Effects of Sediments on the growth of *Vallisneria americana* in Lake Apopka

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Non-Thesis Research Paper

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List of Figures and tables

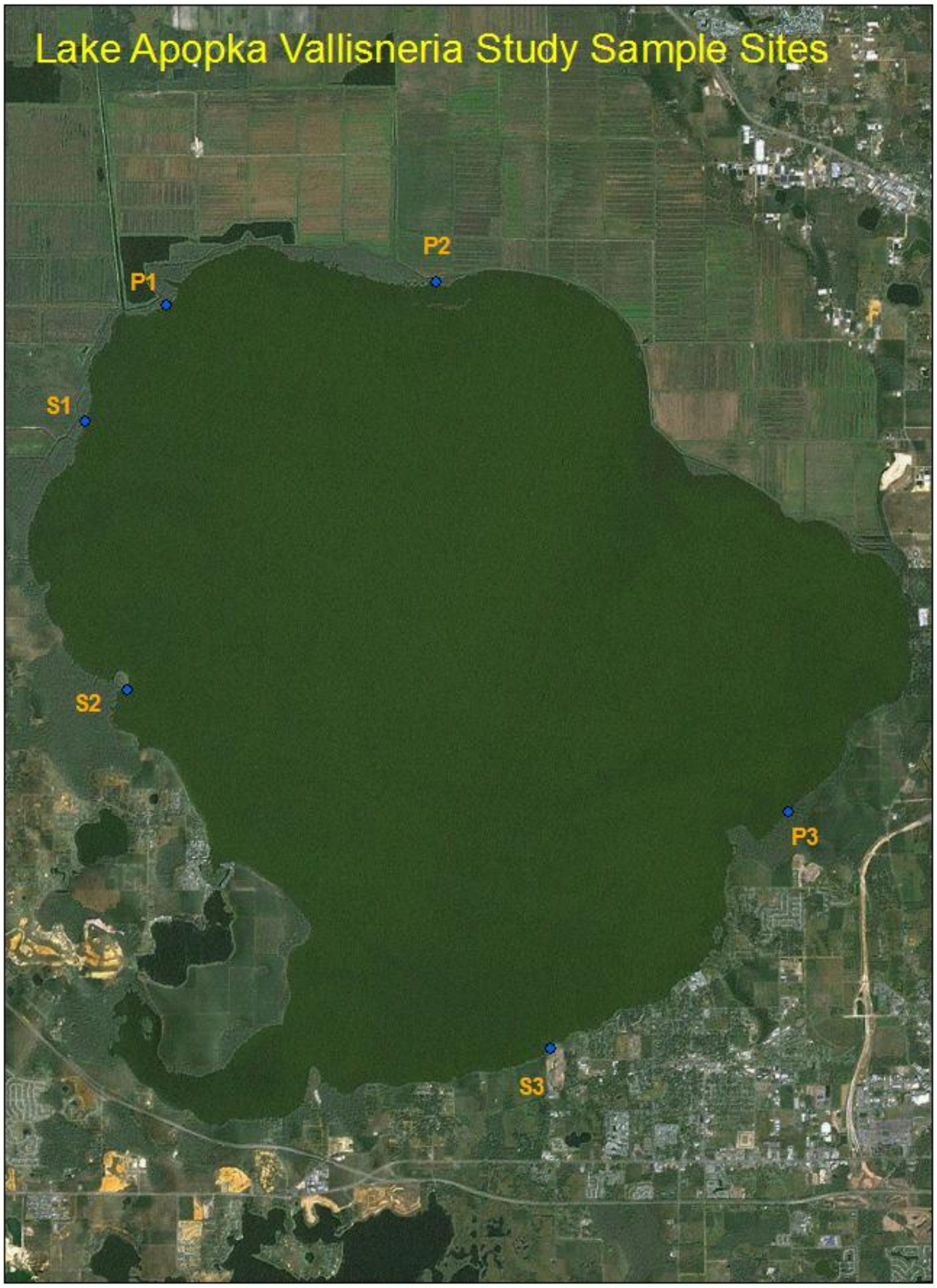

Figure 1. Lake Apopka, Florida and the six study sites of *Vallisneria americana* beds in peat and sand.

Abstract

Vallisneria americana has had a long history in Lake Apopka, once supporting healthy fish populations. The reemergence of the macrophytes is important step in the recovery of a healthy ecosystem for the lake. Conditions for growth in Apopka have been considered to be less than desirable based on water clarity and organic sediment. There have been studies on the lake sediment, however, these did not encompass the littoral zone. The goal of this study was to characterize and understand role of the sediments in Lake Apopka on the growth and expansion of *V. americana* and implications it might have on restoration efforts. The study was done at six sites around the lake in both mineral and organic sediments where *V. americana* occurred. Parameters of interest included nitrogen, phosphorus and carbon of the sediment and shoots as well as measurements of growth characteristics. Results show significant differences in sediment conditions between, *V. americana* growth forms and carbon accumulation in the shoots between the organic and mineral types. Despite these differences, the plants had similar total biomass per area. Nutrients appear to be the main determinant of growth form, though effects of soil redox potential and age of plants may also be involved. The organic sediment showed growth advantages, such as biomass and plant density, over mineral sediment, which showed more signs of nutrient limitations, such as lower plant density, as well as low carbon and phosphorus accumulation in the shoots. Even so, *V. americana* is expanding in all these areas in the lake and the study shows suitable sediment conditions to support growth. Compared to other water bodies the biomass and density are low, but more comparative research is needed on sites similar to those in this study. This study shows that nutrient availability may have important role in *V. americana* growth, and determines areas where further research is required to assist in restoration and management .

Introduction

Vallisneria americana is an important submersed aquatic macrophyte that is found in both freshwater and estuarine environments. It is one of several that have played an important role and have a long history in Lake Apopka along with *Potamogeton illinoensis*. These submersed aquatic vegetation (SAV) support important habitat to popular game fish such as bass, and the lake was once well known for its bass fishing. SAV also provide a food source, stability to the lake edge and traps suspended solids from the lake. *SAV* was once vast in Lake Apopka, but diminished after a shift from macrophyte to phytoplankton dominance in 1947 (Lowe 1999, Schelske et al. 2005). *P. illioensis* is no longer found in the lake, and *V. americana* is rebounding in many areas. Lake Apopka is a large (12,500ha) hypereutrophic, shallow lake in Central Florida with a mean water depth of 1.0m. The majority of the sediments are organic, though it has important sandy areas in the littoral zone.

V. americana has adapted to a wide range of conditions, and there has been a large amount of research on stressors and factors contributing to its decline or health in a given system. While some of this research has been done in large eutrophic lakes, little has been done in Florida in these systems. It is typically found growing in sand or silt sediments, and extensive studies have been done on these sediments and relationships with SAV growth, including parameters such as bulk density, light, nutrient limitations and the organic matter content of sediments (Barko et al. 1991). Some aquatic macrophytes are limited by redox potential or soil oxygen demand of the sediment including some evidence for this in *V. americana* (Dobberfuhl 2006, Jarvis and Moore 2008). The sediments that make up Lake Apopka are characterized by sand, peat and muck with varying layers of unconsolidated floc overlaying the sediments. Light is typically available in Lake Apopka to approximately 4 ft depth, depending on water levels and time of year (unpublished data), based on 2-5% light requirements by *V. americana* (Carter 2000). *V. americana* is highly adaptable to its environment compared to some other SAV and has developed efficient use of resources, though *Hydrilla verticilata* forms thick canopies which may shade out *V. americana*. Current lake management of has included herbicide removal of cattail and *H. verticilata* which both outcompete and thrive in eutrophic water. *H. verticilata* typically outcompetes in areas with low light and high nutrients by forming the thick canopies and utilizing water column nutrients (Wigand et al. 1997, Van et al. 1999).

During the last fifteen years, *V. americana* has been slowly reappearing in various regions of the lake(Lowe 2001). More recently, its observed expansion has become more abundant and occurring in new areas of the lake and is starting to take hold in more diverse substrates. The main areas in which it had been colonizing are peat and sand sediments and recently, it has also been observed in more mucky sediment areas. By understanding the sediment conditions such as bulk density, nutrients and substrate stability, better management techniques could be used to encourage recruitment and sustainability. The typical mode of colonization is likely clonal, but new areas may be coming in from seed. Sediment studies have been done in the open lake areas (Reddy 1991, Schelske 1997), but did not characterize the conditions (bulk density, % LOI, nutrient storage and availability, redox potential) of littoral zone sediments. Based on previous studies, it was hypothesized that the sand substrate in Lake Apopka would produce more healthy plants due to higher bulk densities, higher redox potential, and few organic complexes or production of toxic compounds that would inhibit growth.

Materials and Methods

Site Description

This study was performed in Lake Apopka, located in Central Florida (Figure 1). Six sites were identified around the lake with three in organic sediments and three in mineral sediments. These sites are P1-P3, which were characterized as mostly peat material, and S1-S3, which were characterized as sand. Sites were selected on the criteria to ensure similar conditions. These include similar water depth (~ 60cm), visually abundant growth within the *V. americana* bed with shoots reaching the water surface, and little influence from other macrophytes. Outside samples were taken at a nearby location where macrophyte growth was absent and 60cm water depth. The study was done in July 2010 over a period of two weeks, and redox potential measurements taken in August.

Sediment and plant collection

Three of sediment and plant samples were taken from within the *V. americana* beds, and one sediment sample from outside the bed. Bed samples were taken along a 15m transect. Each sample was composed of three subsamples. Sediments were collected to 10 cm depth using a piston corer. One deeper core was taken to visually characterize the sediment to 30-60cm. Above and belowground biomass was collected using a 0.25m^2 quadrat made of PVC pipe, and a knife to cut the roots and rhizomes around the quadrat. The plants were removed gently from below to collect the roots intact to 10cm. Most of the root content (~90%) is found in the upper 10cm (Titus 1983). The number of stems (plants) were counted within in the quadrat. Due to the large amount of biomass collected(entire quadrat area) on the first day at sites P1 and S1, the samples were divided into a quarter subsample based on the total weight in the lab. The other four samples were collected based on area by dividing the quadrat into four sections and collecting only those plants within one of the quartered section. Roots, including rhizomes, were separated from the shoots and sediment rinsed off the roots. The plant material was bagged and transported on ice to the field station lab where the shoots and roots were laid out and measurements were done on the length, width of shoots and number of leaves per stem were counted. These samples were collected over a period of three days, two sites per day.

Physical and Chemical Measurements

Measurements of water temperature, dissolved oxygen, conductivity, and pH were taken using a YSI 600XL meter at 10cm increments. A secchi disk depth was determined using a Secchi Disk. Photosynthetically active radiation (PAR) readings were collected inside and outside beds using a Li-Cor LI-1000 meter with a deck and bulb reading and taken at 10cm increments to the bottom (samples collected throughout one day). Three measures of sediment redox (Eh) and pH were taken within the bed and three outside the bed using an ExStik RE300 ORP Meter and ExStik PH110 Refillable pH meter. These were pushed gently into a sediment core at the top 3 cm. The Eh measurement was normalized to the pH 7 using a regression. Water quality samples were taken inside and outside the *V. americana* beds. The samples were collected at 30cm using a peristaltic pump and preset bottles based on analyses were filled. Water was filtered for dissolved nutrients using Supor®-450 0.45µm filters and preserved using sulfuric and nitric acid where appropriate.

Nutrient and Isotopic Analyses

Sediment and plant samples were shipped on ice to the University of Florida Wetland Biogeochemistry Laboratory for analyses of wet and dry weights, water content, loss on ignition (%LOI), total nitrogen (TN), total phosphorus (TP) and total carbon (TC) as well as the isotopes δ15N and δ13C. These analyses were done on the sediments as well as the shoot samples. The only analyses on the roots were dry and wet weights. Water samples were shipped on ice to the St Johns River Water Management District Laboratory. Analyses performed were TKN, NH_4^+, NO_x, $P\,O_4^{-3}$, TP and turbidity.

Total N and TC were analyzed using a Thermo FlashEA 1112 series NC soil analyzer (Thermo Fisher Scientific, Inc., Waltham, MA). Loss on ignition (%LOI) was determined after combustion at 550˚C for 3-4 hours. Total P of sediment and plant tissues was determined following sequential combustion at 550˚C for a 4 hour period and dissolution of remaining ash with 6M HCl (Anderson 1976). Dissolved samples were analyzed colorimetrically for reactive P using a Technicon™ Autoanalyzer III (SEAL Analytical, Mequon, WI)(EPA Method 365.1).

Stable C and N isotopic ratios were determined using a Finnigan MAT Delta Plus isotopic ratio mass spectrometer (Finnigan Corp., San Jose, CA) (Inglett & Reddy, 2006) and expressed as permil (‰) differences from the standard isotopic ratio of atmospheric N_2 (for N) and Pee Dee Belemnite (for C) using delta notation (δ): $\delta_{sample} = [(R_{sample}/R_{std}) - 1] \times 1000$. All isotopic ratios were adjusted for accuracy using known isotopic standards including IAEA-N1 ($\delta^{15}N$ = 0.4 ‰) and ANU-Sucrose ($\delta^{13}C$= -10.5 ‰). Analytical precision for isotopic standards was less than ± 0.1 ‰ and ± 0.3 ‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively.

Total P and TKN were analyzed using a Seal QuAAtro segmented flow analyzer specific for orthophosphate ions and ammonia (EPA Method 365.4, EPA Method 351.2). NH_4^+ was analyzed using a Seal Discrete Autoanalyzer, AQ2 Plus (SM 21st edition 4500G- NH3 method). PO_4^{-3} was determined using the colorimetric method using a Seal QuAAtro segmented flow analyzer (EPA Method 365.1). Turbidity analysis used a Turbidity AssayPlus Laboratory Turbidimeter comparing light scatter to a standard reference (EPA Method 180.1).

Statistical Analysis

Statistical analysis was performed using JMP version 7 (SAS Institue, Cary, NC). Differences in sediment parameters between sediment types (Peat vs. Sand) and bed position (in vs. out) were assessed using a multifactor ANOVA. Relationships between Vallisneria productivity parameters and nutrient content, as well as sediment nutrient characteristics and ratios were assessed using least squares regression. Where necessary parameters were log transformed to improve normality.

Results

Sediment Characteristics

The two sediment types, peat and sand were significantly different with regard to most measured parameters (Table 1, Figure 2&3). The amount of organic content of the sediment closely related to both the sediment density and nutrient concentrations. There were significant differences in bulk density, organic matter, nutrients and pH between the organic and sand sediments (Figure 2). As expected, LOI % in the peat sediments was much higher (53.7 to 89.7%) than that of the sands (1.1 to 2.6%). These differences in the sand were visually obvious when collecting the soil cores. Bulk density in the peat were low, with a range of 0.07 to 0.25 g cm^{-3}, while in sandy sites, sediment bulk density ranged from 1.12 to 1.65 g cm^{-3}.

Values for pH were significantly lower ($p<0.001$) in the organic sediments with a mean difference of 0.8 units. Organic sediments are often lower in pH due to their organic acids, but these sediments are neutral with around a 7.0 pH. The sands are slightly higher around a pH of 8.0. Redox values were not significantly different between sediment types, though showed some relationship with the amount of organic content of the sediments. They were all highly reduced sediments with a mean of -156Eh in peat and -111Eh in sand. No significant differences were found with the position inside or outside the beds.

	pH				Eh				LOI %			
	df	MS	F	P	*df*	MS	F	P	*df*	MS	F	P
Sediment Type	3	1.105	27.574	**<.0001**	3	3259.58	0.3908	0.6815	3	28.096	190.49	**<.0001**
Bed Position				0.5511				0.7012				0.5446
Sediment Type x Bed Position				0.4634				0.5420				0.2597
Error	20	0.040			19	8341.08			20	0.1475		

	TP g/kg				TN g/kg				TC g/kg			
	df	MS	F	P	*df*	MS	F	P	*df*	MS	F	P
Sediment Type	3	9.873	14.765	**<.0001**	3	32.6242	132.88	**<.0001**	3	35.706	132.01	**<.0001**
Bed Position				0.4059				0.5321				0.5521
Sediment Type x Bed Position				0.8770				0.2609				0.3880
Error	20	0.667			20	0.2455			20	0.2705		

	TN/TP				TC/TN				TC/TP			
	df	MS	F	P	*df*	MS	F	P	*df*	MS	F	P
Sediment Type	3	6.803	8.8438	**0.0005**	3	18.228	2.694	**0.0119**	3	8.2185	11.031	**0.0001**
Bed Position				0.6623				0.9631				0.6636
Sediment Type x Bed Position				0.6230				0.4213				0.7073
Error	20	0.769			20	6.7657			20	0.7451		

Table 1. ANOVA table of sediment characteristics using least squares analysis. Significant relationships are in bold.

TP, TN and TC were significantly higher in the organic than sandy sediments ($p \leq 0.001$) (Figure 2). Mean TP averaged 2.0 g kg^{-1} inside the peat bed and 0.3 g kg^{-1} inside the *Vallisneria* beds of the sandy sediment sites. TN mean values were 27.0 g kg^{-1} inside peat beds and 0.5 g kg^{-1} inside the sand. N:P (molar ratios) were significantly higher ($p<0.001$) in the peat beds (35.6 N:P) than those of the sandy sediments (mean of 7.2 N:P) (Figure 3). The large deviation in TP, N:P and C:P (molar ratios) in the outside peat values were due to a high value (7.0 g kg^{-1}) at P1. Carbon:N relationships were similar between all sites, but were significantly higher (2.4 units) in peat beds ($p=0.01$).

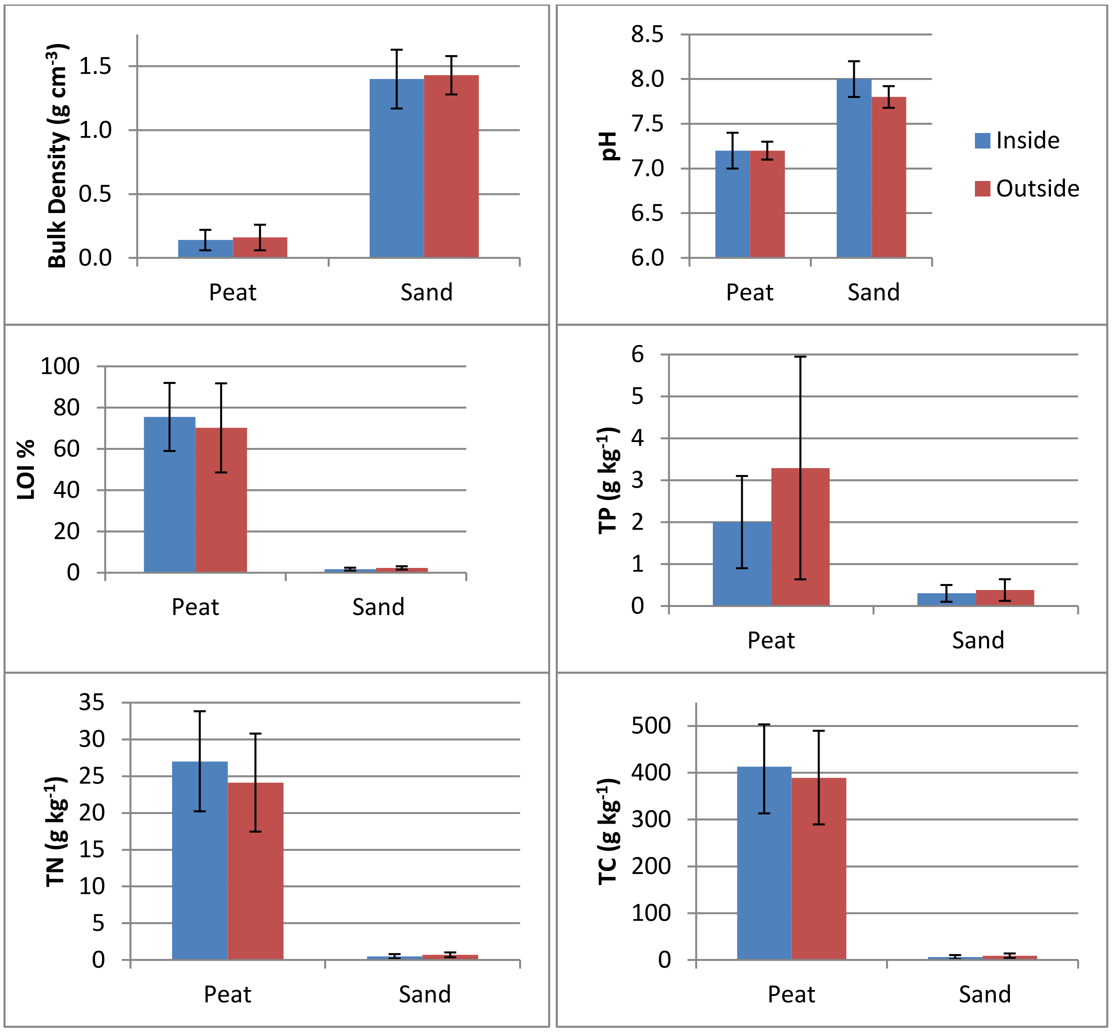

Figure 2. Sediment characteristics of different soil properties depicting the differences inside and outside the *Vallisneria americana* beds and between the two sediment types. N=9 for inside, and N=3 for outside.

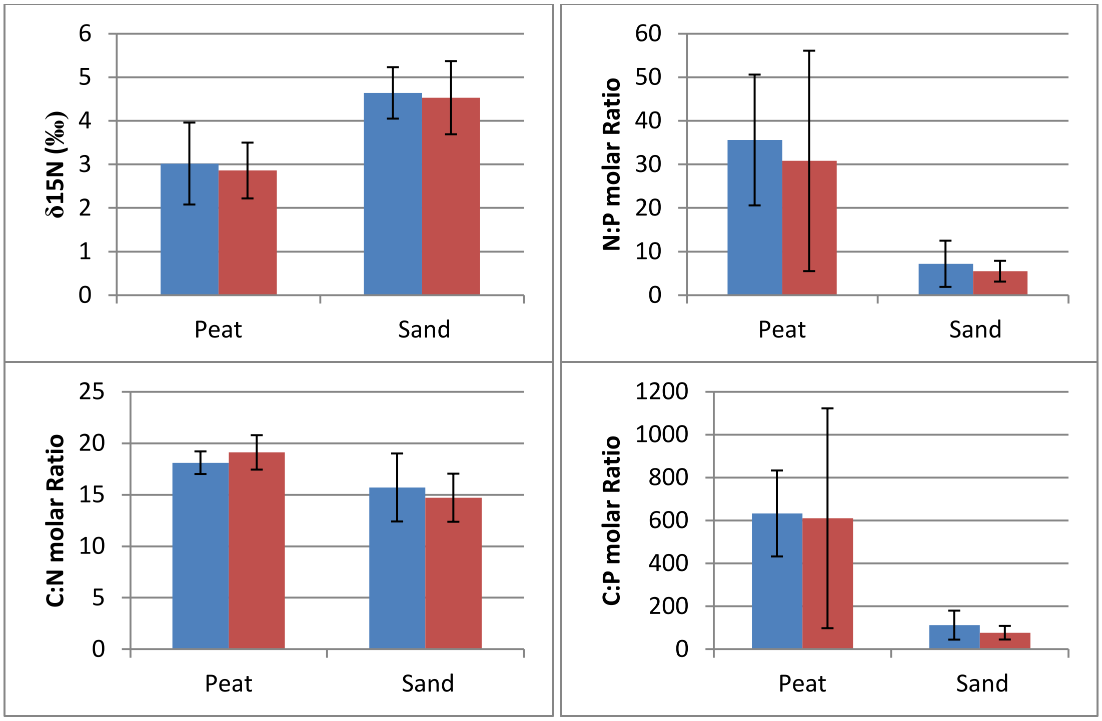

Figure 3. Sediment characteristics of nutrient ratios and isotopes depicting the differences inside and outside the *Vallisneria americana* beds and between the two sediment types. N=9 inside and N=3 outside.

Light Attenuation and Water Quality

Adequate light was found at all of the sampled *V. americana* beds. Some shading by plants is evident within the actual beds from the inside Li-Cor readings. Water quality data was similar throughout the lake, and showed little variation inside and outside the beds. There was two times the amount of NH_4-D within the beds of the peat sites. There was slightly higher turbidity at the sand sites, which could be due to boat disturbance of the sands. Table 2 summarizes the water quality and light of all the sites.

Table 2. Water quality means of six sample sites in Lake Apopka. Inside and outside refers to the position of the sample to the *Vallisneria americana* bed. N=6.

	Inside	**Outside**
Temperature (˚C)	32.3 (±1.31)	32.5 (±1.24)
Dissolved Oxygen (mg L^{-1})	8.45 (±1.51)	8.16 (±1.48)
pH	8.80 (±0.10)	8.77 (±0.20)
Conductivity (µS cm^{-1})	440 (±21.7)	442 (±21.4)
NH4-D (mg L^{-1})	0.04 (±0.03)	0.04 (±0.007)
TKN-T (mg L^{-1})	3.23 (±0.24)	3.13 (±0.19)
NO_x-D (mg L^{-1})	0.01 (±0)	0.01 (±0)
PO4-D (mg L^{-1})	0.005 (±0.007)	0.001 (±0.005)
TP-T (mg L^{-1})	0.07 (±0.01)	0.07 (±0.04)
Turbidity (ntu)	17.5 (±6.06)	15.9 (±8.53)

Shoot Nutrient Characteristic

Shoot nutrient characteristics were more similar between sediment types (Table 3). Overall, nutrients were higher in peats than sands, but only carbon and LOI % were significantly different ($p<.001$). Ash free dry matter content (as LOI) was also significantly higher ($p<.001$) in the shoots of plants growing in organic sediment.

Table 3. Shoot nutrient characteristics of Vallisneria, mean of values by sediment type. Ratios are molar mass. N=9

	Peat	**Sand**	**P-Value**
LOI %	81.7 (±7.2)	62.1 (±6.7)	0.000*
TP (g kg^{-1})	1.6 (±1.0)	1.1 (±0.2)	0.227
TN (g kg^{-1})	20.5 (±2.3)	18.0 (±3.2)	0.082
TC (g kg^{-1})	365 (±19.9)	305 (±19.8)	0.000*
N:P	42.0 (±20.8)	38.2 (±2.9)	0.996
C:N	21.0 (±3.0)	20.2 (±2.9)	0.559
δ15N (‰)	5.98 (±0.81)	5.63 (±0.89)	0.424

Growth Characteristics

Overall, there were significant differences in the growth forms of plant density per area, shoot length, and plant biomass. There was no significant difference in total biomass per area between sediment types, though peat had a higher mean biomass by 63 g m^{-2} (Table 4). Plants growing in peat had an advantage in biomass in number of plants per area and length of leaves, but the plants growing in sand had generally larger number of leaves per stem (1 more leaf per plant) and wider leaves (0.1 cm greater). These characteristics made for larger individual plant biomass in the sand substrates. Belowground biomass was also generally higher in the peat than sand, and is reflected in the higher root:shoot ratios in the peat than sand.

Table 4. Growth Characteristics of *Vallisneria americana* in two sediment types of Lake Apopka. Mean values by sediment type. N=9.

	Peat	Sand	P-Value
Plant Density (stem m^{-2})	141.3 (±49.7)	74.2 (±14.7)	0.001*
Max Shoot Length (cm)	71.7 (±13.4)	68.0 (±6.27)	0.600
Average Shoot Length (cm)	56.5 (±9.5)	44.5 (±4.5)	0.005*
Leaf Width (cm)	0.9 (±0.1)	1.0 (±0.2)	0.185
Total Biomass (g m^{-2})	240.4 (±80.0)	177.5 (±34.6)	0.061
Aboveground Biomass (g m^{-2})	181.9 (±59.9)	141.3 (±33.5)	0.114
Belowground Biomass (g m^{-2})	58.5 (±31.2)	36.2 (±15.6)	0.138
Plant Biomass (g $plant^{-1}$)	1.81 (±0.6)	2.49 (±0.8)	0.037*
Number of Leaves $stem^{-1}$	4.94 (±1.52)	5.98 (±1.65)	0.212
Root:Shoot Ratio	0.33 (±0.142)	0.275 (±0.146)	0.549

Relationships between sediment characteristics and Vallisneria *growth and nutrient parameters*

TN in the shoots in both sand and peat were positively correlated to the sediment nutrients (p=0.094, and 0.0097, respectively) (Figure 4). TC in the shoots decreased with increasing C:N ratios of the sand suggesting nutrient limitations (p=0.0395). Phosphorus in the shoots did not show a significant relationship to the sediment nutrients in the sand, though may be limited to conserving the threshold nutrients (Figure 5). The peat however was positively correlated to the shoot nutrients (p=0.041). The

TC in shoots of the sand sites was not significantly correlated with sediment nitrogen, though showed a positive relationship, while peat had no response to increased sediment TN (Figure 4). There was no response with increases in sediment TP to the shoots TC. Shoot N:P showed a negative correlation to increases in sediment TP, and no correlation to sediment TN.

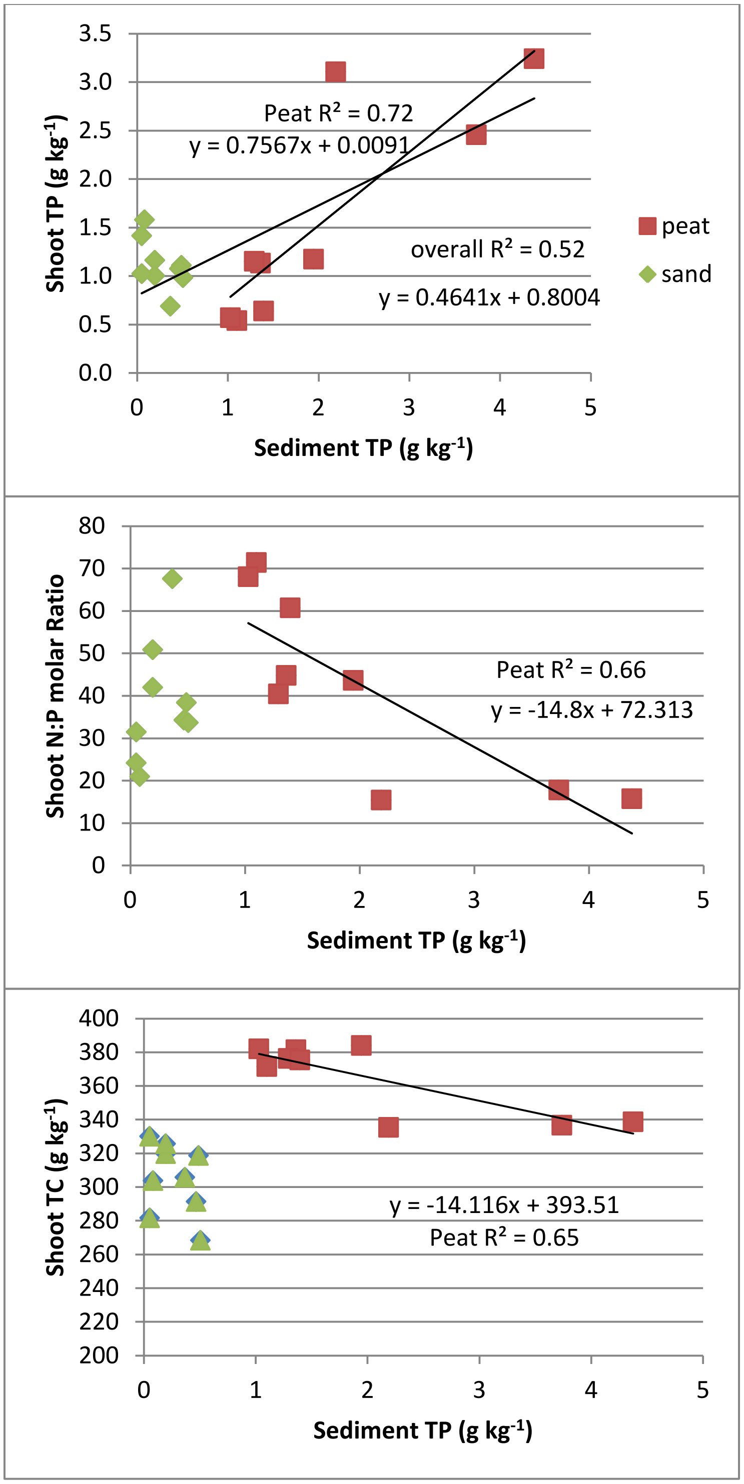

Figure 4. Relationship between total phosphorus (TP) of the sediments and nutrients of the shoots. TP showed a positive relationship overall between sediment and shoots, similar to the relationship on N:P in the shoots of plants growing in peat.

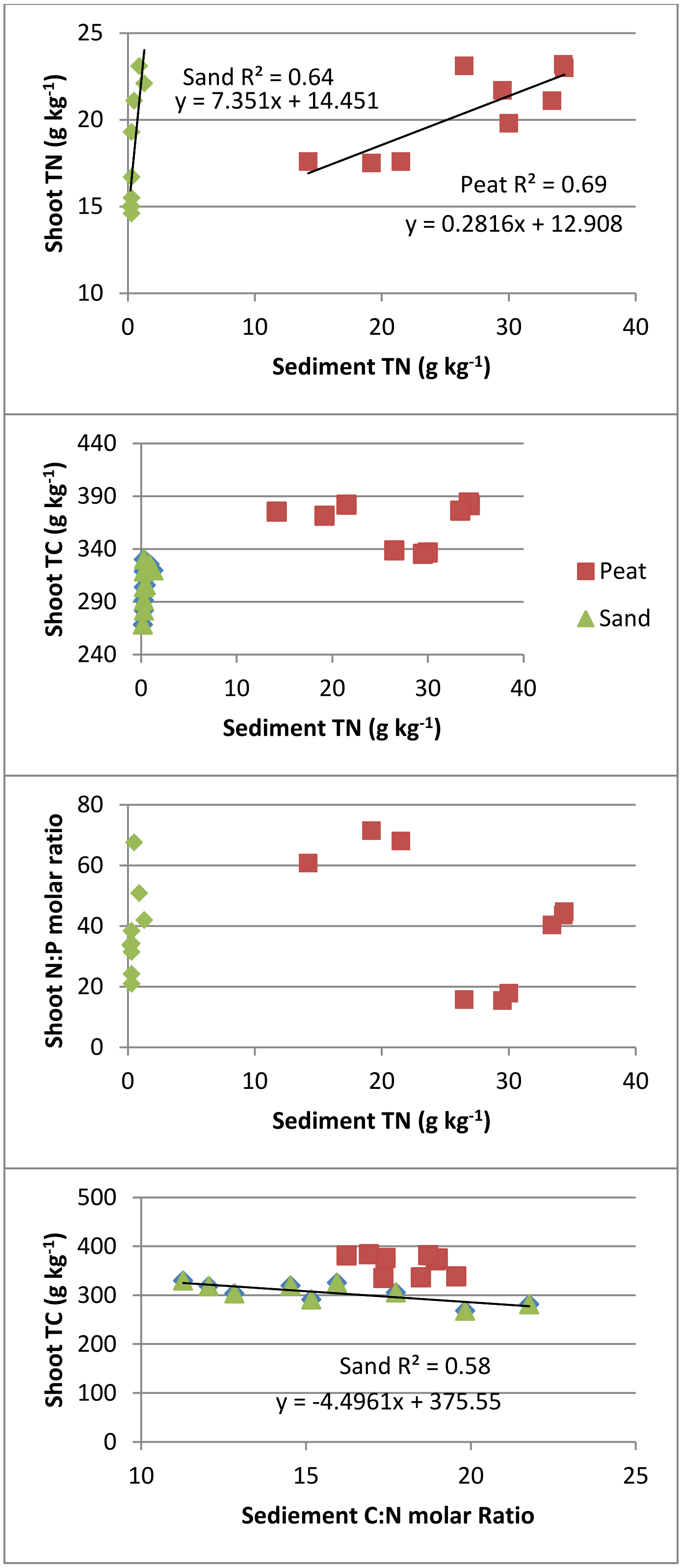

Figure 5. Nitrogen relationships of the sediment with the nutrients of the shoots. There was a positive relationship in both sediment types with increasing sediment nitrogen.

Discussion

Typically studies have found that low light, high organic sediment and low available nutrients limit the growth potential of *Vallisneria americana.* Light is often a significant factor affecting growth forms such as increased shoot length and lower density in low light environments (Barko 1991, Duarte 1990, Chambers 1987). Also, nutrients of the sediments are of critical importance, since *V. americana* takes up the majority of nutrients from the sediment (Bole 1978, Carnignan 1980). *V. americana* is found to adapt its form to the resources available to counter low light, limiting nutrients and competition (Korschgen 1988, Rogers et al. 1995, Van et al. 1999, Li 2010). In Lake Apopka, nutrients appeared to be a large driver of the plant growth forms (stem density, stem height, and plant biomass). The differences in substrate between the two sediment types were significant; however, there was little difference in total growth between the sites. Contrary to the hypothesis, the plants growing in sand did not show an increase biomass over the plants growing in peat, and may have been negatively affected due to low nutrient abundance.

Growth Forms and Shoot Characteristics

Density of the macrophytes is often an indicator of the health of plants due to light limitations and is often coupled with length of leaves. Light limiting plants often have lower density plants with longer leaves, and plants with good a quality of light are often higher in density with shorter leaf length. This mechanism is used to counter self-shading (Duarte 1990, Barko 1991), and *V. americana* has ability to adapt to low light regimes by adapting growth form and efficient carbon usage (Korschgen 1988, Van et al. 1999). Light requirements are typically found to be less than 5% at the sediment surface in freshwater systems (Carter 2000). Since light is adequate and similar between the two sediment types in the Apopka peat and sand beds, it is not likely the factor explaining the density of these macrophytes. Since low nutrient sediments usually have lower plant density, nutrients could be an important driver

(Rogers et al. 1995). Higher density plants also result in lower sediment nutrients (Xie et al. 2006). In Kings Bay, FL which has high aquifer inputs from springs there were mid-season stem densities of 200-800 (Hauxwell 2007) and 500-600 shoots m^{-2} in the Caloosahatchee estuary in June to September (Mazzotti 2008). These are significantly higher than densities in Apopka, which had a mean of 74-141 (Table 4). Stem density was significantly higher in peat sediments (p=0.001). In the shoots of *V. americana* growing in Apopka, there was a significant positive relationship between TC content (p<0.001) of the higher density plants. TN had a positive relationship with nitrogen though was not significant. Another density relationship used in a study by Carlos Duarte (1990), density was measured in biomass (g dry wt. m^{-3}) and averaged around 200 while Apopka values averaged 82 g m^{-3}.

Density of plants also has an affect on the size of the plants and length of roots. In higher density areas, *Vallisneria natans* was found to have lower biomass and longer roots (Xie et al. 2006). This is the same relationship as is found in Apopka, where the higher density of plants was associated with lower plant biomass as found in the peat beds. The mechanism causing this is unclear, as all the shoot nutrient relationships were insignificant.

Increased shoot length is typically found in low light regimes (Chambers 1987, Barko 1991). In a study by Rogers et al. (1995), length increased in response to higher nitrogen availability, while reducing the number of plants as well. Wind, which could be an issue in Apopka, can have an affect on the growth form by causing physical damage to the shoots and thus decrease the shoot length(Korschgen 1988). Shoot length was significantly higher in the peat than sand as the average length (Table 4, p=0.005). The length had inverse relationships with shoot TP (p=0.0011) and N:P (p<.0001, maximum length). In Apopka, the maximum length was not significantly correlated though has the same trend as the average. As phosphorus increased, so did the shoot length.

The number of leaves per plant were not significantly different between the two sediment types, but generally had a higher number in the sand. Increased number of leaves is attributed to low-nutrient sediments and leaf damage. For *Vallisneria spiralis,* high nutrient sediment had 12-15 leaves per plant while low nutrient sediment had 17-19 (Li 2010). Kings Bay, which had a high density of plants, had 6-11 leaves per plant of *V. americana* which is more similar to Apopka values of 5-6 (Table 4) (Hauxwell 2007). In Apopka the number is related to shoot TC ($p=0.0337$).

Total biomass is attributed to different characteristics and stressors. Commonly bulk density and nutrients have been considered as limiting *V. americana* growth. Increasing additions of light were not found to have a profound effect on the total biomass of V. americana (Barko 1991, Carter et al. 1996). Aquatic plants were shown to decrease in biomass at bulk densities around 0.1 g mL^{-1} or less and greater than 1.4 g mL^{-1} (Barko and Smart 1986). Both peat and sand sites in Apopka had values around or beyond these thresholds, but relationships with growth characteristics were not clear and there were no obvious nutrient relationships either. Biomass ranges in different water bodies from 50-900 g m^{-2}, with a max of 1013 g m^{-2} in Kings Bay, FL (Hauxwell 2007). The numbers of Apopka ranged more around 200 g m^{-2} (Table 4). Structural tissue or biomass are often increased in areas of high water movement such as in rivers or exposure to large wind fetch, which *V. americana* are adapted to withstand (Kreiling et al. 2007). Fetch was not accounted for in this study.

Since there were conflicting growth relationships and similar total biomass values, it was important to look at the biomass of each individual plant. The biomass of the plants in the sand sediment were significantly higher than those in the peat sediments ($p=0.37$). This is due to the larger number of leaves per plant and greater leaf width.

Higher belowground biomass is generally associated with lower nutrients and typically these plants have high root to shoot ratios (Barko and Smart 1986, Xie et al. 2006). Root:shoot ratios for *V.*

americana were found to be between 0.16-0.18 (Wigand et al. 1997) or 0.23 in high fertile sediments, and 0.47 in low fertile sediments (Van et al. 1999). Root morphology is dependent on competition and sediment fertility. Competition among itself and other macrophytes cause deep roots, while low fertile sediment create fine, long and usually shallow roots (Xie et al. 2006). Thick roots are unfavorable in low nutrients since they require more resources and energy allocation to produce. No study was found relating root growth to stability in *V. americana*. The roots in this Apopka study varied in appearance and size between different sites, though more study is required.

Sediment and Shoot Relationships

Different sediment conditions may limit the amount of nutrient uptake by the plants, and not all the total nutrients are available to the plants. Nutrients in the sediment are closely related to the amount of organic matter content, though does not reflect nutrient availability. High density soils are characterized with low nutrient holding capacity. Low density sediments which are high organic matter and nutrients often have long diffusion distances and organic complexes which may affect the nutrient availability (Barko et al. 1991). SAV derive most of their nutrients from the sediment (Bole 1978, Carnignan 1980, Xie 2005), so the relationship between them is important to consider. Sediments and water in Lake Apopka are typically high in calcium and a large amount of phosphorus in the sediment was found bound to Ca-Mg (Battoe 1999). Two of the sites, one sand and one organic, had high accumulation of small shells, which could contribute to the accumulation of phosphorus in these sediments, since the sediments are between pH 7 and 8.

Levels of shoot nutrients are typically more valuable to determine nutrient limitations of macrophytes than the sediment nutrients (Duarte 1992, Gueswell 2002). Critical nutrient levels in shoots for *V. americana* were found to be 1.3% TN and 0.13% TP (Gerloff 1966). Also, the critical nutrient ratio for submersed aquatic plants is thought to be around 24-30 N:P (Duarte 1992, Koerselman and Meuleman 1996). Other values typical of freshwater angiosperms are a carbon content around 40 to 45%. Carbon is related to productivity, photosynthesis, and is important for a structural role in aquatic macrophytes (Duarte 1992). In *Vallisneria* studies, TN is usually found to be the more limiting nutrient, especially in sand or organic sediments, and increased additions of TP had little effect on the plant growth (Barko et al. 1991, Rogers et al. 1995, Xie 2005). Nutrient levels of the *V. americana* in Apopka ranged above and below these thresholds (Table 3). The plants in the sand were all near the critical limit for TP in the shoots and all sites had adequate TN in the shoots. The ratios however of N:P showed different nutrient limitations by the plants at each site. The two sites with highest N:P ratios also had a large accumulation of small shells. All of the shoots were below 40% TC in the shoots as well which may indicate something slowing productivity.

Redox potential (Eh) has been shown to affect in some aquatic vegetation types, but *V. americana* has extensive roots and were found to send more oxygen to the root zone than other SAV (Wigand 1997). Even so, in a study in the St. Johns River, FL, there was found to be a decrease in % coverage by *V. americana* with decreasing soil oxygen demand (Dobberfuhl 2006). Also, low oxygen in the sediments was found to limit seed germination (Jarvis and Moore 2008). In the aquatic plant *Myriophyllum verticillatum*, sediment oxidation by roots was not found to counter highly reducing conditions (Carpenter 1983). The sediments in Apopka were highly reducing, but it is unclear what the effect on the plants may have been.

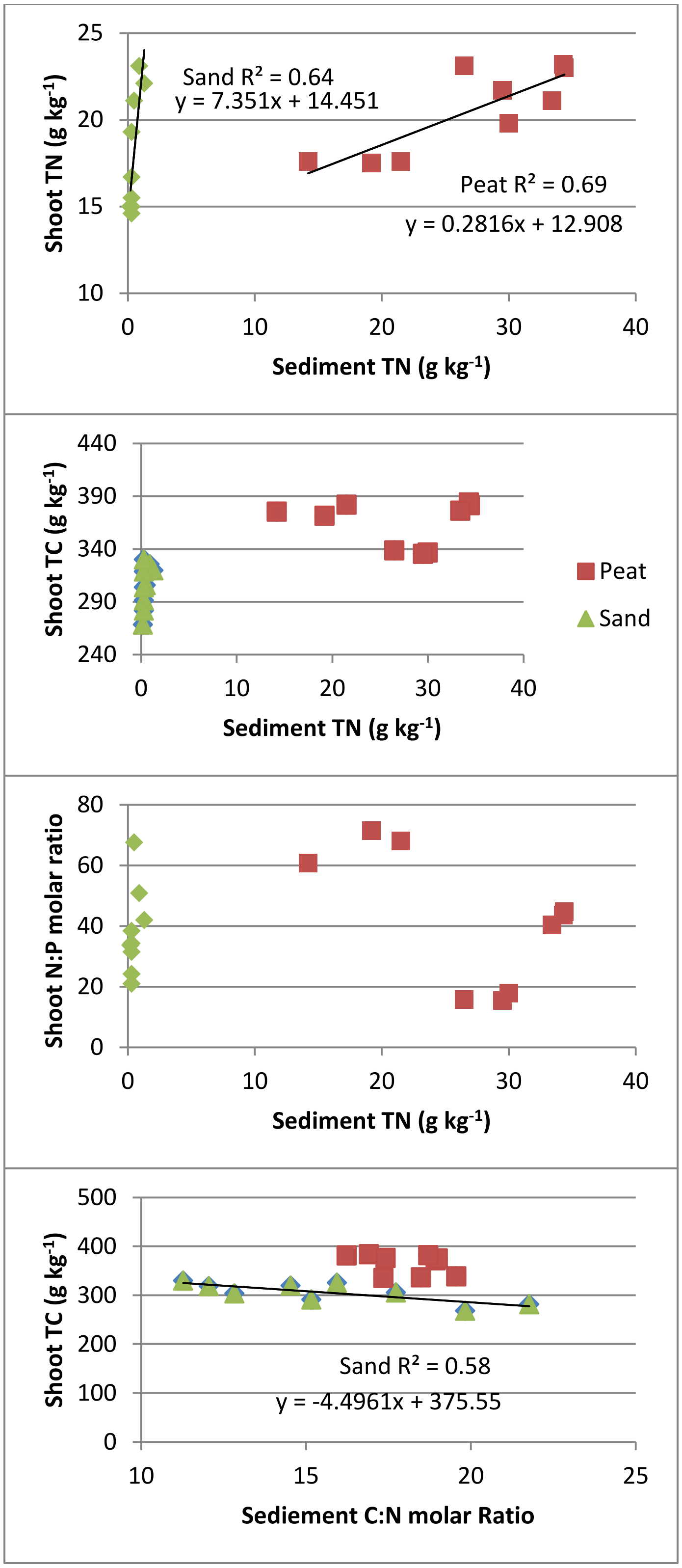

Figure 5. Nitrogen relationships of the sediment with the nutrients of the shoots. There was a positive relationship in both sediment types with increasing sediment nitrogen.

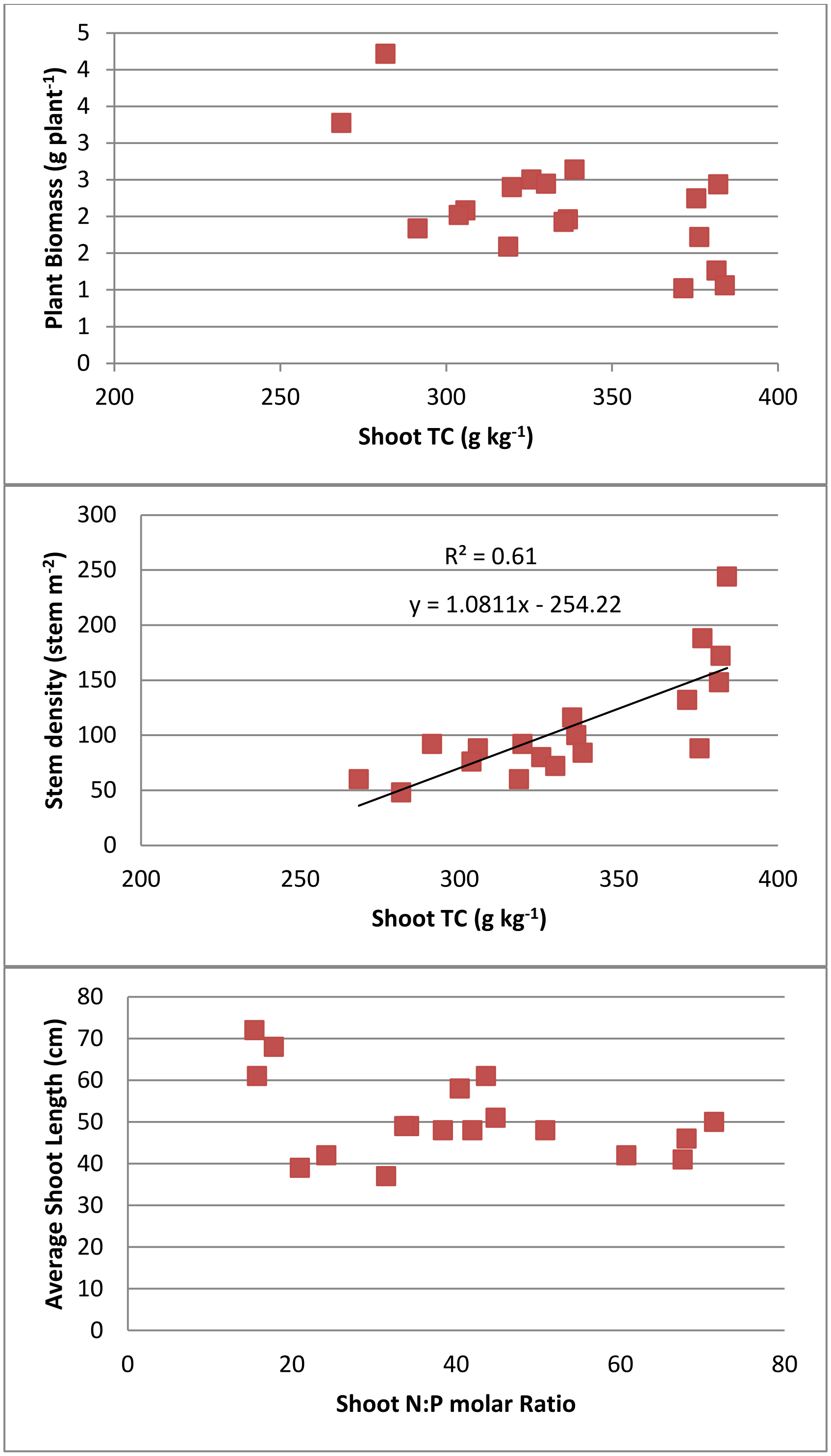

Figure 6. Relationship between the shoot nutrients and growth forms. Stem density showed a positive correlation between increased stem density and increased shoot TC.

Conclusion

- Compared to other water bodies, *Vallisneria americana* growing in Lake Apopka do not appear to be as healthy. This is due to the lower density of plants, total, biomass and lower carbon and organic content of the shoots relative to other studies.
- Growth form appears to be affected by nutrient limitations to the plants, especially at the sand sites. The shoot nutrient levels are all similar in the sands around the critical threshold of 0.13% phosphorus. The plants may be countering this by producing fewer plants with higher biomass. More studies are required to determine phosphorus availability to the macrophytes.
- Sand appeared to have the higher disadvantage in relation to nutrient availability. There were more obvious interactions with these plants due to increases in sediment nutrient content. All sites had a positive correlation between increased nutrient uptake with increased nutrients. The organic sediment had a direct influence with the nutrients where increase TP resulted in longer leaves.
- Some other factors which require more study include redox potential of the sediment, and effects of the sediment on root development. More study is required to determine how the organic sediment effects root development. Based on appearance, some of the roots in organic sediment in Apopka may have had thicker root structure, but was not directly measured. Studies required would look at morphology as well as nutrient accumulations in the roots.

Some factors which may be affecting the growth and need further study are the differences in age of the plants between the two sediments, and the time of year. While the study was done in the July, the peak in Florida is more in the later summer. Another beneficial study would be to compare Apopka *V. americana* to other local freshwater lakes, such as in the Harris Chain. Lake Griffin has similar nutrient issues and has rebounded in recent year with light attenuation and SAV growth.

More study into the growth of *V. americana* in Lake Apopka in the littoral zone substrates around the entire lake perimeter would help understand where it may become established in the future. Work is currently being done to map the distribution and expansion of SAV, particularly *V. americana* to measure expansion in the lake. It includes a rough characterization of the sediments types which may be used in the future along with the data collected in this study to determine suitable areas. The mapping work may give a better indication of actual sediment preference based on the extent and relative rate of expansion. The findings in this research are an important look at two substrate types in Lake Apopka, however the current study did not include all sediment types within the lake (e.g., muck substrate). Recent monitoring has shown increased growth of *V. americana* in these areas (unpublished data). Future work needs to be done to characterize these sediments, which are a less stable substrate for macrophytes growth with bulk densities around 0.02 g m^{-3} (Schelske 1997). Much of Lake Apopka is comprised of mucky sediments (Schelske 1997), including large portions of the littoral zone. Planting to encourage expansion is likely unnecessary in Lake Apopka if it continues on its path of recruitment in various locations around the lake. Some management that may be considered however, are continued treatment of cattail and *Hydrilla* and control of water levels to ensure available substrate for *V. americana* growth. This sediment data along with knowledge of the sediment types around the lake would assist in determining areas for cattail treatment based on suitable peat locations which would likely support *V. americana* growth. Reduction of chlorophyll levels is an ongoing process through wetland treatment cells and very little pumping from the old north shore farms (Lowe 2001). Decreasing chlorophyll supports higher light attenuation which could allow the plants to expand into deeper areas of the lake.

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