THE EFFECTS OF MICROTOPOGRAPHY ON HYDROLOGY, PHYSICOCHEMISTRY, AND VEGETATIVE COMMUNITIES IN FRESHWATER TIDAL SWAMPS OF THE HUDSON RIVER

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Abstract. Hudson River freshwater tidal swamps have dynamic flooding and oxygenation regimes due to daily tidal flooding. Microtopography, small scale differences in elevation, adds even more complexity to this hydrology and has important implications for nutrient flow and wetland plant communities. We measured several hydrological, chemical, and biological processes on higher elevation hummocks for comparison to lower elevation hollows. Microtopography significantly affected flooding duration and redox conditions. Hummocks had lower concentrations of soluble phosphate in their porewater probably due to differing depths of iron oxidation. Hummocks also had lower porewater ammonium concentrations which could be explained by higher plant uptake of nitrogen on hummocks or less ammonium being nitrified and subsequently denitrified in hollows due to lack of oxygen. Therefore, hummocks had less soluble phosphate and ammonium in their porewater available to export during the next tidal cycle. Decomposition rates were found to be slower in hollows. This was attributed to lack of oxygen due flooding or differing decomposer communities. Fewer herbaceous plant species were found in hollows compared to hummocks perhaps because of hollow's anoxic soils. Microtopography affects freshwater tidal swamp ecosystem function by affecting oxygen penetration, nutrient availability, rates of decomposition, and herbaceous plant species distributions.

INTRODUCTION

Ecological functions of freshwater tidal wetlands along the Hudson River include filtering upland runoff by nutrient interception and transformation (Arrigoni et al. 2008). Freshwater tidal wetlands of the Hudson River contain many different community types including 600 ha of freshwater tidal swamp (reviewed by Yozzo et al. 2005). Very few studies have been published specifically on tidal freshwater swamps and little is known about whether their ecological functions differ from more common freshwater tidal wetland community types along the Hudson River, such as emergent marshes (Doumele 1985, Rheinardt 1992, Rheinhardt and Hershner 1992).

Freshwater tidal swamps occur along coastal rivers with only small changes in elevation from the mouth to upstream portions. These swamps are influenced by semidiurnal flooding caused by tidal fluctuations, but are far enough inland that the average salinity is less than 0.5 parts per thousand (Edinger et al. 2002). Freshwater tidal swamps have distinct microtopographies (Rheinhardt and Hershner 1992). Studies of the microtopography of tidal freshwater swamps of the lower Chesapeake Bay have characterized two types of microtopography- hummocks which are elevated, relatively steep sided, flat top mounds between 1-10m^2 in area and hollows which are depressions that lie 14-16 cm below the adjacent hummock (Rheinhardt 1992). Hummocks appear to form from fallen trees, contain very little soil, and are mostly composed of roots. In contrast, hollows are composed of a mucky peat (Rheinhardt and Hershner 1992).

Microtopography, plant scale topographic variability having an elevation range of one centimeter up to as much as one meter, has the potential to influence wetland plant community structure and ecosystem function via microsite variations in hydrology, redox status of sediments, and erosion and deposition processes (Moser et al. 2007). Microtopography can affect hydrology in two ways. It can increase flooding duration and soil moisture through increased depression storage (Kamphorst et al. 2000), and it can affect the frequency and depth of flooding (Rheinhardt 1992). Therefore, through variations in inundation, microtopography can affect redox conditions and redox sensitive nutrients (Bridgham et al. 2001, Moser et al. 2009).

Redox conditions have dramatic effects on phosphorous forms and concentrations through interactions with iron. When iron is oxidized to Fe^{+3}, it forms insoluble iron-phosphate complexes that are released back into the water column upon reduction to Fe^{+2} (Patrick et al. 1973). This has important implications for uptake and release of phosphorous in soils with heterogeneous redox status with more phosphorous being released into the overlying water column in anoxic sites than in aerobic sites (Bridgham et al. 2001, Moser et al. 2009, Aldous et al. 2007, Chambers and Odum 1990, Fiedler et al. 2004). Nitrogen retention and transformation may also be affected by redox status of sediments (Reddy et al. 1984). Bruland and Richardson (2005) found that hummocks had higher nitrate and ammonium concentrations than hollows possibly due to greater mineralization of organic matter and release of inorganic nitrogen. Variation in extent and duration of flooding has been shown to strongly influence decomposition and nutrient release by altering moisture, temperature, and the amount of aerobic vs. anaerobic respiration occurring (Shure et al. 1986, Stoeckel and Miller-Goodman 2001, Ozalp et al. 2007). Microtopography could also affect sediment organic content and depositional processes by affecting flow of water, variation in inundation, and depressional storage (Stoeckel and Miller-Goodman 2001).

This variation in inundation, nutrients, and other abiotic factors caused by microtopography provides environmental heterogeneity that could allow niche differentiation among plants. Microtopography and vegetation composition have been shown to be related in other ecosystems such as mixed conifer deciduous forests (Beaty 1984), hardwood floodplain forests of Florida (Titus 1990), tropical freshwater swamp forests (Koponen et al. 2004), and Ohio fens (Collins et al. 1982). Koponen et al. (2004) found greater species richness on hummocks than hollows. However, there have only been a few studies conducted on the effects of microtopography on vegetation in tidal freshwater swamps (Rheinhardt 1992, Rheinhardt 2007, Rheinhardt and Hershner 1992, Doumlele et al. 1985). Rheinhardt (2007) found that mean water table depth, percent soil organic matter, and Fe^{+2} concentrations were all related to species composition in tidal freshwater swamps of the lower Chesapeake Bay. Observational assessments in freshwater tidal swamps of the Hudson River suggest that herbaceous species are found mostly on top of hummocks with only a few herbs such as *Lythrum salicaria* (purple loosestrife) and *Peltandra virginica* (arrow arum) in the hollows. Species richness has been found to increase with elevation as a general rule throughout Hudson River freshwater tidal wetlands (reviewed by Kiviat et al. 2006). If there are more species on hummocks that hollows, light availability may also be altered due to higher canopy closure on the hummocks than the hollows.

The purpose of this study was to characterize the microtopography of freshwater tidal swamps of the Hudson River and to determine whether this microtopography influenced ecosystem function by affecting the hydrology, physico-chemistry, and vegetative communities of these swamps. Specifically we wanted to determine if microtopography affects 1) the depth and duration of flooding, 2) deposition of sediment, 3) soil organic and water content, 4) sediment redox boundary, 5) phosphorus and nitrate availability, 6) temperature, 7) light intensity, and 8) herbaceous species richness or composition. Our hypotheses were that hollows would have a greater mean amplitude and duration of flooding, more rapid sediment deposition, greater soil organic matter, redox boundary at shallower depths, greater concentrations of phosphate and lower concentrations of nitrate in their porewater, warmer temperatures, more light, and fewer herbaceous species than hummocks.

METHODS

Site Description

North Tivoli Bay is a tidal freshwater wetland along the eastern shore of Hudson River between the villages of Tivoli and Barrytown, in Dutchess County, NY and is part of the Hudson River National Estuarine Research Reserve (HRNERR) (Yozzo et al. 2005). In 1850, North Tivoli Bay was partially separated from the main channel of the Hudson River via a railroad causeway. However, two culverts permit water and tidal exchange with the main channel of the Hudson. North Tivoli Bay has a tidal range of 1.2 m and is freshwater. The swamp is characterized by a mixed deciduous community with a well developed shrub layer and diverse bryophyte community (Yozzo et al. 2005).

Field research was conducted during the summer of 2009 in a tidal freshwater swamp in North Tivoli Bay. The areas of freshwater tidal swamp located in the bay are thought to be pre-railroad wetlands (Kiviat et al. 2006). Tidal swamp was identified from HRNERR GIS vegetation maps and a swamp located near the mouth of Stony Creek was chosen as the study location. Two sites (groupings of five transects) within the swamp were sampled using five m long transects parallel to the stream channel taken at distances of 5, 10, 15, 20, and 25 m from the channel. All variables described below were measured along these transects to compare hummocks and their adjacent hollows. Attributes and processes on hummocks and hollows did not significantly differ as distance from the stream increased. Therefore, data from all transects at each site were combined.

Microtopography

The distance from a level string to the ground was measured every 20 cm along the transects to obtain relative elevation. The lowest point on each transect was considered to have an elevation of zero, and all heights of hummocks were recorded as the difference between this zero and the tallest point on the hummock. To determine length of hummocks and hollows, every absolute change in elevation greater than 9 cm was considered to be a boundary between a hummock and hollow. A total of 44 hummock/hollow pairs were measured along all transects.

Hydrology

Tides entering and exiting North Tivoli Bay through the South railroad culvert were measured using the Hudson River Environmental Conditions Observing System (HRECOS) gauge station. Within North Tivoli Bay, relative water levels during spring and neap tides were continuously measured 25 m from the channel at one site for a period of ten days and at the second site for a period of thirteen days using a pressure transducer connected to a Campbell data logger to determine depth and duration of flooding. Maximum height of hummocks and hollows was used to determine depth of flooding and percent time flooded for thirteen individual hummocks and hollows. Water levels in the channel were also continuously measured in-between the two sites using the depth sensor on a YSI 6000 Sonde during the same ten and thirteen day periods that the pressure transducer was recording water levels in the swamp.

Physico-chemistry

Redox boundary depth was determined by placing 20 steel flagging rods (~ 2 mm diameter shafts) on random hummock and hollow pairs near each transect on both sites for six days. Maximum depth of visible rust on the rod below the soil surface was recorded immediately after removal from the soil. Twenty new rods were placed on new random pairs of hummocks and hollows near each transect and were left for ten days. The maximum depth of oxidation was interpreted to be the depth at which iron no longer oxidized (Bridgham et al. 1991).

Porewater equilibrators, with wells at depths of 1.3, 4.6, 7.9, 11.2, 14.5, 17.8, 21.1, and 24.4 cm below the surface of the soil, were used to sample hummock and hollow porewater and were prepared as described by Findlay et al. 2003. Twelve porewater equilibrators were buried in the sediment on random hummock/hollow pairs (all differed in elevation by at least 14 cm) at distances of 5, 15, and 25 m from the channel on both sites and left for eight days. Water samples were extracted from the wells in the field, acidified, and refrigerated (4°C) until analysis. Phosphate concentrations were determined by analyzing water samples for soluble reactive phosphorus using procedures for concentrations greater than 10µg PO_4-P/L as described by Wetzel and Likens (1991). Nitrate and ammonium were analyzed by automated wet chemistry on a Lachat QuikChem 8000 FIA using Lachat methods #10-107-06-1-J Phenate method (Ammonium) and Method #10-107-04-1-C Cadmium diazotization (Nitrate) each with a detection limit of 0.02 mg/L N. Standards spanning the sample range (0.02- 2.0 mg/L N) were made fresh daily.

Soil cores were taken to a depth of 6 cm on ten pairs of hummocks and hollows randomly along the transects on both sites. The soil samples were oven dried to a constant mass to get percent water content and combusted for 4 hours at 450°C to get percent organic content.

Twenty square rubber mats with an area of 110.25 cm^2 were placed on one random hummock/hollow pair near each transect to collect sediment and organic deposition and were left for ten days. Foil was placed on the bottom of the mats to prevent sediment from sticking to the bottom of the mats and was removed upon collection. Then, mats were placed in re-sealable bags until analysis. Sediment was scraped and rinsed off the mat, suction filtered, and oven dried to a constant mass. Sediment was then combusted for 4 hours at 450°C to get percent organic content.

To measure light intensity, Hobo (H08) temperature, humidity/light sensors were placed on the surface of the soil at distances of 5, 15, and 25 m away from the stream on both sites on random hummock/hollow pairs near each transect and left out for ten days logging measurements every ten minutes. Daily averages were calculated as an overall measure of light intensity. Hobo sensors were covered by sediment deposited during tides so only a few days worth of data could be used before there was an obvious decline in light reception. To measure temperature, twenty iButtons were placed on the surface of the soil on hummock/hollow pairs near each transect on both sites and left for ten days logging measurements every ten minutes. Average daily temperature was calculated for individual hummocks and hollows. In addition, average temperature between and during tidal flooding, when water height was above the mean water level 25 m from the channel at site one, was calculated for individual hummocks and hollows of site one.

Vallisneria americana from nearby wrack accumulations was collected and air dried for 24 hours. Pre-weighed 12 g amounts were placed in plastic mesh bags to assess rates of decomposition. *V. americana* was chosen because it is a native plant that would naturally occur and quickly decompose in the swamp. Twenty bags of *V. americana* were placed on hummock/ hollow pairs near each transect on both sites. After 21 days, bags were retrieved, foreign materials were removed, samples were oven dried to a constant mass, and final mass of *V. americana* was recorded. Handling losses and/or rapid leaching were 17.66% of the initial mass and all masses were corrected for difference between oven and air-dried mass.

Vegetation

One hummock/ hollow pair was sampled near each transect using 46 cm X 46 cm quadrats which were approximately the size of individual hummocks and hollows sampled. All herbaceous plant species within each quadrat were identified and number of stems per quadrat was recorded. Importance values for each species were calculated by averaging relative frequency and relative stem abundance.

Statistical Analysis

All statistical analyses were performed using R version 2.9.0 (R Development Core Team 2009) and using $\alpha = 0.05$. The depth and percent time hummocks and hollows were flooded were compared using two-sample t-tests. Percent time hummocks and hollows were flooded was log-transformed to meet assumptions of normality and homoscedasticity. Percent soil organic content and percent water content were compared between the top, middle, and bottom segments of the soil core using one-way ANOVAs. No differences in log percent soil organic content or reciprocal percent water content were found between segments of the core. Therefore, percent soil organic content and percent water content were averaged for each core and compared between hummocks and hollows using paired t-tests. Porewater phosphate and ammonium concentrations were compared across depths and between hummocks and hollows using two-way ANOVAs and Tukey's tests for posthoc analysis.

Ammonium concentrations were log-transformed. All other variables were compared between hummocks and their adjacent hollow using paired t-tests.

RESULTS

Microtopography

The microtopography at the study site consisted of bowl shaped hollows and raised, flat-topped hummocks clearly formed from stumps, fallen logs, or roots. Mean height of hummocks was 18.6 ± 1.0 cm (SE) and the modal length was 40 cm. Fifty-nine percent of hummocks were 40 cm or less in length.

Hydrology

There were two high and two low tides every day in the channel. Only one tide was high enough each day to inundate the swamp (Figure 1). The tide inundated the swamp for a mean of 4.21 ± 0.14 hours per tidal cycle. Log percent time flooded differed between hummocks and hollows ($P < 0.01$). Hollows were flooded between 2.19% and 8.45% times as long as hummocks. Hollows were flooded between 5.66% and 100.00% of the time and hummocks were flooded between 1.79% and 24.57% of the time. Overall maximum height of inundation was 52.4 cm and overall minimum was -12.5 cm. Water level summary for Site 1 is shown in figure 2. Depth of flooding differed between hummocks and hollows ($P<0.01$). On average, hummocks were flooded to a depth of 8.23 ± 1.34 cm, while hollows were flooded to a depth of 24.30 ± 2.42 cm. Despite the extremely rainy summer, summer 2009 hydrographs for the Hudson River Environmental Conditions Observing System (HRECOS) gauge station had a similar tidal range to those of 2008 confirming that inundation heights were not abnormal.

Physico-chemistry

Percent water content of the soil differed between hummocks and their adjacent hollow (Table 1). On average, hollows had 9.4% greater percent water content than hummocks. However, soils on both hummocks and hollows appeared to be saturated with very high water contents in general.

Hummock soils were very fibrous with fine roots while hollows soils were composed of a very mucky peat. No difference was found between hummock and hollows for percent soil organic content (Table 1), with a total mean of 27.22% ± 1.34 organic matter. Amount of sediment deposited did not differ between hummocks and hollows (Table 1) with a total mean of 0.32619 ± 0.05903 g/110.25 cm^2 of sediment deposited over the course of ten days. Percent organic content of sediment deposited did not differ between hummocks and hollows either (Table 1).

Maximum iron oxidation depths differed between hummocks and hollows (Table 1). On average, hummock iron oxidation depths were 8.9 cm greater than hollows, which had almost no oxidation occurring below the surface of the soil. Mean soluble reactive porewater phosphate concentrations differed considerably between hummocks and hollows. On average, hollow porewater phosphate concentrations were 1.734 mg/L greater than hummock porewater phosphate concentrations ($P<0.001$). Hummocks had a mean of 0.169 ± 0.058 mg/ L and hollows had a mean of 1.810 ± 0.131 mg/L. Porewater phosphate concentrations were significantly different among depths ($P<0.001$; Figure 3). Concentrations at a depth of 1.3 cm below the surface of the soil were significantly less than concentrations at all other depths. Concentrations at a depth of 17.8 cm were significantly greater than concentrations at a depth of 4.6 cm. Concentrations were uniform between all other depths. Porewater ammonium concentrations differed significantly between hummocks and hollows ($P<0.001$) but did not differ among depths ($P=0.722$; Figure 4). Hummocks had a mean of 0.69 ± 0.25 mg N/L and hollows had a mean of 0.94 ± 0.12 mg N/L.

Plant decomposition rates were slower in hummocks than hollows as the percent mass of *V. Americana* remaining after 21 days was greater by 17.1% in the hummocks than the hollows (Table 1). Mean daily temperature differed between hummocks and hollows (Table 1). Hollows were 0.209°C warmer than hummocks. Temperature did not differ in-between tidal cycles when hummocks and hollows were not inundated (Table 1). However, temperature during inundation did differ (Table 1) with hollows having a temperature 0.594°C warmer than hummocks. Data collected from the HRECOS gauge station at the South railroad bridge of North Tivoli Bay showed that water temperatures were warmer than air temperatures during this time period. Therefore, the difference between air and water temperatures accounts for the difference in temperature between hummocks and hollows. Mean daily light intensity did not differ between hummocks and hollows (Table 1).

Vegetation

The freshwater tidal swamp studied was dominated by *Fraxinus* spp. (ash) with a few *Acer rubrum* (red maple) in the canopy. Shrub vegetation consisted mostly of *Alnus* spp. (alder), *Cornus* spp. (dogwood), *Lonicera* spp. (honeysuckle), and *Lindera benzoin* (northern spice bush). Herbaceous species richness per quadrat differed between hummocks and hollows (Table 1). Six species total were found in hollows and seventeen total species were found on hummocks. On average, hummocks had 5 more species than hollows. Stem abundance per quadrat differed between hummocks and hollows (Table 1). On average, hummocks had 31 more stems per quadrat than hollows. Table 2 shows the importance values for species for which stem abundance was able to be counted. In addition to these species, moss was found on all hummocks and a graminoid was found on one hummock. *Lysimachia nummularia* (moneywort), a non-native species from Europe, had the overall highest importance value. Among the sparsely vegetated hollows, *L. nummularia* was the dominate species, as it had the highest importance value. Hummocks were dominated by *Impatiens capensis* (spotted-jewelweed), *L. nummularia*, *Symplocarpus foetidus* (skunk cabbage), and moss.

DISCUSSION

In Hudson River freshwater tidal swamps, hummocks and hollows differed significantly in several key attributes and these were consistent across transects at various distances from the tidal channel. This suggests that the processes that create these hummocks such as tree falls are not affected by frequency of flooding or that flooding occurs uniformly throughout the swamp. Hydrology of the swamp was driven by the daily tidal cycles of the Hudson River. While surface water fluctuations were determined by tidal stage, ground-water below the surface of the lowest hollow appeared to be fairly stable and percent water content of the soil suggested continuous saturation likely due to the high organic content of the soil.

Environmental differences were observed between hummocks and hollows that can be explained by different flooding regimes due to elevation differences. As hypothesized, hollows were flooded to greater depths and for longer periods of time than hummocks, leading to large differences in maximum iron oxidation depth. Hummocks had much lower concentrations of soluble reactive phosphate in their porewater than hollows. This large difference is not likely due solely to plant uptake, and, given the large differences in iron oxidation depths, we conclude that the differences in porewater phosphate concentrations are due to redoximorphic iron-phosphate interactions. Hummocks also had lower porewater ammonium concentrations compared to hollows. We expected hummocks to have higher ammonium concentrations than hollows due to greater mineralization of organic matter and release of inorganic nitrogen. One possible explanation of our results is that in the hollows lack of oxygen penetration may prevent ammonium from being nitrified and subsequently denitrified while the greater availability of oxygen in hummocks allows this nitrogen removal sequence to occur. Additionally, hummocks may have greater plant uptake of nitrogen than hollows.

Compared to hollows, hummocks have less soluble reactive phosphate and ammonium available in their porewater to export into the overlying water during the next tidal inundation. Future studies should quantify the area and coverage of hummocks compared to hollows to determine if this mechanism is a net export or retention of phosphate and ammonium within the swamp. Phosphate levels of the adjacent tributary, Stony Creek, are extremely high due to untreated sewage effluent (Yozzo et al. 2005), and this swamp could intercept and retain some of this phosphate via the above mentioned mechanism before this phosphate enters the Hudson River.

As hypothesized, decomposition rates were found to be slower in hollows. Temperature did not vary enough between hummocks and hollows to cause differing rates of decomposition. Therefore, slower decomposition rates were likely due to lack of oxygen due to flooding or differing decomposer communities. Surprisingly, the amount of sediment deposited and the sediment percent organic content did not differ between hummocks and hollows. Mean organic content was much lower than the 45-60% recorded for Hudson River tidal swamps by DeVries and DeWitt (1986). Mass of sediment deposited in this tidal swamp was much less than that of other vegetation types in the Hudson River (Loaiza and Findlay). It could be that such little sediment was deposited that longer term studies may need to be conducted to find significant differences in deposition between hummocks and hollows. Because decomposition rates were slower in hollows, there should have been more organic matter in hollows. Hummock soils contained large quantities of fibrous roots so perhaps this increased their soil organic content to equal that of hollows.

As hypothesized, herbaceous plant communities were very different on hummocks than in hollows. Nearly all herbaceous vegetation was restricted to hummocks. High levels of nutrients and no difference in light intensity between hummocks and hollows suggests that the physical stress of inadequate oxygen due to duration of flooding is the main limiting factor determining plant distribution. Microtopographic differences of only a few centimeters is enough to affect ecosystem function by affecting soluble phosphate and ammonium retention, rates of decomposition, and herbaceous plant species distributions in Hudson River tidal freshwater swamps.

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APPENDIX

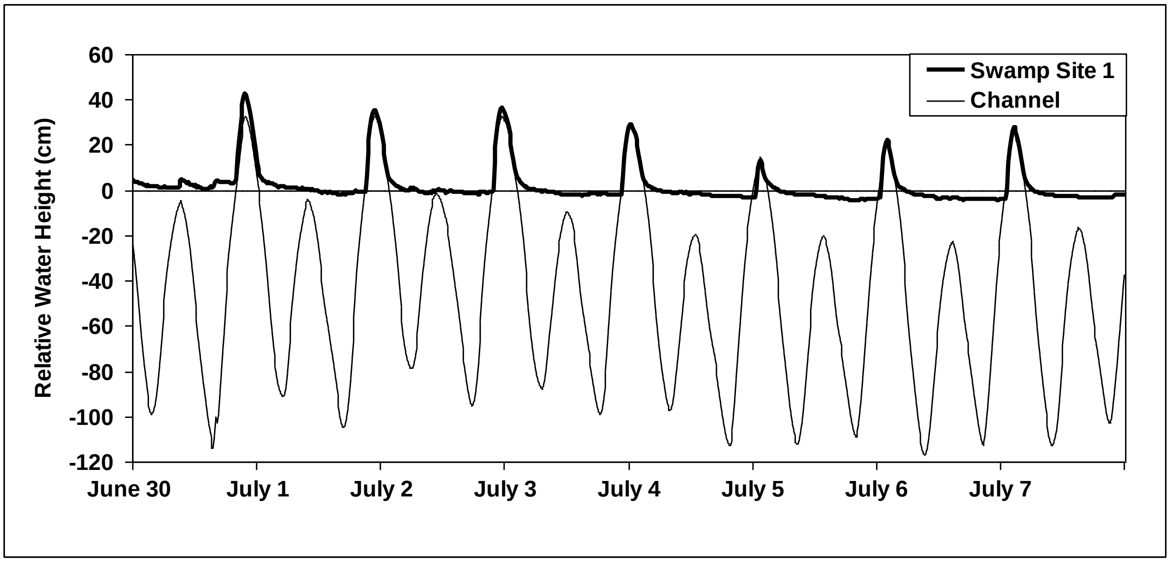

FIGURE 1. Relative water levels in the channel adjacent to the freshwater tidal swamp and water levels 25 m from the channel on Site 1 in the swamp. For the purposes of graphing, water levels for the channel were adjusted to assume a level plane of water with the swamp at the time of the first high tide. Water levels above zero indicate the swamp was inundated. June 30 was a neap tide and July 6 and 7 were spring tides. Site 2 demonstrated the same qualitative pattern.

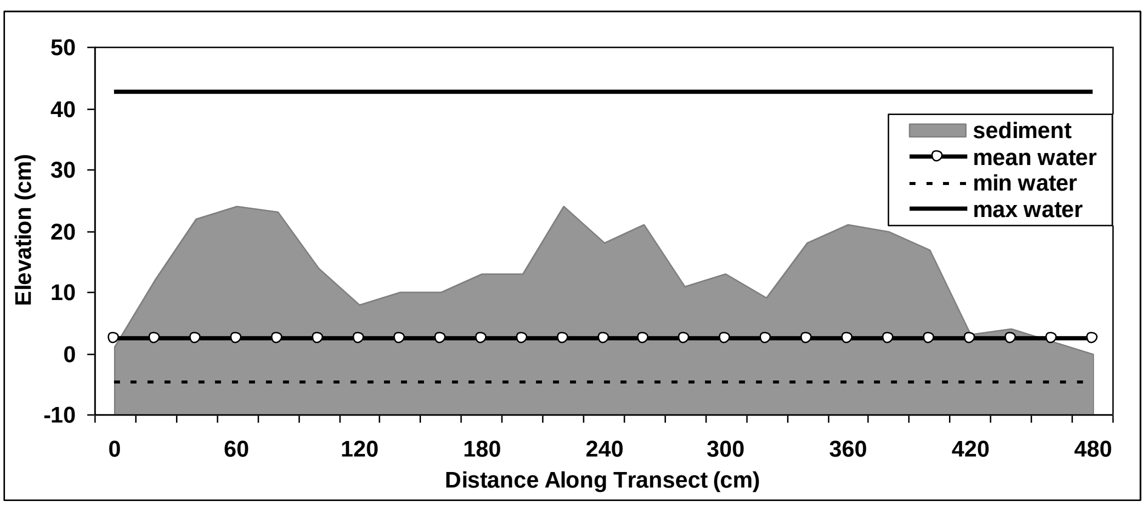

FIGURE 2. The topographical profile for site one transect 25 m from the channel is shown in gray. Maximum, mean, and minimum water levels observed from June 29 to July 8, 2009 are indicated by the horizontal lines. All water levels are relative to the lowest point on the transect which has a value of zero.

TABLE 1. Means, standard errors (SE), and p-values for all paired t-tests.

		Hummock		Hollow		
Variable	**Pairs (n)**	**Mean**	**SE**	**Mean**	**SE**	**P**
percent water content	10	57.9	1.1	67.4	2.0	<0.01
percent organic content	10	25.8	1.6	26.5	2.4	0.74
maximum oxidation depth (cm)	20	9.5	0.8	0.6	0.5	<0.01
daily mean temperature (°C)	10	19.048	0.155	19.257	0.112	<0.01
mean temperature per tidal cycle when not inudated (°C)	13	19.174	0.266	19.095	0.163	0.55
mean temperature per tidal cycle when inundated (°C)	13	18.935	0.314	19.530	0.169	<0.01
mass of sediment deposited (g)	10	0.23567	0.05089	0.33605	0.11313	0.11
percent organic content of sediment deposited	10	16.933	0.939	18.718	0.912	0.11
mean daily light intensity (lum/sqf) (3)	5	52	8	43	5	0.29
percent mass of *V. americana* remaining after 21 days	10	21.0	1.9	38.1	2.5	<0.01
species richness per quadrat	10	7	0.5	2	0.3	<0.01
stem abundance per quadrat	10	35	6	4	1	<0.01

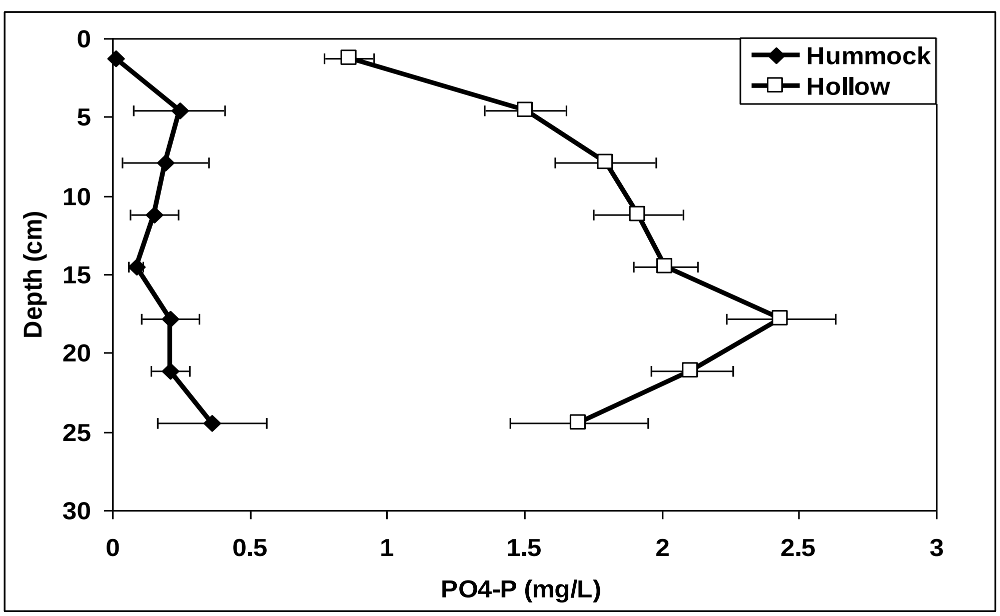

FIGURE 3. Profile of porewater soluble reactive phosphate in the sediment of hummocks and hollows (values are means; error bars represent one standard error).

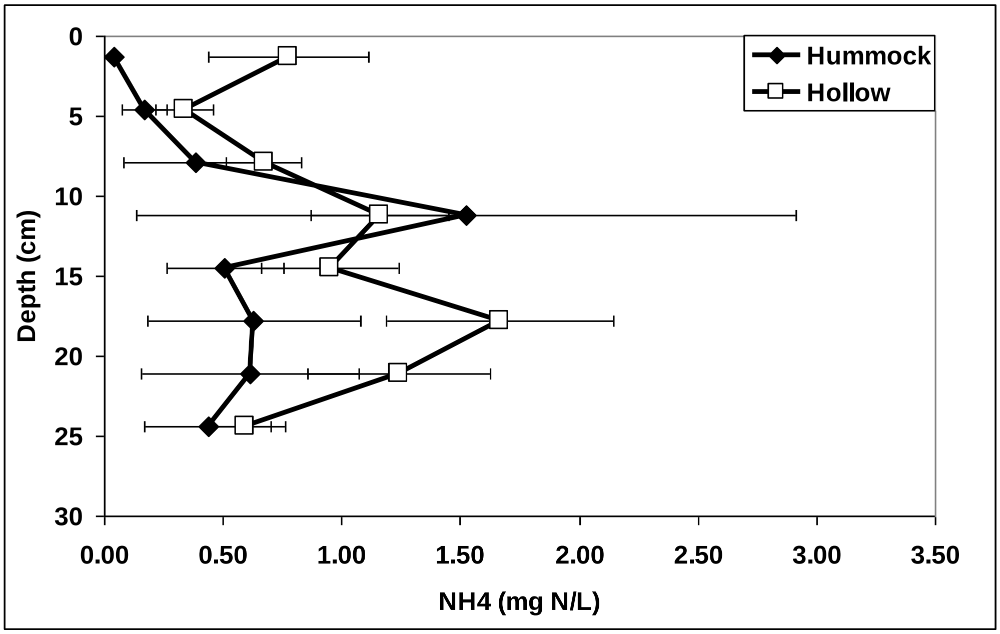

FIGURE 4. Profile of porewater ammonium in the sediment of hummocks and hollows (values are means; error bars represent one standard error)

TABLE 2. Freshwater tidal swamp herbaceous vegetation with relative frequency and relative cover for individual species for all quadrats (total). Relative frequency and relative cover were also calculated separately for hummocks and hollows. Importance value (IV) was calculated by averaging relative frequency and relative cover.

	Total			Hummock	Hollow
Species	**Relative freq**	**Relative cover**	**IV**	**IV**	**IV**
Impatiens capensis	21	11	16	46	11
Lysimachia nummularia	18	57	38	24	39
Symplocarpus foetidus	17	9	13	12	13
Aster spp.	10	7	8	6	9
Viola affinis	8	6	7	0	8
Amohicarpaea bracteata	6	2	4	5	3
Aconitum spp.	3	1	2	0	2
Ranunculus spp.	3	1	2	0	2
Anemonella thalictroides	3	1	2	6	1
Toxicodendron radicans	4	1	3	0	3
Parthenocissus quinquefolia	3	1	2	0	2
Lilium spp.	1	0	1	0	1
Mollugo spp.	1	0	1	0	1
Osmunda regalis	1	0	1	0	1
Iris pseudacorus	1	3	2	0	3