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Hydrologic Measurements and Implications for Tree Island Formation Within Everglades National Park

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ABSTRACT

Tree islands in the Shark River Slough of the Everglades National Park (ENP), in the southern state of Florida in the United States, are part of a wetland system of densely vegetated ridges interspersed within relatively open sloughs. Human alteration of this system has had dramatic negative effects on the landscape of the region and restoration efforts will require adjusting the hydrology of the region to assure the preservation of these important ecologic features. The primary objectives of this study were to document the hydrology in the vicinity of tree islands in ENP by measuring velocities in time and space and by characterizing suspended sediments. The results of such measurements were interpreted with respect to factors that may limit tree island growth. The measurements were conducted in the vicinity of 3 tree islands known as Black Hammock (BH), Gumbo Limbo (GL), and an unnamed island that was named for this study as Satin Leaf (SL). Acoustical Doppler Velocity (ADV) meters were used for measuring the low velocities of the Everglades water flow. Properties of suspended sediments were characterized through measurements of particle size distribution, turbidity, concentration and particle density. Mean velocities observed at each of the tree islands varied from 0.9 cm/s to 1.4 cm/s. Slightly higher mean velocities were observed during the wet season (1.2 to 1.6 cm/s) versus the dry season (0.8 cm/s to 1.3 cm/s). Maximum velocities of more than 4 cm/s were measured in areas of *Cladium jamaicense* die-off and at the hardwood hammock (head) of the islands. At the island's head, water is channelized around obstructions such as tree trunks in relatively rapid flow which may limit the lateral extent of tree island growth. Channelization is facilitated by shade from the tree canopy which limits the growth of underwater vegetation thereby minimizing the resistance to flow and limiting sediment deposition. Suspended sediment concentrations were low (0.5 mg/L to 1.5 mg/L) at all study sites and were primarily of organic origin. The mean particle size of the suspended sediments was 3 microns with a distribution that was exponential. Critical velocities needed to cause re-suspension of these particles were estimated to be above the actual velocities observed. Sediment transport within the water column appears to be at a near steady state during the conditions evaluated with low rates of sediment loss balanced by presumably the release of equivalent quantities of particles of organic origin. Existing hydrologic conditions do not appear to transport sufficient suspended sediments to result in the formation of tree islands. Of interest would be to collect hydrologic and sediment transport data during extreme hydrologic events to determine if enough sediment is transported under these conditions to promote sufficient sediment accumulations.

KEYWORDS: Everglades, Tree Islands, Water Velocity, Suspended Solids, Restoration

INTRODUCTION

Tree islands are familiar features in many wetlands around the world. However, only recently has their formation and hydrology been evaluated. According to Wetzel (2002), the complex environment in which tree islands exist made it very difficult to understand their formation process until aerial photography and radio carbon dating were available. Many hypotheses on the formation of these islands were presented after these technologies developed (Foster et al., 1983; Glaser, 1987; Wetzel, 2002; Gumbricht et al., 2004), but few hydrologic data have been acquired.

Tree islands are patches of woody vegetation within a freshwater wetland with predominantly non-woody species (Wetzel, 2002). Around the world they can have different shapes: elongated or tear drop, round or oval and linear strings or ridges (Wetzel, 2002). Tree islands in the Shark River Slough in the Everglades National Park (ENP) are predominantly elongated in shape and are an integral part of a ridge and slough environment.

The Everglades environment is composed of densely vegetated ridges interspersed with relatively open sloughs following an organized pattern oriented parallel to the direction of flow (Science Coordination Team, 2003). Human intervention has altered the ridge and slough topography by creating a more uniform landscape and this alteration has had dramatic negative effects on the ecology of the Everglades. The Science Coordination Team (2003) emphasized the importance of determining the role of flow in the ridge and slough system and of the Everglades ecosystem as a whole. Furthermore, the Team recommended that the ridge and slough be monitored as a means to assess the progress of the Comprehensive Everglades Restoration Plan (CERP) (Schnettler et al. 2003). Tree islands are an integral part of the ridge and slough system and are particularly susceptible to changes in water flow, which further accentuates their importance as an indicator of the condition of the ecosystem.

In this study, ridge and sloughs are defined based upon the type and density of the emergent vegetation. Sloughs are dominated by *Eleocharis cellulosa* (spikerush) whereas ridges are dominated by *Cladium jamaicense* (sawgrass). Periphyton, a community of algae, bacteria and microfauna (Noe et al., 2001), and several species of *Utricularia* are present in the water both in the ridge and slough areas. Elongated tree islands are part of the ridge system (Figure 1). The upstream and highest part of the largest tree islands in Shark River Slough is called the tropical hardwood hammock or "head" of the islands. The head has a well defined tree canopy. The head of the islands under study have an area that was permanently above water and an area that experiences periods of inundation. The canopy of the hardwood trees extends into areas that are periodically inundated. Downstream of the head, the "tail" or bayhead swamp is much larger than the head portion of the island. The bayhead swamp experiences long periods of inundation because of its lower elevation. The canopy within the tail region is open, allowing sunlight to penetrate areas below (Armentano et al., 2002). In this paper, the “tree line” represents the outer fringe of a tree island and is defined as the point where there is an apparent change in vegetation with respect to the surrounding marsh.

Published hypotheses on the formation of tree islands in the Everglades revolve around the topography of the limestone bedrock in Florida, water flow, nutrient concentrations, plant litter accumulation and sediment transport (Sklar and Van der Valk, 2003). In a study of the interactions of tree island vegetation, hydrology and soils in the Everglades, Ross et al. (2004) reported that the pattern of decreasing canopy height from the raised hardwood hammock to the swamp forests immediately downstream represents a decrease in site productivity, as reflected in litterfall rates. This negative correlation between surface elevation and productivity has been demonstrated more generally in the ridge and slough landscape (Ross et al. 2003), and several authors have postulated that, in organic-rich Everglades substrates, a positive feedback between elevation and below ground production could be the basis for maintaining landscape heterogeneity (Givnish and Volin 2003; Wetzel et al. 2005; Ross et al. in press). Willard et al. (2002), reported in their paleo-ecological study of two tree islands in water conservation area 3-B that tree island origin might be due to localized factors such as topographic highs and prolonged dry periods that allowed the establishment of tree island vegetation. The elongated shapes of the islands points to a hydrodynamic factor (Komar, 1983).

The fact that most of the islands are tear-shaped with their main axis coinciding with the general direction of water flow is a strong indication that water flow is an important factor in their formation, shape and preservation. However, very few field data related to water flow and sediment transport around the tree islands are currently available. Most data published on tree islands of the Everglades has focused on vegetation patterns (Brandt et al., 1999; Armentano et al., 2002; Olmsted and Armentano, 1997), tolerance of vegetation to water levels (Conner et al., 2002; Ross et al., 2003; Ross et al., 2004), peat depth and elevation (Mason and Van der Valk, 2002), nutrient geochemistry (Orem et al., 2002; Noe et al., 2001) and water flow computer simulations (Wu et al., 2002; Bolster and Saiers, 2002). Two studies have evaluated transport within an experimental flume located within the Everglades marsh (Saiers et al. 2003; Harvey et al. 2005). Measurements of water velocity have been reported through the U.S. Geological Survey within the Water Conservation Areas and ENP in areas not immediately adjacent to tree islands (Jenter and Schaffranek, 2001; Riscassi and Schaffranek, 2002, 2003, & 2004). Methods utilized for measuring velocities in these studies were similar as those used in the current study with the exception that these prior studies focused mainly on wet season (June to November) measurements.

The objective of this project was to evaluate flow and suspended sediment dynamics in the vicinity of tree islands within ENP through measurements of water depth, velocity, and suspended sediment characteristics. Results were interpreted to evaluate conditions that may limit tree island formation. The focus of the sediment work, was on suspended sediments that were transported in the water column. This study differs from other work in that the tree islands evaluated through this report are located in ENP, within a region where tree islands appear to be much less impacted by human intervention. Also, the water velocity measurements are unique in that they are located in the vicinity of the tree islands and include measurements along transects across these islands. In addition, efforts were made to include measurements throughout the year. The data are used to estimate the rate of sedimentation accumulation and the critical water velocity required to create sediment re-suspension. The results of this study can be used as a starting point for quantifying target conditions that will promote the ridge and slough landscape and the formation of tree islands of the Everglades. In order to achieve this goal, it will be necessary to determine if critical differences occur in water flow and the characteristics of suspended solids between the ridges and the sloughs. Also of interest are potential differences in flow and suspended solid characteristics among different tree islands. Such differences may indicate whether the effects of water flow and suspended sediments are localized or if they can be applied to the Everglades system as a whole.

SITE DESCRIPTION AND GEOMETRY OF THE DATA COLLECTION PROGRAM

Everglades National Park is situated on the southern tip of Florida encompassing an area of over 600,000 hectares. Shark River Slough is the major water flow pathway through the southern Everglades. This slough is approximately 32 km wide along its northern border, narrowing to about 10 km near its discharge point at the Gulf of Mexico. Water velocities were presumed to be very low since the hydraulic gradients are only of 3-4.7 cm per kilometer along its longitudinal northeast-southwest axis (Olmsted and Armentano, 1997). The climate of this area is characterized by an average annual air temperature of about 24° C, average annual precipitation of 1,320 mm, and periods of intense evapotranspiration (ET) resulting in estimated ET of 70 to 90 percent of the total amount of rainfall (McPherson and Halley, 1997). The rainfall pattern can be divided into a wet season that extends from June to November, and a dry season from December to May (Noe et al., 2001). Surface water inputs to the area are controlled by a series of gates (S-12A, S-12B, S-12C, and S-12D) situated on Tamiami Trail road, which defines the northern boundary of ENP. Releases through these gates are managed by the South Florida Water Management District (SFWMD).

Measurements for this study were conducted in the vicinity of 3 tree islands, known as Black Hammock (BH), Gumbo Limbo Hammock (GL) and a tree island which was named for this study as Satin Leaf Hammock (SL) but that has also been referred to as Indian Camp Hammock and Tiger Hammock in other documents. The smallest tree island was Satin Leaf (length: 0.92 km; width: 0.12 km) and largest was Gumbo Limbo (length: 1.08 km; width: 0.31 km). All three islands are located within Shark River Slough, ENP, Florida (Figure 2). Soils in the vicinity of each are peats (organic matter content > 80%), except in a limited (<1000 m^2) area within the elevated heads of the islands, where carbonate-rich mineral soils have developed above the outcropping limestone bedrock (Ross et al. 2004; Ross et al. in press). Maximum topographic relief observed at the tree islands is 1 meter (Ross et al. 2004). The vegetation pattern near BH, GL, and SL consists of closed canopy forest in the upstream half of the tree islands, open-canopied woodland with a rich herbaceous understory in their extended tails, and a patterned mosaic of dense and open graminoid communities in the marsh matrix (Ross et al. 2004).

Data were collected along transects (110 to 1000 m long) at two of the three tree islands: Gumbo Limbo and Satin Leaf. Transects were oriented perpendicular to the islands' main north-south axis (Figure 2). Four transects were established at GL (G0, G1, G2 and G3) and two were established at SL (S1 and S2). The numbering of each transect corresponded to its geographic location where the northernmost transect was represented by the lowest number. Transects G1, G2, G3, S1, and S2 are located on the west side of the islands only. The westernmost point of these transects is considered the origin from which measuring stations are located every 5 meters. Transect G0 is the longest transect and has measuring stations every 10 meters. It extends to the east and the west upstream of the island in a direction perpendicular to the island's long axis. The origin of transect G0 is located at its midpoint, where this transect intersects the long axis of the island.

METHODS

Two general types of data were collected, those needed to characterize water flow and those needed to characterize the suspended sediment dynamics. Ancillary measurements included wind velocity and direction. Wind velocity was measured at shoulder level using a hand-held anemometer (Kestrel 1000, Lymington, UK). Wind was observed to affect the top few cm of the water column but the instrumentation used in the current study could not measure water velocity in this layer. Since no correlations were observed between wind speed and water velocity at depth or the characteristics of suspended sediments, wind data were not presented. Data collected through this study were then analyzed to estimate accumulation rates through deposition of suspended sediments and evaluate critical velocities needed for sediment resuspension.

Water Depth and Velocity

Water depth was measured with a ruler in conjunction with the transect work. For semi-continuous readings, water depth was measured in 60-minute intervals using a pressure water level data logger (Infinities USA, Inc., Port Orange, Florida) that was installed on the structure used to support the continuous velocity recording instrument at Gumbo Limbo. The resolution of the instrument was 0.0254cm. The period of record for these water level measurements was June 10, 2003 to July 7, 2004. The water level measurements were converted to absolute depth by adding the offset distance between the location of the pressure transducer and soil surface. Water depth measurements were checked during bi-weekly maintenance trips to the site.

Acoustical Doppler Velocity meters (ADV) were used for measuring water velocity. These instruments provided the most reliable and accurate water velocity measurements in 3 dimensions. These units were designed with a "side-looking" orientation where the acoustical signal was transmitted to the side of the instrument rather than below, thereby allowing for measurements in water as shallow as 15 cms. Two types of ADV's were utilized in this study: a handheld ADV (SonTek Handheld FlowTracker ADV, San Diego, CA, firmware version 2.4) for measurements along transects and a fixed ADV (SonTek Argonaut-ADV, San Diego, CA, firmware version 11.6) for semi-continuous measurements in time.

Early during the study it was recognized that the very low particulate load in the water column resulted in low acoustic reflection, low signal to noise ratios (SNR), and consequently erroneous velocity measurements. The manufacturer of the equipment later replaced the receiver boards of all ADVs used for this project with more sensitive units. According to the manufacturer all units purchased after July 11, 2003 contain the new nano-receiver boards. If a unit was purchased prior to that time, the user will need to contact the manufacturer to confirm whether or not the unit was upgraded.

All data reported from the fixed ADVs were obtained with updated nano-receiver boards. The handheld ADV was fitted with the updated nano-receiver board only during measurements for transect G0. All other transect work was completed with the handheld ADVs fitted with the older receiver boards. Seeding of the water column was necessary in order to increase the precision of the handheld ADVs prior to their upgrade. Experiments showed that the standard deviation of the velocity was about 0.04 cm/s when fitted with the new nano-receiver board.

Without the new nano-receiver board the standard deviation of the velocity measurements increased to 0.2 cm/s, due to the effects from seeding. During times when seeding was used all data corresponding to an SNR less than 5 dB were disregarded as the standard deviation of the velocity measurements increased significantly (from 0.2 cm/s to 0.9 cm/s) once the SNR values fell below 5 dB. In addition to the effects on the precision of the measurements, seeding tended to impact velocity measurements in the z-direction. Thus when seeding was used, velocity data were revised with only V_x and V_y values used in computing water speed. More details about additional quality control measurements and the impacts of seeding are provided in Bazante et al. 2004.

The handheld ADV was used for the collection of intensive measurements along the horizontal transects and vertical velocity profiles. Measurements along the horizontal transects were made at a depth of 6/10 of the total water depth. Vertical profiles were obtained by taking measurements every 10 cm. Depth measurements were made with a ruler and wading rod. In areas characterized by dense vegetation, vegetation was removed from a small area in the vicinity of the sensor. The handheld ADV was configured to average data over either 60 or 30 seconds. The waiting time, time between placement of the handheld ADV and the collection of measurements, was 5 minutes when seeding was necessary and 3 minutes when seeding was not used. These waiting times were confirmed through field observation, where the obvious effects of the water disturbance were no longer noticeable.

Continuous measurements of velocity were collected at all 3 tree islands by installing one fixed velocity recording instrument on the west side of each tree island just south of the hardwood hammocks. The period of record of the fixed ADV units at BH and GL was from October 9, 2003 to March 16, 2004. The period of record at Satin Leaf was longer, commencing on July 9, 2003 and also ending on March 16, 2004. Two conditions lead to notable erroneous data: exposure of the probes to air during extremely low water level and entanglement of vegetation in the probe. Such erroneous data were removed from the record. The period of record ended on March 16, 2004 because water levels were below the 15 cm depth required by the equipment. Extreme low water depths were noted when the signal strength of the fixed ADVs dropped significantly and consistently below 30 counts (30 to 60 counts was the normal range). Signal strength is defined as the intensity of the reflected acoustic signal received by the fixed ADV. Such drops were confirmed through subsequent field visits which showed at least one of the probes out of the water. Disturbance through vegetation was noted by persistent signal strengths much greater than 60 followed by field visits confirming the presence of vegetation in the probes. The fixed ADVs were programmed to store averages of 3000 measurements for each 15-minute interval. During each maintenance trip the fixed ADV units were adjusted vertically so that measurements occurred at or near 6/10 depth. A 3-meter long platform was constructed immediately adjacent to each fixed ADV unit to facilitate access to the unit via airboat while minimizing disturbance of the vegetation immediately around the unit. A geo-textile liner about 1 m in diameter was positioned below each fixed ADV unit to prevent the growth of vegetation that could block the acoustic signal. Power was provided to each unit through the use of a solar panel that charged an external battery.

Suspended Sediments

Properties of suspended sediments were characterized through measurements of particle size distributions, turbidity, concentration and particle density. Particle size distributions were measured using a Coulter counter (Beckman Coulter, Miami, FL) fitted with a 100 μm aperture which was calibrated with 20 μm latex spheres as recommended by the instrument manufacturer.

Bin sizes for particle size distribution analysis ranged from 2 μm to 60 μm. Data compiled from the particle size analysis included the number of particles per size category, the total number of particles, and the average particle size. Each sample was analyzed in triplicate. Turbidity of the water was measured using a nephelometer (Turner Designs Model 40, Sunnyvale, CA). The nephelometer was calibrated with 2 NTU and 20 NTU formazin standard suspensions prior to the analysis of each sample batch. Total suspended solids, and organic and inorganic fractions (mg/l) were analyzed on samples that were filtered in the field with an in-line filtration system using glass fiber filters (Metrigard Product number XE20935) with a nominal 0.5 μm pore size. Total suspended sediments were measured by drying the filters at 100 ^{o}C for a period of 1 hour. Organic and inorganic fractions were determined after igniting the filters at 550 ^{o}C for 15 minutes. Particle density analysis was performed with an in-line filtration system that was capable of collecting at least 0.5 grams of suspended sediments. The in-line filtration system included a yarn-wound filter (1 micron effective pore size) for capturing suspended particles. Once the sample was collected, the sediments were eluted from the yarn-wound filter (U.S. EPA 1994). The sediments were then freeze dried with the exception of one sample which was oven dried at 75 ^{o}C. Once dried, the sediment concentrates were analyzed for particle density using the standard pycnometer method (ASTM 2002). Controls of known particle density were also analyzed within each experimental batch.

Data Analyses

Calculations of soil accumulation rate were used to evaluate whether the low concentrations of suspended solids could have a significant impact on the formation of ridges and tree islands under the conditions in which the data was collected for this study. Direct deposition of material on the soil surface by sinking periphyton and vegetation senescence was not considered within the analysis. The rate at which suspended sediments accumulate is a function of the particles' settling velocity (Chin, 2000) and their concentration in the water. The average concentration measured at GL (1.3 mg/L) was utilized for computation purposes. The Stokes' setting velocity was computed from a water kinematic viscosity and density corresponding to the average measured temperature of 27.5ºC, a mean particle size of 3.3 μm, a sediment particle density of 1,480 kg/m^3, and a particle shape factor of 1 based upon the assumption of a spherical shape. Particles in water have complex shapes with shape factors < 1 (Chin, 2000). The most used shape factor which is physically meaningful is the Corey Shape Factor (CSF) (Dietrich, 1982), where a lower CSF represents a flatter particle. According to Dietrich (1982) and based on the work of Schultz et al. (1954), the mean CSF for most particles in a natural environment is between 0.5 to 0.8, generally decreasing from 0.8 to 0.5 with decreasing size. Samples of bottom sediments were observed through an environmental scanning electron microscope (XL30 Model, Koninklijke Philips, Amsterdam, The Netherlands) and values of 0.3 to 0.4 for CSF were obtained from measurements of particles observed in the images.

Critical velocities for particle re-suspension were computed using the method of Kadlec and Knight (1996) since it applies directly to wetlands. According to these authors, flow in the wetlands is slow enough that it can be considered laminar for the water layers in the immediate vicinity of the bottom particles, thereby allowing for the simplification of the calculations.

According to Kadlec and Knight (1996) critical velocity (u) is defined as:

$$u = 7.2\left(\frac{\omega_s^{1/3} H^{1/6}}{n d^{2/3}}\right) \tag{1}$$

Where ω_s = Stokes settling velocity, m/s (varies with shape factor); H = average transect water depth, 0.63 m; n = Manning's coefficient for open channel, 0.05 s/m$^{1/3}$; and d = particle diameter, 3.3×10^{-6} m. Kadlec and Knight (1996) calculated a Manning's coefficient of 0.05 s/m$^{1/3}$ for a wetland bottom described as flat and un-vegetated. This description corresponds to the open areas of *Cladium jamaicense* die-offs where the highest water speeds were recorded. Since the calculation was based on the laminar theory, the criteria were checked for the appropriate Reynolds number as recommended by the authors.

RESULTS

Water Depth and Velocity

Water depth data collected at GL varied seasonally with the lowest elevation of 1.47 m (NGVD 88) recorded on June 10, 2003, and the highest elevation of 1.85 m (NGVD 88), recorded on October 1, 2004, resulting in a maximum difference of 38 cm. Water depth measurements also showed that the bottom topography was characterized by the largest gradient (0.004 cm/m) at transect G1 (Figure 3) which was the transect aligned with the head of the tree island. Transect G2 was characterized by the second largest topographic gradient (0.0006 cm/m) and the topography at the remaining transects, G3 and G0, was essentially flat. The hardwood hammock portions of the tree islands are topographic highs with sharper elevation gradients in the vicinity of the tree island "head." There was no clear topographic gradient across transect G3, which was located in the tail portion of the tree island. Topographic gradients measured at Satin Leaf tree island were consistent with those measured at Gumbo Limbo with S1 measuring at 0.003 cm/m and S2 measuring at 0.002 cm/m.

The overall average water speed at each of the fixed ADVs was similar, within the 0.8 to 1.6 cm/s range (Table 1). This range agreed with measurements by others (Riscassi and Schaffranek 2002, 2003, & 2004) who observed 0.7, 0.7, and 1.4 cm/s on average for stations

(Figure 1) GS-203, GS-33, and GS-36, respectively, during the 2003 to 2004 season (October to April) and 1.2 and 0.7 cm/s at GS-203 and GS-33 for the 2002 to 2003 season. These measured values were high in comparison to measurements recorded during the 2000 to 2001 season which were observed at 0.55 cm/s at GS-203 (Riscassi and Schaffrank 2002). A slight decrease in the average water speed was noted during the wet season at BH (1.2 cm/s) in comparison with the average speed measured at GL and SL (1.6 cm/s). During the dry season, the highest average water speed was recorded at GL at 1.3 cm/s with BH and SL measuring at 0.8 cm/s. The higher speed measured during the dry season was expected since GL is located towards the center of Shark River Slough at a lower elevation than the other two tree islands, resulting in a greater accumulation of water. The predominant direction of flow was in the horizontal direction. Vertical components of flow were found to be consistently low (<0.1 cm/s). The primary direction of water flow at GL was aligned almost exactly with the main axis of the tree island during wet and dry seasons. At Satin Leaf the direction was generally offset towards the east at 20 degrees. Black Hammock tree island experienced the largest change in flow direction with flow aligned slightly towards the east (5^o) during the wet season and strongly towards the west (26^o) in the direction towards the center of the slough during the dry season. This change in direction at BH could be due to drainage effects along the outer fringes of Shark River Slough.

The range of water speed at BH was typically between 0.5 and 2 cm/s with occasional spikes outside of these values. An analysis of the data indicated that the occasional spikes did not affect the overall statistics of the results and so these data were retained. A decrease in water speed was observed during the dry season as water levels dropped considerably. Water speed at GL was typically between 1 and 2.2 cm/s with occasional spikes outside of this range between October of 2003 and February of 2004. Time series plots from the fixed ADV installed at SL indicated that water speed was more variable than the speed measured at the other 2 locations, with speeds measuring between near zero to 3.5 cm/s (Figure 4). The change in speed observed at Satin Leaf is associated with upstream gate operations. High flows through the S-12 gates correspond to higher velocity measurements at Satin Leaf. The larger variability in water speed at Satin Leaf relative to the other 2 tree islands was still observed when consistent periods of record are compared (Figure 5). Water speed at Satin Leaf exhibited a larger decrease in speed towards the end of October of 2003 and January of 2004, than the other 2 tree islands. This larger variation in water speed is likely due to the closer proximity of this tree island to the flow control gates along Tamiami Trail road. The Shark River observation tower road located immediately east of the tree island (Figure 2) may contribute to the variability by limiting the movement of water.

At transect G0 speeds varied spatially by a factor of 5 from 0.4 to 2.0 cm/s (Figure 6). Also of interest is an apparent decrease in speed towards the middle of the wider sloughs, as well as an increase in speed along the edge of the sloughs. *Cladium jamaicense* in the ridge might present a greater resistance to flow than *Eleocharis cellulosa* in the slough. The slower speed in the center of the sloughs could be attributed to higher concentrations of floating vegetation. Water speeds at transects G1 and G2 varied from less than 1 cm/s to more than 4 cm/s, with most measurements between 1 cm/s and 2.5 cm/s. The highest speeds were present in open areas (free from *Eleocharis cellulosa* and *Cladium jamaicense*) outside the tree line and high peaks were also observed inside the tree line. Transect 1 was located at the head of the island and transect 2 was located just to the south of the head. Therefore, the portion of these transects located inside the tree line was covered by the tree canopy. This cover did not allow for the growth of underwater vegetation. The water was free to flow through various channels with relatively little resistance from underwater plant growth. This was the presumed cause of the peaks below the tree canopy, which in turn helped to maintain these water paths by decreasing the rate of sediment accumulation. Water speed at transect 3 was similar to the other transects. The highest speeds occurred in the open areas where standing stem densities of *Cladium jamaicense* were much lower (Figure 7). However, this transect is located at the tail of the island and did not have hardwood cover. As a result, sunlight penetrates into the water and underwater vegetation flourishes in this area, creating a barrier for water flow. Water speeds decrease beyond the tree line (G3 + 175) at this transect. As observed at GL, the speeds measured along SL transects were dominated by vegetation type. Water speed was lower in places where vegetation was very thick (S2+10) and comparatively faster in open water areas (S2+30) (Figure 8). Water speed was not related to mean suspended sediment particle size or turbidity.

Vertical velocity profiles were measured at representative ridge versus slough dominated areas along transect G0. Water speeds measured in 10-cm increments throughout the water column were observed to vary from 0.2 cm/s to 1.5 cm/s within waters characterized as either ridge or slough (Figure 9). No distinct pattern was observed in the profiles. On average, the speed measured on the ridges was slightly lower (0.8 cm/s) than in the sloughs (0.9 cm/s). The speed profile at the ridge-slough interface was characterized by high variability, with velocities ranging from 0.1 cm/s to 2.3 cm/s.

Suspended Sediments

Particle size distribution of most samples was exponential in nature with the largest number of particles having a smaller average diameter. Mean particle size was relatively constant for all three transects at GL (Table 2). The mean for each transect varied from 2.9 to 3.6 μm with a standard deviation of about 1.3 to 1.5 μm within a transect. The median values for the particle sizes were typically in the same range as the mean. The number of particles per ml was found to be relatively constant at approximately 2×10^5 particles/ml at GL and 1.5×10^5 particles/ml at SL. Turbidity for GL was relatively low and constant at all three transects. Values ranged from 0.32 NTUs to 0.84 NTUs. Most values were in the 0.45 NTUs to 0.55 NTUs range. For SL, the turbidity values ranged from 0.34 NTUs to 0.75 NTUs (Table 3). Results for suspended sediment concentration were relatively constant between stations. Total suspended sediment values were on the order of 0.5 to 1.5 mg/L, with the exception of one station at S2 and one at G2 where it was above 2.5 mg/L (Figure 10). At this station, a large amount of decaying *Cladium jamaicense* could be observed in the water. The breakdown of the decay material might locally produce light detritus that would account for the higher suspended solids concentrations in these areas. As expected, most of the total suspended solids for all sites were composed primarily of organic matter, between 60 to 65%. Suspended solids concentrations were not observed to be correlated with the hydrologic variables measured in study. Results from the pycnometer analysis indicate the particle density of the 3 suspended sediment samples collected at GL and SL were consistent and on the order of 1.5 to 1.6 g/cm^3 (Table 4).

Data Analyses

The average settling velocity was computed as 2.93×10^{-1} m/day for G0 based upon Stokes settling velocity and measured parameters from GL, assuming a CSF of 1. The settling velocity was computed as 8.8×10^{-2} m/day for a CSF of 0.3. For the highest settling velocity of 2.93×10^{-1} m/d (CSF of 1), the accumulation rate was computed as 3.81×10^{-1} g/(m^2•day) which is equivalent to 140 kg/m^2 during a 1,000 year period. Since the average particle density at GL was 1480 kg/m^3, 140 kg/m^2 represents a potential accumulation of 19 cm in this period of time, assuming a porosity of 50% and without considering decay or oxidation.

To obtain the entire range of possible critical velocities that cause particle re-suspension, the lowest and highest values for CSF were used in the calculations, yielding a critical velocity of 7 cm/s (CSF = 0.3) and 10.5 cm/s (CSF = 1.0). This range of velocity was only measured as occasional spikes by the fixed ADVs and was never measured by the handheld ADV during transect work at any of the tree islands. Under the conditions observed during this study, velocities were apparently not high enough to promote sediment re-suspension.

DISCUSSION AND CONCLUSION

In this study vegetation was found to play an important role in controlling velocities. In tidal marsh environments, which have similar elongated landscape features as observed in the Everglades, flow pathways and velocities have been observed to be dictated by vegetation density and vegetation types (Leonard and Reed 2002; Reed et al. 1999). Specifically within the Everglades, stem spacing of emergent vegetation (Lee et al., 2004) and floating periphyton mats (Harvey et al. 2005) have been identified as important factors in controlling water velocities. This study found specifically that, in the vicinity of the tree islands, differences in vegetation types and shade from hardwood tree cover plays a key role in controlling the characteristic shape of the tree islands. In this study, the highest speeds recorded were consistently observed in open areas of *Cladium jamaicense* die-offs and the lowest speeds were measured in areas of high density from *Eleocharis cellulosa* and *Cladium jamaicense*. Relatively high speeds were observed inside the tree line in the areas closer to the head of the island, most likely due to the lack of underwater vegetation in this part of the island (due to cover from the trees). Although water flow was obstructed under the canopy due to the presence of tree trunks, roots, and ferns, water was generally channelized and moved around these obstructions in relatively high speed flow. These channels can be visually detected during the dry season. Velocity measurements in these channelized areas, although high relative to velocities measured in other areas, were below the critical value necessary to cause sediment re-suspension or scouring. These results suggest that as water accelerates through these channels around the islands' hardwood hammock, it creates differences in the rate of sediment accumulation. Sediments that would otherwise settle around the island's hammock are carried downstream by the faster moving water in the channels. The development of a canopy which indirectly creates a higher sediment transport rate might impose a limit on how much a tree island is able to grow in the direction perpendicular to flow. This limit in head width might also limit the length of the island as longitudinal growth is associated with litter deposition downstream of the head in the direction of flow. Water speeds generally decrease in areas downstream of the head within the tail portion of the tree island. Within the tail, the trees are sparse and should not impede light penetration into the water, thereby permitting underwater vegetation to flourish. This underwater vegetation impedes flow and decreases water speeds in this area. These conditions would increase sedimentation rates in the tail and promote the elongation of the tree island.

Time series measurements emphasize the differences in hydrologic parameters between wet and dry seasons. Of interest was the relatively small change in water level (38 cm) measured during this study coupled with the flat topography that suggests a system that is sensitive to small changes in water level. Water speeds were generally less than 3 cm/s at each of the tree islands lowering to near zero at Satin Leaf during the dry season. The differences in average water speed among tree islands were too small to make any conclusions about localized differences within the area of study with the exception that speeds are higher in the center of Shark River

Slough during the dry season due to the accumulation of water in this lower topographic elevation. The variability of water speed appears to be influenced by upstream gate operations, with tree islands located closer to the gates showing a larger range in flow velocities. Also a change in predominant flow direction was observed for BH tree island during the dry season, which is presumably due to drainage effects. This tree island is located on the eastern edge of Shark River Slough far from upstream gate operations. Of interest would be to evaluate the long term impacts of this change in flow direction on tree island shape and orientation. Overall the vertical component of flow was found to be consistently low (<0.1 cm/s). This observation may be due to the clearing of vegetation during velocity measurements as other researchers have observed vegetation to induce vertical flow components (Nepf and Koch 1999). Also water levels may have been too low near the tree islands in order induce vertical temperature stratification and subsequent vertically driven flows which have been observed by others in 0.7 m water within the Everglades system (Jenter and Schaffranek 2003). The Argonaut units used in this study were located in roughly 0.4 m of water.

The suspended sediments characteristics were very similar within and between the tree islands. Overall during this study suspended solids were very low and relatively constant, which suggests that suspended sediment transport is at an equilibrium condition where deposition is balanced by the introduction of particles, primarily of organic origin. Interception of particulates by vegetation within the water column (Saiers et al. 2003) also plays a likely role in maintaining equilibrium concentrations. The computed accumulation rates indicate that the rate of suspended sediment deposition is small in open water and it is doubtful that the deposition of suspended sediment under the conditions observed in this study is sufficient to cause the net sediment accumulation needed to form the foundation of the tree islands. It is expected that during storm conditions that are common during the wet season and during extreme events, such as hurricanes, the amount of suspended solids will increase dramatically. It would be of interest to obtain measurements during and immediately following an extreme hydrological event to asses its impact on suspended solids, and their contribution to the formation of ridges and tree islands. Other factors not measured in the current study, including periphyton deposition and vegetation senescence, likely play key roles in tree island formation. It would be of interest to evaluate these other sources of sediments to evaluate their contribution to this process.

ACKNOWLEDGMENTS

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References

American Society for Testing and Materials, 2002. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, D 854-00. ASTM International, West Conshohocken, PA.

Armentano, T.V., Jones, D.T., Ross, M.S., Gamble, B.W., 2002. Vegetation Pattern and process in tree islands of the southern Everglades and adjacent areas. In: Sklar, F.H., and A. Van Der Valk (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 8, 225-282.

Bazante, J., Jacobi, G., and Solo-Gabriele, H., 2004. Draft Technical Report, Documenting the Importance of Water Flow to Everglades Landscape Structure and Sediment Transport in Everglades National Park, Subcontract to the University of Miami. Everglades National Park, Homestead, FL. Available at: http://www.eng.miami.edu/~hmsolo/tree/members_only/progrep/ENP_Final.pdf and at: http://www.eng.miami.edu/~hmsolo/tree/members_only/progrep/ENP_Appendix.pdf

Bolster, C.H., Saiers, J.E., 2002. Development and evaluation of a mathematical model for surface-water flow within the Shark River Slough of the Florida Everglades. Journal of Hydrology 259, 221-235.

Brandt, L.A., Portier, K.M., Kitchens, W.M., 1999. Patterns of change in tree islands in Arthur R. Marshall Loxahatchee National Wildlife Refuge from 1950 to 1991. Wetlands 20, 1-14.

Chin, D.A., 2000. Water-resources engineering. Prentice-Hall, Upper Saddle River, New Jersey.

Conner, W.H., Doyle, T.W., Mason, D., 2002. Water depth tolerances of dominant tree islands species: What do we know? In: Sklar, F.H., and A. Van Der Valk (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 7, 207-224.

Dietrich, W.H., 1982. Settling Velocity of Natural Particles. Water Resources Research 18(6), 1615-1626.

Foster, D.R., King, G.A., Glaser, P.H., Wright, H.E., 1983. Origin of string patterns in northern peatlands. Nature 306, 256-258.

Givnish, T. J. & J. C. Volin, 2003. Self-assembly of Slough-Ridge-Tree island landscapes in the central Everglades: A model for the integration of Hydrological and Ecological Processes. Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem April 13-18, 2003. Palm Harbor, Florida, USA. Abstract.

Glaser, P.H., 1987. The development of streamlined bog islands in the continental interior of North America. Arctic and Alpine Research 19, 402-413.

Gumbricht, T., McCarthy, J., McCarthy, T.S., 2004. Channels, wetlands and islands in the Okavango Delta, Botswana, and their relation to hydrological and sedimentological processes. Earth Surface Processes and Landforms 29, 15-29.

Harvey, J., Saiers, J., and Newlin, J., 2005. Solute transport and storage mechanisms in wetlands of the Everglades, south Florida. Water Resourcs Researchr, 41, W05009.

Jenter, H.J., Schaffranek, R.W., 2001. Vegetative resistance to flow. Continuing project work plan - FY 2001. Project number: 4384-16300. USGS, Reston, VA.

Jenter, H.J., Schaffranek, R.W., 2003. Thermally-driven vertical mixing in the Everglades. Proceedings of the joint conference on the science and restoration of the Greater Everglades and Florida Bay ecosystem from Kissimmee to the Keys held in Palm Harbor, Fl. South Florida ecosystem restoration task force working group chaired by Ronnie Best. USGS, Miami, Fl., 290-292.

Kadlec, R.H., Knight, R.L., 1996. Treatment Wetlands. Boca Raton: Lewis Publishers.

Komar, P.D., 1983. Shapes of streamlined islands on Earth and Mars-experiments and analyses of the minimum-drag form. Geology 11, 651-654.

Lee, J.K., Roig, L.C., Jenter, H.L., and Visser, H.M., 2004. Drag coefficients for modeling flow through emergent vegetation in the Florida Everglades. Ecological Engineering 22:237-248.

Leonard, L.A., Reed, D.J., 2002. Hydrodynamics and sediment transport though tidal marsh canopies. Journal of Coastal Research 36, 459-469.

Mason, D.H., Van der Valk, A., 2002. Vegetation, peat elevation and peat depth on two tree islands in water conservation area 3-A. . In: Sklar, F.H., Van der Valk, A., (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 11, 311-336.

Mcpherson, B.F., Halley, R., 1997. The South Florida environment: a region under stress. U.S. Geological Survey Circular 1134.

Nepf, H.M., Koch, E.W., 1999. Vertical secondary flows in submersed plant-like arrays. Limnol. Oceanogr. 44, 1072-080.

Noe, G.B., Childers, D.L., Jones, R.D., 2001. Phosphorous biogeochemistry and the impact of phosphorous enrichment: Why is the Everglades so unique? Ecosystems. 4, 603-624.

Olmsted, I., Armentano, T.V., 1997. Vegetation of Shark Slough, Everglades National Park. SFNRC Technical Report 97-001.

Orem, W.H., Willard, D.A., Lerch, H.E., Bates, A.L., Boylan, A., Comm, M., 2002. Nutrient geochemistry of sediments from two tree islands in water conservation area 3B, the Everglades, Florida. In: Sklar, F.H., and A. Van Der Valk (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 5, 153-186.

Reed, D.J., Spencer, T., Murray, A.L., French, J.R., Leonard, L., 1999. Marsh surface sediment deposition and the role of tidal creeks: Implications for created and managed coastal marshes. Journal of Coastal Conservation. 5, 81-90

Riscassi, A.L., Schaffranek, R.W., 2002. Flow velocity, water temperature and conductivity in Shark River Slough, Everglades National Park, Florida: July 1999-August 2001. USGS open file report 02-159. USGS, Reston, VA.

Riscassi, A.L., Schaffranek, R.W., 2003. Flow velocity, water temperature and conductivity in Shark River Slough, Everglades National Park, Florida: August 2001-June 2002. USGS open file report 03-348. USGS, Reston, VA.

Riscassi, A.L., Schaffranek, R.W., 2004. Flow velocity, water temperature and conductivity in Shark River Slough, Everglades National Park, Florida: June 2002-July 2003. USGS open file report 04-1233. USGS, Reston, VA.

Ross, M.S., Reed, D.L., Sah, J.P., Ruiz, P.L., Lewin, M.T., 2003. Vegetation: environment relationships and water management in Shark Slough, Everglades National Park. Wetlands Ecology and Management 11, 291-303.

Ross, M. S., D. T. Jones, G. L. Chmura, H. C. Cooley, H. Hwang, K. Jayachandran, S. F. Oberbauer, D. L. Reed, P. L. Ruiz, J. P. Sah, S. Sah, D. Stockman, P. A. Stone & J. Walters, 2004. Tree islands in the Shark Slough landscape: interactions of vegetation, hydrology and soils. Final Report. Submitted to the Everglades National Park, Homestead, Florida, USA.

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

Saiers, J.E., Harvey, J.W., Mylon, S.E., 2003. Surface-water transport of suspended matter through wetland vegetation of the Florida Everglades. Geophysical Research Letters, 30(19).

Schnettler, J., Yerkes, E., Burch, S., 2003. Unleashing the flow. Civil Engineering. June 2003, 70-75.

Sklar, F.H., Van der Valk, A. (EDS.), 2003. Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers.

Schultz, E.F., Wilde, R.H., Albertson, M.L., 1954. Influence of shape on the fall velocity of sedimentary particles, Sediment. Ser. Rep 5, 161 pp., Missouri River Div., Corps of Eng., US Army, Omaha, Nebraska.

Science Coordination Team, 2003. The role of flow in the Everglades ridge and slough landscape. South Florida Ecosystem Restoration Working Group. Aumen, N.G. (ED.). Available at: http//sofia.usgs.gov/publications/paper/sct_flows

U.S. Environmental Protection Agency, 1994. Code of Federal Regulations, Appendix C to Subpart M, proposed ICR protozoan method for detecting Giardia cysts and Cryptosporidium oocysts in water by a fluorescent antibody procedure. Federal register, Vol. 59, No. 28. U.S. Environmental Protection Agency, Washington, D.C.

Wetzel, P.R., 2002. Analysis of tree island vegetation communities. In: Sklar, F.H., and A. Van Der Valk (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 12, 357-390.

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

Willard, D.A., Holmes, C.W., Korvela, M.S., Mason, D., Murray, J.B., Orem, W.H., Towles, D.T., (2002). Paleocological insights on fixed tree island development in the Florida Everglades: I. Environmental controls. In: Sklar, F.H., and A. Van Der Valk (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 4, 117-152.

Wu, Y., Rutchey, K., Guan, W., Vilchek, L., Sklar, F.H., 2002. Spatial simulations of tree islands for Everglades restoration. . In: Sklar, F.H., Van der Valk, A. (EDS.). Tree islands of the Everglades, 1st ed. Kluwer Academic Publishers. Chapter 16, 469-498.

Parameter	Wet Season[a]			Dry Season[b]			Overall		
	Oct 9/03 - Nov 30/03			Dec 1/03 - Mar 16/04			Oct 9/03 - Mar 16/04		
	SL	**GL**	**BH**	**SL**	**GL**	**BH**	**SL**	**GL**	**BH**
Mean Water Speed, cm/s	**1.61**	**1.59**	**1.20**	**0.75**	**1.32**	**0.77**	**1.07**	**1.41**	**0.88**
Direction of Flow, Degrees Clockwise from Main Axis of Tree Island[c]	**-25**	**8**	**-5**	**-13**	**1**	**26**	**-20**	**4**	**14**
Direction of Flow, Degrees from Magnetic North	**184**	**213**	**219**	**196**	**206**	**250**	**189**	**209**	**238**

[a] The wet season extends for six months from June to November. Data were collected during 52 days within this time period.

[b] The dry season extends for six months from December to May. Data were collected during 105 days within this time period.

[c] Primary orientation of the tree islands are 209°, 205°, and 224° from magnetic north for SL, GL, and BH, respectively.

Note 1: Velocity in the z-direction (vertical) is not included because of the very low range of the values (less than 0.1 cm/s) in this direction.

Note 2: Data from the following days was not included because of vegetation entangled in the equipment's probe or because of low water levels. BH: from October 13, 2003 to October 30, 2003 and from February 5, 2004 to February 6, 2004. GL: from February 15, 2004 to February 26, 2004. SL: from February 6, 2004, at 12:00 p.m. to February 24 , 2004, at 1:15 p.m.

Table 1: Mean Values of Variables Measured by the Fixed ADVs at Each Tree Island.

Site	Number of Samples	Average Number Particles/mL Analyzed per Sample	Mean Particle Size (µm)	Median Particle Size (µm)	Standard Dev. of Particle Size (µm)
GL Transect 1	26	2.0E+05	2.9	2.7	1.3
GL Transect 2	38	2.2E+05	3.1	3.0	1.3
GL Transect 3	18	2.0E+05	3.6	3.7	1.4
SL Transect 2	5	1.5E+05	3.2	3.1	1.3

Table 2: Summary of Particle Size Characteristics for Each Transect.

	Gumbo Limbo	Satin Leaf
Mean Particle Size[a]	3.13 µm	3.17 µm
Mean Suspended Sediment Concentration	1.3 mg/L	2.0 mg/L
Range of Suspended Sediment Concentration	0.2 to 2.6 mg/L	1.7 to 2.6 mg/L
Turbidity Transect 1	0.63 NTU	0.48 NTU
Transect 2	0.51 NTU	0.49 NTU
Transect 3	0.58 NTU	

[a] Mean Particle Size for a sample from Black Hammock was 2.97 µm.

Table 3: Summary of Suspended Sediment Data.

Location	Date Sample Collected	Particle Density	% Organic
Satin Leaf	June 13, 2003	1.57 g/cm^3	65%
Satin Leaf	Aug. 19, 2003	1.52 g/cm^3	66%
Gumbo Limbo	July 25, 2003	1.48 g/cm^3	62%

Table 4: Results from Particle Density and % Organic Analysis for Suspended Sediments.

Figure 1: (above) Aerial and Ground Photographs of Gumbo Limbo Tree Island within Everglades National Park, Florida

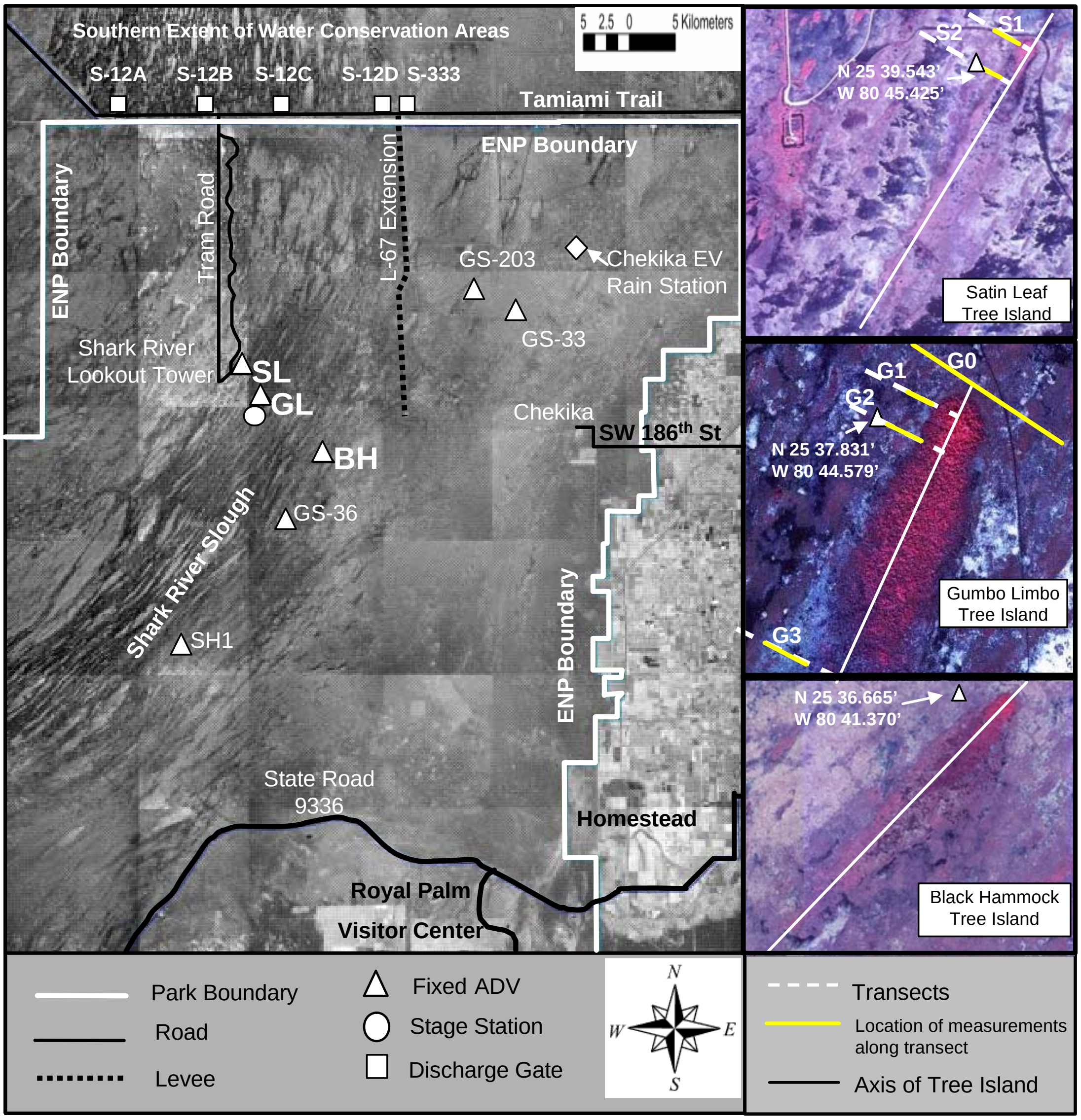

Figure 2: Location of Monitoring Stations Established by this Study Along with the Locations of Other Velocity Monitoring Stations and a Rain Gauge. Aerial Photos of Each Tree Island Show Orientation of Central Axis and Transect Locations. USGS Station SH1 not referenced in text as the period of record for this station did not coincide with the period of record for the current study.

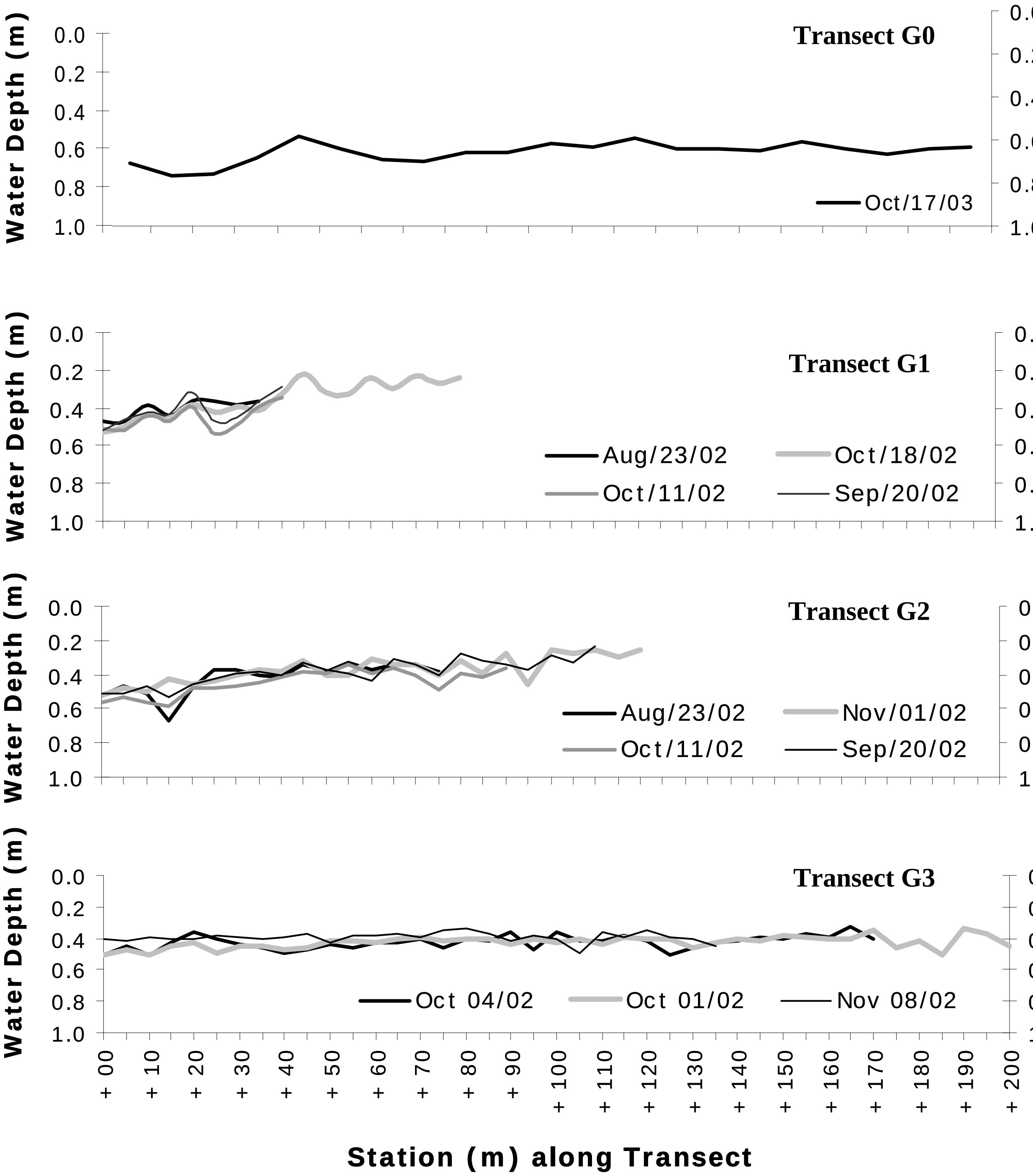

Figure 3: Water Level in Vicinity of Gumbo Limbo Hammock.

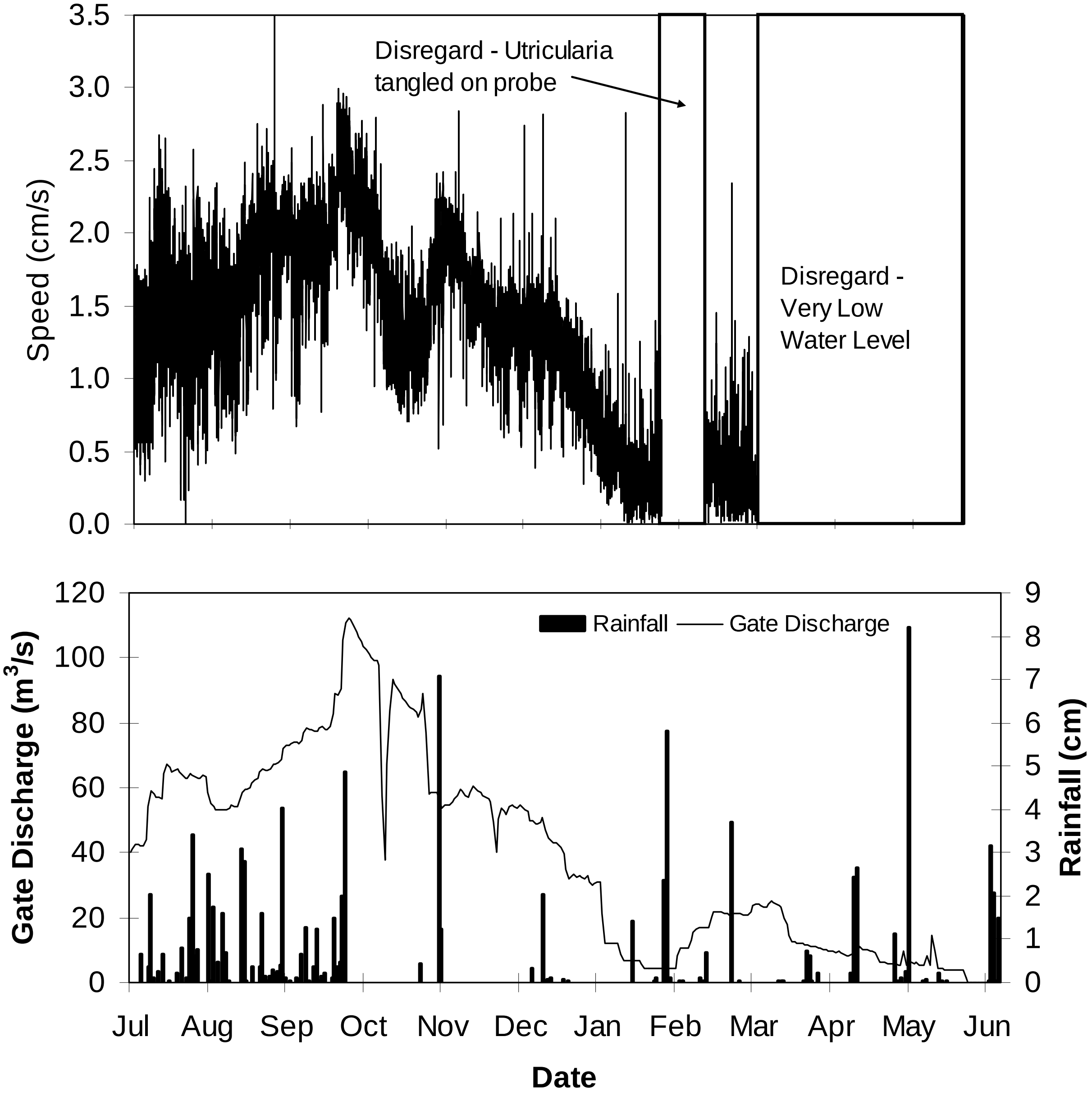

Figure 4: Water Speed Measured at Satin Leaf for the July 9, 2003 to June 8, 2004 Period of Record. Gate flow corresponds to the sum of flow through gates S-12A, S-12B, S-12C, and S-12D.

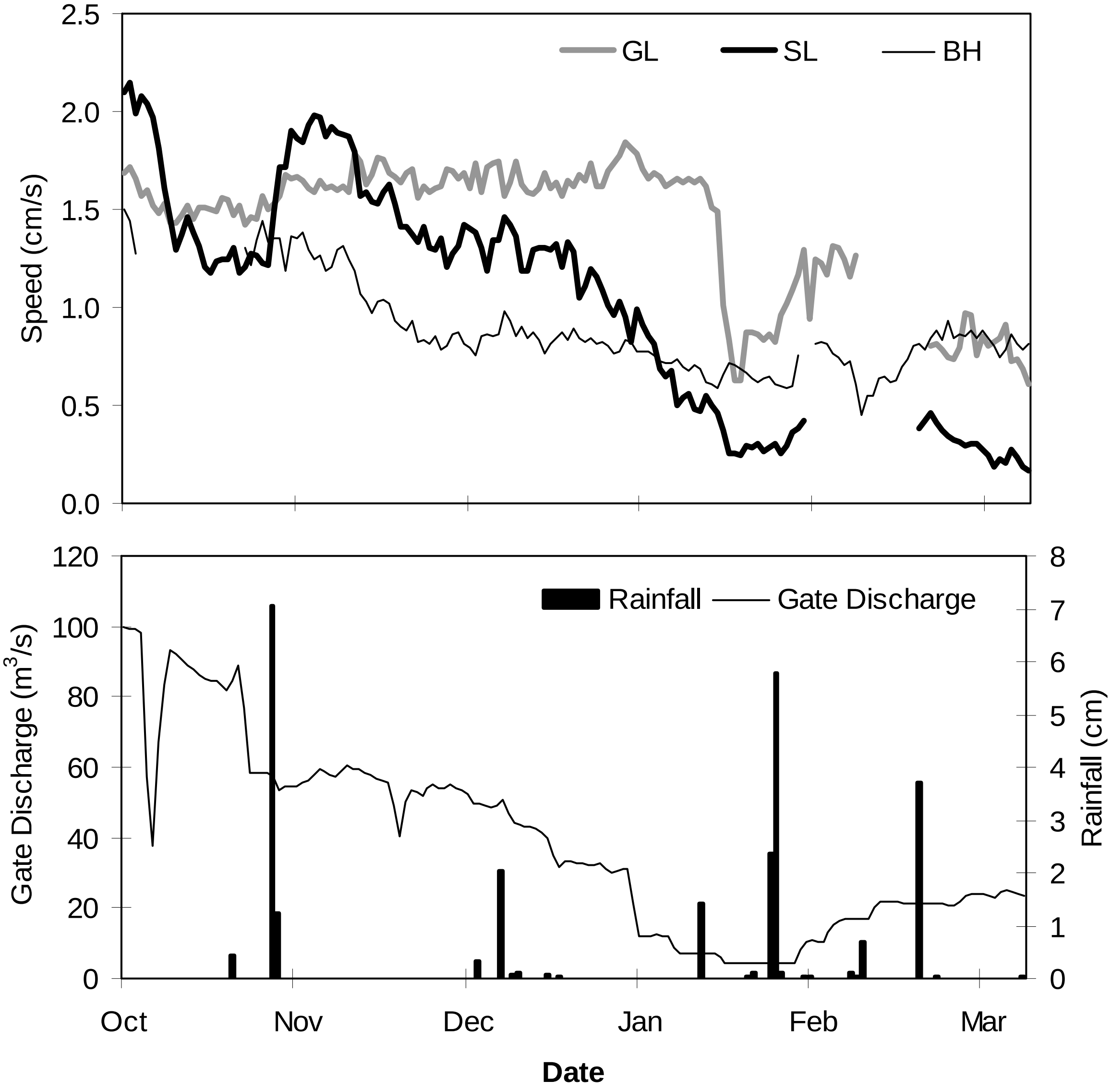

Figure 5: Time Series Plots of Daily Average Water Speed at BH, GL, and SL for the October 10 to March 15, 2004 Time Period. Note: Missing data is due to vegetation entangled in the equipment's probe. Gate flow corresponds to the sum of flow through gates S-12A, S-12B, S-12C, and S-12D.

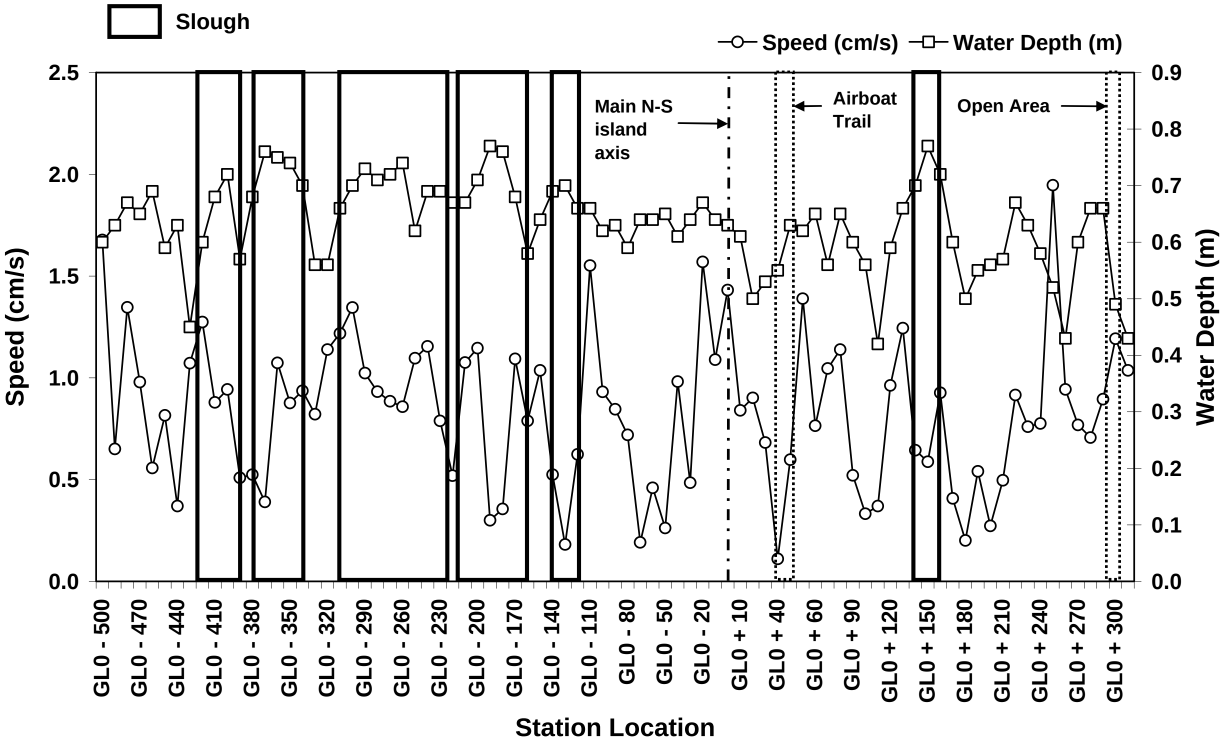

Figure 6: Water Depth and Speed Along Transect 0 at GL Tree Island. Data Collected September 25 through October 23, 2003.

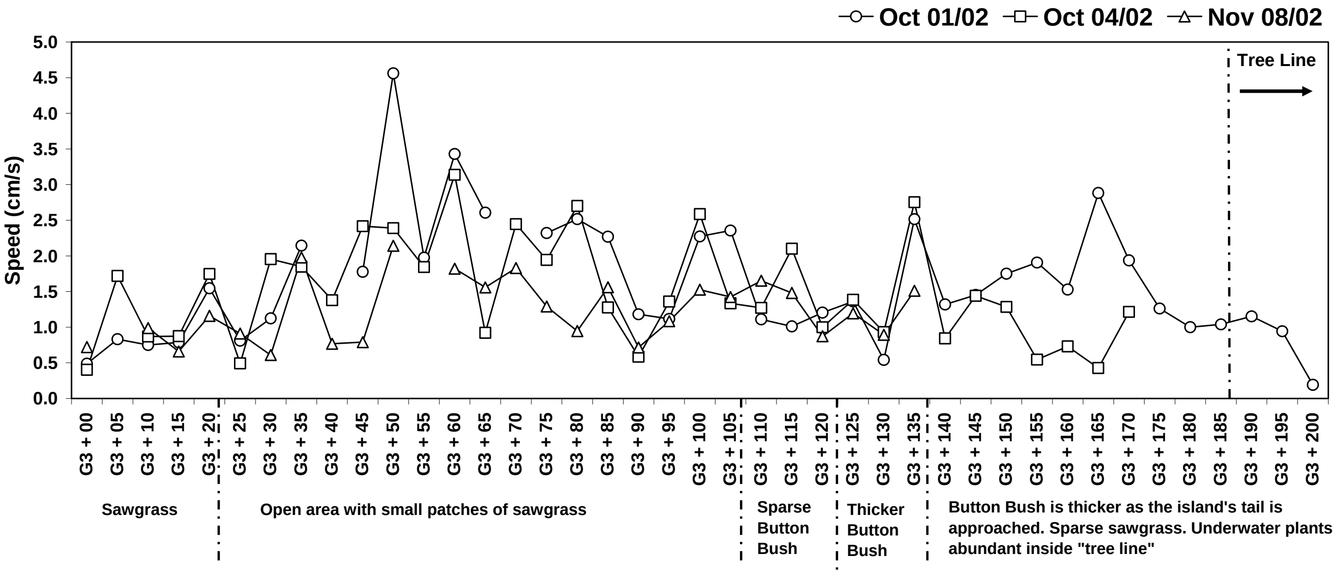

Figure 7: Water Speed Data Collected at GL Transect 3 on October 1, 2002, October 4, 2002, and November 8, 2002.

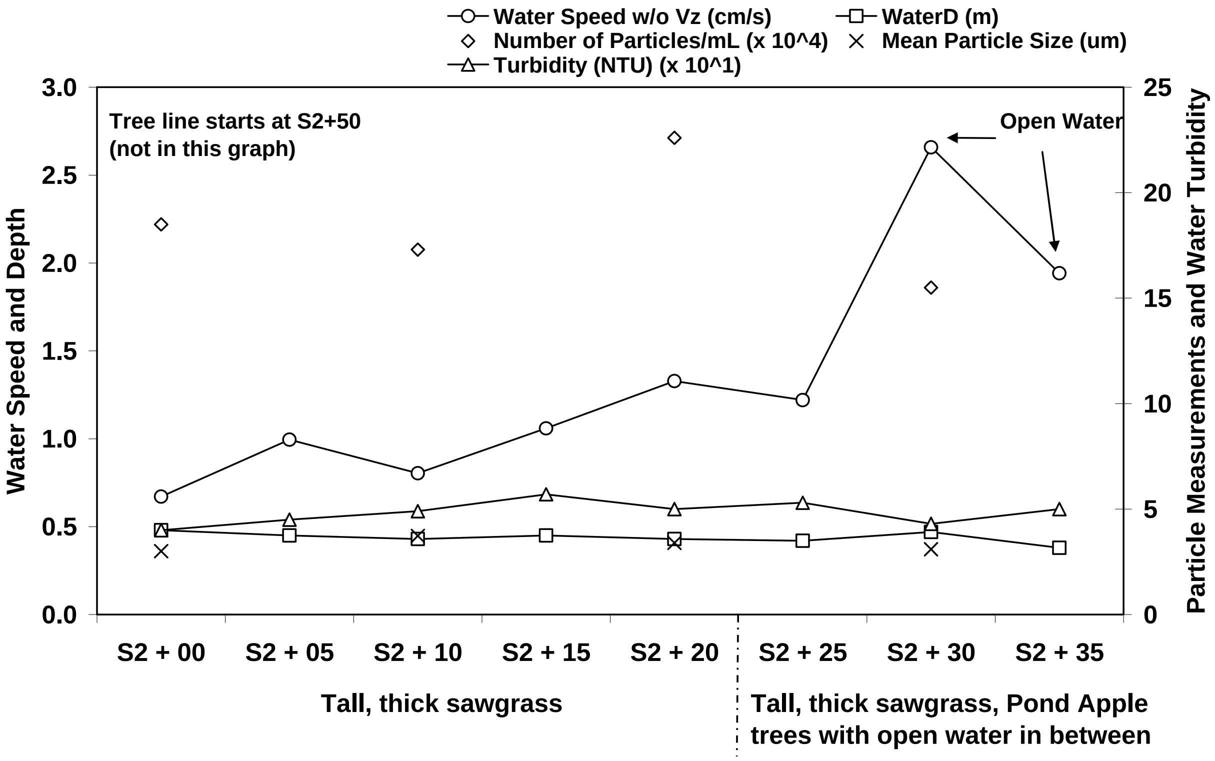

Figure 8: Water speed, depth and turbidity, and suspended solids measurements at SL. Data Collected on October 25, 2002 along Transect 2 at SL Tree Island.

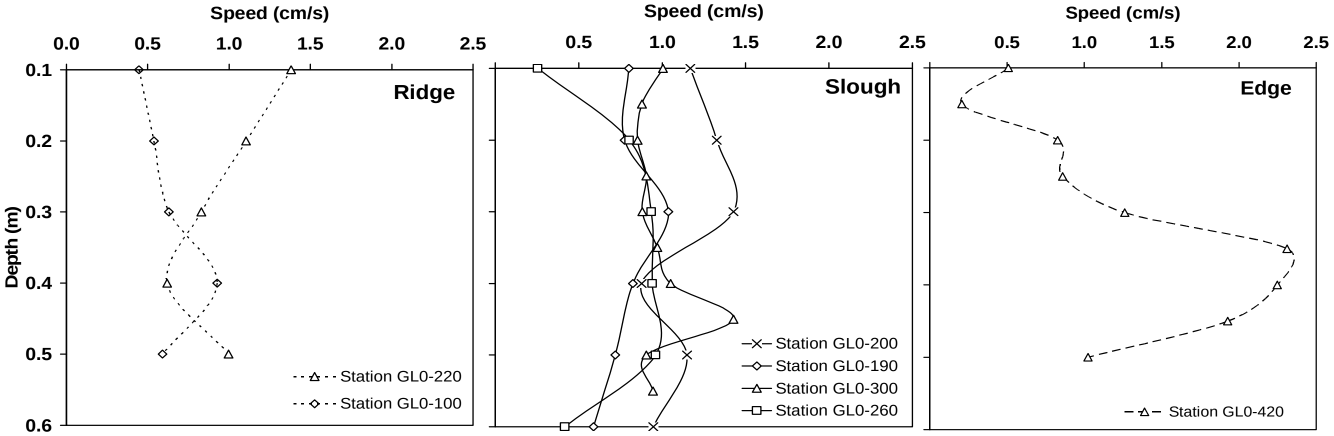

Figure 9: Vertical Velocity Profiles at GL Transect 0. Data Collected in 10 cm Depth Intervals on November 13, 2003.

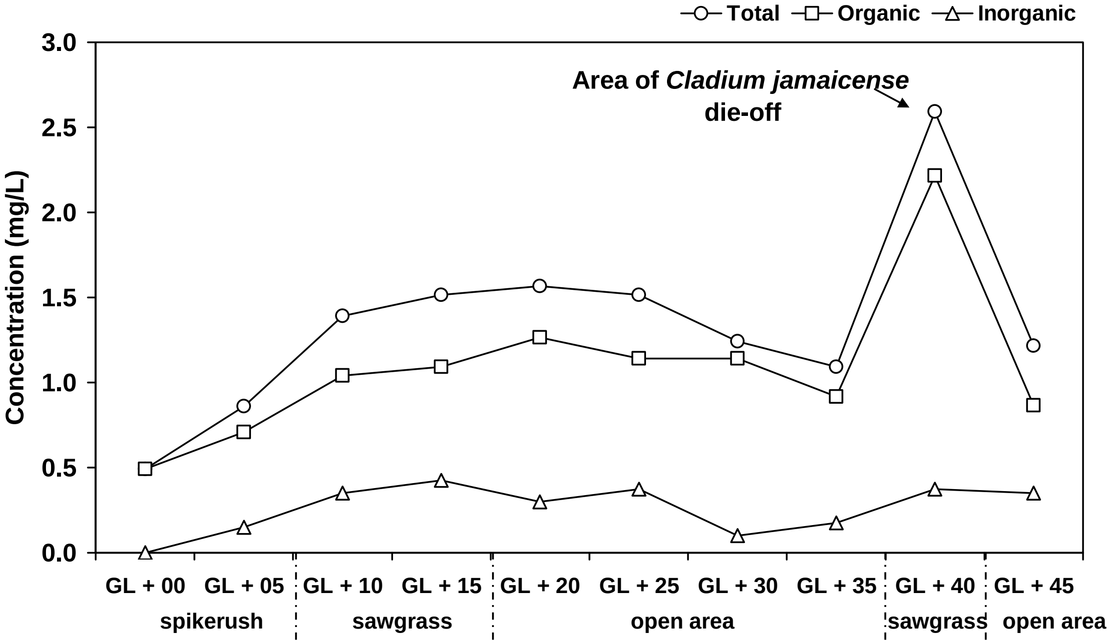

Figure 10: Suspended Solid Data Collected at GL Transect 2 on July 25, 2003.