least 15cm below the soil surface before it was inundated in late

October 2011 (Figure 10A). In the WH, water levels approximated the soil surface at this time when water levels were highest throughout the region. In the Ghost Island, the soil surface of the entire tree island (all plant communities) was submerged by late August and maintained above the soil surface beyond the period of record (December 2011).

Previously reported daily hydraulic head levels at 60cm depth appeared to generally follow the topographic variation among the HH (X12D), WH (N3D) and NT (S8D). However, survey elevation data provided by Keith and Schnarr's were in error for the HH well cluster resulting in incorrect reference benchmarks for X12D and X12S. This error has been corrected in all water level data. With these corrected data, average daily hydraulic head levels in the HH are nearly indiscernible from daily hydraulic head levels for the WH and NT in 3AS3. Similar trends were found for the Ghost Island. In the Twin Heads island, daily head levels in the Near Tail were about 10cm below the that of other plant communities. This is possible but unlikely and a second set of elevation data should be collected to verify the elevation of the well in the Near Tail of Twin Heads. Otherwise, head levels in the HH and WH closely track reflecting a shallow or imperceptible lateral gradient from HH to WH during this period of the dry season.



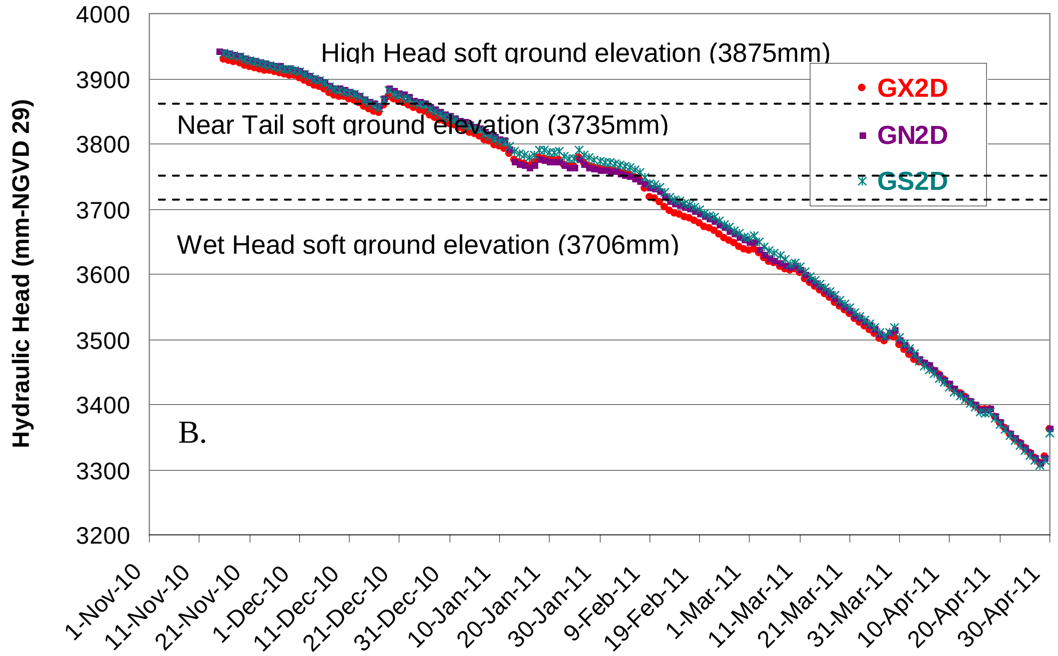
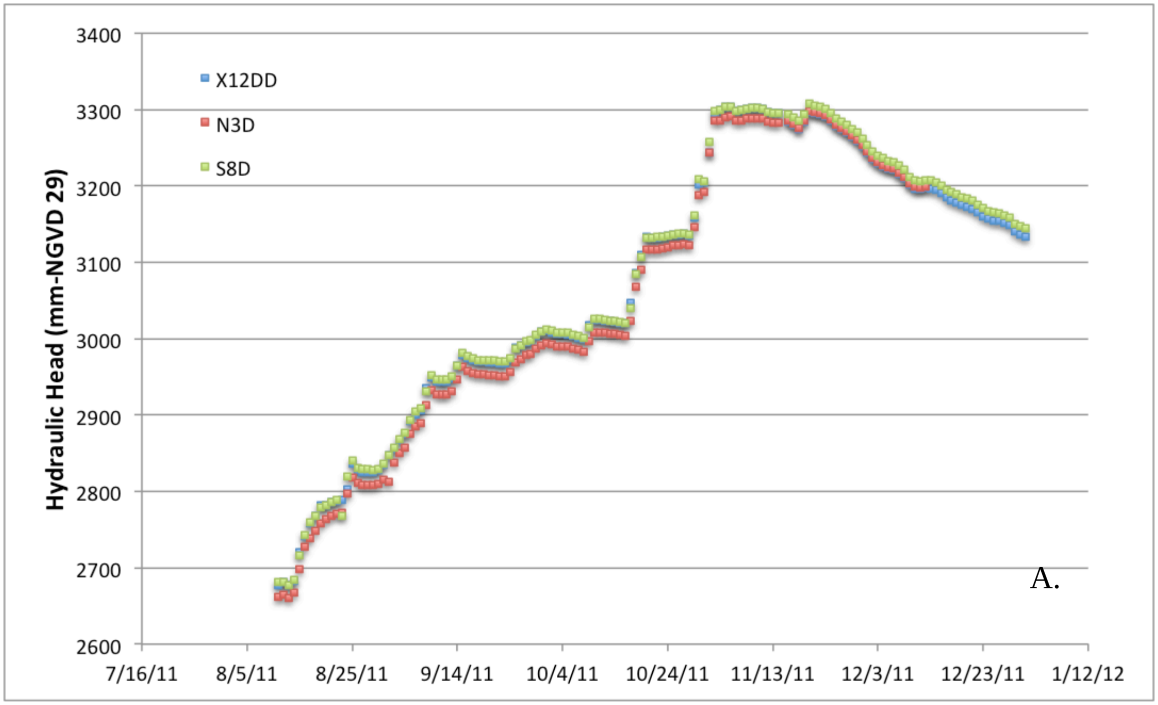
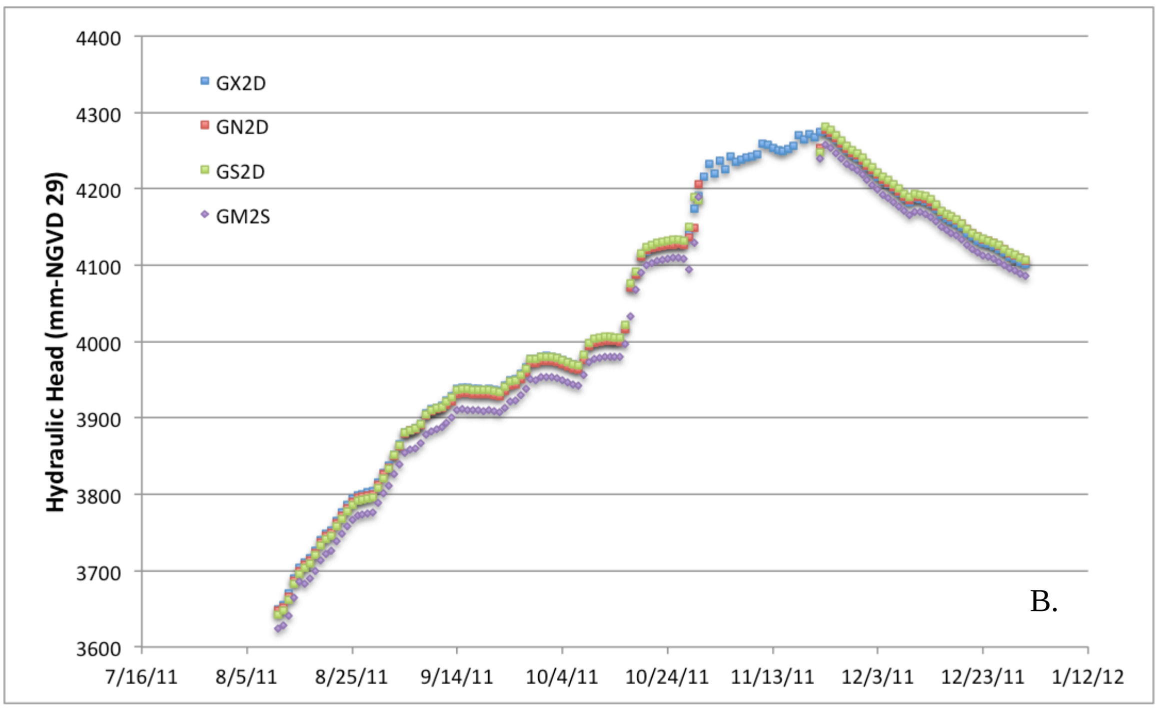


Figure 9. Wet and Dry Down Periods (November 2010 – April 2011) - Daily average hydraulic head (mm) relative to the NGVD 29 datum in A) High Head (X12D), Wet Head (N3D), and Near Tail (S8D) in 3AS3 and B) High Head (GX2D), Wet Head (GN2D), and Near Tail (GS2D) in Ghost Island. Relative benchmarks for Ghost Island requires verification. X12D in 3AS3 was dry in April 2011.

Overall, the rewetting period was characterized by a 50cm increase in water levels between early August and late October in WCA3A (3AS3 and Ghost Island; Figure 10). Thus, for the period between January 2010 and December 2011, the hydroperiod in the HH of the Ghost Island was at least 10 months longer than in the HH of 3AS3.

The change in water levels in WCA3B was less than 15cm during the same period. These new hydrology data from the dry, degraded Twin Heads tree island in the WCA3B illustrated the exceedingly different water management practices for this area. Historical water level data for WCA3B will be important in interpreting the present ecological condition of the Twin Heads tree island. Notably, in late March – early April 2011, the sawgrass marsh and *Typha* stands adjacent to this island was completely burned (see photos in Appendix). Thus, fire history is another important record that could help to elucidate the landscape factors that have shaped the present (dry, degraded) condition of the Twin Heads tree island.


3400
3300
3200
3100
3000
2900
2800
2700
2600
Hydraulic Head (mm-NGVD 29)
X12DD
N3D
S8D
A.
7/16/11
8/5/11
8/25/11
9/14/11
10/4/11
10/24/11
11/13/11
12/3/11
12/23/11
1/12/12


4400
4300
4200
4100
4000
3900
3800
3700
3600
Hydraulic Head (mm-NGVD 29)
GX2D
GN2D
GS2D
GM2S
B.
7/16/11
8/5/11
8/25/11
9/14/11
10/4/11
10/24/11
11/13/11
12/3/11
12/23/11
1/12/12

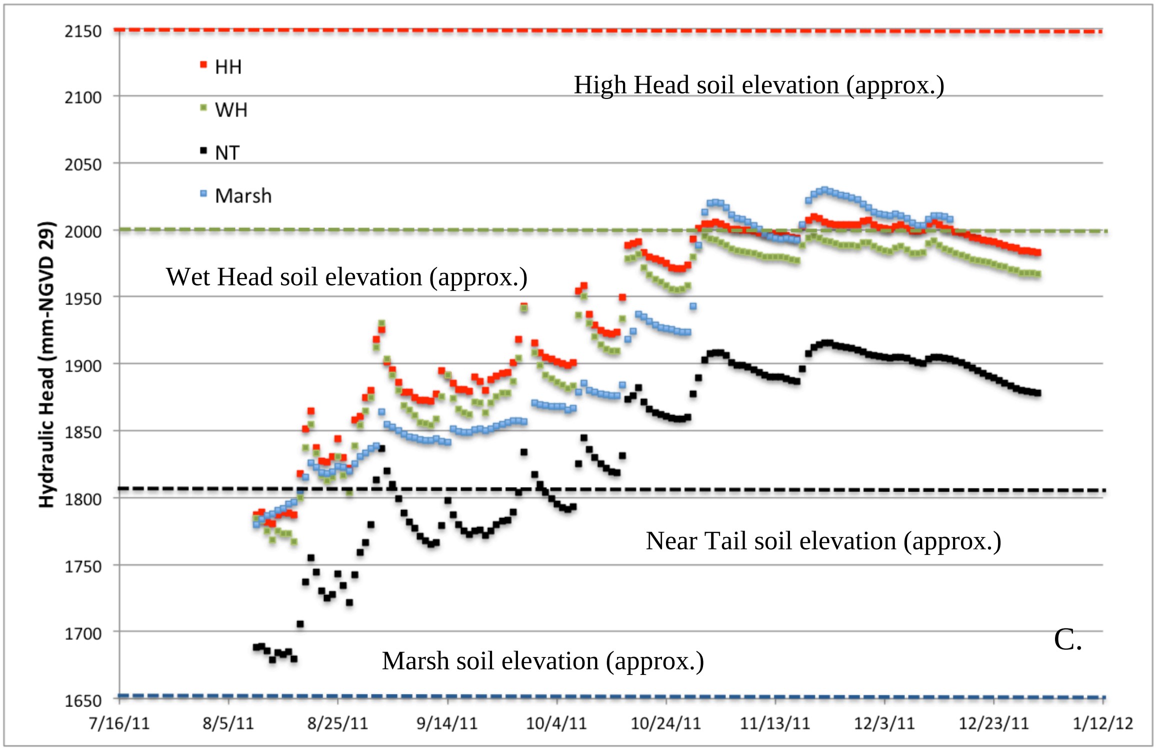
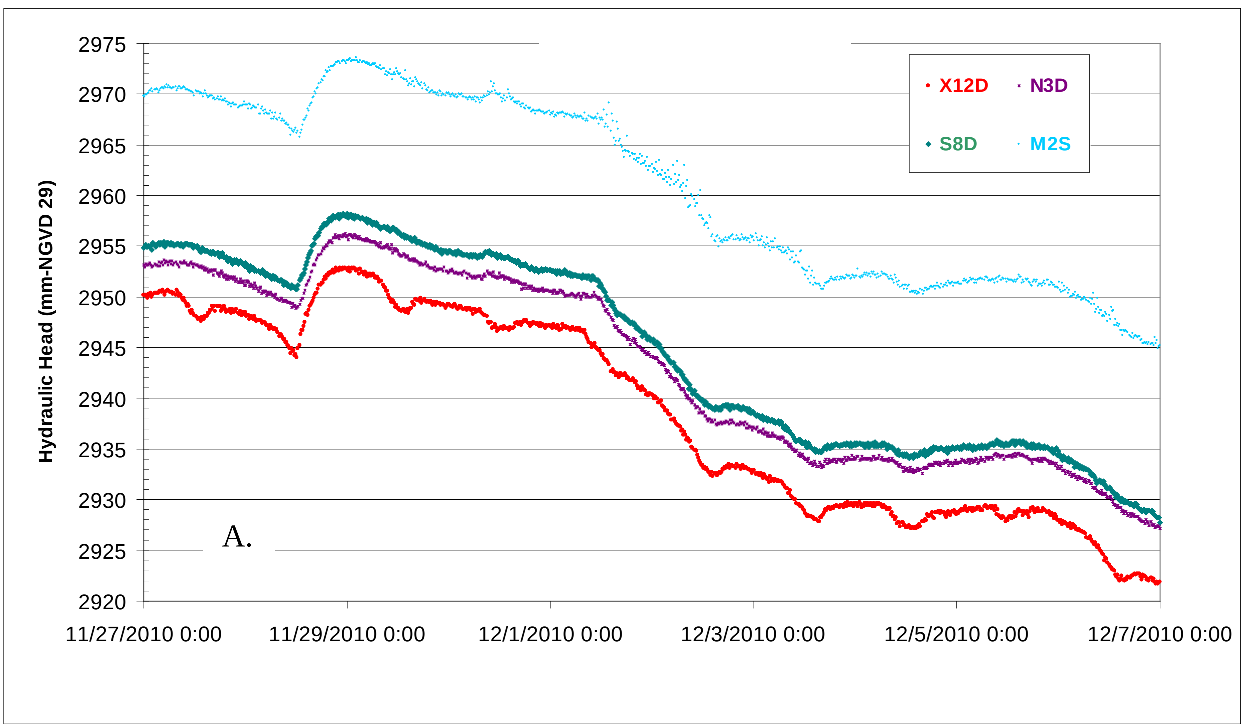


Figure 10. Rewetting and Wet Periods (August 2011 – December 2011) - Daily average hydraulic head (mm) relative to the NGVD 29 datum for in A) High Head (X12D), Wet Head (N3D), and Near Tail (S8D) in 3AS3, and B) High Head (GX2D), Wet Head (GN2D), Near Tail (GS2D) and Marsh (GM2S*) in Ghost Island and C) High Head (TX1D&TX2DD), Wet Head (TN2D), Near Tail (TS2D) and Marsh (TM1D*) in Twin Heads. Some relative benchmarks for Ghost Island and Twin Heads require verification. *30cm depth; **90cm depth**

The diurnal patterns in well locations of the HH (X12D), WH (N3D), NT (S8D) and marsh (M2S) of 3AS3 and HH (GX2D), WH (GN2D), NT (GS2D) and marsh (GM2S) of Ghost Island were largely absent in the wet season period of November-December 2010 (Figure 11). Diurnal patterns in 3AS3 for the HH (X12D) were absent at 60cm as the water level receded below 60cm depth but patterns were similar and pronounced for WH (N3D) and NT (S8D) in the dry period (April-May 2011; Figure 12A). The WH and NT had a maximum mid-day drawdown of about 4mm. In the marsh

(M2S) near the 3AS3 tree island, the mid-day drawdown was about 1mm. Diurnal patterns in Ghost Island for the HH (GX2D) and WH (GN2D) were similar and pronounced at 60cm depth in the dry period but had a lower mid-day drawdown than 3AS3 (less than 3mm). There was also a notable diurnal signal in the NT (GS2D) that corresponded to a 1-2mm mid-day drawdown (Figure 12B). In the marsh (GM2S) near the Ghost Island a diurnal pattern was also discernible and approximated about a 1mm mid-day drawdown. Thus, although marsh drawdown was similar for 3AS3 and Ghost Island, there were discernible differences in diurnal patterns for plant communities in the tree islands. Most notable however is the difference in marsh and tree island hydraulic head levels between the two islands. 3AS3 marsh water levels are always higher than tree island water levels. Although preliminary and requiring independent verification of survey elevation data for the Ghost Island, marsh water levels are nearly always similar or lower than Ghost Island water levels. This suggests a water table reversal that is evident in the intact island 3AS3, but not present in the degraded Ghost Island. If a verifiable trend, this is likely due to the overall higher water levels found for the ghost tree island and aspects of the vegetation communities present there.

Post-dry season diurnal trends for the drier, degraded Twin Heads in early-mid July 2011 illustrated significant evapotranspiration patterns in each plant community except the marsh (Figure 12C). Similar to 3AS3 and Ghost Island, there is an appreciable pattern of diurnal evapotranspiration in Twin Heads plant communities as compared with the adjacent marsh. There is also a similar maximum drawdown depth at this time. Given the upward trend in water levels, it is evident that rewetting is underway and not directly comparable to dry season trends for 3AS3 and Ghost Island. As with 3AS3 but not evident in Ghost Island is a tree island effect on water table compared to the marsh. As previously stated, marsh well elevations require verification but available data suggest that tree island vegetation in Twin Heads influences the local water table depth as was found for the intact island 3AS3. Regionally moderate or dry conditions of areas with WCA-3A and WCA-3B influence the depth to water table in tree island communities through water use by trees thereby locally modifying hydrology and potentially nutrient use.



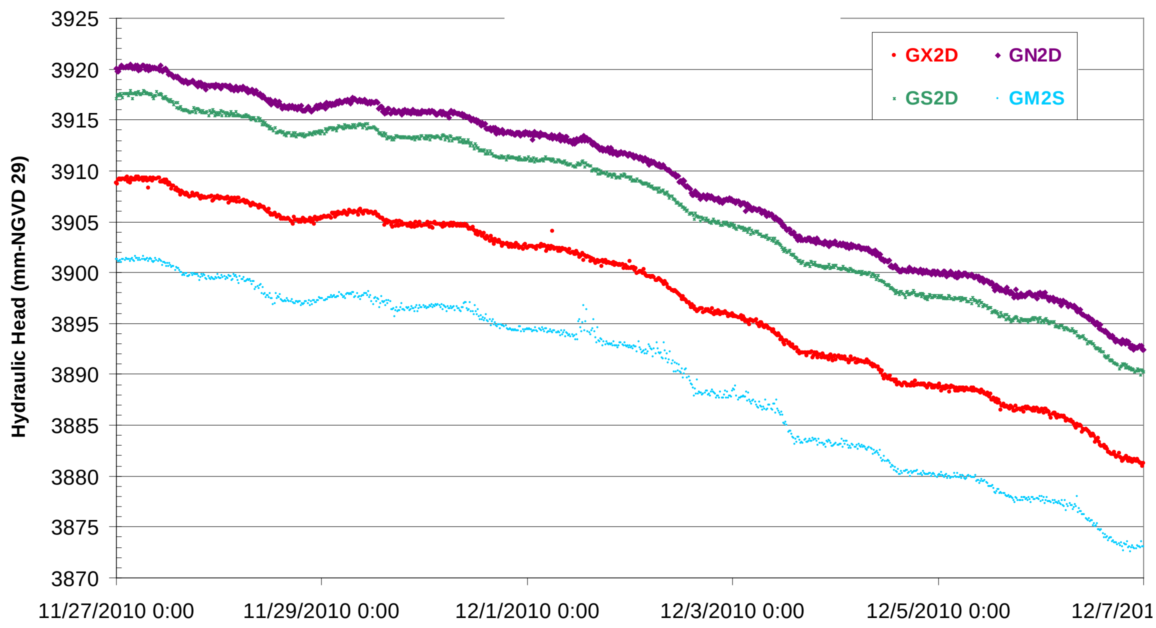
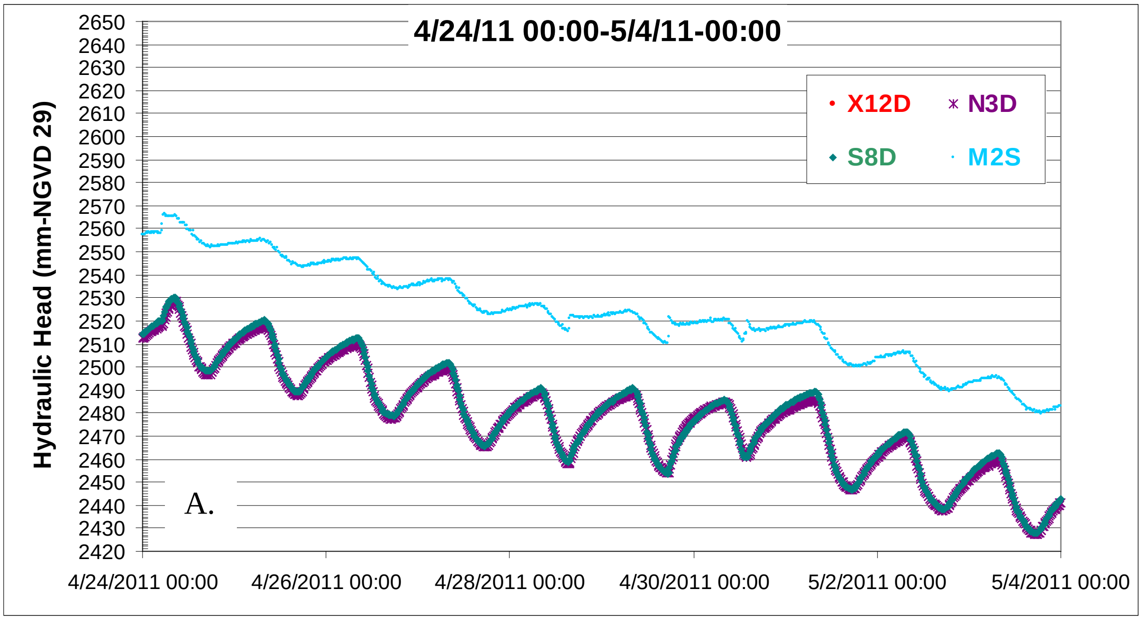
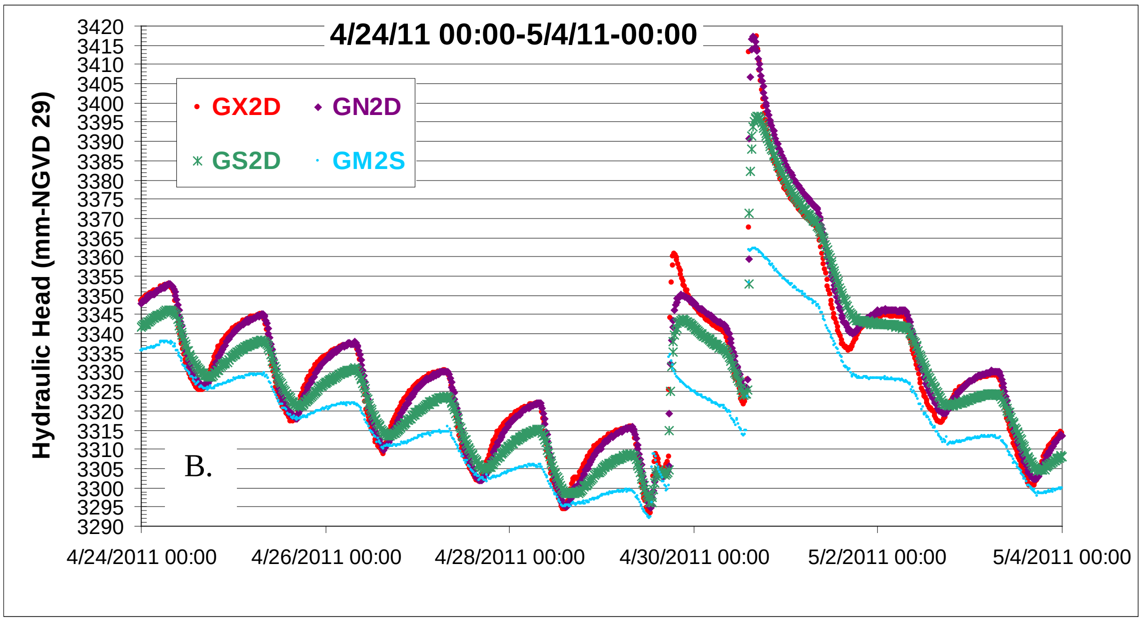


Figure 11. Wet period (November – December 2010) diurnal hydraulic head levels (mm) relative to NGVD 29 datum at 60cm depth for A) High Head (X12D), Wet Head (N3D), and Near Tail (S8D) for 3AS3 and B) High Head (GX2D), Wet Head (GN2D), Near Tail (GS2D) and Marsh (GM2S) in Ghost Island. Relative benchmark for Ghost Island requires verification.


4/24/11 00:00-5/4/11-00:00
Hydraulic Head (mm-NGVD 29)
X12D
N3D
S8D
M2S
A.
2650
2640
2630
2620
2610
2600
2590
2580
2570
2560
2550
2540
2530
2520
2510
2500
2490
2480
2470
2460
2450
2440
2430
2420
4/24/2011 00:00
4/26/2011 00:00
4/28/2011 00:00
4/30/2011 00:00
5/2/2011 00:00
5/4/2011 00:00


4/24/11 00:00-5/4/11-00:00
Hydraulic Head (mm-NGVD 29)
GX2D
GN2D
GS2D
GM2S
B.
3420
3415
3410
3405
3400
3395
3390
3385
3380
3375
3370
3365
3360
3355
3350
3345
3340
3335
3330
3325
3320
3315
3310
3305
3300
3295
3290
4/24/2011 00:00
4/26/2011 00:00
4/28/2011 00:00
4/30/2011 00:00
5/2/2011 00:00
5/4/2011 00:00

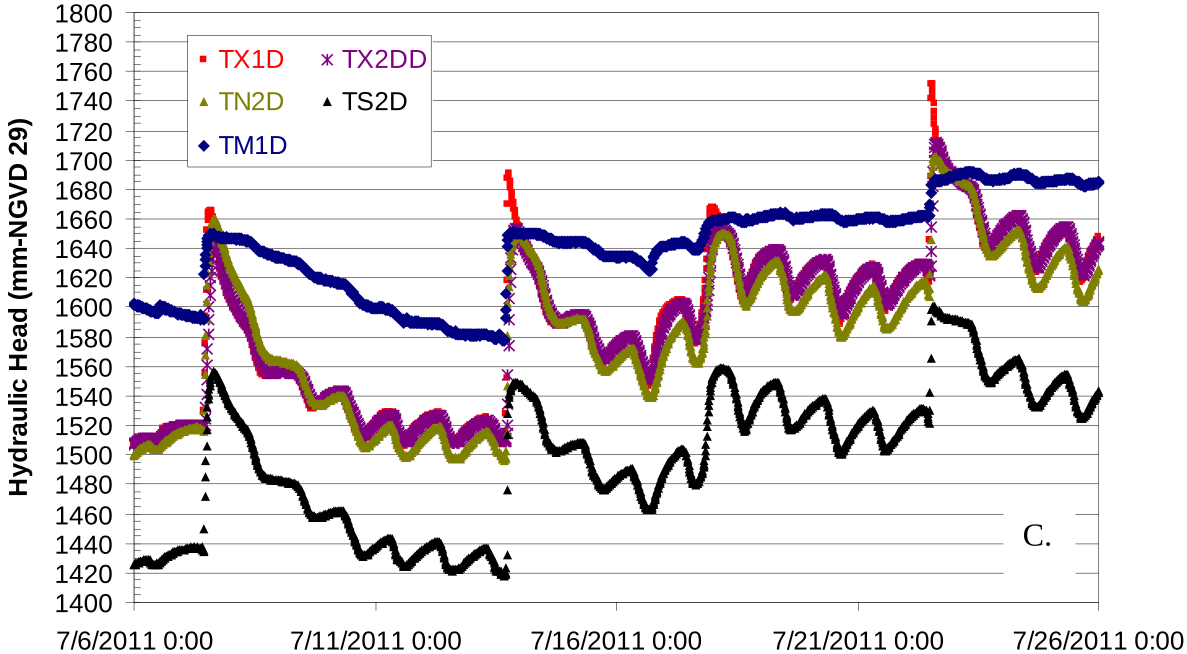
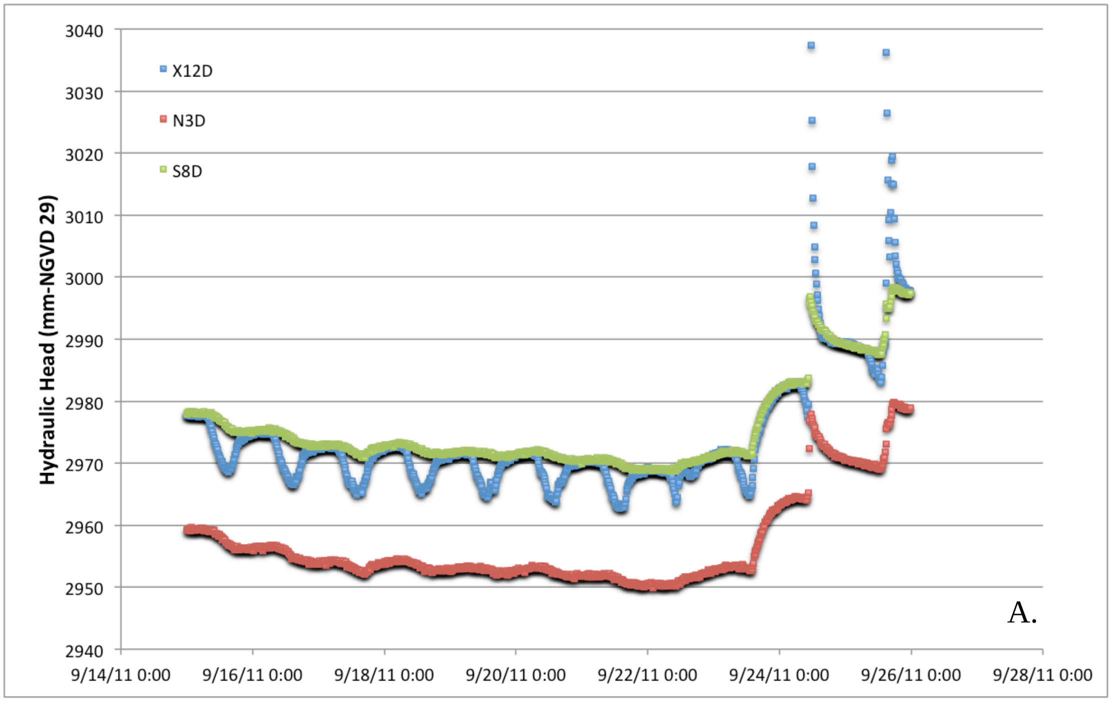
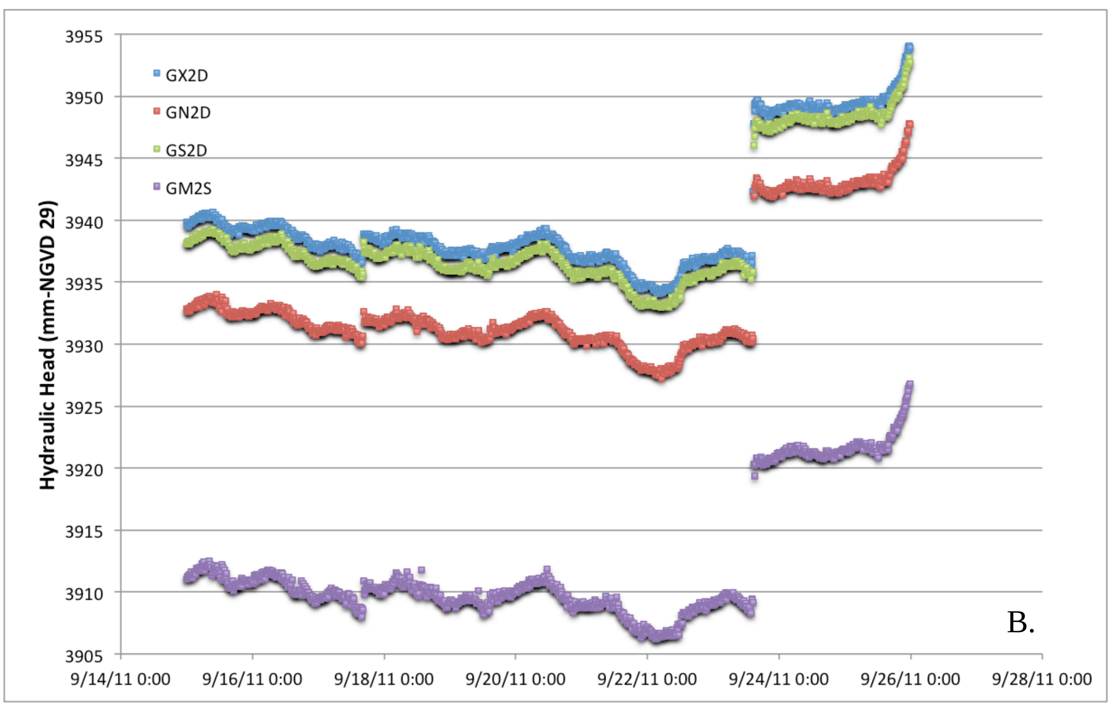


Figure 12. Dry period (April – May 2011) diurnal hydraulic head levels (mm) relative to NGVD 29 datum for 60cm depth for: A) High Head (X12D), Wet Head (N3D), and Near Tail (S8D) in 3AS3, and B) High Head (GX2D), Wet Head (GN2D), Near Tail (GS2D) and Marsh (GM2S*) in Ghost Island and C) High Head (TX1D&TX2DD), Wet Head (TN2D), Near Tail (TS2D) and Marsh (TM1D*) in Twin Heads. Relative benchmarks for Ghost Island and Twin Heads require verification. X12D in 3AS3 was dry in April 2011. *30cm depth; **90cm depth**

Diurnal hydraulic head levels were also monitored during the rewetting period in September 2011 (Figure 13). Comparing the wet, intact and wet, degraded islands, only the HH plant community of the wet, intact island (3AS3) influenced a diurnal drawdown of the water table. Otherwise, the diurnal signal in the WH, NT and marsh of 3AS3 and HH, WH, NT and marsh of the Ghost Island were nearly imperceptible. However, there was significant (2-3cm) diurnal drawdown in the HH and WH plant communities of the dry, degraded Twin Heads island. In the NT plant community, diurnal drawdown was also evident although averaging about 1 cm during this period. The diurnal signal in the marsh was nearly imperceptible. Thus, at the time of sampling, the plant rooting zone in all communities but the HH of 3AS3 and Ghost Island were in inundated. Whereas, in the Twin Heads island, only the marsh soil surface was inundated.





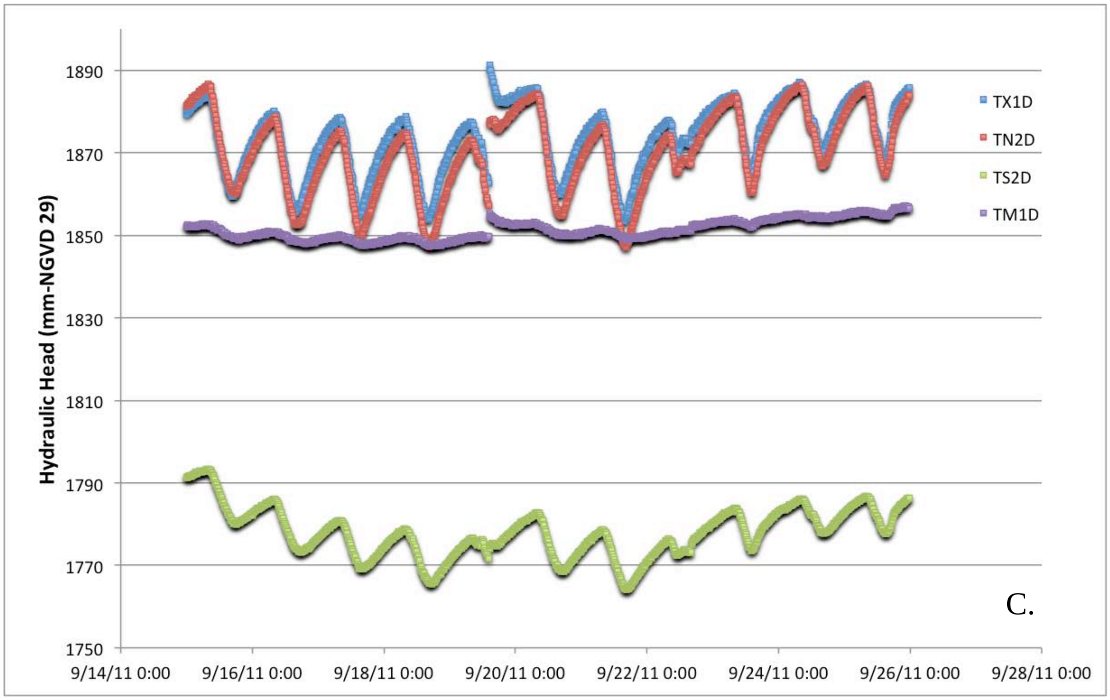


Figure 13. Rewetting period (September 2011) diurnal hydraulic head levels (mm) relative to NGVD 29 datum for 60cm depth for: A) High Head (X12D), Wet Head (N3D), and Near Tail (S8D) in 3AS3, and B) High Head (GX2D), Wet Head (GN2D), Near Tail (GS2D) and Marsh (GM2S*) in Ghost Island and C) High Head (TX1D&TX2DD), Wet Head (TN2D), Near Tail (TS2D) and Marsh (TM1D*) in Twin Heads. Relative benchmarks for Ghost Island and Twin Heads require verification. *30cm depth; **90cm depth**

C. Hydrogeochemical Patterns.

Satin Leaf and Twin Heads were sampled in the wet season of the 2010-2011 water year to correspond with a wet season sampling at 3AS3 and Ghost Island in September 2010. A subset of water quality data was collected from 3AS3 and Ghost Island to verify within season comparisons. 3AS3 and Ghost Island data are available in Final Report submitted to the SFWMD (Troxler 2010) and are only summarized here in Piper diagrams.

In February 2011 during regional dry down, $TDPO_4$ concentrations were consistently low at 90cm depth except in the HH of Satin Leaf, the dry, intact island (Table 1). However, $TDPO_4$ concentration in the HH of Satin Leaf was an order of magnitude lower than found in Twin Heads at the same depth in the HH. pH was lower and DOC concentrations higher in SL than in TH with the exception of the HH which had comparable concentrations of DOC to most locations in TH. In Twin Heads, the WH had $TDPO_4$ concentrations similar to what has previously been reported for the 3AS3 tree island.

Feb - Mar 2011				TEMP	COND	DO	pH	TDN	$TDPO_4$	DOC
island	**comm**	**location**	**depth**	**Deg C**	**umhos/cm**	**mg/L**	**pH Units**	**mg/L**	**mg/L**	**mg/L**
Satin Leaf	High Head	C	90cm	21.3	718	0.61	7.00	1.250	0.052	12.21
	Wet Head	C	90cm	20.9	1730	0.28	6.60	3.512	0.009	49.31
	Near Tail	C	90cm	20.8	1327	0.34	6.60	2.188	0.006	36.38
	Marsh	E	90cm	21	775	0.37	6.50	1.691	0.003	21.91
		E	0cm	21.2	806	0.86	6.70	2.294	0.004	23.26
Twin Heads	High Head	C	60cm	n/a	n/a	n/a	6.74	0.578	0.103	11.23
		C	90cm	20.5	1261	4.85	7.10	3.297	0.195	11.60
		E	30cm	n/a	n/a	n/a	6.92	1.967	0.122	19.18
		E	60cm	n/a	n/a	n/a	6.76	1.407	0.241	17.08
		W	30cm	n/a	n/a	n/a	6.84	1.420	0.193	18.18
		W	60cm	n/a	n/a	n/a	6.64	0.887	0.103	12.80
	Wet Head	C	30cm	17.9	1214	0.71	6.70	5.128	0.326	30.42
		C	60cm	18.7	972	0.76	6.70	3.644	0.098	16.99
		C	90cm	20	1077	0.69	6.80	1.420	0.090	19.06
	Near Tail	C	30cm	19.4	1840	0.37	6.90	1.570	0.095	22.50
		C	60cm	19.5	1114	0.36	6.80	1.358	0.228	13.77
	Marsh	W	0cm	n/a	n/a	n/a	6.93	2.046	0.001	12.17
		W	60cm	n/a	n/a	n/a	6.83	1.897	0.005	12.50
		E	0cm	n/a	n/a	n/a	7.13	1.173	0.002	13.25
		E	60cm	n/a	n/a	n/a	6.82	1.675	0.005	13.74

Table 1. Water quality parameters for Satin Leaf and Twin Heads during Dry Down (February-March 2011). Temperature (Temp), specific conductivity (Cond), dissolved oxygen (DO), field pH, dissolved organic carbon (DOC), total dissolved Kjeldahl nitrogen (TDKN), total dissolved phosphate ($TDPO_4$) by vegetation community (comm.) and well depth at intact island 3AS3 in Water Conservation Area 3A. Station names are also provided.

Water quality samples were also collected in February 2011for analyses of ions (Tables 2&3). Calcium concentrations were consistently higher than chloride in both islands in each location sampled. However, chloride concentrations were higher in all tree island communities and adjacent marsh of Satin Leaf than in Twin Heads. Magnesium concentrations generally followed that of chloride. Sodium was moderate in all communities except marsh surface water but was highest in Twin Heads at east and west locations of the HH at 30 cm depth. These soils were found to be very mucky (for lack of a quantitative description) and presumably of low permeability. Sulfate concentrations in Satin Leaf soil waters were comparable to marsh surface water. Charge balance indicated low analytical error.

Feb - Mar 2011				Alk	Ca	Cl	K	Mg	Na	SO_4			charge
island	**comm**	**location**	**depth**	**meq/L**	**meq/L**	**meq/L**	**meq/L**	**meq/L**	**meq/L**	**meq/L**	**Σcations**	**Σanions**	**balance (%)**
Satin Leaf	High Head	C	90cm	5.44	4.56	2.11	0.05	0.87	2.00	0.00	7.48	7.55	-0.47
	Wet Head	C	90cm	14.10	12.10	5.30	0.01	2.01	5.35	0.01	19.46	19.41	0.15
	Near Tail	C	90cm	10.70	9.32	3.67	0.00	1.60	3.84	0.02	14.76	14.39	1.29
	Marsh	E	90cm	5.28	4.92	2.50	0.03	1.18	2.46	0.02	8.58	7.79	4.83
		E	0cm	4.12	3.17	2.73	0.19	1.23	2.62	0.04	7.21	6.89	2.27
Twin Heads	High Head	C	60cm	10.30	7.86	1.84	0.02	1.09	4.62	1.40	13.59	13.54	0.20
		C	90cm	10.72	7.70	2.15	0.01	1.03	5.10	1.16	13.84	14.04	-0.71
		E	30cm	13.12	7.67	1.96	0.09	1.43	16.50	12.80	25.69	27.88	-4.09
		E	60cm	10.46	7.10	1.67	0.04	1.03	6.20	2.66	14.36	14.80	-1.48
		W	30cm	13.60	8.41	2.09	0.07	1.32	11.16	5.77	20.97	21.46	-1.15
		W	60cm	9.46	8.12	1.76	0.01	1.04	2.77	0.67	11.94	11.89	0.21
	Wet Head	C	30cm	8.24	5.74	1.58	0.05	0.98	5.45	2.44	12.21	12.25	-0.17
		C	60cm	6.56	4.94	1.44	0.05	0.85	4.38	2.35	10.21	10.35	-0.65
		C	90cm	6.70	5.56	1.53	0.06	0.89	4.83	3.27	11.34	11.49	-0.68
	Near Tail	C	30cm	10.88	6.61	2.18	0.05	1.23	8.92	4.29	16.82	17.35	-1.56
		C	60cm	8.28	6.73	1.64	0.03	0.95	3.60	1.72	11.31	11.64	-1.41
	Marsh	W	0cm	5.62	4.66	n/a	0.05	0.73	1.43	n/a	6.88	5.62	10.07
		W	60cm	6.84	4.53	1.65	0.07	0.90	6.58	3.83	12.07	12.32	-1.02
		E	0cm	5.68	4.90	1.63	0.04	0.82	1.61	0.01	7.37	7.33	0.32
		E	60cm	7.36	4.95	1.52	0.06	0.80	4.65	2.35	10.46	11.23	-3.56

Table 2. Ion composition (meq L^{-1}) for the Satin Leaf and Twin Heads during Dry Down (February-March 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride and alkalinity [Alk ($CaCO_3$)] with calculated charge balance by vegetation type, well depth and sampling station.

Feb - Mar 2011				Alk	Ca	Mg	Na	K	Cl	SO_4
island	comm	location	depth	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Satin Leaf	High Head	C	90cm	272	91.3	10.6	46	2.1	74.8	0.1
	Wet Head	C	90cm	705	242.5	24.4	123.1	0.2	188.0	0.3
	Near Tail	C	90cm	535	186.8	19.4	88.4	0.1	130.0	1.0
	Marsh	E	90cm	264	98.6	14.3	56.5	1.2	88.5	0.8
		E	0cm	206	63.5	15	60.2	7.4	96.8	1.9
Twin Heads	High Head	C	60cm	515	157.5	13.3	106.3	0.6	65.1	67.3
		C	90cm	536	154.3	12.5	117.3	0.5	76.4	55.9
		E	30cm	656	153.7	17.4	379.6	3.4	69.6	615
		E	60cm	523	142.2	12.5	142.6	1.6	59.3	128
		W	30cm	680	168.6	16.1	256.7	2.7	74.1	277
		W	60cm	473	162.8	12.6	63.6	0.5	62.3	32.2
	Wet Head	C	30cm	412	115	11.9	125.3	1.9	56	117
		C	60cm	328	99	10.3	100.7	1.9	50.9	113.0
		C	90cm	335	111.5	10.8	111	2.4	54.1	157.0
	Near Tail	C	30cm	544	132.4	15	205.2	2.1	77.3	206
		C	60cm	414	134.9	11.6	82.8	1.1	58.2	82.4
	Marsh	W	0cm	281	93.4	8.9	33	2	n/a	n/a
		W	60cm	342	90.7	10.9	151.3	2.8	58.5	184.0
		E	0cm	284	98.1	10	37.1	1.7	57.9	0.7
		E	60cm	368	99.2	9.7	106.9	2.5	53.9	113.0

Table 3. Ion composition (mg L^{-1}) for the Satin Leaf and Twin Heads during Dry Down (January-February 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity [Alk ($CaCO_3$)] and hardness by vegetation community type (comm.), well depth and sampling station.

The September-October 2011 sampling corresponded to a period of regional rewetting. In 3AS3, $TDPO_4$ was highest in the central well cluster of the HH (X12S, X12D; Table 4A). Otherwise, P was only found to be high at the central WH well cluster (N3). $TDPO_4$ was high at this location in surface water as well. TDN concentrations were higher in the peat soils of the WH, NT and marsh as compared with more mineral soils of the HH. DOC concentrations coincided with TDN concentrations and were lowest in all locations of the

HH. DO and specific conductivity were variable and did not show consistent replication across similar well locations within communities (i.e. X12DD and X14DD). Field pH was higher in soil water of the HH and marsh and in marsh surface water.

island	comm	depth	station	Temp Deg C	Cond umhos/cm	DO mg/L	pH pH Units	DOC mg/L	TDKN mg/L	$TDPO_4$ mg/L
3AS3	High Head	60cm	WXD	26	1001	2.03	6.7	17.7	1.19	0.044
		30cm	X11S	26.5	1145	0.57	6.5	19.6	1.26	0.297
		60cm	X11D	25.6	1224	0.36	6.7	13.5	1.87	0.051
		30cm	X12S					12.11	0.8	0.294
		60cm	X12D	27.1	324	1.74	6.9	7.9	0.69	0.166
		90cm	X12DD	26.4	186	0.99	6.8	10.4	0.97	0.063
		60cm	X14D	26.6	243	3.51	7.1	8.5	0.61	0.08
		90cm	X14DD	25.8	1444	3.55	6.8	7.8	0.82	0.063
		60cm	X15D	26.7	254	2.27	6.9	7.2	0.58	0.094
		90cm	X15DD	25.3	178	0.97	6.7	8.2	0.76	0.148
	Wet Head	30cm	N2S	26.4	438	0.25	6.2	43.5	2.66	0.019
		60cm	N2D	25.8	642	0.41	6.1	51.3	2.75	0.014
		0cm	N3SW	26.1	455	2.41	6.7	56.8	2.99	0.171
		30cm	N3S	26.1	794	0.56	6.2	61.4	3.09	0.283
		60cm	N3D	26.2	1097	0.78	6.4	56.6	4.08	0.276
		30cm	N4S	26.7	1087	0.37	6.5	43.5	2.07	0.029
		60cm	N4D	25.7	1234	4.88	6.7	32.3	1.65	0.021
	Near Tail	30cm	S7S	26.1	333	0.69	6.2	42.4	2.07	0.019
		60cm	S7D	25.2	486	0.34	6	46.9	2.28	0.013
		30cm	S8S	26.7	558	1.24	6.5	56.4	2.68	0.03
		60cm	S8D	25.9	1237	0.44	6.1	46.1	2.45	0.008
		0cm	S9SW	28.5	389	0.95	6	60.6	2.64	0.073
		30cm	S9S	26.3	604	0.46	5.8	47.1	2.1	0.031
		60cm	S9D	25.9	861	0.42	5.9	31.2	1.54	0.022
	Marsh	0cm	M1	27.5	335	1.69	6.9	24.4	1.48	0.005
		30cm	M1S	27.9	738	1.09	6.4	48.5	3.55	0.006
		0cm	M2	28.5	322	2.03	7	21.4	1.46	0.005
		30cm	M2S	27.6	1013	0.37	6.4	63.7	3.95	0.006
		60cm	M2D	27.6	1004	0.33	6.5	50	2.66	0.005

Table 4. Water quality parameters for 3AS3 during Rewetting (September-October 2011). Temperature (Temp), specific conductivity (Cond), dissolved oxygen (DO), field pH, dissolved organic carbon (DOC), total dissolved Kjeldahl nitrogen (TDKN), total dissolved phosphate ($TDPO_4$) by vegetation community (comm.) and well depth at intact island 3AS3 in Water Conservation Area 3A. Station names are also provided.

In Ghost Island, soil waters of the HH had generally higher P concentrations than the HH of 3AS3 that were typically higher at the more shallow depths (Table 5B). There was some variation with depth, however concentrations in some locations were up to 10 times higher in the Ghost Island than at 3AS3. When comparing similar locations with 3AS3, the central WH of Ghost Island had lower P concentrations whereas other locations had higher P concentrations than 3AS3. Overall, TDN was higher in Ghost Island with little variation among soil water of different plant communities, including the HH. There were three sampling locations in the HH of the Ghost Island that had comparable DOC concentrations as 3AS3, but were otherwise similar to DOC concentrations in the WH and NT of 3AS3. However, several locations within the WH of the Ghost Island were twice as DOC concentrations of waters sampled from peat soils of 3AS3. The pattern in specific conductivity were better differentiated between vegetation community types in Ghost Island than 3AS3 during this sampling period with specific conductivity generally higher in soil water of the HH than other communities. Surface water specific conductivity was consistently lower in both islands.

island	comm	depth	station	Temp Deg C	Cond umhos/cm	DO mg/L	DOC mg/L	pH pH Units	TDKN mg/L	$TDPO_4$ mg/L
Ghost Island	High Head	30cm	GX3S	27.6	1234	0.96	45.4	6.4	2.54	1.758
		60cm	GX3D	26.9	1740	0.18	16.2	6.6	1.04	0.325
		0cm	GX2SW	28.8	340	0.58	22.4	7.0	1.47	0.139
		30cm	GX2S	27.3	1201	0.38	34.1	6.7	1.9	0.596
		60cm	GX2D				13.8		1.32	0.447
		90cm	GX2DD				12.1		0.75	0.38
		30cm	GX1S	27.6	1600	0.26	56.5	6.6	2.94	1.358
		60cm	GX1D	26.8	1820	0.35	34.1	6.4	2.15	1.23
		0cm	GNX1SW	29.0	327	1.33	20.0	7.0	1.15	0.007
		30cm	GNX1S	27.7	1317	0.14	78.3	6.4	4.12	0.967
		60cm	GNX1D	26.9	1385	0.43	41.1	6.5	2.59	0.531
		60cm	GWXD	27.2	1130	0.42	80.4	6.2	5.05	1.062
	Wet Head	30cm	GN3S	26.9	1042	0.31	114.0	6.1	6.8	0.044
		60cm	GN3D	26.7	1029	0.28	106.0	6.1	6.41	0.061
		0cm	GN2SW	28.0	335	0.64	23.5	6.9	1.39	0.078
		30cm	GN2S	27.7	944	5.93	108.0	6.6	5.73	0.102
		60cm	GN2D	26.7	1118	0.22	112.0	6.1	5.73	0.177
		30cm	GN1S				85.3		5.83	0.025
		60cm	GN1D				79.9		5.5	0.028
	Near Tail	30cm	GS3S	27.3	677	0.27	46.1	6.2	3.54	0.011
		60cm	GS3D	26.3	814	0.28	55.2	6.2	3.91	0.014
		0cm	GS2SW	26.8	334	0.44	20.6	6.8	1.55	0.008
		30cm	GS2S	27.2	364	0.36	31.0	6.3	1.91	0.012
		60cm	GS2D	26.3	827	0.39	56.7	6.2	3.02	0.041
		30cm	GS1S	28.0	437	0.32	27.5	6.5	1.61	0.008
		60cm	GS1D	27.4	921	0.6	50.2	6.3	3.03	0.032
	Marsh	0cm	GM2SW	29.6	321	3.63	20.1	7.2	1.27	0.003
		30cm	GM2S				39.1		3.12	0.005
		60cm	GM2D	27.7	859	0.18	42.3	6.4	3.37	0.007
		0cm	GM1SW	29.8	314	2.53	19.0	7.2	1.23	0.003
		30cm	GM1S	28.7	894	0.64	66.8	6.3	5.87	0.014
		60cm	GM1D	28.0	983	0.15	51.5	6.4	4.63	0.014

Table 5. Water quality parameters for Ghost Island during Rewetting (September-October 2011). Temperature (Temp), specific conductivity (Cond), dissolved oxygen (DO), field pH, dissolved organic carbon (DOC), total dissolved Kjeldahl nitrogen (TDKN), total dissolved phosphate ($TDPO_4$) by vegetation community (comm.) and well depth in Water Conservation Area 3A. Station names are also provided.

In Satin Leaf, conductivity was higher in soil water as compared with surface water (Table 6). DOC concentrations were generally positively correlated with TDKN concentrations. As in the dry down period, $TDPO_4$ was found to be elevated about relative to other communities only in the HH location. At Twin Heads, DOC was higher upon rewetting in most locations and $TDPO_4$ was only high at the central High Head location as compared with the sampling during dry down in February 2011.

In Satin Leaf, ions were in highest concentration in the WH location as was the case for the dry down period. (Tables 6&7) At this time however, SO_4 concentrations were higher in soil water as compared with surface water. In Twin Heads, SO_4 concentrations were lower in the HH and varied little with depth but in the WH, NT and marsh, SO_4 concentrations were higher at lower depth in the soil profile during the rewetting period. This may indicate that more shallow soils were less reducing as water levels and precipitation events were increasing with the onset of the wet season.

Sept - Oct 2011				**TEMP**	**COND**	**DO**	**pH**	**DOC**	**TDKN**	**$TDPO_4$**
island	**comm**	**depth**	**station**	**Deg C**	**umhos/cm**	**mg/L**	**pH Units**	**mg/L**	**mg/L**	**mg/L**
Satin Leaf	High Head	90cm	SL-HH-C-DD	25.4	1087	0.37	7.0	8.6	0.6	0.088
	Wet Head	0cm	SL-WH-C-SW	26.8	587	0.99	6.7	40.5	1.95	0.015
		90cm	SL-WH-C-DD	25.6	1780	0.2	6.6	67.0	3.1	0.005
	Near Tail	0cm	SL-NT-C-SW	27.1	296	2.14	6.9	13.9	0.91	0.004
		90cm	SL-NT-C-DD	26.7	1240	0.35	6.5	44.8	2.36	0.003
	Marsh	0cm	SL-SL-E-SW	28.3	242	5.49	7.4	7.6	0.71	0.002
		90cm	SL-SL-E-DD	28.4	254	4.19	7.1	8.0	0.67	0.002
Twin Heads	High Head	30cm	TH-HH-C-S	24.4	1490	1.52	7.0	14.7	1	0.194
		60cm	TH-HH-C-D	26.1	1312	0.26	6.8	9.2	0.71	0.247
		90cm	TH-HH-C-DD	26.2	1102	1.39	6.7	11.8	1.04	0.178
		30cm	TH-HH-E-S	26.0	1260	0.33	6.8	19.7	1.3	0.056
		60cm	TH-HH-E-D	25.9	991	0.32	6.5	14.7	0.94	0.056
		30cm	TH-HH-W-S	24.7	1183	1.79	6.8	17.5	1.22	0.028
		60cm	TH-HH-W-D	25.5	1104	0.67	6.5	16.4	1.1	0.035
	Wet Head	90cm	TH-WH-C-DD	25.7	1226	0.44	6.5	34.5	3.04	0.106
	Near Tail	0cm	TH-NT-C-SW	25.9	928	0.58	6.7	57.6	2.75	0.025
		30cm	TH-NT-C-S	25.5	948	0.45	6.4	49.3	2.3	0.007
		60cm	TH-NT-C-D	26.4	1145	0.73	6.3	35.0	2.11	0.005
	Marsh	0cm	TH-SL-W-SW	26.8	658	1.29	7.0	18.6	1.34	0.003
		30cm	TH-SL-W-S	25.1	724	0.47	6.7	16.7	1.75	0.003
		60cm	TH-SL-W-D	25.3	1022	0.6	6.9	19.0	2.67	0.02
		0cm	TH-SL-E-SW	27.6	674	4.42	7.4	25.7	1.27	0.003
		30cm	TH-SL-E-S	26.3	739	0.38	6.8	20.2	1.83	0.003
		60cm	TH-SL-E-D	26.6	1200	0.27	6.9	19.8	2.25	0.014

Table 6. Water quality parameters for Satin Leaf and Twin Heads during Rewetting (September-October 2011). Temperature (Temp), specific conductivity (Cond), dissolved oxygen (DO), field pH, dissolved organic carbon (DOC), total dissolved Kjeldahl nitrogen (TDKN), total dissolved phosphate ($TDPO_4$) by vegetation community (comm.) and well depth in Water Conservation Area 3A. Station names are also provided.

Sept - Oct 2011

island	comm	depth	station	Alk meq/L	Ca meq/L	Cl meq/L	K meq/L	Mg meq/L	Na meq/L	SO_4 meq/L	Σcations	Σanions	charge balance (%)
Satin Leaf	High Head	90cm	SL-HH-C-DD	7.00	5.41	3.78	0.02	0.91	4.75	0.07	11.09	10.85	1.1
	Wet Head	0cm	SL-WH-C-SW	3.92	3.21	1.79	0.05	0.88	2.03	0.01	6.18	5.72	3.9
		90cm	SL-WH-C-DD	12.40	11.32	6.09	0.01	1.86	6.10	0.42	19.29	18.91	1.0
	Near Tail	0cm	SL-NT-C-SW	2.24	1.75	0.66	0.05	0.48	0.81	0.02	3.08	2.92	2.6
		90cm	SL-NT-C-DD	8.98	8.55	3.30	0.00	1.37	3.73	0.73	13.65	13.01	2.4
	Marsh	0cm	SL-SL-E-SW	1.96	1.56	0.43	0.04	0.39	0.55	0.03	2.54	2.42	2.4
		90cm	SL-SL-E-DD	2.08	1.65	0.46	0.03	0.39	0.58	0.03	2.66	2.57	1.7
Twin Heads	High Head	30cm	TH-HH-C-S	8.67	N/A	6.05	N/A	N/A	N/A	0.27	N/A	N/A	N/A
		60cm	TH-HH-C-D	7.84	7.55	3.89	0.02	1.07	5.02	1.93	13.66	13.66	0.0
		90cm	TH-HH-C-DD	8.66	8.19	2.58	0.01	0.95	2.66	0.52	11.81	11.76	0.2
		30cm	TH-HH-E-S	10.08	10.85	2.43	0.01	0.95	2.48	1.35	14.29	13.86	1.5
		60cm	TH-HH-E-D	7.64	7.70	1.89	0.00	0.90	2.40	1.05	11.02	10.58	2.0
		30cm	TH-HH-W-S	9.88	10.23	2.12	0.01	0.99	2.05	1.13	13.27	13.13	0.5
		60cm	TH-HH-W-D	8.96	9.44	2.16	0.00	1.08	1.92	1.17	12.44	12.29	0.6
	Wet Head	90cm	TH-WH-C-DD	7.40	6.61	2.12	0.03	1.00	5.41	3.21	13.04	12.73	1.2
	Near Tail	0cm	TH-NT-C-SW	7.42	7.44	2.25	0.01	0.91	2.02	0.07	10.37	9.74	3.1
		30cm	TH-NT-C-S	6.40	7.62	2.49	0.00	0.86	1.90	0.40	10.38	9.29	5.5
		60cm	TH-NT-C-D	6.34	6.46	2.07	0.00	0.82	4.59	3.23	11.87	11.64	1.0
	Marsh	0cm	TH-SL-W-SW	5.54	4.73	1.46	0.04	0.73	1.37	0.03	6.87	7.03	-1.2
		30cm	TH-SL-W-S	6.02	4.37	1.50	0.06	0.86	2.12	0.14	7.41	7.66	-1.6
		60cm	TH-SL-W-D	7.72	3.48	1.53	0.08	0.79	6.37	1.63	10.72	10.88	-0.7
		0cm	TH-SL-E-SW	5.12	4.51	1.82	0.03	0.72	1.65	0.01	6.90	6.95	-0.4
		30cm	TH-SL-E-S	6.14	5.50	1.52	0.04	0.72	1.51	0.09	7.78	7.75	0.2
		60cm	TH-SL-E-D	9.20	4.36	1.49	0.09	1.10	7.41	2.66	12.96	13.36	-1.5

Table 7. Ion composition (meq L^{-1}) for the Satin Leaf and Twin Heads during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride and alkalinity [Alk ($CaCO_3$)] with calculated charge balance by vegetation type, well depth and sampling station.

Sept - Oct 2011				Alk	Ca	Cl	K	Mg	Na	SO_4
island	comm	depth	station	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Satin Leaf	High Head	90cm	SL-HH-C-DD	350	108.4	134.0	0.6	11.1	109.3	3.4
	Wet Head	0cm	SL-WH-C-SW	196	64.4	63.4	2.1	10.7	46.8	0.7
		90cm	SL-WH-C-DD	620	226.9	216.0	0.2	22.6	140.3	20.0
	Near Tail	0cm	SL-NT-C-SW	112	35	23.4	1.8	5.8	18.6	1.2
		90cm	SL-NT-C-DD	449	171.3	117.0	0.1	16.6	85.8	35.2
	Marsh	0cm	SL-SL-E-SW	98	31.3	15.2	1.4	4.7	12.7	1.4
		90cm	SL-SL-E-DD	104	33	16.3	1.3	4.8	13.4	1.3
Twin Heads	High Head	30cm	TH-HH-C-S	433		214.4				13.0
		60cm	TH-HH-C-D	392	151.3	138.0	0.7	13	115.5	92.5
		90cm	TH-HH-C-DD	433	164.1	91.6	0.2	11.6	61.2	24.8
		30cm	TH-HH-E-S	504	217.4	86.2	0.4	11.5	57.1	64.8
		60cm	TH-HH-E-D	382	154.4	66.9	0.1	11	55.3	50.5
		30cm	TH-HH-W-S	494	205	75.1	0.3	12	47.1	54.4
		60cm	TH-HH-W-D	448	189.2	76.6	0.1	13.1	44.1	56.0
	Wet Head	90cm	TH-WH-C-DD	370	132.4	75.2	1.2	12.1	124.4	154.0
	Near Tail	0cm	TH-NT-C-SW	371	149	79.9	0.2	11.1	46.4	3.3
		30cm	TH-NT-C-S	320	152.7	88.4	0.1	10.4	43.7	19.1
		60cm	TH-NT-C-D	317	129.5	73.5	0.1	10	105.5	155.0
	Marsh	0cm	TH-SL-W-SW	277	94.7	51.9	1.5	8.9	31.5	1.3
		30cm	TH-SL-W-S	301	87.6	53.2	2.5	10.4	48.8	6.7
		60cm	TH-SL-W-D	386	69.8	54.3	3	9.6	146.6	78.4
		0cm	TH-SL-E-SW	256	90.3	64.6	1.1	8.7	38	0.5
		30cm	TH-SL-E-S	307	110.3	53.8	1.4	8.8	34.8	4.5
		60cm	TH-SL-E-D	460	87.4	52.9	3.4	13.4	170.5	128.0

Table 8. Ion composition (mg L^{-1}) for the Satin Leaf and Twin Heads during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity [Alk ($CaCO_3$)] and hardness by vegetation community type, well depth and sampling station.

Average charge balance errors (Σcations-Σanions/Σcations+Σanions) were generally < ±7% but were between 7 and 10% for about 1/3 of the samples (Table 9). In 3AS3, the ions in greatest concentration expressed as meq L^{-1} were Cl, Na, and Mg in the HH at 60cm depth where the highest sums of cations and anions were generally found (Table 10). Sulfate concentrations were generally lower for WH, NT and marsh samples than HH samples. Notably, when expressed as meq/L, Cl ion concentration was higher than Ca in at 60cm depth in all three sampling locations of the HH indicating a low Ca:Cl. In all other locations, Ca:Cl was notably higher. In Ghost Island, concentrations of Cl, Na and Mg were lower in the HH than 3AS3 (Table 11). Comparing Ca and Cl, no locations within the Ghost Island HH had higher Cl than Ca resulting in consistently high Ca:Cl throughout the tree island. Concentrations of SO_4 were higher in several locations of the HH than soils of other communities (e.g.G X2D, GX2DD) in Ghost Island, but showed much higher differences between depths throughout the tree island. These differences were more easily discernible when evaluating concentrations in units of mg/L (Table 12).

island	comm	depth	station	Alk meq/L	Ca meq/L	Cl meq/L	K meq/L	Mg meq/L	Na meq/L	SO_4 meq/L	cations Σ	anions Σ	charge balance (%)
3AS3	High Head	60cm	WXD	7.74	8.57	1.44	0.01	0.41	1.37	0.22	10.36	9.40	4.9
		30cm	X11S	5.38	9.12	4.96	0.01	0.48	2.13	0.44	11.74	10.79	4.2
		60cm	X11D	9.68	11.37	2.14	0.02	0.70	1.55	0.37	13.64	12.19	5.6
		30cm	X12S	10.09		14.64							
		60cm	X12D	6.80	8.37	21.43	0.01	5.26	15.86	0.56	29.50	28.79	1.2
		90cm	X12DD	8.08	8.54	9.05	0.02	1.88	7.32	0.14	17.76	17.28	1.4
		60cm	X14D	7.82	5.21	13.25	0.01	1.91	16.68	1.73	23.80	22.81	2.1
		90cm	X14DD	9.16	7.13	3.84	0.02	1.69	6.04	0.77	14.87	13.76	3.9
		60cm	X15D	6.92	7.98	15.88	0.02	1.29	16.25	1.17	25.54	23.96	3.2
		90cm	X15DD	9.42	8.31	7.19	0.02	1.55	9.10	0.79	18.97	17.40	4.3
	Wet Head	30cm	N2S	2.80	3.32	1.16	0.01	0.35	1.08	0.01	4.76	3.97	9.0
		60cm	N2D	3.74	4.89	2.01	0.00	0.44	1.45	0.14	6.78	5.89	7.1
		0cm	N3SW	2.68	3.41	1.66	0.02	0.36	1.51	0.01	5.30	4.34	9.9
		30cm	N3S	4.64	6.29	2.88	0.01	0.65	2.03	0.10	8.98	7.61	8.2
		60cm	N3D	8.26	9.72	2.61	0.01	0.73	1.82	0.04	12.28	10.90	5.9
		30cm	N4S	7.66	9.24	2.76	0.01	0.73	2.10	0.22	12.08	10.64	6.4
		60cm	N4D	9.44	11.37	2.51	0.01	0.71	1.78	0.32	13.86	12.26	6.1
	Near Tail	30cm	S7S	2.08	2.30	0.91	0.00	0.35	0.90	0.04	3.55	3.03	7.9
		60cm	S7D	2.78	3.45	1.49	0.00	0.32	1.20	0.15	4.98	4.43	5.9
		30cm	S8S	2.48	3.50	2.21	0.00	0.41	1.68	0.15	5.59	4.84	7.3
		60cm	S8D	11.04	12.19	2.85	0.00	1.04	2.30	0.81	15.53	14.70	2.8
		0cm	S9SW	2.62									
		30cm	S9S	4.58	5.29	1.77	0.00	0.47	1.29	0.05	7.05	6.40	4.9
		60cm	S9D	7.38	8.12	1.80	0.00	0.66	1.41	0.15	10.19	9.34	4.4
	Marsh	0cm	M1	2.42	2.31	0.74	0.04	0.28	0.77	0.00	3.40	3.16	3.6
		30cm	M1S	5.62	5.51	1.34	0.14	0.53	1.72	0.00	7.89	6.96	6.3
		0cm	M2	2.20	2.27	0.72	0.05	0.28	0.80	0.00	3.39	2.93	7.3
		30cm	M2S	8.12	5.65	2.14	0.16	0.58	5.25	0.00	11.65	10.27	6.3
		60cm	M2D	9.04	5.66	1.38	0.11	0.56	4.75	0.01	11.09	10.43	3.1

Table 9. Ion composition (meq L^{-1}) for 3AS3 during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity [Alk ($CaCO_3$)] with calculated charge balance by vegetation community type, well depth and sampling station.

island	comm	depth	station	Alk meq/L	Ca meq/L	Cl meq/L	K meq/L	Mg meq/L	Na meq/L	SO4 meq/L	cations Σ	anions Σ	charge balance (%)
Ghost Island	High Head	30cm	GX3S	7.12	9.26	4.51	0.01	0.59	3.49	0.56	13.35	12.19	4.5
		60cm	GX3D	11.26	9.97	5.22	0.01	0.99	8.12	1.67	19.08	18.15	2.5
		0cm	GX2SW	2.40	2.32	0.63	0.05	0.39	0.83	0.01	3.59	3.04	8.3
		30cm	GX2S	8.40	6.00	2.79	0.00	0.65	6.47	1.11	13.12	12.29	3.2
		60cm	GX2D	12.18		2.95				2.58		17.71	
		90cm	GX2DD	14.21		2.54				2.46		19.21	
		30cm	GX1S	8.90	5.41	4.12	0.01	0.72	10.68	1.85	16.81	14.86	6.1
		60cm	GX1D	7.96	10.58	8.83	0.01	1.04	7.03	0.95	18.66	17.74	2.5
		0cm	GNX1SW	2.38	2.30	0.71	0.05	0.36	0.79	0.01	3.50	3.10	6.1
		30cm	GNX1S	8.06	5.47	3.44	0.03	0.75	7.68	1.42	13.93	12.92	3.8
		60cm	GNX1D	8.06	7.59	3.86	0.02	0.77	6.57	2.01	14.95	13.93	3.5
		60cm	GWXD	5.80	4.31	3.33	0.02	0.58	6.91	1.64	11.81	10.77	4.6
	Wet Head	30cm	GN3S	5.36	5.26	3.30	0.01	0.83	4.99	0.96	11.09	9.62	7.1
		60cm	GN3D	5.68	5.34	3.16	0.01	0.80	5.11	0.91	11.26	9.75	7.2
		0cm	GN2SW	2.30	2.22	0.77	0.06	0.39	0.84	0.00	3.51	3.07	6.6
		30cm	GN2S	5.40	6.57	3.21	0.01	0.90	2.69	0.29	10.16	8.90	6.6
		60cm	GN2D	5.68	6.02	3.78	0.00	0.77	4.89	0.78	11.68	10.24	6.6
		30cm	GN1S	4.32	4.76	2.82	0.02	0.74	3.36	0.45	8.88	7.59	7.8
		60cm	GN1D	4.48	4.52	3.07	0.02	0.71	4.57	1.01	9.81	8.56	6.8
	Near Tail	30cm	GS3S	4.30	4.55	1.97	0.03	0.69	1.94	0.14	7.21	6.41	5.9
		60cm	GS3D	3.92	3.98	2.20	0.03	0.62	4.18	1.76	8.80	7.88	5.5
		0cm	GS2SW	2.24	2.13	0.87	0.07	0.35	0.96	0.01	3.52	3.12	5.9
		30cm	GS2S	2.32	2.28	1.10	0.07	0.35	1.30	0.00	4.01	3.42	7.9
		60cm	GS2D	4.02	4.19	2.37	0.02	0.67	3.77	1.38	8.65	7.77	5.3
		30cm	GS1S	2.72	2.52	0.96	0.06	0.53	1.57	0.07	4.68	3.75	11.0
		60cm	GS1D	4.44	2.74	2.10	0.04	0.59	6.28	1.99	9.65	8.53	6.2
	Marsh	0cm	GM2SW	2.24	2.14	0.72	0.05	0.35	0.80	0.02	3.34	2.97	5.8
		30cm	GM2S	3.70	3.58	1.36	0.10	0.57	1.69	0.11	5.94	5.17	6.9
		60cm	GM2D	5.76	3.66	2.14	0.18	0.61	4.54	0.24	9.00	8.14	5.0
		0cm	GM1SW	2.24	2.20	0.68	0.05	0.34	0.78	0.01	3.37	2.93	6.9
		30cm	GM1S	5.84	3.09	1.68	0.03	0.72	6.41	0.82	10.24	8.34	10.3
		60cm	GM1D	6.90	3.95	1.93	0.04	0.67	5.73	0.73	10.38	9.56	4.1

Table 10. Ion composition (meq L^{-1}) for the Ghost Island during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride and alkalinity [Alk ($CaCO_3$)] with calculated charge balance by vegetation type, well depth and sampling station.

island	comm	depth	station	Alk mg/L	Ca mg/L	Cl mg/L	Hardness mg/L	K mg/L	Mg mg/L	Na mg/L	SO_4 mg/L
3AS3	High Head	60cm	WXD	387	171.7	51.0	449.5	0.2	5.0	31.6	10.6
		30cm	X11S	269	182.8	176.0	480.6	0.4	5.8	49.0	21.3
		60cm	X11D	484	227.9	75.8	587.4	0.7	8.5	35.7	18.0
		30cm	X12S	504		519.1					44.7
		60cm	X12D	340	167.8	760.0	682.6	0.2	64.0	364.8	27.0
		90cm	X12DD	404	171.1	321.0	521.2	0.8	22.8	168.4	6.9
		60cm	X14D	391	104.4	470.0	356.1	0.3	23.2	383.6	83.2
		90cm	X14DD	458	142.8	136.0	441.0	0.6	20.5	139.0	36.8
		60cm	X15D	346	159.9	563.0	464.0	0.8	15.7	373.8	56.1
		90cm	X15DD	471	166.5	255.0	493.0	0.7	18.8	209.3	37.8
	Wet Head	30cm	N2S	140	66.6	41.2	184.0	0.2	4.3	24.9	0.6
		60cm	N2D	187	97.9	71.2	266.6	0.1	5.4	33.4	6.6
		0cm	N3SW	134	68.3	58.7	184.7	0.6	4.4	34.8	0.4
		30cm	N3S	232	126.1	102.0	347.5	0.2	7.9	46.7	4.7
		60cm	N3D	413	194.7	92.5	522.9	0.3	8.9	41.9	1.7
		30cm	N4S	383	185.1	97.8	498.7	0.3	8.9	48.4	10.5
		60cm	N4D	472	227.8	88.9	604.1	0.2	8.6	41.0	15.2
	Near Tail	30cm	S7S	104	46.1	32.1	132.3	0.1	4.2	20.7	2.1
		60cm	S7D	139	69.2	53.0	188.8	0.1	3.9	27.7	7.3
		30cm	S8S	124	70.2	78.3	195.7	0.1	5.0	38.6	7.2
		60cm	S8D	552	244.3	101.0	648.8	0.1	12.6	52.9	38.8
		0cm	S9SW	131							
		30cm	S9S	229	106.1	62.7	288.4	0.1	5.7	29.6	2.3
		60cm	S9D	369	162.8	64.0	439.6	0.1	8.0	32.4	7.3
	Marsh	0cm	M1	121	46.3	26.1	129.7	1.6	3.4	17.6	0.1
		30cm	M1S	281	110.5	47.6	302.3	5.3	6.4	39.5	0.1
		0cm	M2	110	45.5	25.7	123.5	1.8	3.4	18.3	0.2
		30cm	M2S	406	113.3	76.0	312.2	6.4	7.1	120.8	0.2
		60cm	M2D	452	113.5	48.9	311.3	4.4	6.8	109.3	0.4

Table 11. Ion composition (mg L^{-1}) for 3AS3 during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity [Alk ($CaCO_3$)] and hardness by vegetation community type (comm.), well depth and sampling station.

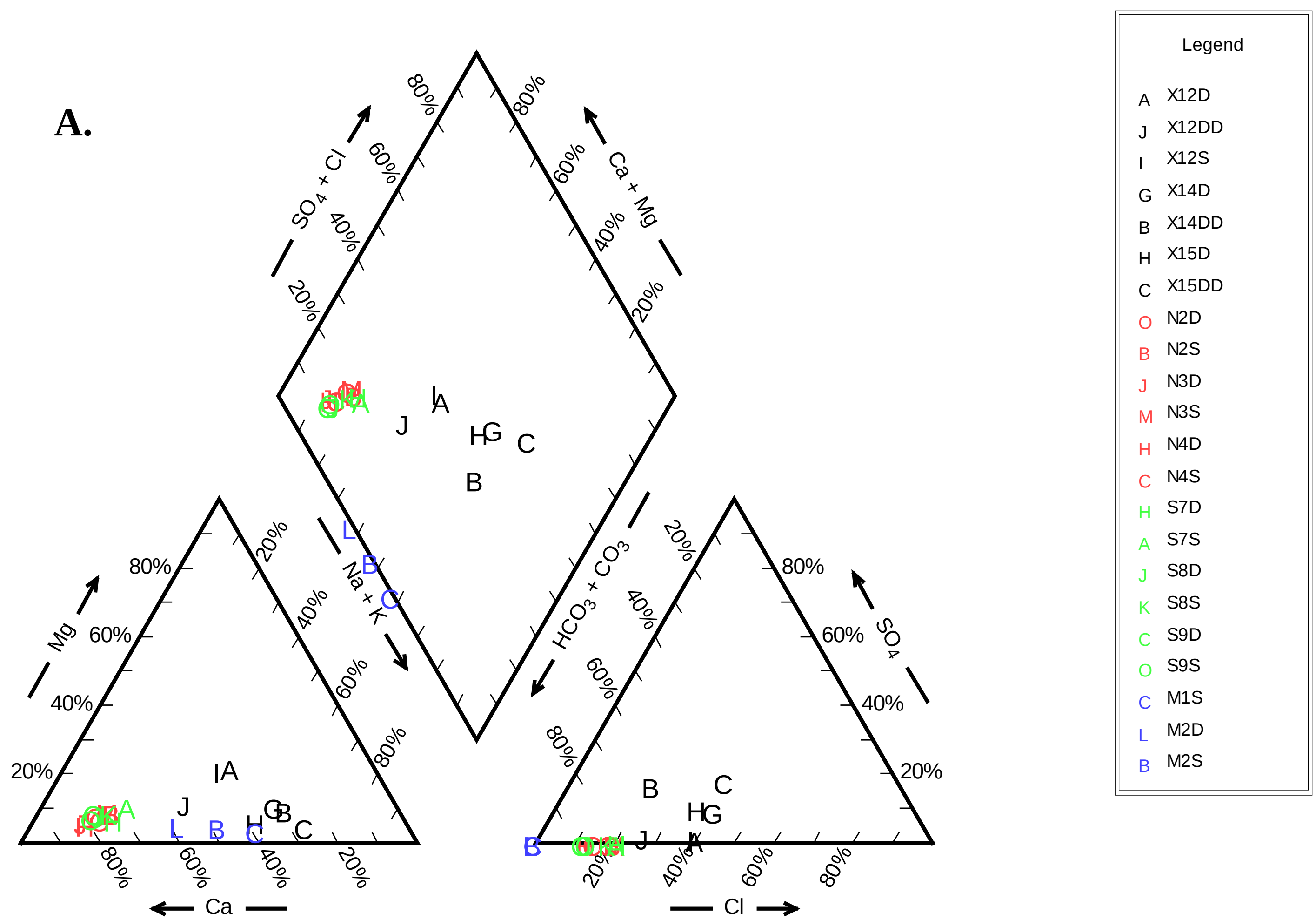
island	comm	depth	station	Alk mg/L	Ca mg/L	Cl mg/L	Hardness mg/L	K mg/L	Mg mg/L	Na mg/L	SO_4 mg/L
Ghost Island	High Head	30cm	GX3S	356	185.6	160.0	493.1	0.2	7.2	80.3	27.0
		60cm	GX3D	563	199.8	185.0	548.4	0.2	12.0	186.8	80.3
		0cm	GX2SW	120	46.5	22.5	135.3	2.0	4.7	19.2	0.3
		30cm	GX2S	420	120.2	98.8	332.8	0.1	7.9	148.7	53.1
		60cm	GX2D	609		104.6					124.0
		90cm	GX2DD	710		89.9					118.3
		30cm	GX1S	445	108.4	146.0	306.5	0.2	8.7	245.6	88.7
		60cm	GX1D	398	212.1	313.0	565.1	0.2	12.6	161.8	45.6
		0cm	GNX1SW	119	46.0	25.0	132.7	2.1	4.4	18.1	0.5
		30cm	GNX1S	403	109.7	122.0	311.4	1.2	9.1	176.6	68.1
		60cm	GNX1D	403	152.1	137.0	418.6	0.6	9.4	151.1	96.4
		60cm	GWXD	290	86.3	118.0	244.2	0.6	7.0	158.9	78.7
	Wet Head	30cm	GN3S	268	105.5	117.0	304.9	0.5	10.1	114.7	46.3
		60cm	GN3D	284	107.0	112.0	307.0	0.4	9.7	117.5	43.9
		0cm	GN2SW	115	44.5	27.2	130.5	2.2	4.7	19.4	0.2
		30cm	GN2S	270	131.7	114.0	373.6	0.2	10.9	61.8	13.8
		60cm	GN2D	284	120.6	134.0	339.8	0.1	9.4	112.4	37.4
		30cm	GN1S	216	95.4	100.0	275.5	0.7	9.0	77.2	21.8
		60cm	GN1D	224	90.5	109.0	261.5	0.7	8.6	105.1	48.3
	Near Tail	30cm	GS3S	215	91.1	69.7	262.0	1.2	8.4	44.6	6.8
		60cm	GS3D	196	79.7	78.0	229.9	1.0	7.5	96.1	84.4
		0cm	GS2SW	112	42.7	31.0	124.4	2.9	4.3	22.0	0.4
		30cm	GS2S	116	45.7	39.0	131.7	2.9	4.3	30.0	0.2
		60cm	GS2D	201	83.9	84.2	243.0	0.8	8.1	86.8	66.2
		30cm	GS1S	136	50.6	33.9	153.1	2.2	6.5	36.0	3.6
		60cm	GS1D	222	55.0	74.3	166.7	1.4	7.2	144.4	95.8
	Marsh	0cm	GM2SW	112	42.9	25.4	124.3	2.1	4.2	18.4	0.8
		30cm	GM2S	185	71.8	48.2	207.8	3.9	6.9	38.8	5.5
		60cm	GM2D	288	73.4	75.8	213.8	7.2	7.4	104.5	11.6
		0cm	GM1SW	112	44.1	24.1	127.0	1.9	4.1	18.0	0.7
		30cm	GM1S	292	61.9	59.4	190.5	1.1	8.7	147.4	39.4
		60cm	GM1D	345	79.2	68.3	231.0	1.5	8.1	131.7	35.3

Table 12. Ion composition (mg L^{-1}) for the Ghost Island during Rewetting (September-October 2011). Calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity [Alk ($CaCO_3$)] and hardness by vegetation community type, well depth and sampling station.

Comparing key water quality parameters for all islands, Ghost Island had the highest $TDPO_4$ concentrations, 3AS3 had the highest Cl concentrations and Twin Heads had the highest SO_4 concentrations. High $TDPO_4$ concentrations suggest the potential for greatest phosphorus loss to soil water. High Cl indicates the highest potential for evapoconcentration of subsurface salts. High SO_4 concentrations indicate a highly reducing soil environment with low potential for subsurface water exchange (i.e. groundwater-surface water interaction) in locations of the HH.

D. Summary of Hydrogeochemical Patterns. A Piper diagram clearly depicts general differences among individual sample locations and soils of plant communities of each of the islands (Figures 14-17). Patterns are illustrated for 3AS3 and Ghost Island for a wet period (October – November 2010) and rewetting period (September – October 2011). Plant community ion composition, illustrating integrated vegetation/hydrology patterns, showed the 3AS3 tree island to have the greatest differentiation among plant communities, most evident in comparing the HH with other plant communities. In 3AS3, soil waters of different plant communities are clearly discernible due to variation in several ions in two wet season samplings (wet - October 2010, rewetting – September 2011; Figure 15). In Ghost Island, plant communities are not clearly differentiated and well sample locations appear to separate mostly along gradients in Ca and SO_4. Notably differences among all four islands are the patterns of 3AS3. Soil water from this island, especially in the HH, is distinctly different from other islands. In Satin Leaf, there was more differentiation among plant communities during rewetting than dry down (Figure 16). Twin Heads ion composition patterns illustrated that there was greater variation along a Ca gradient than other ions in both dry down and rewetting periods within a narrow range of Cl concentrations for all communities (Figure 17).

A.


SO4 + Cl
Ca + Mg
Mg
Na + K
HCO3 + CO3
SO4
Ca
Cl
80%
60%
40%
20%
Legend
A X12D
J X12DD
I X12S
G X14D
B X14DD
H X15D
C X15DD
O N2D
B N2S
J N3D
M N3S
H N4D
C N4S
H S7D
A S7S
J S8D
K S8S
C S9D
O S9S
C M1S
L M2D
B M2S

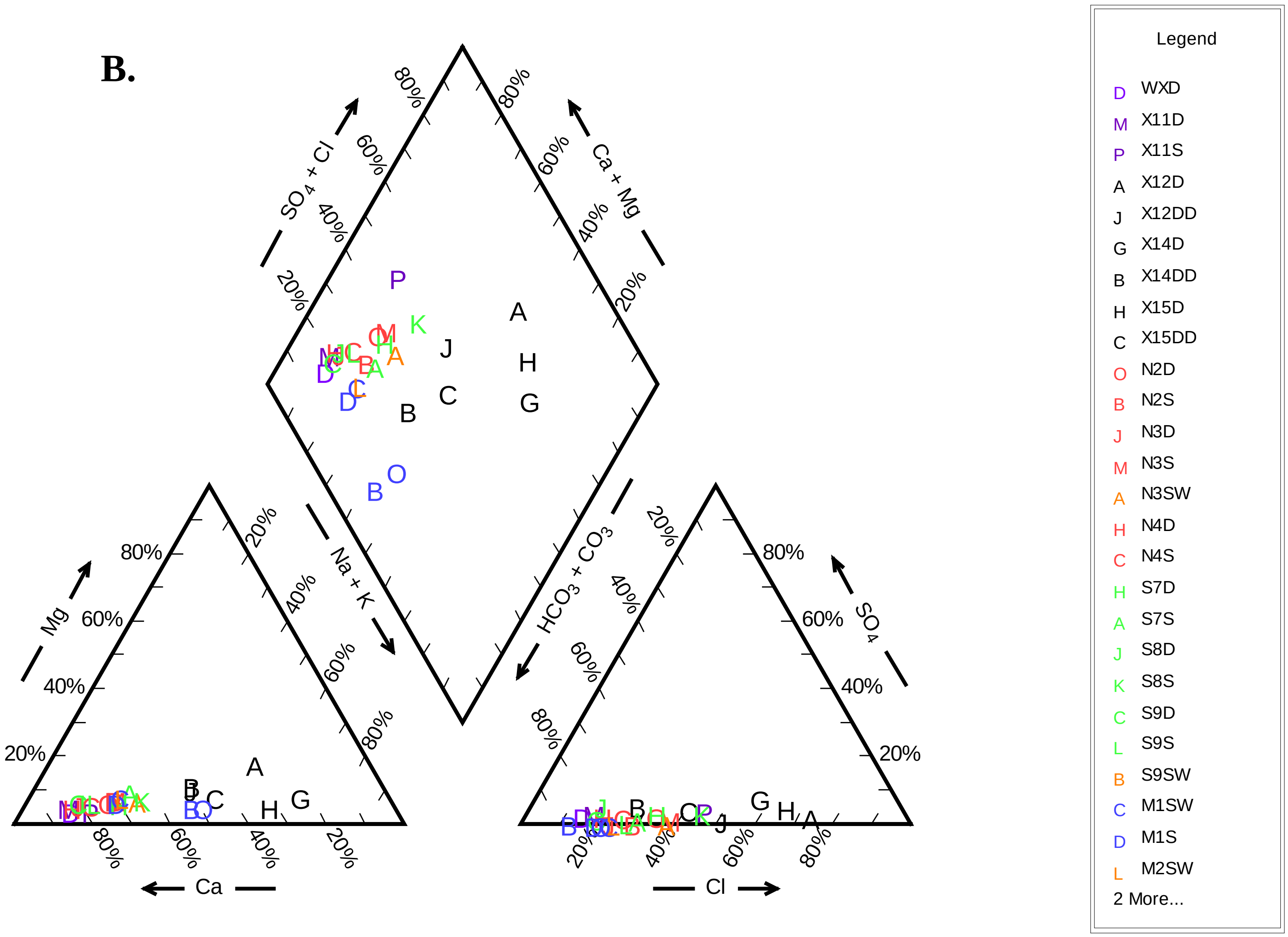
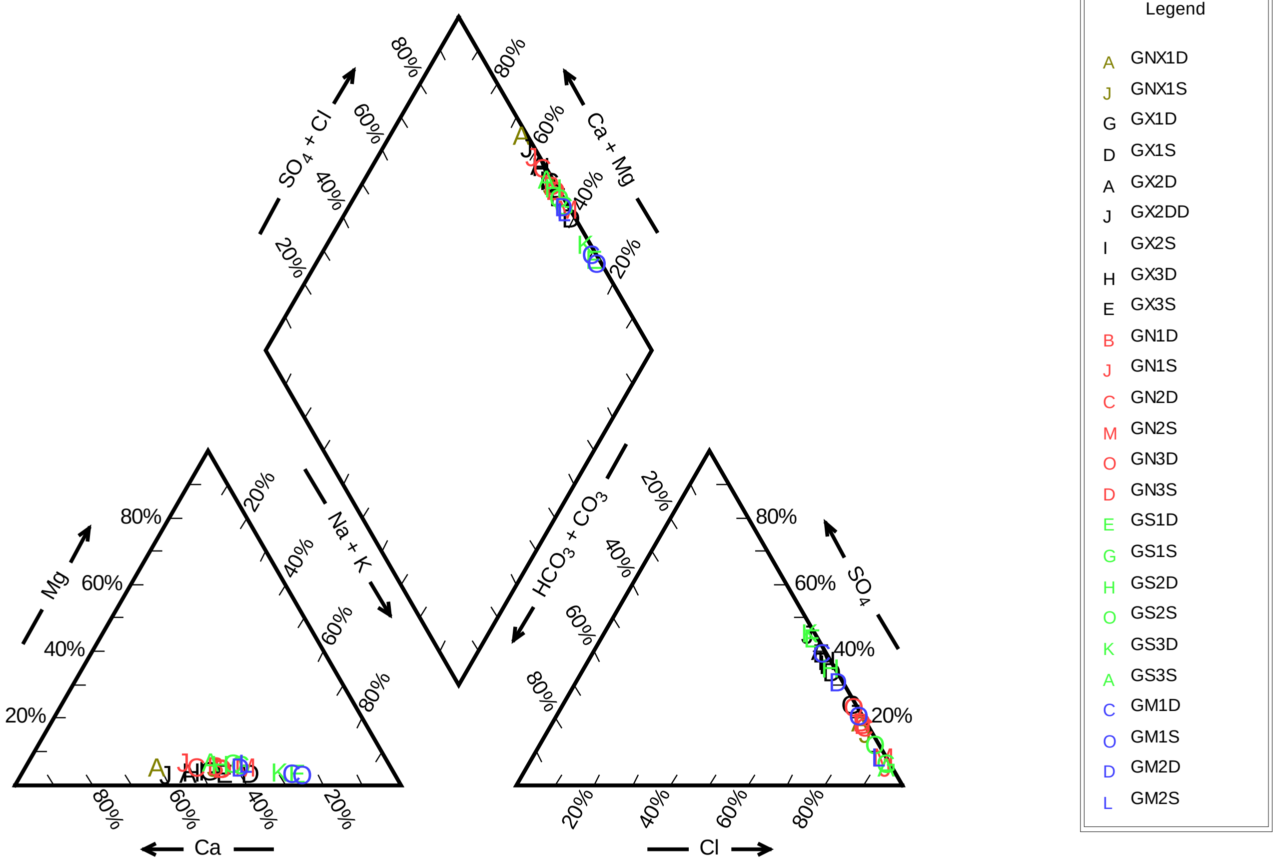


Figure 14. Piper diagrams summarizing ion composition for 3AS3 in A) October 2010 and B) August-October 2011 samplings. Black symbols represent High Head water samples, red symbols identify Wet Head water samples, green symbols mark Near Tail water samples and marsh samples are identified by blue symbols.

A.


SO4 + Cl
Ca + Mg
Na + K
HCO3 + CO3
Mg
Ca
SO4
Cl
20%
40%
60%
80%
Legend
A GNX1D
J GNX1S
G GX1D
D GX1S
A GX2D
J GX2DD
I GX2S
H GX3D
E GX3S
B GN1D
J GN1S
C GN2D
M GN2S
O GN3D
D GN3S
E GS1D
G GS1S
H GS2D
O GS2S
K GS3D
A GS3S
C GM1D
O GM1S
D GM2D
L GM2S

B.

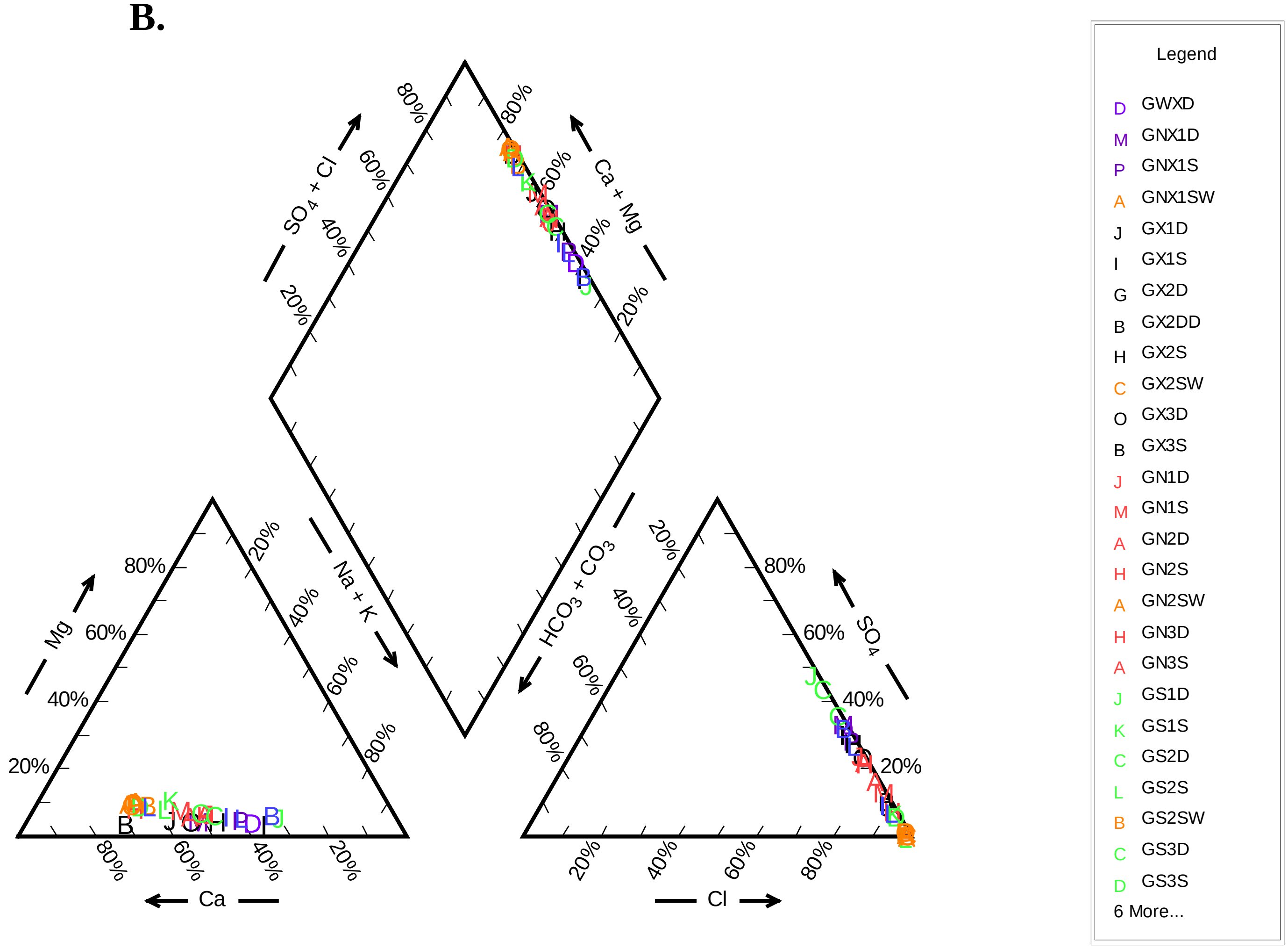
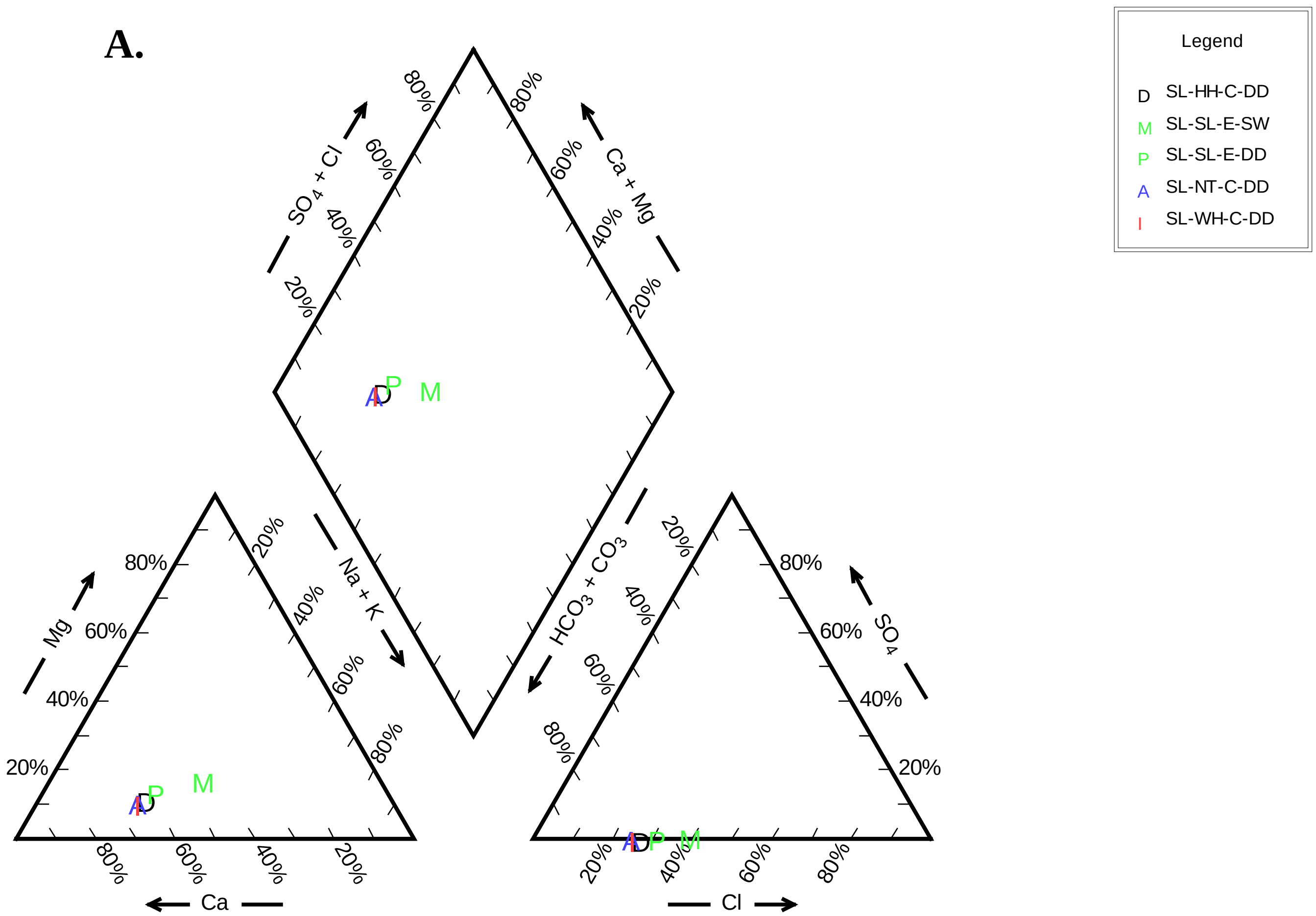


Figure 15. Piper diagrams summarizing ion composition for Ghost Island in A) October 2010 and B) August-October 2011 samplings. Black symbols represent High Head water samples, red symbols identify Wet Head water samples, green symbols mark Near Tail water samples and marsh samples are identified by blue symbols.

A.



SO4 + Cl
Ca + Mg
Mg
Ca
Na + K
HCO3 + CO3
SO4
Cl
20%
40%
60%
80%
Legend
D SL-HH-C-DD
M SL-SL-E-SW
P SL-SL-E-DD
A SL-NT-C-DD
I SL-WH-C-DD

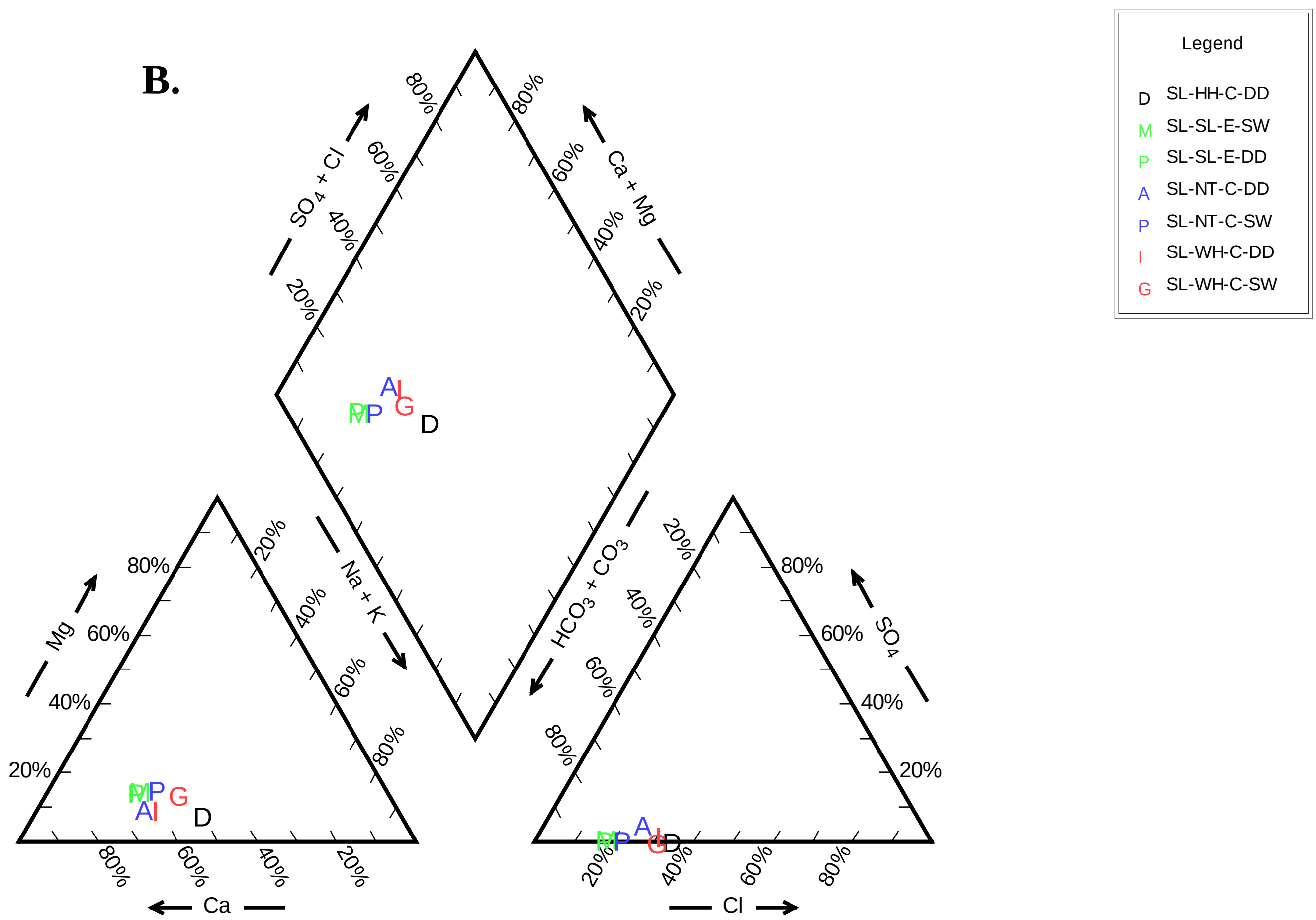
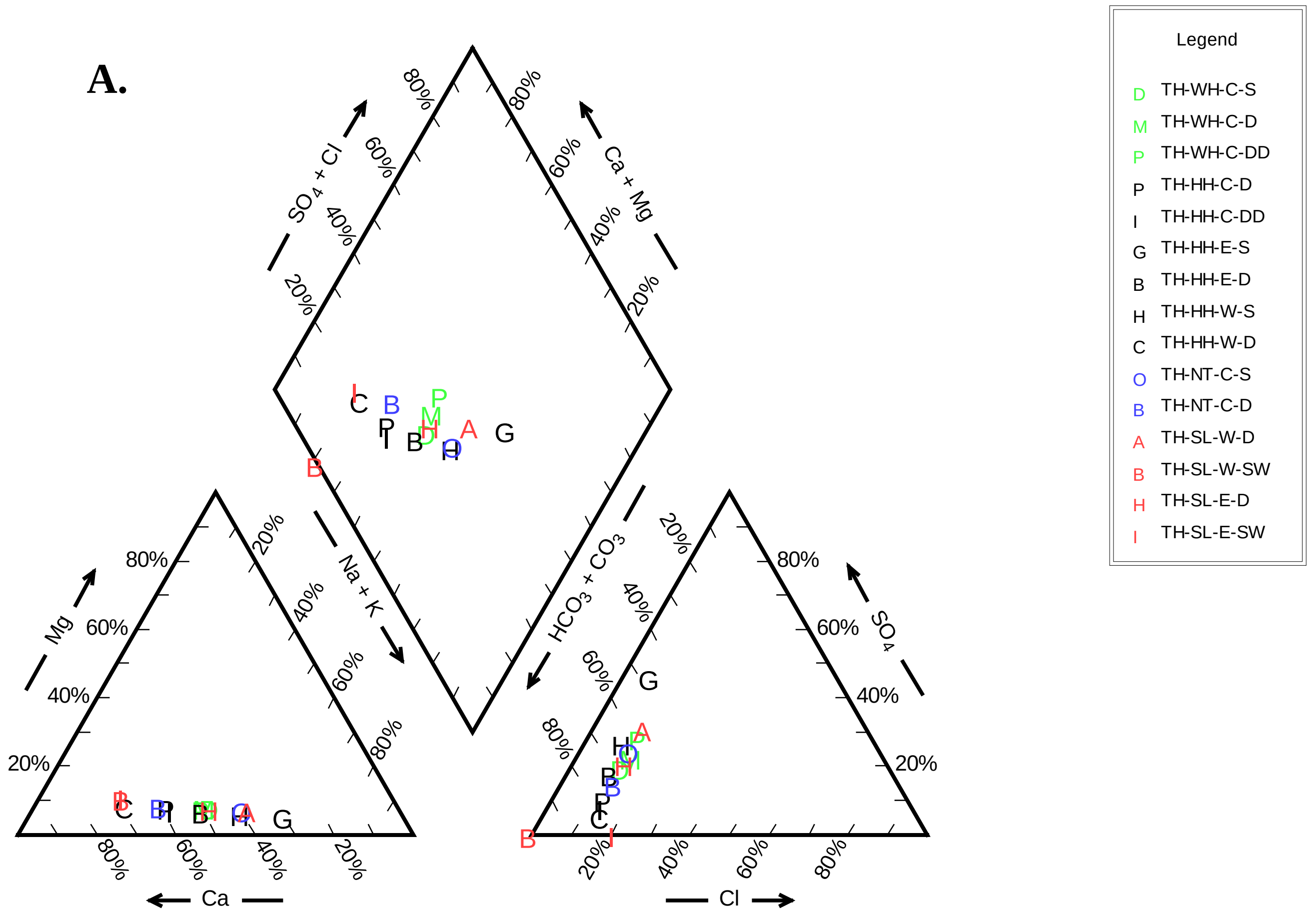


Figure 16. Piper diagrams summarizing ion composition for Satin Leaf in A) February 2011 and B) August-October 2011 samplings. Black symbols represent High Head water samples, red symbols identify Wet Head water samples, green symbols mark Near Tail water samples and marsh samples are identified by blue symbols.

A.



SO$_4$ + Cl
Ca + Mg
Na + K
HCO$_3$ + CO$_3$
Mg
Ca
Cl
SO$_4$
Legend
D TH-WH-C-S
M TH-WH-C-D
P TH-WH-C-DD
P TH-HH-C-D
I TH-HH-C-DD
G TH-HH-E-S
B TH-HH-E-D
H TH-HH-W-S
C TH-HH-W-D
O TH-NT-C-S
B TH-NT-C-D
A TH-SL-W-D
B TH-SL-W-SW
H TH-SL-E-D
I TH-SL-E-SW

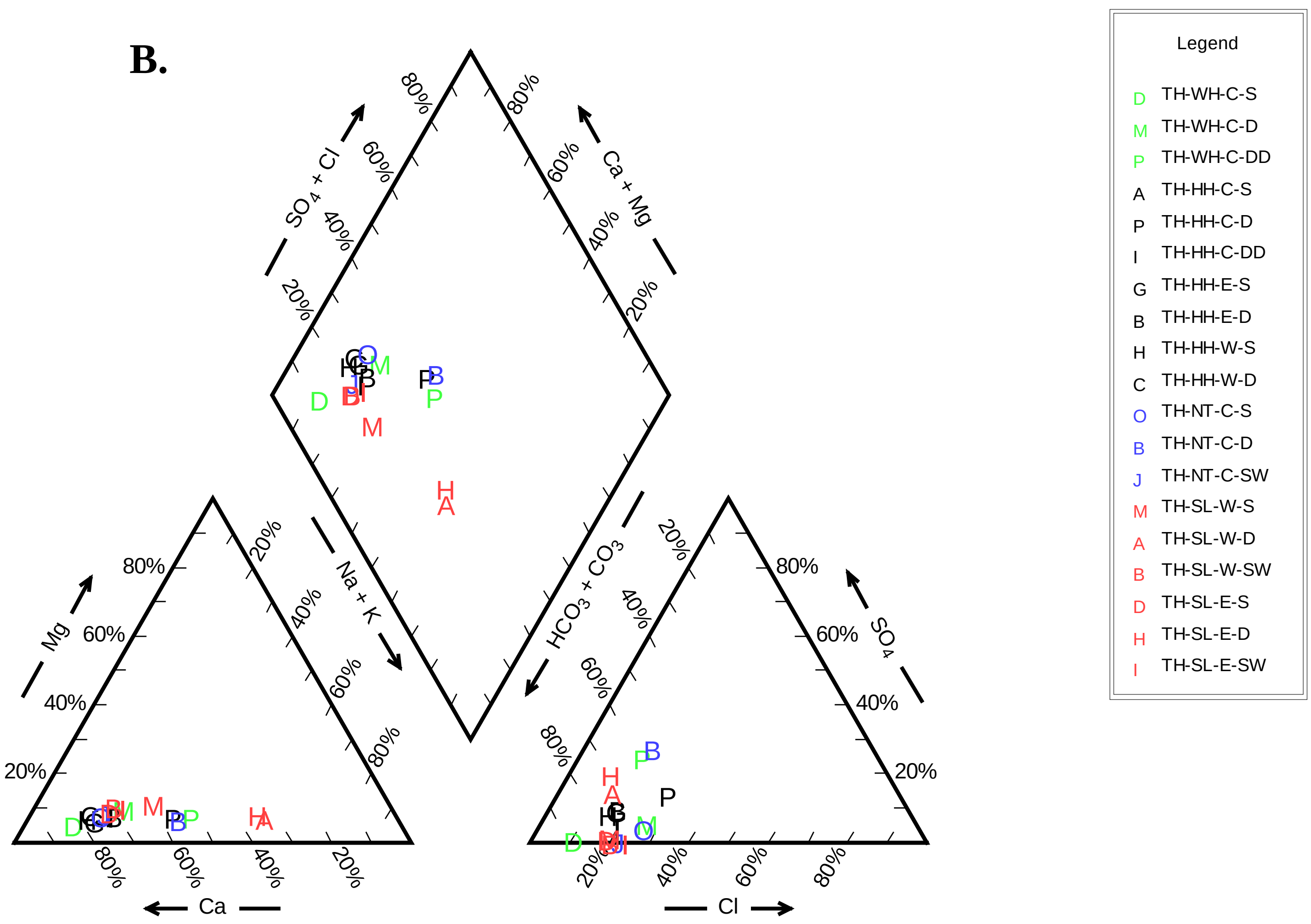


Figure 17. Piper diagrams summarizing ion composition for Twin Heads in A) February 2011 and B) August-October 2011 samplings. Black symbols represent High Head water samples, green symbols identify Wet Head water samples, blue symbols mark Near Tail water samples and marsh samples are identified by mauve symbols.

Summarizing key water quality parameters along with saturation indices of calcite and aragonite (Tables 13-16) further illustrate important differences in hydrogeochemical characteristics among the wet, intact tree island (3AS3), the wet, degraded tree island (Ghost Island), the dry, degraded island (Twin Heads) and the dry, intact island (Satin Leaf). Saturation indices indicate a tendency toward mineral precipitation or dissolution that are thought to be influenced by the active evapoconcentration of salts, especially Cl. Thus, a tree island that showed high Cl and soil waters indicating a tendency toward mineral precipitation would be characteristic of a "healthy" tree island because increased ion concentrations can promote stability of high P mineral soils found in the dry heads of many tree islands (Wetzel et al 2011; Ross et al 2011). Thus, $CaCO_3$ saturation index, in combination with $TDPO_4$ and other water quality parameters, is a key index of tree island structure and function.

Although the sampling was limited for both collections periods, during dry down at Satin Leaf, the dry, intact island shows consistently higher ion concentrations in the WH based on this and previous studies (Sullivan 2011). High ion concentrations in the WH coincide with water that tends toward supersaturation of $CaCO_3$ relative to calcite and thus mineral precipitation. This is an interesting result as WH soils are typically peat with waters that tend toward dissolution. Either soils in the WH of Satin Leaf have considerable mineral composition or wetland trees promote accumulation of salts in WH soil water. We are unable to collect soil samples at Satin Leaf to verify these results. Also interesting is that in the HH waters that might be expected to show potential for mineral saturation because of interaction with mineral soils otherwise show that they are approximately saturated. In addition, on the basis of meq L^{-1}, Ca > Cl in all locations sampled at Satin Leaf - considering the limited sampling that was permitted there. Samples collected during dry down at the dry, degraded island Twin Heads revealed high ion concentrations in the HH that led to tendency toward mineral precipitation, however Ca also >> Cl in HH as with other locations in the island. During regional rewetting, $CaCO_3$ supersaturation coincided with Cl concentrations that exceeded Ca concentrations in the HH of Satin Leaf and Ca and Cl concentrations that were similar (based on meq L^{-1}) in the WH. At Tiwn Heads, although Ca and Cl more closely approximated in the Central HH location, $CaCO_3$ supersaturation coincided with soil water with Ca > Cl.

Feb - Mar 2011				**Ca**	**Cl**	**pH**	**SO_4**	**$TDPO_4$**	**SI**		**SI**	
island	**comm**	**location**	**depth**	**mg/L**	**mg/L**	**pH Units**	**mg/L**	**mg/L**	**calcite**		**aragonite**	
Satin Leaf	High Head	C	90cm	91.3	74.8	7.00	0.1	0.052	0.107	S	-0.058	A
	Wet Head	C	90cm	242.5	188.0	6.60	0.3	0.009	0.437	S	0.272	S
	Near Tail	C	90cm	186.8	130.0	6.60	1.0	0.006	0.237	S	0.072	A
	Marsh	E	90cm	98.6	88.5	6.50	0.8	0.003	-0.386	U	-0.551	U
		E	0cm	63.5	96.8	6.70	1.9	0.004	-0.469	U	-0.634	U
Twin Heads	High Head	C	60cm	157.5	65.1	6.74	67.3	0.103	0.354	S	0.190	S
		C	90cm	154.3	76.4	7.10	55.9	0.195	0.716	S	0.552	S
		E	30cm	153.7	69.6	6.92	615	0.122	0.541	S	0.377	S
		E	60cm	142.2	59.3	6.76	128	0.241	0.334	S	0.170	S
		W	30cm	168.6	74.1	6.84	277	0.193	0.551	S	0.387	S
		W	60cm	162.8	62.3	6.64	32.2	0.103	0.244	S	0.079	A
	Wet Head	C	30cm	115	56	6.70	117	0.326	0.080	A	-0.084	A
		C	60cm	99	50.9	6.70	113.0	0.098	-0.638	A	-0.228	U
		C	90cm	111.5	54.1	6.80	157.0	0.090	0.093	A	-0.072	A
	Near Tail	C	30cm	132.4	77.3	6.90	206	0.095	0.439	S	0.275	S
		C	60cm	134.9	58.2	6.80	82.4	0.228	0.268	S	0.104	S
	Marsh	W	0cm	93.4	n/a	6.93	n/a	0.001	0.126	S	-0.039	A
		W	60cm	90.7	58.5	6.83	184.0	0.005	0.034	A	-0.131	U
		E	0cm	98.1	57.9	7.13	0.7	0.002	0.342	S	0.178	S
		E	60cm	99.2	53.9	6.82	113.0	0.005	0.108	S	-0.056	A

Table 13. Water quality summary parameters for Satin Leaf and Twin Heads during Dry Down (January-February 2011) including Ca, Cl, field pH, SO_4, $TDPO_4$, and calcium carbonate saturation indices (SI) relative to calcite and aragonite by vegetation community type, well depth and sampling station. Saturation indices indicate supersaturation (SI>0=S), approximate saturation (SI~0=A), and undersaturation (SI<0=U). Identifiers are provided for ease of interpretation.

Sept - Oct 2011				Ca	Cl	pH	SO_4	$TDPO_4$	SI		SI	
island	comm	depth	station	mg/L	mg/L	pH Units	mg/L	mg/L	calcite		aragonite	
Satin Leaf	High Head	90cm	SL-HH-C-DD	108.4	134.0	7.0	3.4	0.088	0.322	S	0.158	S
	Wet Head	0cm	SL-WH-C-SW	64.4	63.4	6.7	0.7	0.015	-0.392	U	-0.556	U
		90cm	SL-WH-C-DD	226.9	216.0	6.6	20.0	0.005	0.422	S	0.258	S
	Near Tail	0cm	SL-NT-C-SW	35	23.4	6.9	1.2	0.004	-0.643	U	-0.807	U
		90cm	SL-NT-C-DD	171.3	117.0	6.5	35.2	0.003	0.113	S	-0.051	A
	Marsh	0cm	SL-SL-E-SW	31.3	15.2	7.4	1.4	0.002	-0.221	U	-0.385	U
		90cm	SL-SL-E-DD	33	16.3	7.1	1.3	0.002	-0.473	U	-0.637	U
Twin Heads	High Head	30cm	TH-HH-C-S	N/A	214.4	7.0	13.0	0.194	N/A		N/A	
		60cm	TH-HH-C-D	151.3	138.0	6.8	92.5	0.247	0.305	S	0.141	S
		90cm	TH-HH-C-DD	164.1	91.6	6.7	24.8	0.178	0.308	S	0.144	S
		30cm	TH-HH-E-S	217.4	86.2	6.8	64.8	0.056	0.535	S	0.371	S
		60cm	TH-HH-E-D	154.4	66.9	6.5	50.5	0.056	-0.003	A	-0.167	U
		30cm	TH-HH-W-S	205	75.1	6.8	54.4	0.028	0.541	S	0.377	S
		60cm	TH-HH-W-D	189.2	76.6	6.5	56.0	0.035	0.192	S	0.028	A
	Wet Head	90cm	TH-WH-C-DD	132.4	75.2	6.5	154.0	0.106	-0.069	A	-0.233	U
	Near Tail	0cm	TH-NT-C-SW	149	79.9	6.7	3.3	0.025	0.171	S	0.007	A
		30cm	TH-NT-C-S	152.7	88.4	6.4	19.1	0.007	-0.154	U	-0.318	U
		60cm	TH-NT-C-D	129.5	73.5	6.3	155.0	0.005	-0.336	U	-0.500	U
	Marsh	0cm	TH-SL-W-SW	94.7	51.9	7.0	1.3	0.003	0.226	S	0.062	A
		30cm	TH-SL-W-S	87.6	53.2	6.7	6.7	0.003	-0.116	U	-0.280	U
		60cm	TH-SL-W-D	69.8	54.3	6.9	78.4	0.02	0.087	A	-0.077	A
		0cm	TH-SL-E-SW	90.3	64.6	7.4	0.5	0.003	0.561	S	0.397	S
		30cm	TH-SL-E-S	110.3	53.8	6.8	4.5	0.003	0.129	S	-0.035	A
		60cm	TH-SL-E-D	87.4	52.9	6.9	128.0	0.014	0.240	S	0.076	A

Table 14. Water quality summary parameters for Satin Leaf and Twin Heads during Rewetting (September-October 2011), including Ca, Cl, field pH, SO_4, $TDPO_4$, and calcium carbonate saturation indices (SI) relative to calcite and aragonite by vegetation community type, well depth and sampling station. Saturation indices indicate supersaturation (SI>0=S), approximate saturation (SI~0=A), and undersaturation (SI<0=U). Identifiers are provided for ease of interpretation.

In general, the wet, intact tree island (3AS3) had lower $TDPO_4$ concentrations in the HH that coincided with soil waters that were supersaturated with respect to calcite and aragonite and indicating a theoretical tendency for mineral precipitation. In the wet, degraded tree island (Ghost Island), $TDPO_4$ concentrations were higher in the HH with saturation tendency more frequently toward mineral dissolution. This key relationship illustrates the potential for degradation of highly concentrated mineral P in the degraded tree island.

				Ca	Cl	pH	SO_4	$TDPO_4$	mineral saturation			
island	comm	depth	station	mg/L	mg/L	pH Units	mg/L	mg/L	calcite		aragonite	
3AS3	High Head	60cm	WXD	171.7	51.0	6.7	10.6	0.044	0.270	S	0.106	S
		30cm	X11S	182.8	176.0	6.5	21.3	0.297	-0.066	A	-0.230	U
		60cm	X11D	227.9	75.8	6.7	18.0	0.051	0.453	S	0.289	S
		30cm	X12S		519.1		44.7	0.294				
		60cm	X12D	167.8	760.0	6.9	27.0	0.166	0.315	S	0.151	S
		90cm	X12DD	171.1	321.0	6.8	6.9	0.063	0.345	S	0.181	S
		60cm	X14D	104.4	470.0	7.1	83.2	0.08	0.396	S	0.232	S
		90cm	X14DD	142.8	136.0	6.8	36.8	0.063	0.333	S	0.168	S
		60cm	X15D	159.9	563.0	6.9	56.1	0.094	0.320	S	0.156	S
		90cm	X15DD	166.5	255.0	6.7	37.8	0.148	0.281	S	0.117	S
	Wet Head	30cm	N2S	66.6	41.2	6.2	0.6	0.019	-1.015	U	-1.015	U
		60cm	N2D	97.9	71.2	6.1	6.6	0.014	-0.858	U	-1.022	U
		0cm	N3SW	68.3	58.7	6.7	0.4	0.171	-0.535	U	-0.699	U
		30cm	N3S	126.1	102.0	6.2	4.7	0.283	-0.574	U	-0.738	U
		60cm	N3D	194.7	92.5	6.4	1.7	0.276	0.030	A	-0.134	U
		30cm	N4S	185.1	97.8	6.5	10.5	0.029	0.092	A	-0.072	A
		60cm	N4D	227.8	88.9	6.7	15.2	0.021	0.444	S	0.279	S
	Near Tail	30cm	S7S	46.1	32.1	6.2	2.1	0.019	-1.286	U	-1.450	U
		60cm	S7D	69.2	53.0	6.0	7.3	0.013	-1.221	U	-1.385	U
		30cm	S8S	70.2	78.3	6.5	7.2	0.03	-0.751	U	-0.915	U
		60cm	S8D	244.3	101.0	6.1	38.8	0.008	-0.072	A	-0.237	U
		0cm	S9SW			6.0		0.073				
		30cm	S9S	106.1	62.7	5.8	2.3	0.031	-1.030	U	-1.194	U
		60cm	S9D	162.8	64.0	5.9	7.3	0.022	-0.575	U	-0.739	U
	Marsh	0cm	M1	46.3	26.1	6.9	0.1	0.005	-0.493	U	-0.657	U
		30cm	M1S	110.5	47.6	6.4	0.1	0.006	-0.314	U	-0.478	U
		0cm	M2	45.5	25.7	7.0	0.2	0.005	-0.426	U	-0.590	U
		30cm	M2S	113.3	76.0	6.4	0.2	0.006	-0.175	U	-0.339	U
		60cm	M2D	113.5	48.9	6.5	0.4	0.005	-0.021	A	-0.185	U

Table 15. Water quality summary parameters for 3AS3 during Rewetting (September-October 2011), including Ca, Cl, field pH, SO_4, $TDPO_4$, and calcium carbonate saturation indices (SI) relative to calcite and aragonite by vegetation community type, well depth and sampling station. Saturation indices indicate supersaturation (SI>0=S), approximate saturation (SI~0=A), and undersaturation (SI<0=U). Identifiers are provided for ease of interpretation.

island	comm	depth	station	Ca mg/L	Cl mg/L	pH pH Units	SO_4 mg/L	$TDPO_4$ mg/L	mineral saturation calcite		aragonite	
Ghost Island	High Head	30cm	GX3S	185.6	160.0	6.4	27.0	1.758	-0.037	A	-0.201	U
		60cm	GX3D	199.8	185.0	6.6	80.3	0.325	0.353	S	0.189	S
		0cm	GX2SW	46.5	22.5	7.0	0.3	0.139	-0.378	U	-0.542	U
		30cm	GX2S	120.2	98.8	6.7	53.1	0.596	0.152	S	-0.012	A
		60cm	GX2D		104.6		124.0	0.447				
		90cm	GX2DD		89.9		118.3	0.38				
		30cm	GX1S	108.4	146.0	6.6	88.7	1.358	0.015	A	-0.149	U
		60cm	GX1D	212.1	313.0	6.4	45.6	1.23	0.026	A	-0.138	U
		0cm	GNX1SW	46.0	25.0	7.0	0.5	0.007	-0.380	U	-0.544	U
		30cm	GNX1S	109.7	122.0	6.4	68.1	0.967	-0.211	U	-0.375	U
		60cm	GNX1D	152.1	137.0	6.5	96.4	0.531	0.011	A	-0.153	U
		60cm	GWXD	86.3	118.0	6.2	78.7	1.062	-0.652	U	-0.816	U
	Wet Head	30cm	GN3S	105.5	117.0	6.1	46.3	0.044	-0.705	U	-0.869	U
		60cm	GN3D	107.0	112.0	6.1	43.9	0.061	-0.676	U	-0.840	U
		0cm	GN2SW	44.5	27.2	6.9	0.2	0.078	-0.525	U	-0.689	U
		30cm	GN2S	131.7	114.0	6.6	13.8	0.102	-0.088	A	-0.252	U
		60cm	GN2D	120.6	134.0	6.1	37.4	0.177	-0.626	U	-0.790	U
		30cm	GN1S	95.4	100.0		21.8	0.025				
		60cm	GN1D	90.5	109.0		48.3	0.028				
	Near Tail	30cm	GS3S	91.1	69.7	6.2	6.8	0.011	-0.715	U	-0.879	U
		60cm	GS3D	79.7	78.0	6.2	84.4	0.014	-0.845	U	-1.009	U
		0cm	GS2SW	42.7	31.0	6.8	0.4	0.008	-0.672	U	-0.836	U
		30cm	GS2S	45.7	39.0	6.3	0.2	0.012	-1.130	U	-1.294	U
		60cm	GS2D	83.9	84.2	6.2	66.2	0.041	-0.806	U	-0.970	U
		30cm	GS1S	50.6	33.9	6.5	3.6	0.008	-0.813	U	-0.976	U
		60cm	GS1D	55.0	74.3	6.3	95.8	0.032	-0.834	U	-0.998	U
	Marsh	0cm	GM2SW	42.9	25.4	7.2	0.8	0.003	-0.226	U	-0.390	U
		30cm	GM2S	71.8	48.2		5.5	0.005				
		60cm	GM2D	73.4	75.8	6.4	11.6	0.007	-0.486	U	-0.650	U
		0cm	GM1SW	44.1	24.1	7.2	0.7	0.003	-0.212	U	-0.375	U
		30cm	GM1S	61.9	59.4	6.3	39.4	0.014	-0.656	U	-0.820	U
		60cm	GM1D	79.2	68.3	6.4	35.3	0.014	-0.389	U	-0.553	U

Table 16. Water quality summary parameters for Ghost Island during Rewetting (September-October 2011), including Ca, Cl, field pH, SO_4, $TDPO_4$, and calcium carbonate saturation indices (SI) relative to calcite and aragonite by vegetation community type, well depth and sampling station. Saturation indices indicate supersaturation (SI>0=S), approximate saturation (SI~0=A), and undersaturation (SI<0=U). Identifiers are provided for ease of interpretation.

The variation in Ca:Cl, $TDPO_4$ and SI among islands is clearly illustrated with a plot of average values for HH soil water (Figure 18). The wet, intact and dry, degraded islands have SI values indicating potential for mineral precipitation with low variability within the HH. However, the wet, intact island suggests preferential evapoconcentration of Cl relative to Ca (Ca:Cl < 1) whereas high Ca:Cl in the dry, degraded island suggests a lack of Cl evapoconcentration. Despite the high concentrations of Ca in soil water, trees are not concentrating Cl ions, suggesting less potential for mineral precipitation. Soil water from the HH of the dry, intact island Satin Leaf falls between 3AS3 and Twin Heads with respect to SI and Ca:Cl. It is likely that this island represents an outlier rather than a comparable dry, intact island using the hydrologic-degradation approach we have employed in this study. Observations about vegetation community structure of the HH (tropical hardwood hammock), apparent HH soil elevation above the marsh surface, and landscape characteristics (relatively short hydroperiod, rocky glades type marsh) suggest that the difference in its ecological structure may exceed the difference due to its degree of dryness or "health" along a hydrology-degradation continuum. Ghost Island also falls between 3AS3 and TH but SI indicates lower potential mineral precipitation coinciding with a higher Ca:Cl than the wet, intact island. For reference, marsh soil water is also plotted, illustrating high Ca relative to calcite and interaction with peat soils having no potential for mineral precipitation (SI << 1).

Despite variation in Ca:Cl, HH soil waters of tree islands except Ghost Island showed elevated $TDPO_4$ relative to marsh soil water, but average values below 0.25 mg L^{-1}. Ghost Island however had average $TDPO_4$ nearly 4 times the average concentration of other islands. Lower potential for mineral precipitation and high $TDPO_4$ suggests that HH soils are less stable and likely releasing phosphorus. Moreover, the overflooded Ghost Island illustrated the greatest deviation from other islands in Ca:Cl, $TDPO_4$ and $SI_{calcite}$.

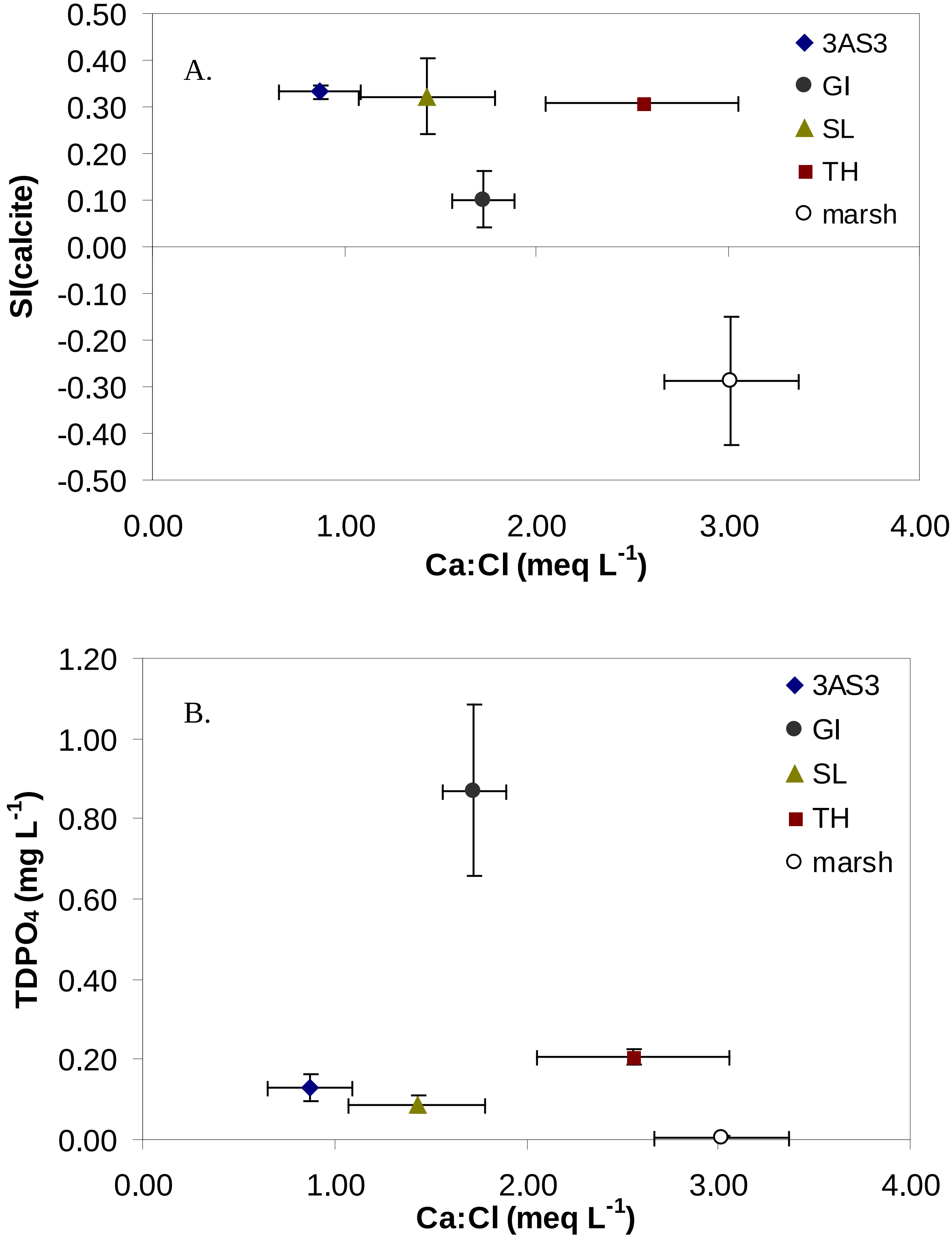


Figure 18. Plots of average Ca:Cl with A) saturation index of $CaCO_3$ relative to calcite and B) $TDPO_4$ for soil water from the High Head and Marsh for rewetting period (September – October 2011) with bars indicating standard error.

D. Four Island Comparison of Select Hydrogeochemical Parameters

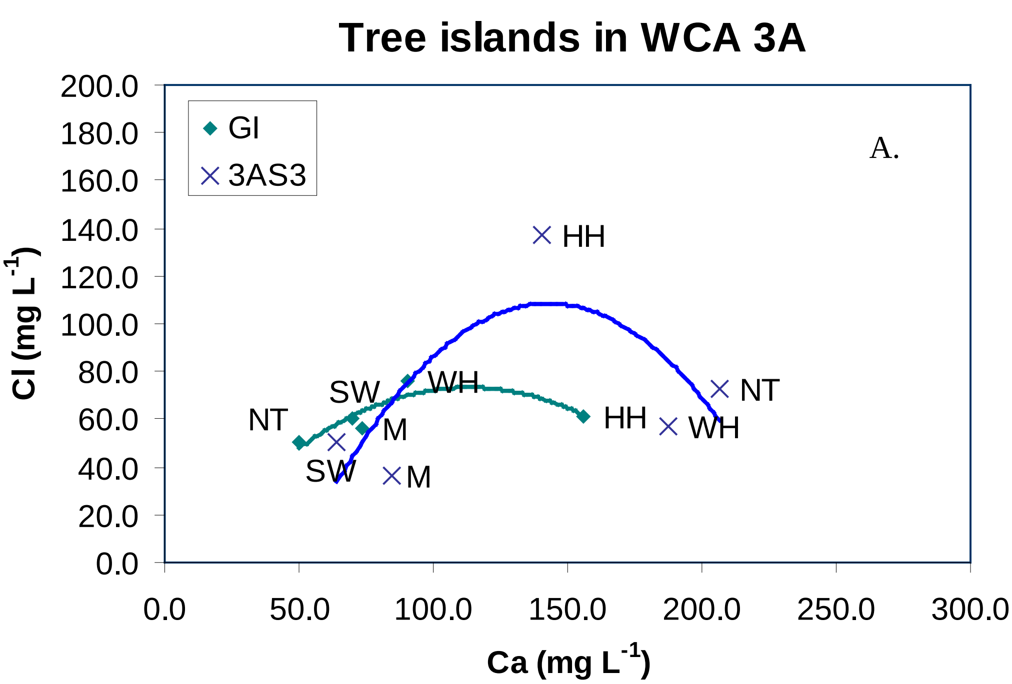
The tree islands span a hydrologic and degradation continuum of intact-wet (3AS3), intact-dry (Satin Leaf), degraded-wet (Ghost Island) and degraded-dry (Twin Heads). These assessments are based on extant vegetation communities and water management history. Moreover, the sampling design and water quality parameters of the study provide information suggestive of tree island hydrogeochemical processes with respect to variation in vegetation community, ecological condition and hydrologic setting. Average values of key water quality parameters Ca:Cl, SI and $TDPO_4$ reveal important differences in HH soils among islands. There is also pronounced variation within and among communities indicating areas of maximum activity. The results from this project illustrate key areas for the development of tree island indicators and where further sampling should be focused for monitoring and assessment of tree islands across the Everglades.

i. Ca/Cl – plant community comparisons of dry down and rewetting periods

Comparing patterns of Cl and Ca illustrate some important differences among the islands with respect to evapoconcentration potential (i.e. an indicator of tree island "health"). Where Cl concentrations are found to be higher in soil water relative to other water pools provides evidence of ion exclusion or evapoconcentration by plants. Comparing Cl and Ca concentrations is especially useful for identifying zones of Cl accumulation of Everglades water profiles since Cl is non reactive as compared with Ca which can be precipitated as $CaCO_3$ or other mineral compounds or released with dissolution.

While the specific mechanism or combination of mechanisms for Cl accumulation have not been determined experimentally or otherwise precisely known, high Cl concentrations may result from ion exclusion by plants and/or low dilution by water pools low in Cl. Whereas, low Cl concentrations may coincide with low potential for accumulation (low plant water uptake) or high dilution by other water pools low in Cl. Patterns of Ca and Cl in the "intact" (3AS3) tree island of the WCA 3A illustrated pronounced Cl accumulation in shallow soil water (60cm depth) of the dry head (HH) community as compared with wet head (WH), near tail (NT), marsh (M) soil water and marsh surface water (SW). HH soil water in 3AS3 was approximately twice as high as the mean of other water samples. Cl concentrations were also significantly higher in the HH of 3AS3 than Ghost Island (Tables 3 and 4). Comparing communities of both islands, there was a significant increase in Cl concentrations with Ca concentrations in the Ghost Island (y=1.02x-8.76; r^2=0.95) whereas a polynomial-type relationship in 3AS3 (Figure 19; NS). In 3AS3, this pattern was described by a non-linear trend (not significant) between Ca and Cl (Figure 19A) as HH soil water had higher Cl but lower Ca than WH or NT indicating high potential for evapoconcentration and either: 1) Ca precipitation or 2) low potential for dilution by surface water/groundwater. In the degraded island (Ghost Island – GI), there was also evidence of a non-linear trend, but WH soil water Cl concentrations were somewhat higher than the mean for other samples. Another useful trend to note is the difference in the patterns for the HH as compared with WH and NT for these two islands. Available Ca is nearly four times higher in the WH and NT communities of the intact island as compared with the degraded island. Furthermore, in the HH of the intact island, Ca concentrations are lower than WH and NT whereas, in the degraded island, Ca concentrations are higher in the HH than the WH and NT. This suggests that Cl accumulation may be associated with Ca precipitation in the soil water of the HH community of the intact island but not the degraded island or other plant communities. Ca precipitation is an important mechanism for tree island stabilization and resilience that appears intact in the HH of the wet, intact island 3AS3 but absent in the degraded island.

The drier conditions of the WCA 3B and ENP are associated with different patterns of Ca relative to Cl. The Satin Leaf tree island (dry, intact) is situated in a short hydroperiod rocky glade. The vegetation community in the HH is dominated by upland hammock species including *Chrysophyllum oliveforme* (satin leaf), *Bursera simarouba* (gumbo limbo) and *Coccoloba diversifolia* (pigeon plum) suggesting that the position of the water table is lower or the duration of root zone inundation is shorter on the HH than is found on the wetter islands in the WCA 3A. In fact, water levels in the Satin Leaf island were approximately 15cm lower in the HH and 45cm lower in the WH as compared with these communities in the wet, intact 3AS3 island in November 2010. This is only a preliminary comparison as the hydropattern of WCA3A and ENP are significantly different but suggested that the hydrology of the HH on 3AS3 is comparably to the hydrology of the WH on Satin Leaf. The Cl concentrations found at Satin Leaf (at 70cm depth) suggest low evapoconcentration the HH during dry down (similar to values for SW and M) and possible mixing or dilution with marsh water as compared to the WH (Figure 19B). We also found a positive, linear relationship between Ca and Cl (r^2=0.86, F=18.94, p=0.022). However Ca concentrations are in the range of values for WH and NT of the wet, intact island and may suggest that there is less potential for Ca precipitation in the WH of Satin Leaf at this depth (70cm). In the dry, degraded island Twin Heads in WCA 3B, the vegetation community appears to have a history of disturbance characterized by a large, downed *Ficus aurea* (strangler fig), *Lantana camara* (exotic lantana) and *Eupatorium capillifolium* (dog fennel). There is a narrow range of both Cl and Ca concentrations suggesting little differentiation among communities and low potential for ion accumulation based on Cl concentrations. However, the trend is similar to that of the dry, intact island although not significant (p=0.09). Similar to the degraded, wet Ghost Island, Ca concentrations are highest in the HH suggesting little potential for precipitation (or possible dilution) by marsh water (Saha et al 2010, Sullivan 2011).



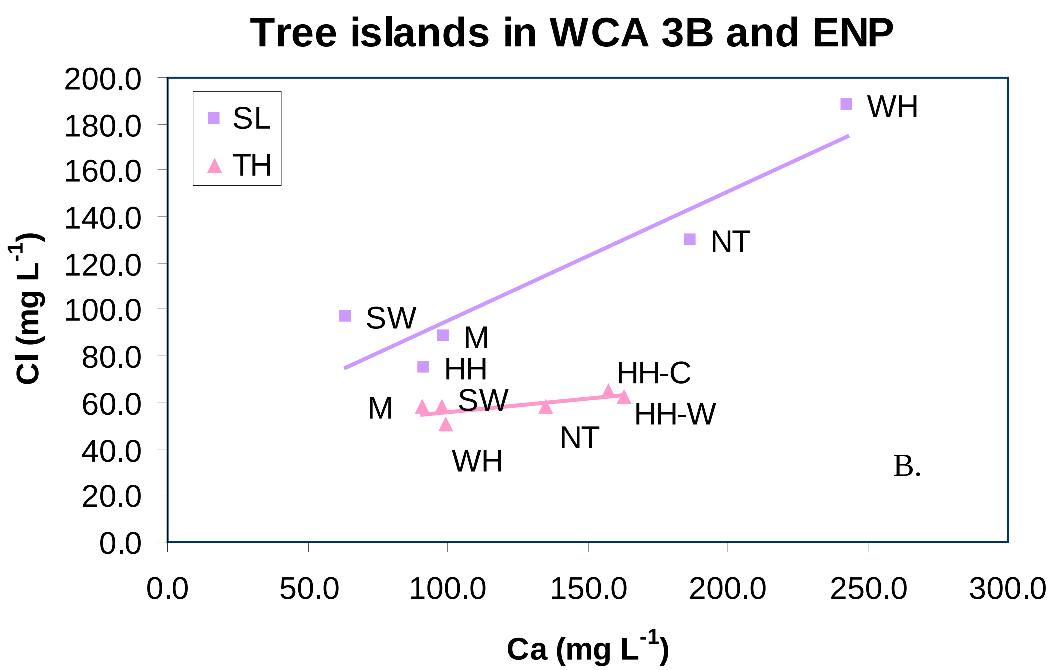
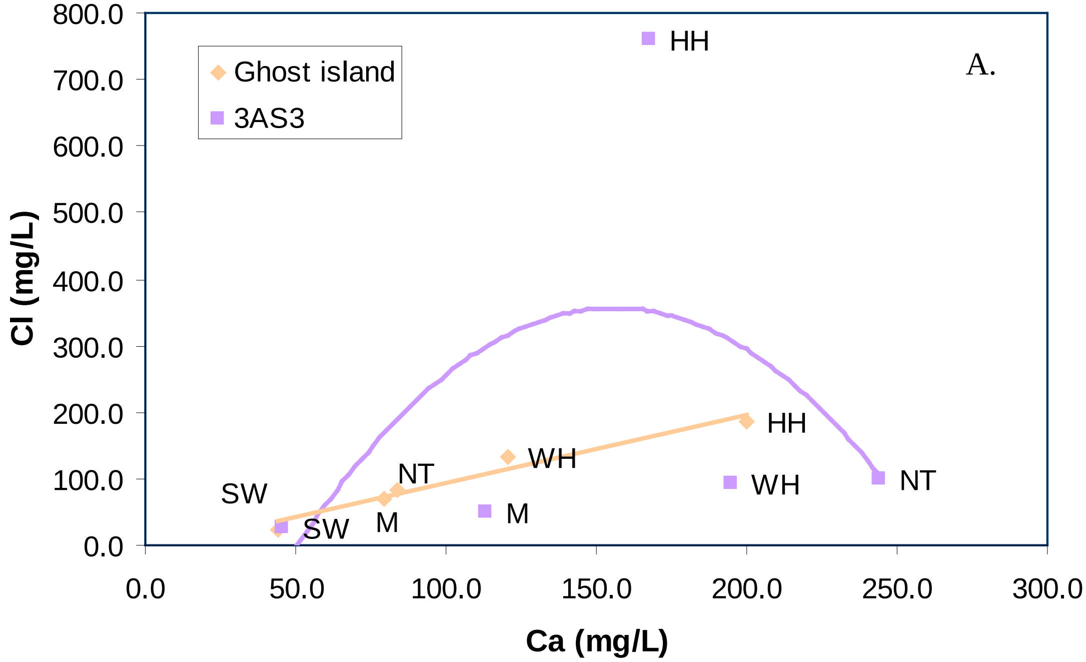


Figure 19. Soil water Ca and Cl concentrations for A) a wet, degraded island (Ghost Island-GI) and a wet, intact island (3AS3) in the WCA 3A and B) a dry, degraded island (twin heads-TH) and a dry, intact island (satin leaf – SL) during dry down (January – February 2012).

During rewetting, there were similar patterns in wet and dry islands (Figure 20). One notable difference between dry down and rewetting that was common to all islands was that Cl concentrations in the HH were higher during rewetting. In the intact islands, 3AS3 and Satin leaf, Cl concentrations were four times and twice as high during rewetting as compared with the dry down period. Despite this high seasonal variation in Cl concentrations in the HH, neither Cl concentrations for other plant communities nor Ca concentrations varied between the dry down and rewetting periods. The implication is that Cl concentrations are highly influenced by local hydrology and plant-water interactions in the HH. Moreover, the evapoconcentration of Cl is very sensitive to hydrologic variation.



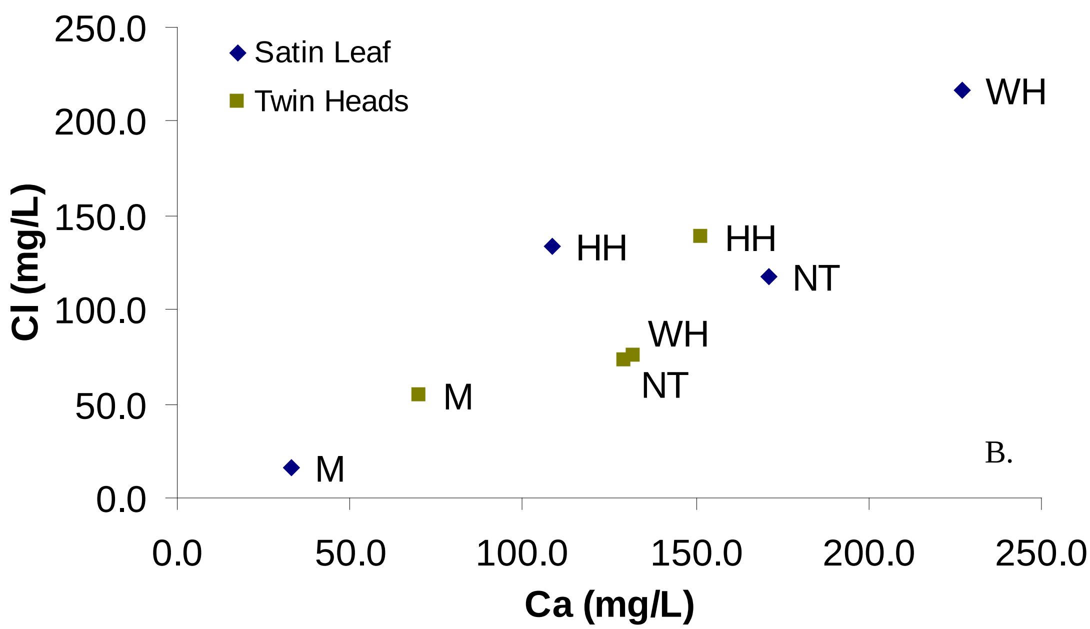


Figure 20. Ca and Cl concentrations at 60cm depth among communities of A) 3AS3 and Ghost Island and B) Satin Leaf and Twin Heads during rewetting (September-October 2011).

ii. $TDPO_4$, Cl and $SI_{calcite}$ – among and within communities during rewetting

Overall, the most important water quality parameters differentiating the HH of 3AS3 and Ghost Island were Cl, $SI_{calcite}$ and $TDPO_4$. Differences were found both within and among communities. While Cl indicates potential for plant-water interactions that accumulate ions in soil water, $SI_{calcite}$ provides a value indicating potential for $CaCO_3$ precipitation or dissolution relative to calcite. Comparing values of $TDPO_4$ and $SI_{calcite}$ may be useful for determining tree island characteristics that maintain the stability of P contained in HH soils, a key goal of this work.

In comparing values among communities in all islands, average values for SI in the HH indicated potential for mineral precipitation, specifically relative to calcite (Figure 21). Average $TDPO_4$ in soil water was higher in the degraded islands than in the intact islands. In the WH, the intact wet island 3AS3 continues to indicate elevated concentrations of $TDPO_4$ (Troxler et al in revision). A tree island P budget for the 3AS3 tree island suggests this originates from the HH in lateral transport downstream. Due to variability among communities, trends in calcite SI and Cl concentrations showed strong positive relationships in the intact islands 3AS3 and Satin Leaf (Figure 23; polynomial and linear, respectively). However, in the intact, dry island Satin Leaf, the WH had higher $SI_{calcite}$ and Cl than the HH community. This was in contrast to the wet, intact island that had higher $SI_{calcite}$ and Cl in the HH community. Although there was a wide range in $SI_{calcite}$ among communities of the Ghost Island, there was a narrow range in Cl concentrations. Patterns for the dry, degraded Twin Heads islands were similar as for the wet, degraded Ghost Island (Figure 23).

Within the HH and WH communities, the wet, degraded Ghost Island exhibited the highest variability; there was a significant negative relationship between calcite SI and $TDPO_4$ (Figure 22; $y=12.45x^2-7.58x+1.45$; $r^2=0.99$). In 3AS3, these values were strongly clustered around moderate concentrations of $TDPO_4$ and high $SI_{calcite}$. There was also considerable variability within the Twin Heads, dry degraded island. The central HH had the highest $TDPO_4$ values but moderate tendency for mineral precipitation in soil water as compared with other samples in the HH. However, the Ghost Island showed strong evidence for high $TDPO_4$ coinciding with tendency for mineral dissolution. This pattern is suggestive of a destabilization of the mineral-bound P in degraded, wet GI soils.

In contrast to within-community patterns for $TDPO_4$ and $SI_{calcite,}$ there was a wide range in Cl concentrations in the HH of 3AS3 with values higher than within other communities but within a narrow range of (high) $SI_{calcite}$; there was high variability in Cl (100-780 mg L^{-1}) within this narrow range of SI (~0.3-0.4; Figure 24). In 3AS3, the high Cl concentrations within this narrow range of SI suggest plant-water interactions favoring net accumulation of Cl prior to rewetting. Comparing this to soil water values of the dry down period, Cl is evidently diluted and flushed during wet season inundation. In the HH of the Ghost Island, variability in Cl was due to one sample location producing values of ~300 mg Cl L^{-1}. Otherwise, Cl concentrations were in the range of 100-200, but within a wider range of SI (~-0.05 – 0.4) than the HH of 3AS3. Interestingly, despite an even drier condition in the Twin Heads islands that might be thought to favor Cl accumulation, Cl concentrations do not exceed 150 mg L^{-1} in the rewetting period. These low concentrations also coincide with a wide range of $SI_{calcite}$ (~-0.05 – 0.50) found for the

Ghost Island. While there are fewer sample points available for the dry, intact island, the Cl concentrations vary little from the dry down period with both HH and WH samples showing potential for mineral precipitation. Cl concentrations in the HH are more comparable to the dry, degraded Twin Heads islands, presumably because within a range of dryness, the extent of dryness within that range is a more important predictor of Cl concentrations than extent of degradation. For instance, given a certain average water table depth below the soil surface may result in decoupling of soil water and groundwater processes, focusing root activity deeper in the soil profile where inundation by marsh groundwater is more frequent, minimizing accumulation of Cl. Work by Saha et al (2009) showed greater groundwater uptake in a drier pineland than in a hardwood hammock of ENP. In contrast, plant species in the wetter hardwood hammock relied more on water uptake from more shallow soil. Even with fewer sample data, it is clear that the Satin Leaf tree island is not directly comparable to WCA islands, likely due to its regional hydrologic setting (located in a relatively short hydroperiod, rocky glade) and lower duration of inundation in the HH (Sullivan 2011). These observations suggest that the variability due to the island's drier condition exceeds the range of variability in patterns describing intact and degraded islands in the WCAs, regardless of the intact character assigned to the Satin Leaf tree island based on what is known about its hydrologic and ecological history.

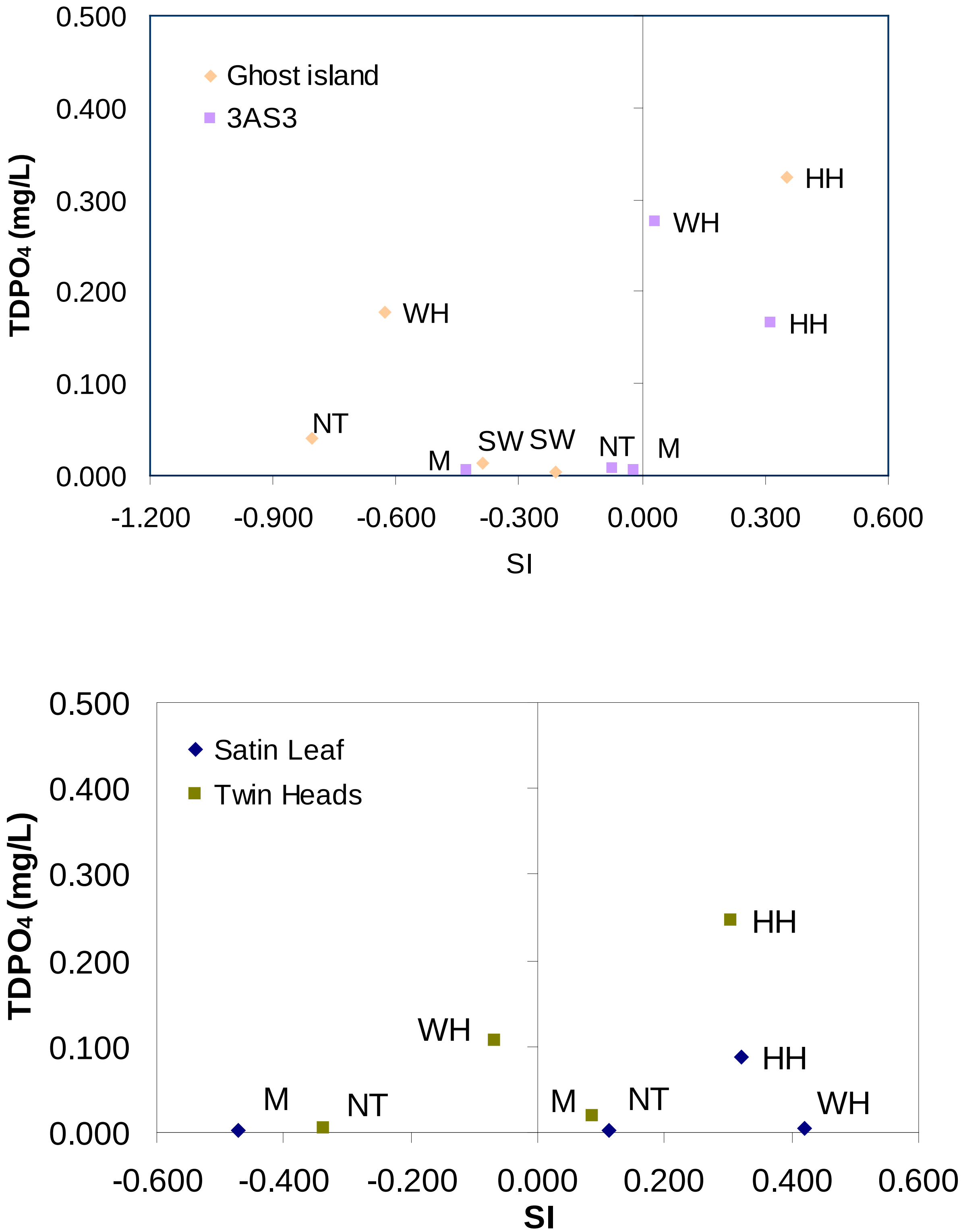
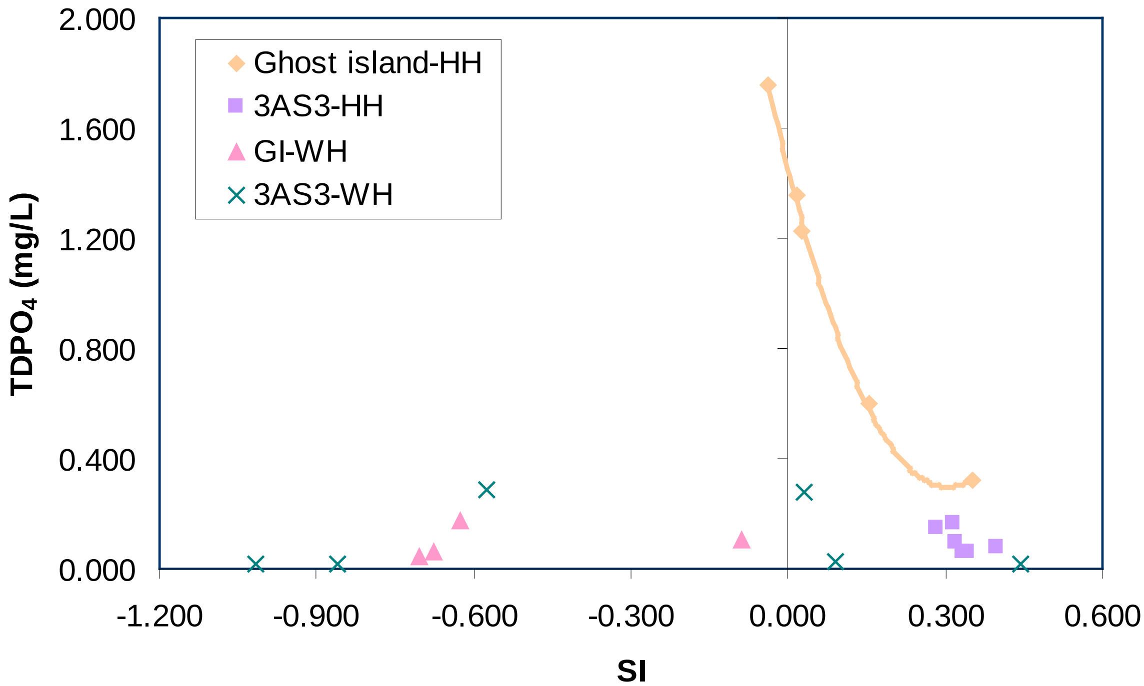


Figure 21. $TDPO_4$ concentrations and $CaCO_3$ saturation index relative to calcite at 60 cm depth among communities of A) 3AS3 and Ghost Island and B) Satin Leaf and Twin Heads during rewetting.



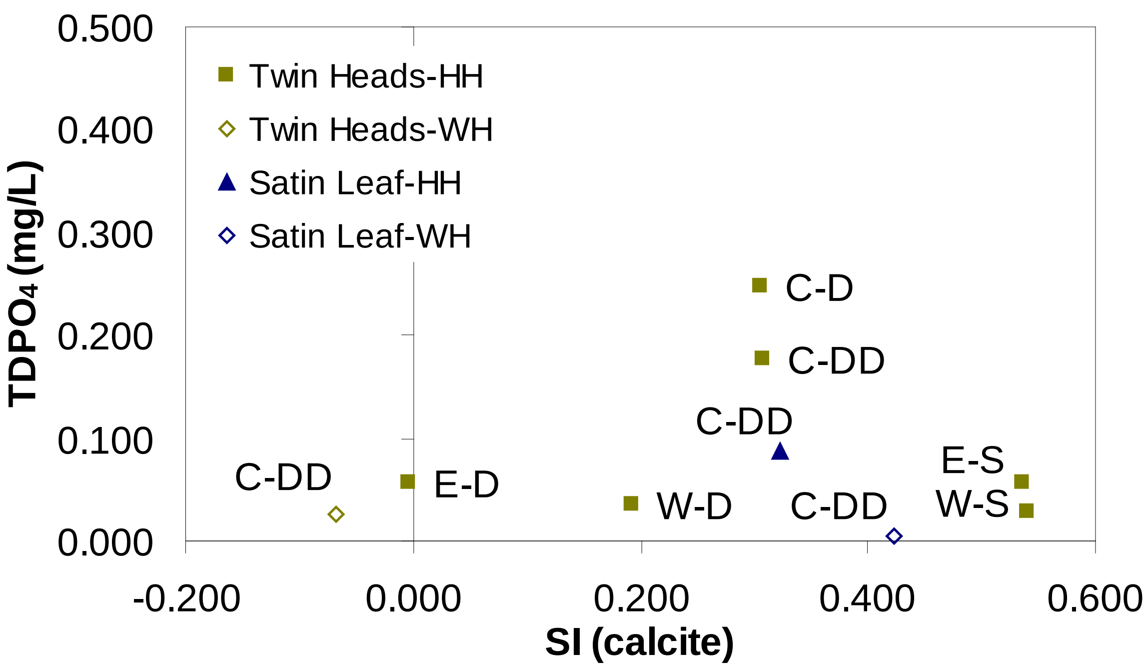


Figure 22. $TDPO_4$ concentrations and $CaCO_3$ saturation index relative to calcite at 60 cm depth within High Head (HH) and Wet Head (WH) communities of A) 3AS3 and Ghost Island and B) Satin Leaf and Twin Heads during rewetting.

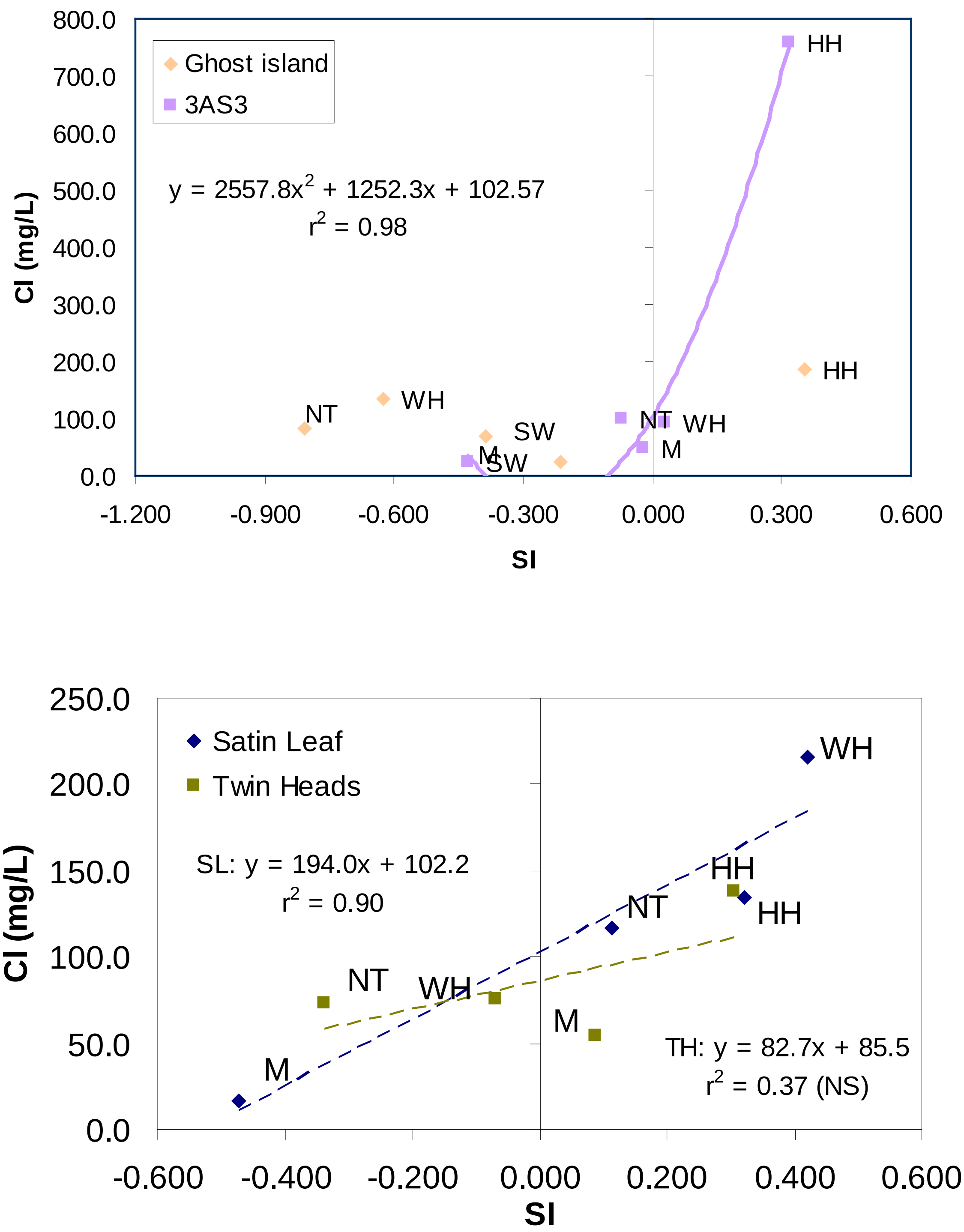
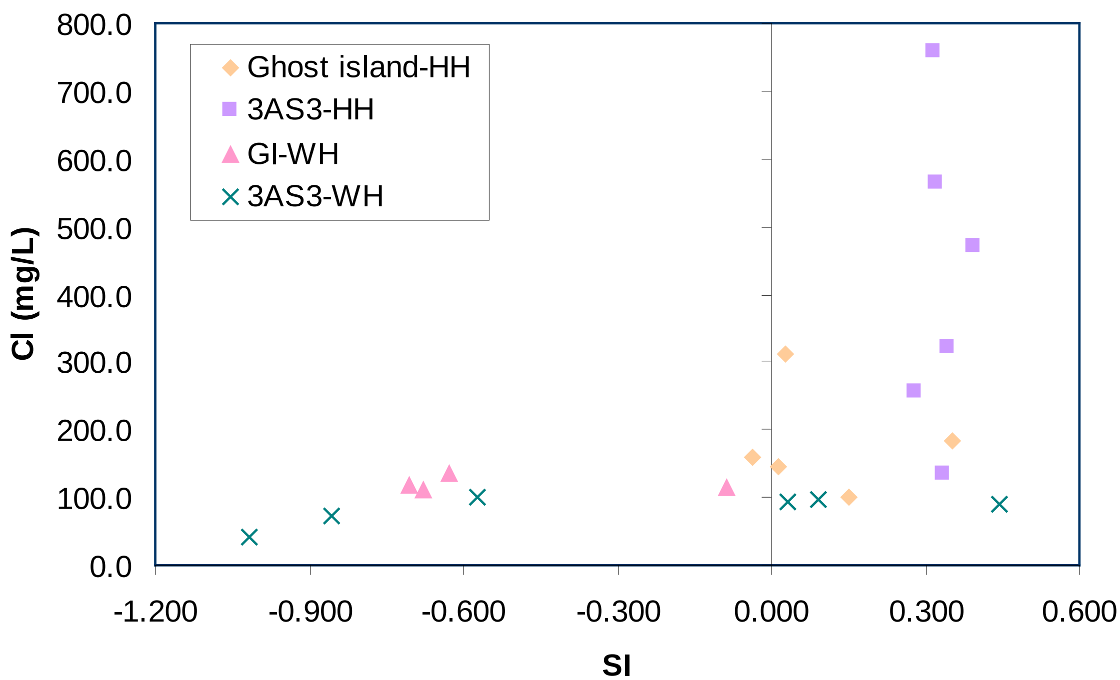


Figure 23. Cl concentrations and $CaCO_3$ saturation index relative to calcite at 60 cm depth among communities of A) 3AS3 and Ghost Island and B) Satin Leaf and Twin Heads during rewetting. Polynomial and linear models significant at p<0.05 unless noted otherwise.



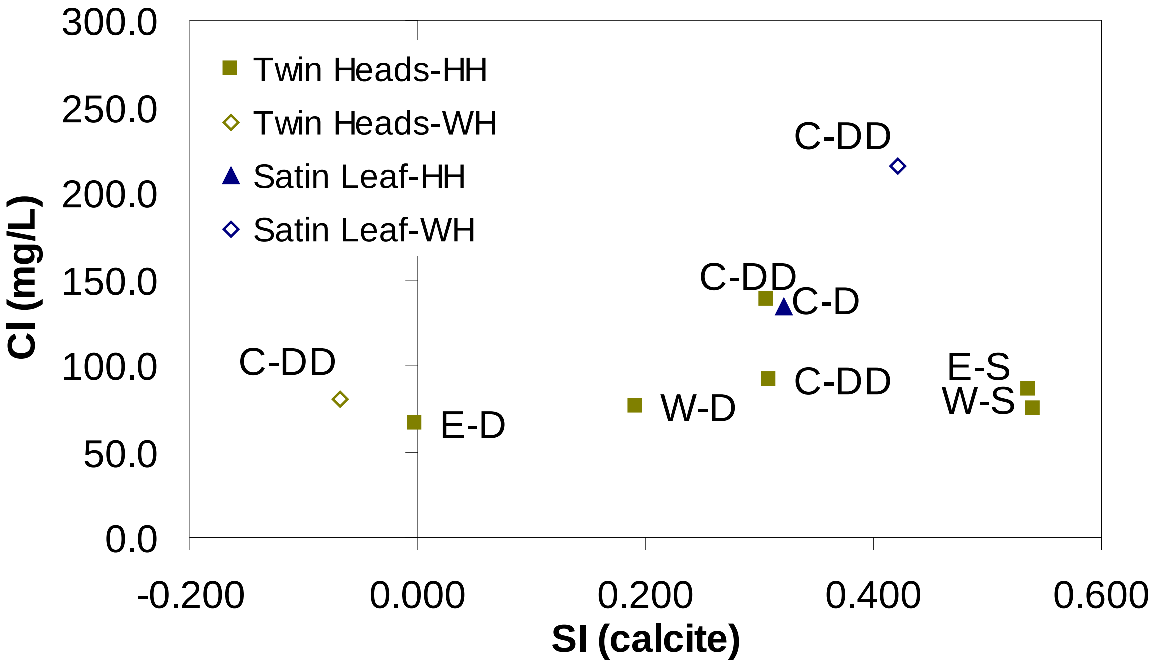


Figure 24. Cl concentrations and $CaCO_3$ saturation index relative to calcite at 60 cm depth within High Head (HH) and Wet head (WH) communities of A) 3AS3 and Ghost Island and B) Satin Leaf and Twin Heads during rewetting.

E. Isotope Characterization of Water, Stem and Leaf Tissue.

We characterized plant-water relations for each tree island by season, community and depth. Isotopic composition of surface water, soil water (groundwater) and plant stem water were sampled and reported.

i. Plant stem water.

A plot of plant stem water $\delta^{18}O$ and $\delta^{2}H$ illustrates the pronounced seasonal difference in water use between the dry down period in February – March 2012 and the rewetting period in September - October 2012 (Figure 25). There was a much stronger evaporation signal during the dry down period as indicated by values that were more enriched in ^{18}O and ^{2}H. What is also notable is the range in isotopic composition for stem water in the dry down period, illustrating the potential to differentiate water sources among species during this period.

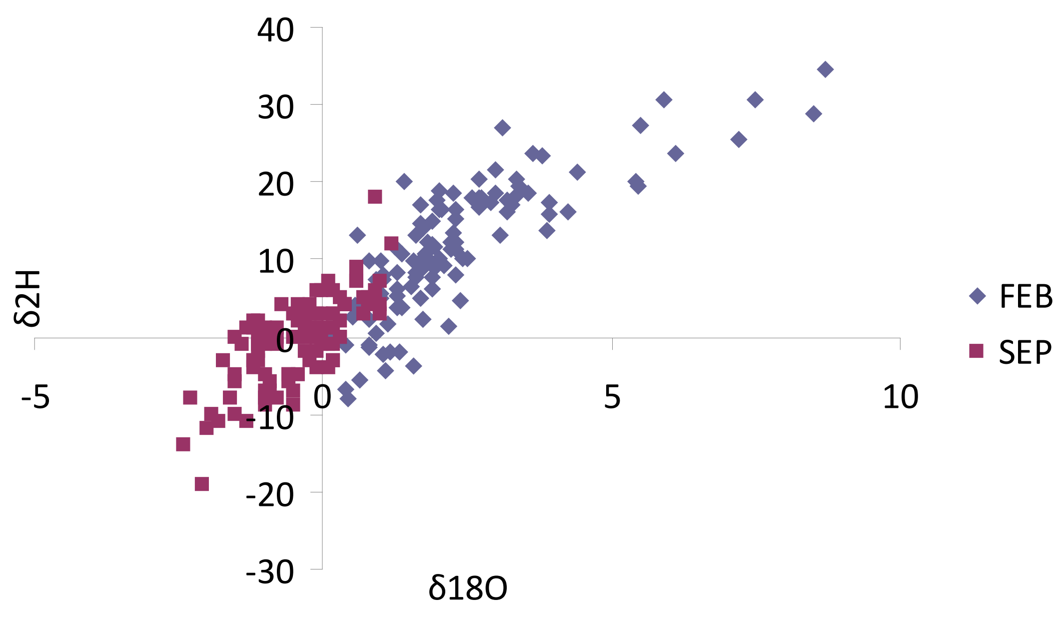
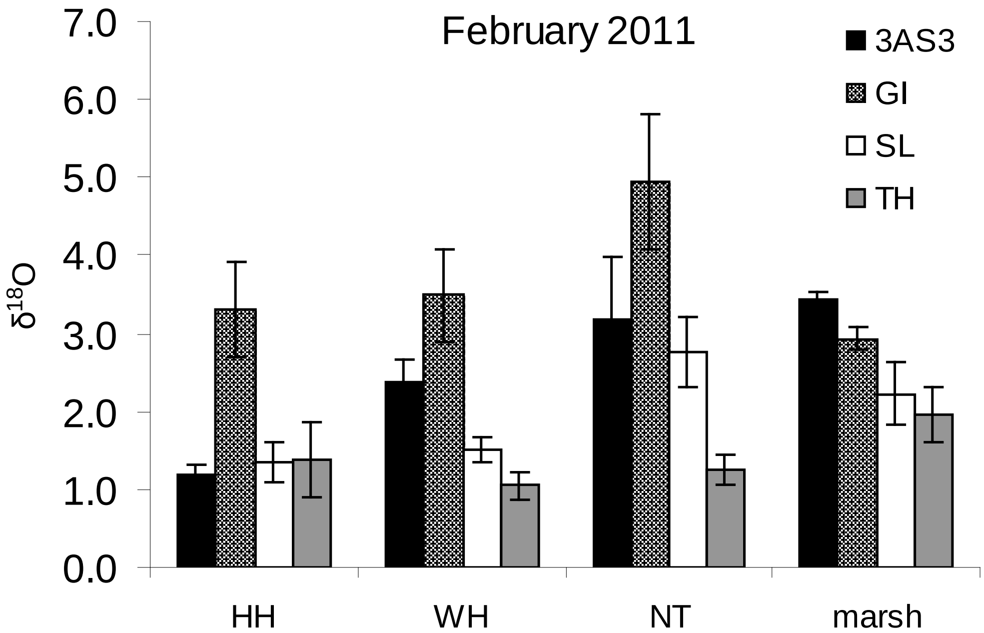


Figure 25. Plant stem $\delta^{18}O$ and $\delta^{2}H$ for tree island species from all communities of four tree islands. See text for list of species sampled.

Sampling during these transitional dry down and rewetting periods was advantageous for interpreting plant-water source relations. In general, a water source that undergoes relatively more water loss through evaporation will have a isotopic signature indicating ^{18}O enrichment, because evaporative losses result in loss of the lighter O isotopes. Marsh surface water, typically exposed to the highest potential for evaporative losses is typically more enriched in ^{18}O. However, during a dry down period, all water would be exposed to evaporative losses, but these would be higher in more surficial water sources and those with less exposure. Thus, stem water with higher ^{18}O indicates plant use of marsh surface water or water sources closer to the soil-water interface in the tree island or marsh. More depleted values indicate a relatively greater proportion of soil water (predominantly rain-derived; Saha et al 2009, 2010).

Plant stem water $\delta^{18}O$ averaged by island and community suggested stronger use of surficial water sources by the wet, degraded Ghost Island that was greatest for the Near Tail community, but did not differ significantly among communities (Figure 26). In the wet, intact island 3AS3, there was an increase of surficial water source use from the driest plant community (HH) to the wetter communities, indicating greatest soil water use in the HH community during regional dry down. In the dry, intact island Satin Leaf, there was little difference in proportion of surficial water used between HH and WH communities whereas NT and marsh community stem water indicated greater surficial water use. In the dry, degraded island Twin Heads, there was also little difference in water use among tree island communities, indicating relatively higher proportion of soil water use. Marsh species stem water was no different from plants found in GI or SL. At this time in Twin Heads, there was no surface water present in the tree island and average depth below the soil surface was approximately 20cm, 10cm and 0-2cm in the HH, WH and NT, respectively.

During the rewetting period, stem water of plant species in the HH of the intact islands 3AS3 and SL indicated use of the highest proportion of soil water as compared to HH communities of the degraded islands (i.e. more depleted in ^{18}O; Figure 26). However, extent of soil water use was similar among HH, WH and NT communities within 3AS3 but was significantly different between these communities in SL, with stem ^{18}O becoming less depleted as a function of average water depth. As was found for the dry down period, there was little variation in ^{18}O of stem water among tree island communities in the degraded islands with the wet, degraded island indicating the least depleted stem water ^{18}O suggesting that plant species used more marsh surface water regardless of tree island community where it was sampled (i.e. found to occur). A study by Saha et al (2010) showed that swamp forest plant communities (similar to those found on Ghost Island) used more marsh surface water/groundwater throughout the year.



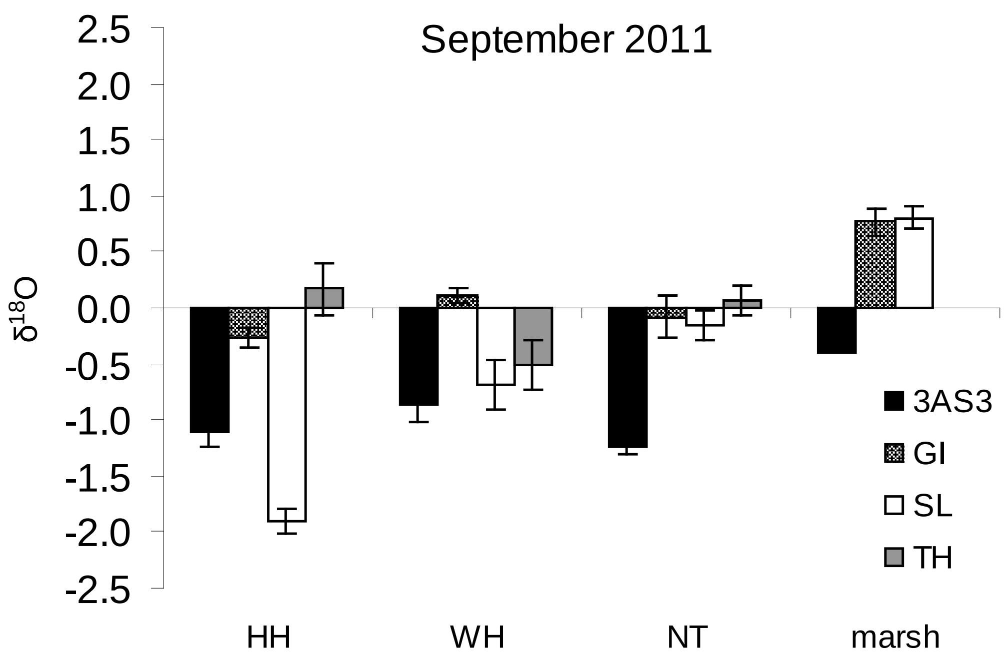


Figure 26. Plant stem $\delta^{18}O$ for tree island species average by island and community type for A) February 2011 (dry down) and B) September 2011 (rewetting). Error bars are standard error. See text for list of species sampled.

These data suggest that: 1) the greatest differentiation in tree island community water use occurred during dry down for the wet, intact island and during rewetting for the dry, intact island, and 2) intact islands used a greater proportion of soil water but the extent varied with hydrology of the plant community; the driest, intact community used the greatest proportion of soil/groundwater. Overall, intact islands used a greater proportion of soil water regardless of season sampled. The extent (i.e. duration) of surficial water use can be roughly approximated as the water table relative to the soil surface for plant species found in the WCA tree islands. There is no overlap in species composition between island of the WCA and Satin Leaf in the HH and this may not be a reasonable approximation for the Satin Leaf island occurring farther south in ENP. However, this relationship appears more a function of variation among plant communities rather than plant species. A plot of water level and stem water ^{18}O show positive linear relationships for the intact islands 3AS3 and Satin Leaf (Figure 27). These relationships are driven by within island variation among communities (i.e. there was little variation among tree island communities in the degraded Ghost Island and Twin Heads). These results illustrate the strong potential for predictive modeling coupling these and data from previous MAP projects (ex. “Tree island stage duration and the measurement of water depth on tree islands located in WCA 3A and 3B”, PI Carlos Coronado-Molina). These strong trends indicate that a strategically-planned regional program to characterize stem water ^{18}O and water table depth among communities within tree islands would provide a key measure of ecological “health” of tree islands, but more data will be required to improve the predictability of these models.

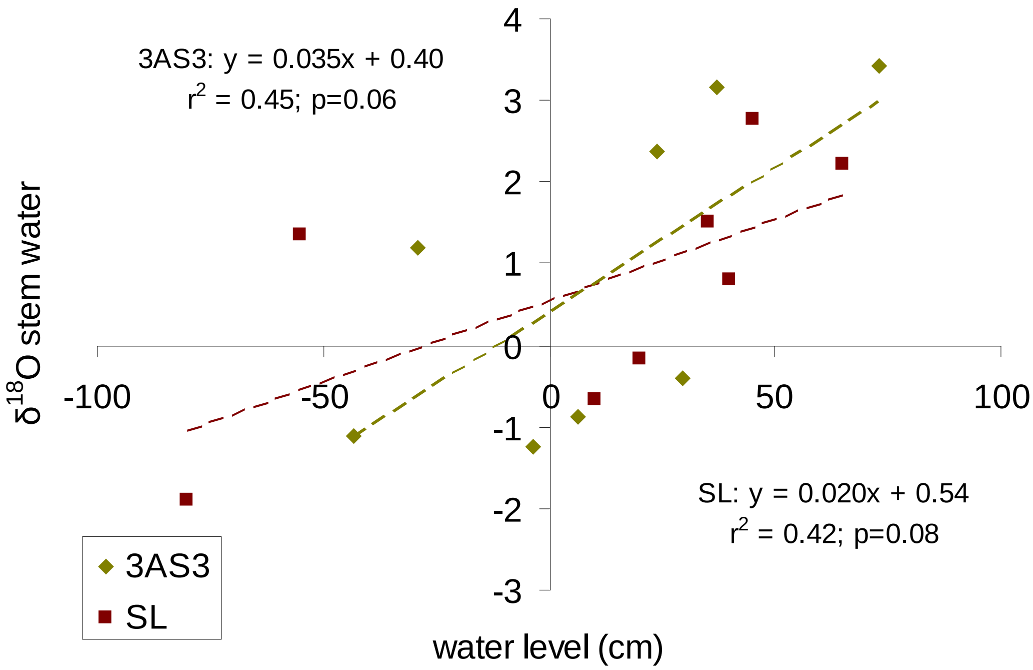
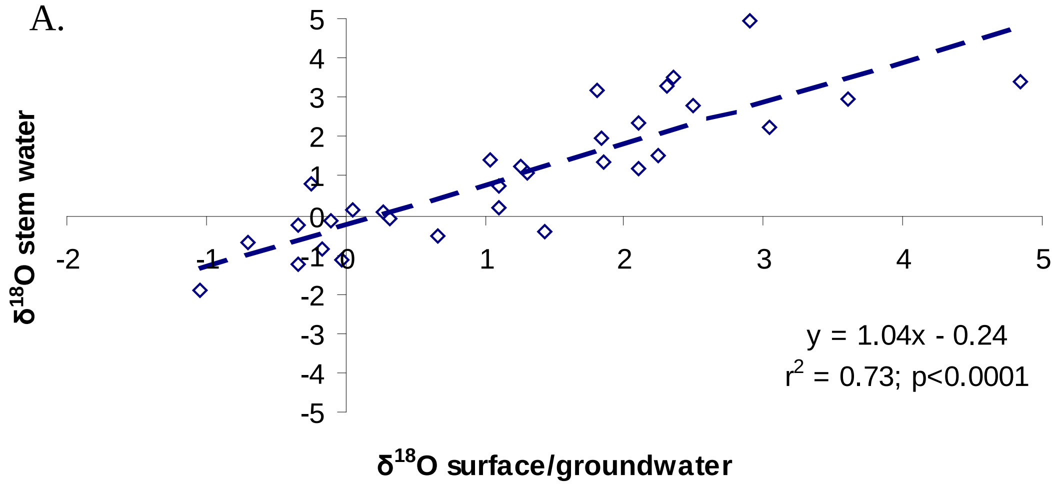


Figure 27. Water level relative to soil surface and stem water δ^{18}O averaged by community for two intact tree islands 3AS3 and Satin Leaf ($p<0.10$). There were no relationships for the degraded islands.

ii. Tree island and marsh source water

Values of δ^{18}O and δ^{2}H surface/groundwater plotted against stem water illustrate strong relationships between source water and plant water use among islands and communities for each sampling event. Surface/groundwater δ^{18}O and δ^{2}H explained over 70% of the variance in stem water δ^{18}O and δ^{2}H (Figure 28).

A.



B.

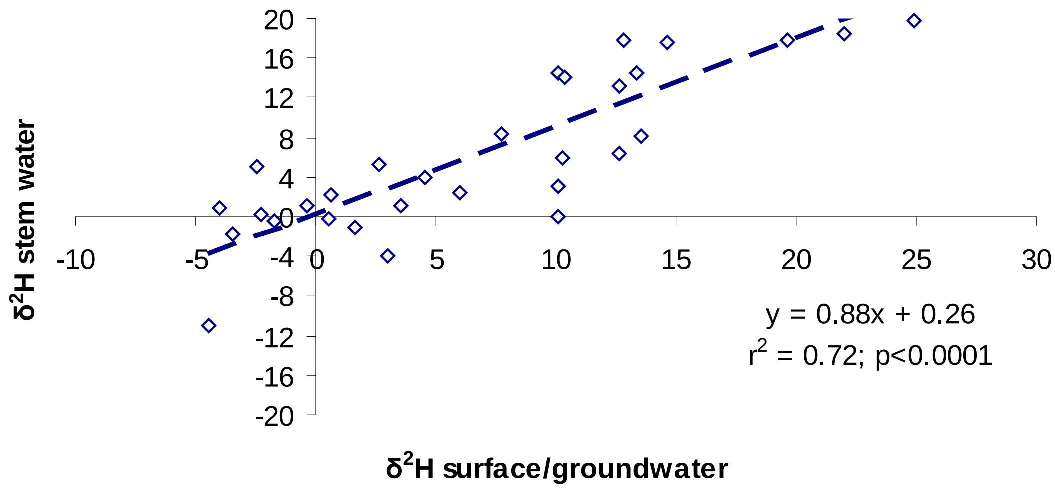
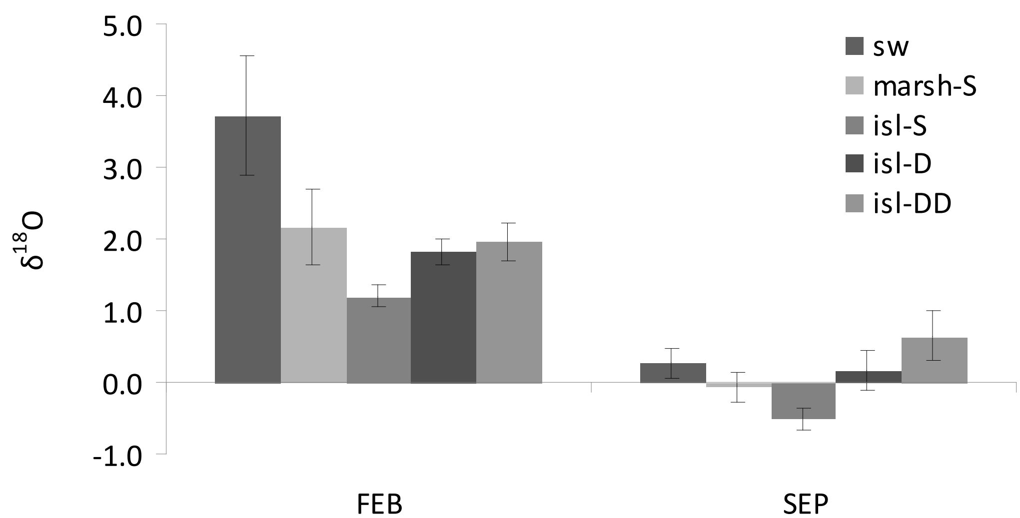


Figure 28. Surface/groundwater and plant stem water A) δ^{18}O and B) δ^{2}H for four tree islands.

On average, surface water values were more enriched in ^{18}O and ^{2}H than soil water with the least enriched values in soil water at 30cm depth during dry down (Figure 29A). A similar pattern was found during rewetting in that soil water at 30cm was least enriched but values for surface water were not significantly different from soil water values collected from 60 and 90cm depths (Figure 29B). These results suggests that during dry down, surface water was undergoing the greatest evaporative losses at compared with soil water and that during rewetting only shallow soil water maintained a signature of low evaporative losses. These averages are most useful for differentiating general seasonal trends. These results indicate higher overall evaporative losses during dry down and lower (near 0) values for rewetting when the isotopic signal was closest to rain water.



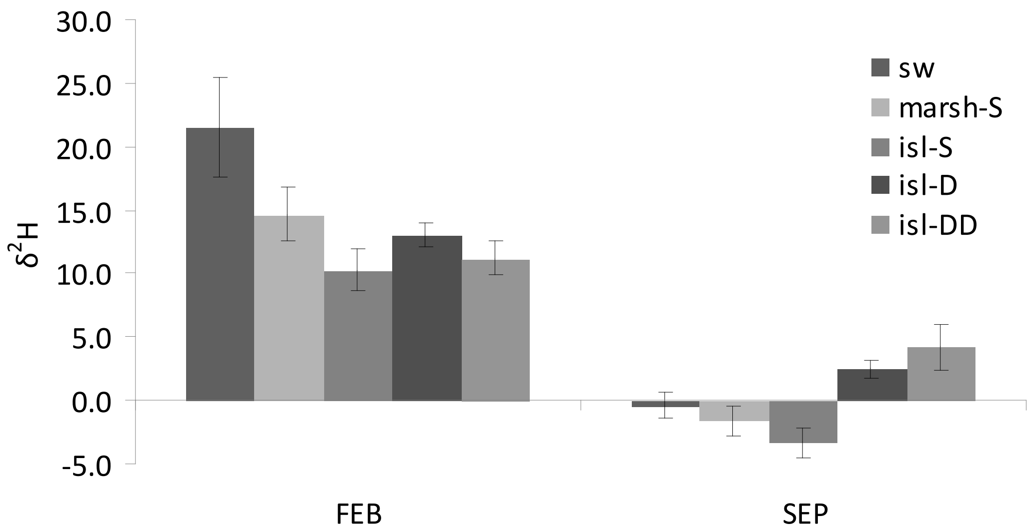
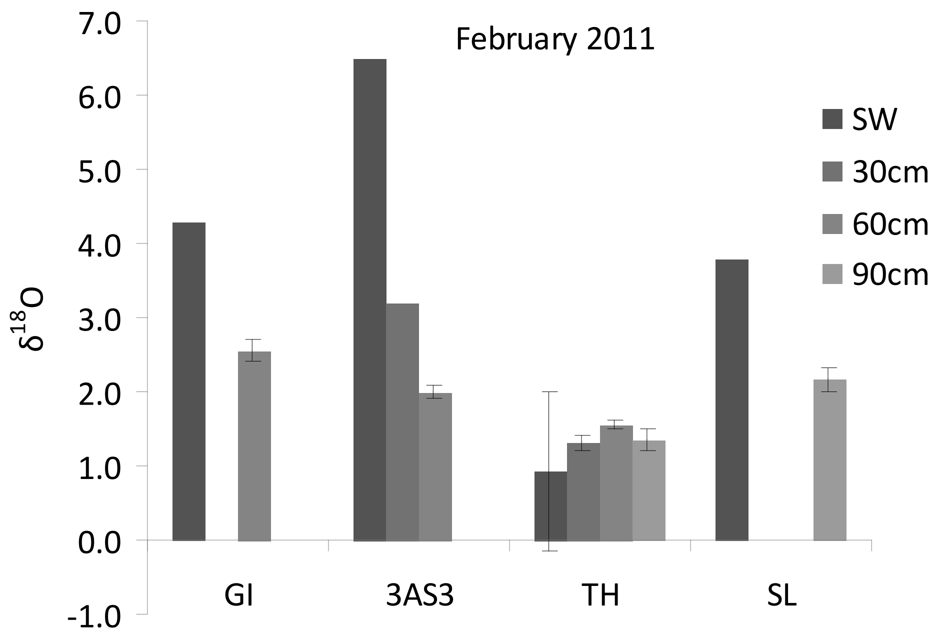


Figure 29. Seasonal average (and standard error) in source water A) δ^{18}O and B) δ^{2}H for four tree islands.

When values were averaged by season, island and depth fewer data points made some interpretations less robust, but variation with depth was consistent with values averaged across islands. During dry down, surface water values were more enriched in ^{18}O than soil/groundwater except in the dry, degraded island Twin Heads (Figure 30A). During rewetting, this difference was less pronounced despite some variation with depth that was absent from Twin Heads (Figure 30B). However, averaging values by season, community and depth produced the most robust differences (Figure 31). For example, during dry down, there was clear variation with depth between soil water at 30cm as compared with 60cm and 90cm in HH, WH and NT communities (Figure 31A). Marsh surface water underwent higher evaporative losses than marsh soil water (which was comparable to tree island soil water at 60 and 90cm depth). During rewetting, while the magnitude of differences was smaller, they were robust (Figure 31B). For example, there was more variation with depth through the soil profile in all communities, most notably in the HH and marsh communities, where values became more enriched with soil depth. Whereas in WH and NT communities, more shallow water (surface and at 30cm depth) was on average more depleted than water deeper in the soil profile (at 60 and 90cm depth). It is clear from these and other isotopic data presented, that rewetting influences the isotopic signature of source water with depleted rainwater. There is no evidence comparing these sampling events that water 60cm depth or below ("groundwater") is the source of more depleted values.



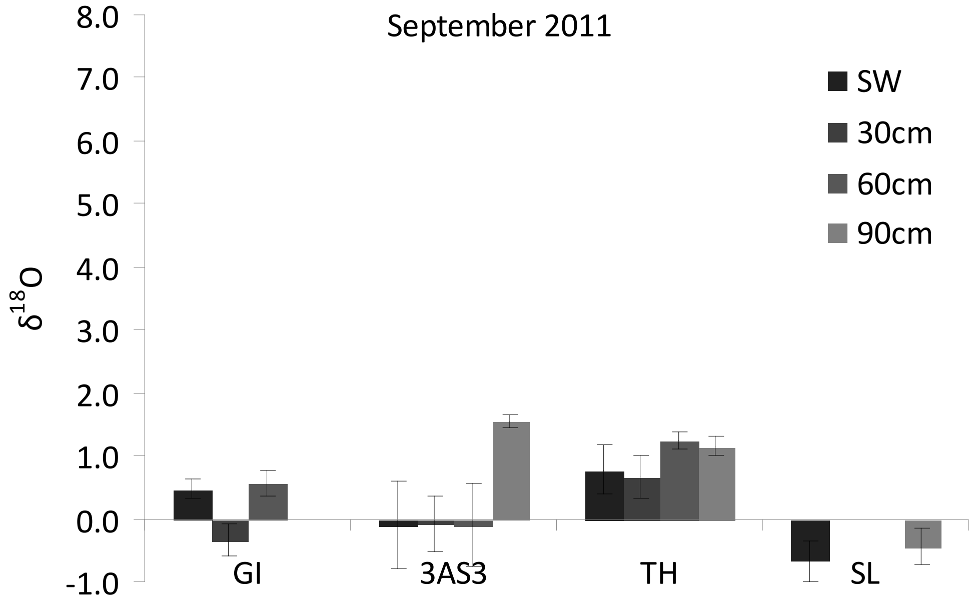


Figure 30. Source water $\delta^{18}O$ in A) February 2011 and B) September 2011 averaged by tree island and water depth. Error bars are standard error.

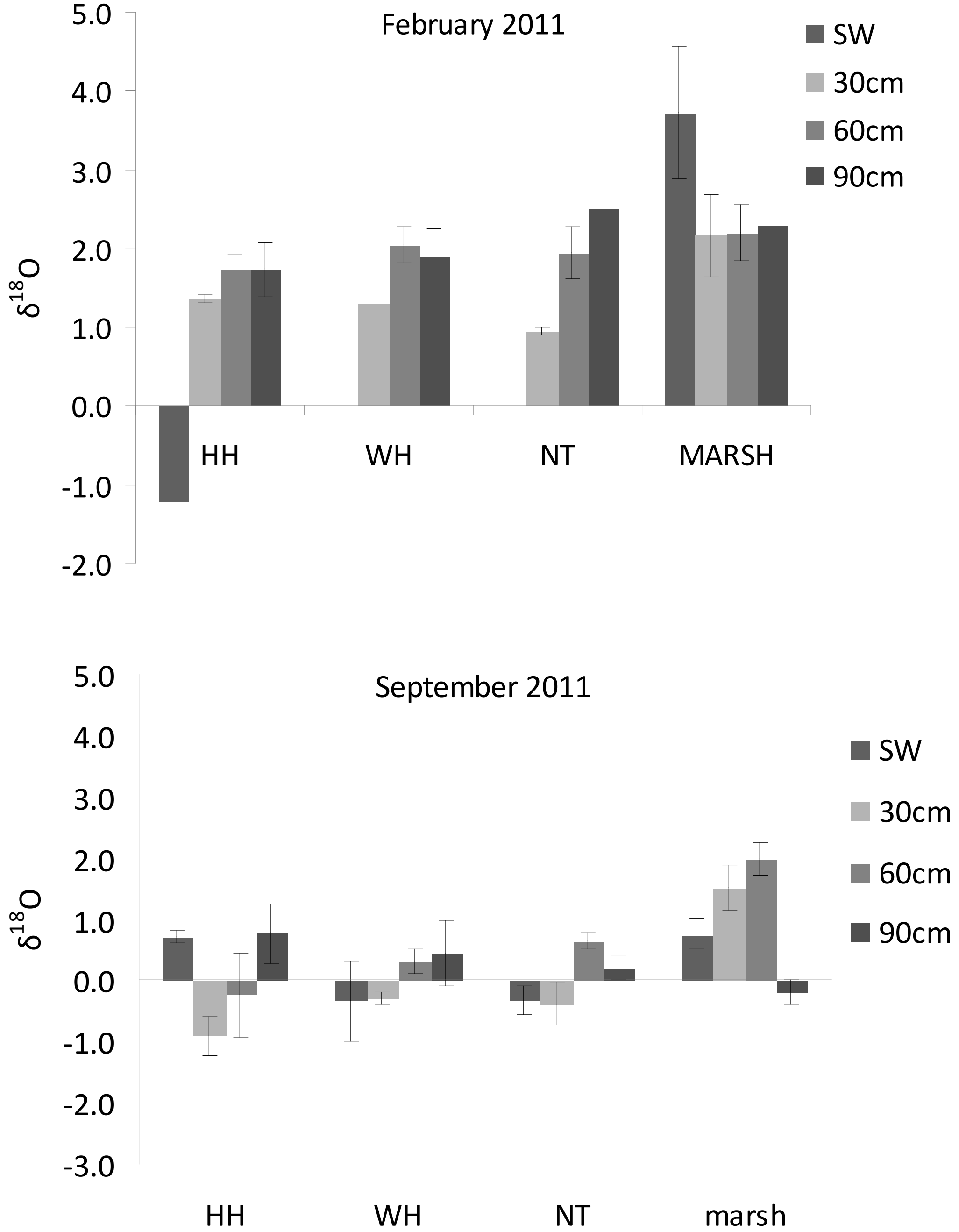


Figure 31. Source water $\delta^{18}O$ in A) February 2011 and B) September 2011 averaged by community and water depth. Error bars are standard error.

iii. Carbon and nitrogen isotopic composition of leaf tissue

Leaf tissue nitrogen and carbon content and $\delta^{15}N$ and $\delta^{13}C$ were averaged by tree island and community type (Table 17; n=113). Tissue nitrogen and carbon concentrations were not significantly different among islands or plant communities. For leaf tissue $\delta^{15}N$, islands were not significantly different from one another but the High Head community has significantly higher $\delta^{15}N$ than Wet Head, Near Tail and Marsh communities that were not different from each other ($F=5.49$, $p<0.0001$). There were also numerous interaction effects that will not be described here. Leaf tissue $\delta^{13}C$ varied by island and by community type with numerous significant interaction effects ($F=5.74$, $p<0.0001$). Plants from the Ghost Island and 3AS3 were significantly more enriched in ^{13}C as compared with the drier islands Satin Leaf and Twin Heads. Leaf tissue from Marsh and Near Tail communities were also significantly more enriched in ^{13}C than the drier Wet Head and High Head communities. There were also numerous interaction effects that will not be described here.

More enriched ^{15}N in leaf tissue of species in the High Head suggests that these plants have greater access to soil P. More available P is often correlated with more enriched ^{15}N signatures in plants of both wetland and upland communities (McKee et al 2002, Troxler 2007, Wang et al 2011). As all islands had soils with high P in the High Head community, it is reasonable that there would be no difference in ^{15}N among islands. All islands had high concentrations of phosphorus in soil water in the high head sufficient to enrich N isotopic composition regardless of water source use. More enriched ^{13}C in wetter islands and communities are also well supported by the literature (McKee et al, Wang et al 2011). In general, plants that experience more water-logged conditions reduce their stomatal conductance and ^{13}C accumulates in leaf tissue.

			%C		%N		$\delta^{15}N$		$\delta^{13}C$	
ISLAND	*Community*	n	mean	se	mean	se	mean	se	mean	se
3AS3	HH	6	47.74	0.73	1.76	0.22	-30.15	0.23	4.82	0.86
	WH	9	49.75	0.80	2.32	0.37	-29.71	0.47	4.46	0.36
	NT	9	47.59	0.64	1.87	0.30	-29.35	0.71	3.09	0.31
	marsh	3	49.21	0.62	3.30	1.05	-29.71	0.16	-0.17	0.86
GI	HH	6	52.33	0.59	2.64	0.32	-28.98	0.46	5.06	0.45
	WH	9	52.55	0.45	2.32	0.27	-29.77	0.58	2.52	1.11
	NT	9	52.82	1.08	2.25	0.26	-28.56	0.45	0.70	1.12
	marsh	3	53.67	3.21	1.77	0.07	-28.98	0.23	-0.62	0.50
SL	HH	9	45.61	0.41	1.35	0.09	-32.76	0.31	5.42	0.63
	WH	9	49.98	0.52	1.55	0.14	-31.25	0.32	0.48	0.61
	NT	9	48.92	0.86	1.67	0.18	-29.12	0.40	2.79	1.09
	marsh	3	50.21	0.54	2.30	0.13	-27.73	0.52	-3.59	0.15
TH	HH	10	48.60	1.16	1.84	0.13	-30.15	0.52	1.63	0.92
	WH	9	49.16	1.45	1.95	0.22	-30.97	0.43	2.20	1.00
	NT	9	50.43	0.54	1.48	0.12	-30.69	0.33	0.29	1.10
	marsh	3	51.42	0.27	1.81	0.18	-30.15	0.56	5.95	1.10

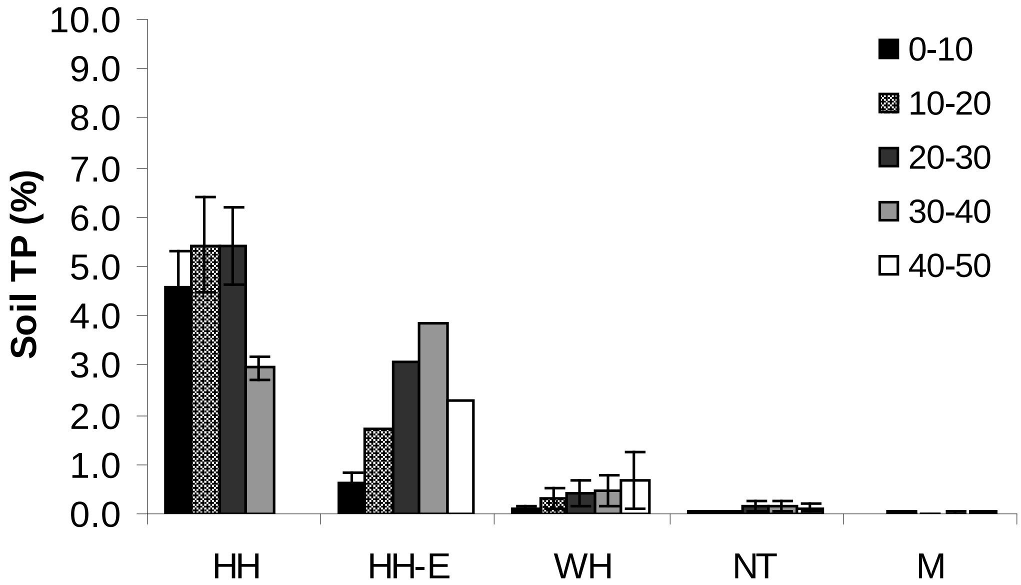
Table 17. Leaf $\delta^{15}N$ and $\delta^{13}C$ for tree island species (leaves) averaged by tree island and community with standard error (±se).

F. Soil Phosphorus

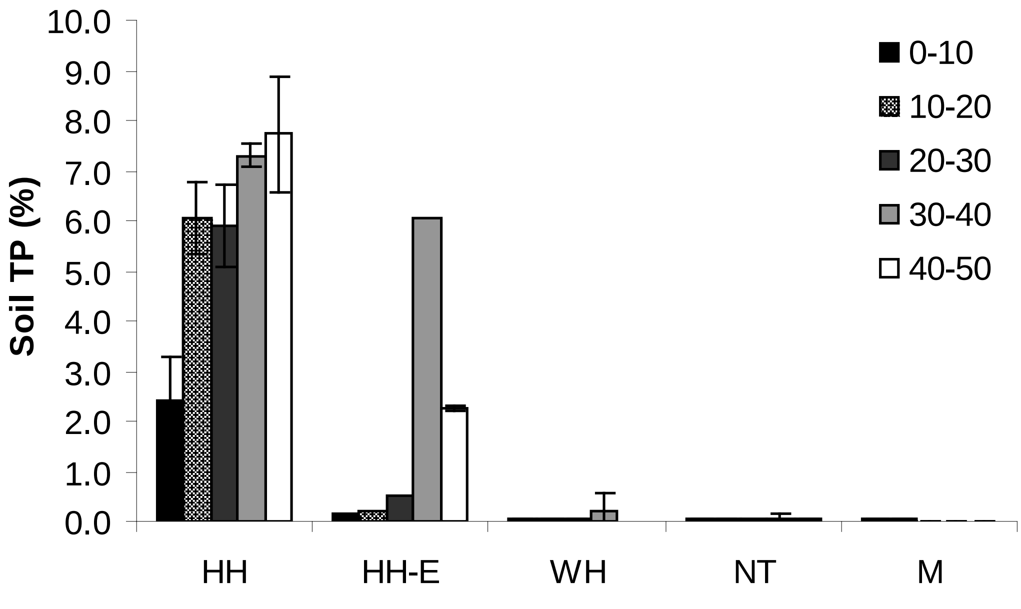
Soil phosphorus concentrations in tree island soils (3AS3, Ghost Island and Twin heads) varied most among communities and secondarily by island and depths (Figure 32). When all islands were grouped, HH TP values (4.77 ± 0.36%) were significantly higher than

HH-edge soils (1.58 ± 0.36%) and Wet Head, Near Tail and Marsh soils (0.25 ± 0.06%, 0.08 ± 0.01%, and 0.032 ± 0.003%, respectively), the latter three not significantly different from one another ($F=100$, $p<0.0001$). While it is not possible to determine the development of soil P from this study, comparing soil TP concentrations across the soil depth profile within the High Head of each island suggests the potential for soil P loss in the upper profile of the degraded islands. Assuming that soil TP at lower depths represent the stable TP concentrations in the soil profile, soil TP of both the Ghost Island and Twin Heads are less than half the average of the TP concentration lower in the profile (30-50cm depth). Notably, the deviation from the average soil TP value in the HH suggests stable soil P in 3AS3, loss at 0-10cm depth in the wet, degraded Ghost Island and loss at 0-20cm depth in the dry, degraded Twin Heads island. Evaluating the spatial variability in soil TP concentrations between the central and edge soils of the High Head (Figure 32, HH and HH-edge, respectively) provides some evidence of the spatial extent of the high P soils. These are preliminary observations as the sampling of the HH-edge community was limited. Additional soil cores in these edge habitats would provide an estimate of extent of the high P layers and quite possibly enable a credible estimate of the mass of soil P currently retained in these islands.

A.


10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Soil TP (%)
0-10
10-20
20-30
30-40
40-50
HH
HH-E
WH
NT
M

B.


10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Soil TP (%)
0-10
10-20
20-30
30-40
40-50
HH
HH-E
WH
NT
M

C.

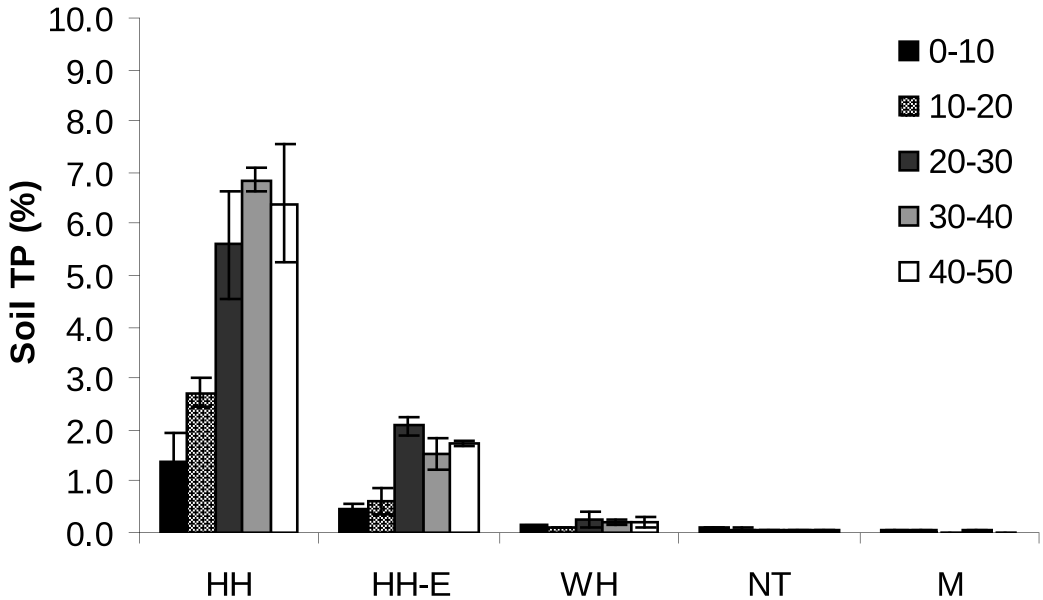


Figure 32. Total P concentrations in soils by depth (0-10cm, 10-20cm, 20-30cm, 30-40cm and, where available, 40-50cm) and community type (HH – High Head, HH-E – High Head – Edge, WH – Wet Head, NT – Near Tail, M – Marsh) in A) 3AS3, B) Ghost Island and C) Twin Heads. Values are averages of 2 – 3 cores except where no error bars are presented in which case values for one core are reported.

Tree island soil TP concentrations varied significantly with organic matter content for each island sampled (Figure 31). Organic matter content explained 92 and 84% of the variance in TP concentration in polynomial relationships in the Ghost Island and Twin Heads, respectively (GI: $y = -0.0016x^2 + 0.079x + 5.72$, F=193.4, $p<0.0001$; TH: $y = 0.0012x^2 - 0.201x + 8.73$, F=107.6, $p<0.0001$) . Organic matter content explained 47% of the variance in TP concentrations in a linear relationship in 3AS3 ($y = -0.047x + 4.05$; F=33.3, $p<0.0001$). The lower coefficient of variation for the model describing the 3AS3 pattern was due to a number of samples in the Near Tail with high mineral content (cores extracted near S8 and S9 well clusters). These samples also had high soil specific conductivity.

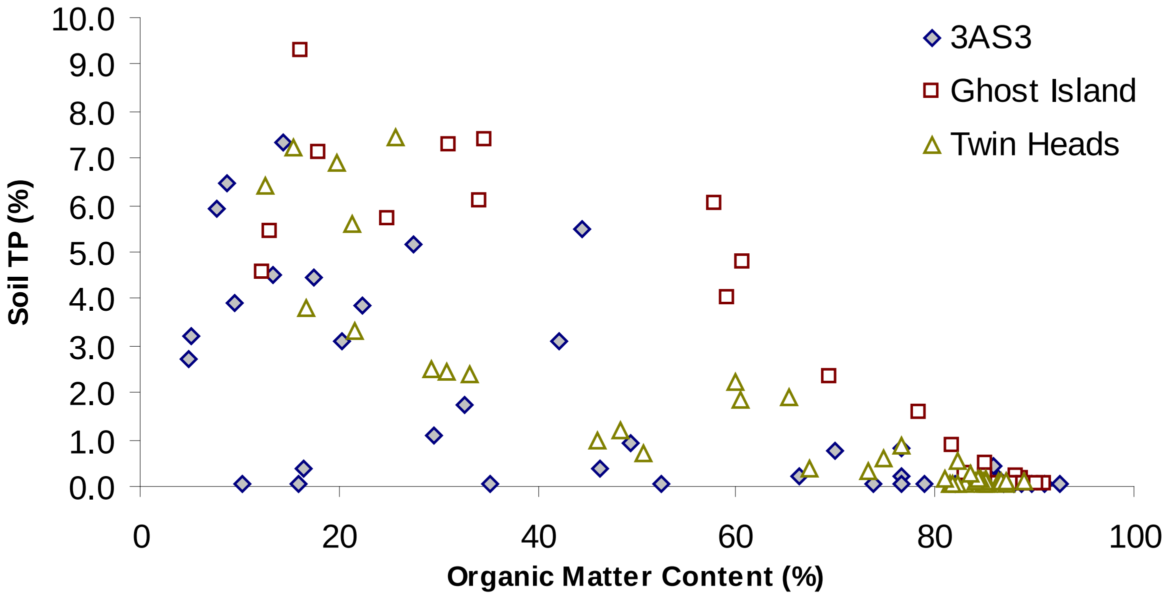


Figure 33. Relationship between soil organic matter content (%) and TP content (%) of the 0-40cm depth profile in three tree islands.

IX. CONCLUSIONS

In this study, we compared the hydrologic and geochemical patterns among four tree islands that were differentiated by hydrology and degree of degradation. 3AS3, a relatively intact island in the south central WCA, retains distinct hydrologic and hydrogeochemical variation among the three primary tree island vegetation types HH, WH and NT and the marsh community. The Ghost Island, an island subject to overflooding, appeared to have a lesser gradient in hydrologic conditions associated with HH, WH and NT community types. The dry, degraded Twin Heads island was generally similar to that of the Ghost Island with some notably exceptions. In Satin Leaf, the island was in a hydrologic and topographic setting that made it more difficult to directly compare to the WCA tree islands with the study design we employed to evaluate intact and degraded tree islands along a hydrology gradient. Hydrogeochemical characterization clearly indicated that the tree islands varied along spatial and temporal scales resulting in considerably different patterns. New hydrologic information for the Ghost Island and Twin Heads along with plant stem and source water isotopic composition corroborated these findings.

We summarized the key characteristics that differentiated tree islands of this study (Table 18). Taken together, these results illustrate patterns for intact and degraded tree islands subject to variation in regional hydrology that control hydropattern of the tree islands and plant communities therein. Undoubtedly, tree islands are complex systems. However, the factors that lend to this complexity can be distilled to provide a useful framework for monitoring and assessment of tree islands in the Everglades. Results from this and other studies illustrate an important context for interpreting patterns.

In general, plants in drier communities utilize more regional (marsh) groundwater (Saha et al 2009, 2010; Wetzel et al 2011; Sullivan 2011) that is low in PO_4 and other ions (Saha et al 2010). However, there is a hydrologic range in which species in moderately dry communities have the greatest access to rain-derived, moderately P-rich soil water. Given these hydrologic conditions (characteristic of the hydrology of the HH in wet, intact island 3AS3), P-rich soil water is preferentially used by the HH plant community. As a result, the soil water becomes progressively enriched in Cl ions as roots exclude them during water uptake. Soil water use may have a positive feedback on ion accumulation, while uptake of P-enriched soil water would maintain nutrient requirements and level of plant productivity. While ion accumulation has been suggested to promote mineral precipitation in the HH (Troxler et al 2010, Troxler et al in revision, Sullivan 2011), utilization of rain-derived soil water by tree island plants may also indirectly promote mineral soil and soil P stability in the HH by preferentially concentrating ions in this profile as compared with root water uptake from regional groundwater that would occur lower in the soil profile. Moreover, water levels that are: 1) too low may promote soil oxidation and reduced potential for ion accumulation in soil water and 2) too high may dilute soil water Cl (and potential for mineral precipitation), dissolution of mineral P and promote low soil water use (relative to surface water use).

Soil phosphorus data suggest that P sequestered in soils is still largely retained within soils of degraded tree islands and that restoration of surface water levels would facilitate stabilization of the remaining soil P. It appears that the zone of Cl accumulation is more related to water table than vegetation community so that an increase in water levels in WCA 3B and a decrease in water levels in WCA 3A would enhance soil water use and Cl accumulation in these islands, increasing ionic strength and promoting soil P stability. Continuous monitoring of aqueous CO_2 and pH would contribute to a better understanding of $CaCO_3$ soil dynamics and soil stabilization in the HH soils.

A proposed model for accumulation of tree island phosphorus, the focused nutrient redistribution (FNR) hypothesis suggests that among other indicators, evapotranspirational pumping (ET; indicated by overnight drawdown of the tree island soil water table) and the concentrations of chloride (Cl) ions (indicating plant-water interactions that build ionic strength and promote mineral soil stability) are characteristics of "healthy" tree islands (Table 18). Based on these models, soil P and ionic strength of soil water should be reduced in degraded tree islands. Our results partially support these hypotheses. Ionic strength of the soil water beneath degraded islands were reduced compared to a an intact, wet tree island but all islands retained high soil P, at least with depth, in the soil profile. We did find that release of mineral soil P was a feature of an island degraded by overflooding. The more quickly hydrology can be restored to these basins, the lower the potential for soil P loss from tree islands.

	INTACT	*DEGRADED*
^{18}O of stem water	Greater proportion of rain-derived soil water uptake upon rewetting in the High Head	Wet used consistently less rain-derived soil water under conditions of both regional drying and rewetting; greater indication of rain-derived soil water use in dry island during drying but less pronounced in High Head with rewetting
	Greater differentiation in soil water use among plant communities (during drying for wet island and rewetting in dry island)	Weak differentiation of soil water use among communities except in Wet Head of dry island
Diurnal evapotranspiration signal	Evident - average diurnal drawdown high in wet, intact island; dry, intact-data pending	Evident - average diurnal drawdown lower in wet, degraded island as compared to wet, intact and dry, degraded islands
Evapoconcentration potential	High Cl in High Head of wet island, highest during rewetting; moderate Cl in Wet Head of dry island (but Cl in High Head low (??))	Degraded islands had low Cl that could only be differentiated from marsh community; GI had moderate Cl in one location in High Head
	Low Ca:Cl in High Head of wet island and slightly lower only in High Head of dry island	High Ca:Cl with no differentiation among communities in degraded islands
	Ratio of Ca:Cl negatively correlated to SIcalcite	Ratio of Ca:Cl positively correlated to SIcalcite
Phosphorus in shallow soil water	Moderate levels in High Head of intact islands	Dry, degraded island similar concentration and community differentiation as wet, intact island; Wet degraded island 2-5 times higher than wet, intact and dry, degraded
Soil phosphorus	Appears stable through depth profile in wet, intact island; N/A for dry, intact island	Variation over depth profile suggests potential for loss in upper soil profile in degraded islands that is greater for dry, degraded

Table 18. Indicators of hydrogeochemical features characteristic of intact and degraded tree islands

X. REFERENCES CITED

Gawlik D.E. and Rocque D.A. 1998. Avian communities in bayheads, willowheads, and sawgrass marshes of the central Everglades. Wilson Bulletin 110:45-55.

Graf, M.-T., M. Schwardon, P.A. Stone, M. Ross, G.L. Chmura. 2008. An enigmatic carbonate layer in Everglades tree island peats. EOS, Transactions, AGU 89: 117-118.

Givnish, T.J., J.C. Volin, V.D. Owen, V.C. Volin, J.D. Muss, and P.H. Glaser. 2007. Vegetation differentiation in the patterned landscape of the Central Everglades: importance of local and landscape drivers. Global Ecology and Biogeography 17:384-402.

Jayachandran, K., S. Sah, J. Sah, M. Ross. 2004. Tree Islands in the Shark Slough Landscape: Interactions of Vegetation, Hydrology and Soils. Chap. 3, Characterization, Biogeochemistry, Pore Water Chemistry, and Other Aspects of Soils in Tree Islands of Shark Slough. Final Report to Everglades National Park, Southeast Environmental Research Center, 185pp.

McNeill, D.F., Cunningham, K.J. 2003. Hydrostratigraphy of tree island cores from Water Conservation Area 3. U.S. Geological Survey Open-file Report 03-68, Miami, FL, USA, 130pp.

Saha, AK, Sternberg, LSO, Miralles-Wilhelm, F. 2009. Linking water sources with foliar nutrient status in upland plant communities in the Everglades National Park, USA. Ecohydrology 2: 42-54.

Saha, AK, Sternberg, LSO, Ross, MS, Miralles-Wilhelm, F. 2010. Water source utilization and foliar nutrient status differs between upland and flooded plant communities in wetland tree islands. Wetlands Ecology and Management 18: 343-355.

Sklar, F.H. and van der Valk, A.G. 2002. Tree islands of the Everglades: An overview. p. 1–18. p.357–389. *In* F. H. Sklar and A.G. van der Valk (eds.) Tree islands of the Everglades. Dordrecht, The Netherlands, Kluwer Academic Publishers.

Solorzano, L. and J. Sharp. 1980. Determination of total dissolved P and particulate P in natural waters. Limnology and Oceanography 25: 754-758.

Sullivan, PL. 2011. Groundwater-surface water interactions on tree islands in the Everglades, south Florida. PhD Dissertation, Florida International University, Miami, FL. 248pp.

Troxler, TG, Coronado-Molina, C, Sklar, FH, Wetzel P, Krupa, S. Loss of treed patches represents additional nutrient source to a large wetland landscape. In revision.

Troxler, TG, Coronado-Molina, C, Rondeau, D, Krupa, M, Sklar, FH, Wetzel P, Price, RM. 2010. Interactions of biological and hydrogeochemical processes facilitate phosphorus dynamics in an Everglades tree island. Abstract presented at the Greater Everglades Ecosystem Restoration Meeting, Naples, FL.

Troxler, TG, Coronado-Molina, C, Rondeau, D, Krupa, S, Newman, S, Manna, M, Sklar, FH, Wetzel P, Price, RM. Interactions of biological and hydrogeochemical processes facilitate phosphorus dynamics in an Everglades tree island. In revision.

Troxler, TG. 2011. Hydrogeochemical patterns at temporal and spatial scales of a “pristine” island and a degraded tree island located in WCA-3A: Restoring ecological function of degraded tree islands. Final Report submitted to the South Florida Water Management District, West Palm Beach, FL. 56p.

Troxler Gann, T. G., D. L. Childers and D. N. Rondeau. 2005. Ecosystem nutrient dynamics and hydrologic variation in tree islands of the southern Everglades. Forest Ecology and Management 214: 11-27.

Vendramini PF, Sternberg L. 2007. A faster plant stem-water extraction method. *Rapid Communications in Mass Spectrometry* 21: 164-168.

Wetzel P.R. 2002. Analysis of tree island vegetation communities. p.357–389. *In* F. H. Sklar and A.G. van der Valk (eds.) Tree islands of the Everglades. Dordrecht, The Netherlands, Kluwer Academic Publishers.

Wetzel, P.R., A.G. van der Valk, S. Newman, Gawlik, D.E, T. Troxler Gann, C. A. Coronado-Molina, D. L. Childers, and F. H. Sklar. 2005. Maintaining tree islands in the Florida Everglades: nutrient redistribution is the key. Frontiers in Ecology and the Environment 3:370-376.

Wetzel, P.R., Sklar, F.H., Coronado, C.A., Troxler, T.G., Krupa,, S.L, Sullivan, P.L., Ewe, S., Price, R.M., Newman, S.M., Orem, W.H. 2011. Biogeochemical processes on tree islands in the Greater Everglades: Initiating a new paradigm. Environmental Science and Technology Reviews.

Willard, D. A., C. E. Bernhardt, C. W. Holmes, B. Landacre, and M. Marot. 2006. Response of Everglades tree islands to environmental change. Ecological Monographs 76:565–583.

Worth, D.F. 1988. Environmental response of WCA-2A to reduction in regulation schedule and marsh drawdown. Technical Publication 88-2. West Palm Beach: South Florida Water Management District.

XI. APPENDIX

Fire in early 2011 that burned sawgrass marsh and *Typha* stands in very close proximity to the Twin Heads tree island (and instrumentation installed there)