Lake and Reservoir Management 21(4):403-410, 2005

Community Structure and Environmental Conditions in Florida Shallow Lakes Dominated by Submerged Aquatic Vegetation

Binhe Gu
Everglades Division
South Florida Water Management District
3301 Gun Club Rd.
West Palm Beach, FL 33406

Mark V. Hoyer
Department of Fisheries and Aquatic Sciences
University of Florida
7922 NW 71st St.
Gainesville, FL 32653

Abstract

Gu, B. and M.V. Hoyer. 2005. Community structure and environmental conditions in Florida shallow lakes dominated by submerged aquatic vegetation. Lake and Reserv. Manage. 21(4):403-410.

Florida inland waters are dominated by shallow lakes, many of which support the growth of submerged aquatic vegetation (SAV). We examined the species composition and selected environmental variables of SAV-dominated lakes using data from the Florida LAKEWATCH program. Our analysis revealed eight genera with approximately 15 species of SAV among these shallow lakes, which range in size from <2-2,300 ha. The SAV community within each lake primarily consisted of a single or a few species. *Utricularia* and *Hydrilla* were the most common SAV genera found in these lakes. Many SAV species grew well in a wide range of water quality conditions, although biodiversity and biomass tended to increase with increasing alkalinity and calcium concentration. More SAV species were also found in lakes with higher pH and Secchi depth. On average, *Ceratophyllum*, *Najas* and *Vallisneria* dominated lakes with high total phosphorus (TP) concentrations (0.034-0.053 mg/L) while *Chara*, *Utricularia*, *Potamogeton* and *Myriophyllum* corresponded with relatively low TP concentrations (0.008-0.013 mg/L). However, there was a large overlap in nutrient concentrations in lakes dominated by different species.

Key Words: biodiversity, biomass, Florida lakes, light, phosphorus, submerged aquatic vegetation (SAV).

Submerged aquatic vegetation (SAV) is often an important component of the flora community in shallow lakes, estuaries and wetlands. Its roles in ecosystem functioning have been the subject of intensive research (see summary by Barko and James 1998). Briefly, SAV is capable of stabilizing sediments, reducing flow velocity, providing habitat for aquatic animals and assimilating nutrients that might otherwise be used by bloom-forming phytoplankton under favorable environmental conditions. Recently, interest in using SAV for nutrient reduction from stormwater treatment systems has grown (Dierberg *et al.* 2001, Gu *et al.* 2001). Phosphorus (P) removal occurs through plant uptake and photosynthetically induced co-precipitation with calcium carbonate under high pH (Murphy *et al.* 1983, Dierberg *et al.* 2002).

Not all shallow lakes are dominated by SAV, and species composition, coverage and biomass vary considerably across SAV-dominated systems; therefore, understanding conditions that favor SAV growth is a prerequisite for better ecosystem management and restoration. Recently, Bachmann *et al.* (2002) reported an analysis of relations between trophic state indicators and plant biomass in 319 Florida lakes. Their study showed that SAV was absent from lakes with high total P (TP) concentration (>0.166 mg/L), but that typical trophic state indicators were otherwise not good predictors of SAV biomass.

Florida has over 7,700 lakes that range in size from 4 to more than 180,000 ha (Canfield and Hoyer 1992). Many of these are shallow lakes vegetated with SAV (Bachmann *et*

Table 1.-Basic statistics of selected environmental variables from the study lakes.

	Area (ha)	PAC (%)	PVI (%)	Biomass (kg wt/m^2)	pH (SU)	ALK (mg/L)	COND (µS/cm)	Color (Pt-Co unit)	Cl (mg/L)	Fe (mg/L)
Mean	340	74	29	6.0	7.3	38.0	198.6	20.4	29.9	0.1
Median	113	77	20	4.5	7.4	32.0	153.0	13.0	21.5	0.0
Standard Deviation	631	20	24	5.7	1.2	41.3	168.1	20.8	35.2	0.1
Minimum	1.6	42	6	0.3	4.6	<0.1	20.0	<0.1	<0.1	0.0
Maximum	2331	100	83	22.1	11.8	175.0	763.0	98.0	161.3	0.5
Count	34	42	42	42	39	35	35	33	34	25

	Sulfate (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	TP (mg/L)	TN (mg/L)	CHLA (µg/L)	Secchi Depth (m)	Water Depth (m)
Mean	16.9	10.6	6.5	11.1	3.1	0.021	0.758	12.0	2.4	2.5
Median	11.6	12.5	4.4	7.8	1.6	0.014	0.665	6.0	2.2	2.4
Standard Deviation	16.8	7.0	9.0	10.3	3.3	0.019	0.389	13.1	1.2	1.4
Minimum	<0.1	1.0	0.8	1.8	0.1	0.004	0.130	2.0	0.6	0.4
Maximum	59.5	33.2	42.2	55.8	11.0	0.097	2.227	63.0	6.2	6.6
Count	33	26	26	26	26	42	42	42	41	42

al. 2002). In this analysis we used the existing data base from Florida LAKEWATCH, a citizens' lake monitoring program operated by Department of Fisheries and Aquatic Sciences of University of Florida. The objectives of this paper are to (1) document community structure (*i.e.*, species composition, coverage and biomass) and (2) assess relationships between SAV biodiversity, biomass and environmental conditions in Florida SAV-dominated lakes.

Methods

Lake data available from Florida LAKEWATCH (1997) were used in the selection of SAV-dominated lakes for this analysis. Lakes in the LAKEWATCH program are monitored for major water quality variables including TP, total nitrogen (TN), chlorophyll *a* (CHLA), Secchi depth and several other physical and chemical variables. Between 1992 and 1996, many of these lakes also were surveyed for aquatic plant species composition, coverage, frequency of occurrence, biomass and average lake depth (referred to as water depth hereafter) by Florida LAKEWATCH personnel. Sampling methods for water quality variables are discussed in detail elsewhere (Canfield *et al.* 2002). Percent area covered (PAC) and percent volume inhabited (PVI) with aquatic macrophytes were determined according to the methods of Maceina and Shireman (1980). The above-ground biomass was measured along 9-30 uniformly-placed transects, depending on size of the lake. At each transect, the above-ground biomass within a 0.25 m^2 plastic square randomly selected in each plant zone was harvested and weighed after excessive water was removed. All plant species observed during sampling were counted according to their frequency in the transects (Florida LAKEWATCH 1997), termed frequency of occurrence (%).

Only SAV-dominated lakes were of concern in this study; therefore only those lakes having PAC $\geq$40% and PVI $\geq$5% were considered. The latter was included in the selection process because field surveys indicate that SAV is the major component of the aquatic macrophyte biomass when the PVI is $\geq$5%. This selection process produced a list of 42 SAV-dominated systems for analysis.

Frequency of occurrence (%) was used to indicate the probability of each SAV appearing in each lake. Additionally, SAV biodiversity index (SBI) was calculated for each study lake. The SBI is defined as the number of SAV genera in each lake (N_l) relative to the total number of SAV genera (N_t) found in all the study lakes:

$$SBI = N_l / N_t$$

SBI will equal 1 if a lake contains the entire possible assemblage of SAV genera identified from all the surveys.

The lake variables were summarized to provide mean, median, standard deviation, minimum, maximum and count. Descriptive statistics were calculated on non-transformed data. Correlation analysis using log-transformed data was performed to compare the SAV biomass and SBI to various environmental variables. All statistics were calculated using SAS JMP analytical software (SAS Institute 2001).

Table 2.-List of SAV species found in the study lakes from the Florida LAKEWATCH database.

Scientific Name	Common Name
Chara spp.	musk-grass
Ceratophyllum demersum	coontail
Hydrilla verticillata	hydrilla
Myriophyllum aquaticum	parrot's-feather
Myriophyllum heterophyllum	variable-leaf milfoil
Najas guadalupensis	southern naiad
Najas minor	slender naiad
Potamogeton diversifolius	variable-leaf pondweed
Potamogeton illinoensis	Illinois pondweed
Utricularia foliosa	leafy bladderwort
Utricularia floridana	Florida yellow bladderwort
Utricularia gibba	cone-spur bladderwort
Utricularia purpurea	purple bladderwort
Utricularia resupinata	lavender bladderwort
Vallisneria americana	tapegrass

Results

Selected morphological, physical, chemical and biological variables for the study lakes are presented in Table 1. The surface area of these lakes varied considerably, ranging from 1.6-2,300 ha. Average water depth was 2.5 m and ranged from 0.4-6.6 m. The average Secchi depth was 2.4 m, which was slightly less than the average water depth. PAC and PVI ranged from 42-100% and 6-83%, respectively. The average SAV biomass was 6.0 kg wet weight/m^2 with a range from 0.3-22.1 kg wet weight/m^2.

The lakes selected for this study typically exhibited a wide range of water chemistry. The average pH, alkalinity and calcium concentrations were 7.3, 38.0 mg/L and 10.6 mg/L, respectively. Average CHLA, TP and TN concentrations were 12.0 mg/L, 0.021 mg/L and 0.758 mg/L, respectively, indicating that the average lake was eutrophic. However, wide spectrums of TP (0.004-0.097 mg/L) and CHLA (2.0-63.0 µg/L) were recorded for these lakes. The average color content was 20.4 Pt-Co units, with a range of <0.1-98.0 Pt-Co units, indicating that these lakes were not highly colored. Other water quality variables are also presented in Table 1.

SAV were identified for the study lakes (Table 2). Eight genera and approximately 15 species were documented. The survey of species composition by the LAKEWATCH program was not exhaustive because only 9-30 transects in each lake were sampled. Additional sampling would likely reveal more species in these lakes.

The SAV biomass, frequency of occurrence and biodiversity were recoded (Table 3). *Utricularia* occurred most frequently (44.3%) in the 42 lakes, followed by *Hydrilla* (31.0%), while *Myriophyllum* occurred in only 13.2% of the SAV lakes. Of the five *Utricularia* species found, four (*U. foliosa*, *U. floridana*, *U. gibba* and *U. purpurea*) were common to the study lakes. Excepting *Utricularia*, when two or more species of the same genus was found in a study lake, only one of those species (*Myriophyllum heterophyllum*, *Najas guadalupensis* or *Potamogeton illinoensis*) was dominant. In all the study lakes, no lake had an SBI of 1 (*i.e.*, populations of all possible genera were never present; Table 3). Lakes Dodd and Hernando had the highest SBI of 0.875, with 7 of 8 genera identified. Conversely, six lakes were found to have an SBI of 0.125, with only one genus of SAV present, recalling that those lakes with no SAV presence were culled from the LAKEWATCH roster for this study. In these six lakes, only genera *Utricularia*, *Najas* and *Chara* were represented. Fifty-seven percent of the lakes (24 of 42) had SBI values <0.5, while only 19% (8 of 42) of the lakes had SBI values >0.5, and 10 lakes (23%) had SBI values of 0.5.

Table 4.-Correlation analysis of SAV biodiversity index (SBI), biomass and selected environmental variables. N is the number of lakes. Results at P $\leq$ 0.05 are bold faced.

	SBI			Biomass		
Variables	**r**	**P**	**N**	**r**	**P**	**N**
Alkalinity	0.43	**0.01**	35	0.34	**0.05**	35
Calcium	0.40	**0.03**	26	0.49	**0.01**	28
CHLA	0.18	0.30	42	0.15	0.33	42
Chloride	0.05	0.80	33	0.00	0.99	34
Color	0.22	0.20	33	0.51	**0.01**	34
Conductivity	0.09	0.60	35	0.06	0.73	35
Magnesium	0.02	0.90	26	0.17	0.41	25
PAC	0.31	**0.04**	42	0.40	**0.01**	42
pH	0.36	**0.03**	35	0.32	0.06	35
Potassium	0.16	0.50	26	-0.04	0.83	21
PVI	0.28	**0.05**	42	0.28	0.07	42
Secchi depth	0.11	0.35	41	-0.08	0.60	41
Sodium	0.11	0.60	26	0.03	0.89	25
Sulfate	0.23	0.20	32	-0.10	0.63	32
Surface area	0.18	0.40	35	0.18	0.32	34
TN	0.09	0.50	42	0.28	0.07	42
TP	0.10	0.40	42	0.23	0.14	42
Water depth	0.25	0.10	42	-0.13	0.41	42

Correlations between SBI, biomass and most environmental variables were not significant (Table 4). However, significant correlations were found between SBI and PAC, PVI, pH, alkalinity and calcium concentration. SAV biomass was significantly correlated with PAC, alkalinity, calcium concentration and color. Correlations between SBI, or SAV biomass and nutrient concentrations were weak.

We conducted a further screening by selecting lakes with SAV frequency of occurrence $\geq$80%. The purpose of this process was to understand physical and chemical gradients of lakes nearly completely occupied by SAV. Dominant SAV

Table 3.-SAV biomass, frequency of occurrence and biodiversity index in the study lakes. Blank spaces indicate that no SAV was found at any of the sampling sites. Data are sorted by biomass.

	SAV Biomass	Frequency of occurrence (%)								
Lake	**(kg wt/m²)**	***Chara***	***Ceratophyllum***	***Hydrilla***	***Myriophyllum***	***Najas***	***Potamogeton***	***Vallisneria***	***Utricularia***	**SBI**
Smith	0.3			30			40		100	0.375
Conway South	0.5			10			80	40		0.375
Spirit	0.5	30						10		0.250
Little Weir	1.1						22		100	0.250
Sharon	1.1					100				0.125
Fanny	1.2								70	0.125
Blue Heron	1.3					90		10		0.250
Church	1.6	10		90			10		70	0.500
Spring Garden	1.6		60	90				30		0.375
Todd	1.6		10		60		70	20	100	0.625
Dinner	1.7	60		10			60		70	0.500
Bay	1.8					70				0.125
Grasshopper	1.9								100	0.125
Deborah	2.2	80								0.125
Saxon North	2.3		30	100		30		30		0.500
Halfmoon	2.6	50								0.125
Clay	2.8		10	10		20		80	100	0.625
Hall	4.0		30		50	70			30	0.500
Van Ness	4.3					10	60	10	100	0.500
Howell	4.4			90	10					0.250
Floyd	4.5	70							100	0.250
Osceola	4.5	30							100	0.250
Erie	4.6				90				80	0.250
Blue	4.7		80		10	100				0.375
Iamonia	5.2					3	3		100	0.375
Magdalene	5.8	80					90		50	0.375
Silver	6.0						30	50	20	0.375
Dodd	6.4	10		40	70	30	50	10	100	0.875
Eagle	6.5						70	90	90	0.375
Ola	7.2	20	90	70		40		70		0.625
Maurine	7.6	50	10	90				10		0.500
Lochloosa	7.8		81	94						0.250
Croft	8.0				80		90	70	100	0.500
Marsha	8.3	70		80		30			40	0.500
Hernando	8.8		10	40	70	40	50	60	90	0.875
Bellamy	10.0		10	90	100		10		90	0.625
Asbury South	11.4			80		80		40		0.375
Hartridge	15.4		30	90				70	20	0.500
Panasoffkee	17.5		100	100	13	67	33	90		0.750
Pierce	19.3		20	100				13	20	0.500
South	21.3	10	40			100		60	20	0.625
Bethel	22.1		90			100				0.250

Table 5.-Average and range (in parenthesis) of concentrations of major nutrients and water depth of the study lakes and their dominant SAV species (≥80% frequency of occurrence). N = number of lakes.

SAV	TP (mg/L)	TN (mg/L)	Water Depth (m)	N
Ceratophyllum	0.053 (0.011-0.097)	1.00 (0.54-1.33)	1.8 (0.8-3.4)	4
Najas	0.040 (0.014-0.097)	0.89 (0.41-1.21)	1.4 (0.8-3.1)	7
Vallisneria	0.034 (0.011-0.068)	0.92 (0.46-1.33)	2.9 (1.3-4.6)	3
Hydrilla	0.029 (0.008-0.068)	0.82 (0.41-1.81)	2.6 (0.4-3.3)	11
Chara	0.013 (0.001-0.015)	0.57 (0.51-0.64)	1.6 (1.0-2.3)	2
Potamogeton	0.011 (0.007-0.015)	0.58 (0.51-0.64)	1.9 (1.0-2.4)	4
Utricularia	0.011 (0.004-0.023)	0.64 (0.40-0.97)	2.4 (1.0-3.2)	15
Myriophyllum	0.008 (0.006-0.013)	0.57 (0.42-0.69)	2.2 (1.1-3.1)	3

genera, nutrient concentrations and average water depth of the lakes they populated were recorded (Table 5). Generally, *Ceratophyllum*, *Najas* and *Vallisneria* dominated lakes with higher mean concentrations of TP (≥0.034 mg/L) and TN (≥0.92 mg/L), while *Chara*, *Utricularia*, *Potamogeton* and *Myriophyllum* dominated lakes with relatively low average TP (≤0.013 mg/L) and TN concentrations (≤0.57 mg/L). *Hydrilla* was often found in lakes with intermediate nutrient levels. Considerable overlap was found among average water depths of the lakes inhabited by each SAV. Water depth of these lakes ranged from 0.4-4.6 m with an average of 2.1 m. *Vallisneria* tended to inhabit deeper waters with an average depth of 2.9 m. *Chara* was often found in shallower waters with an average depth of 1.6 m.

Discussion

In this analysis, 14 of the 42 study lakes were dominated by a single SAV species, although several SAV species may have been present. For example, Lake Iamonia was dominated by *Utricularia* with small amounts of *Najas* and *Potamogeton* also present. This finding is supported by studies for other Florida lakes (O'Dell *et al.* 1995, Knight *et al.* 2003) and rivers (Knight *et al.* 2003).

Some physical and chemical variables may influence species richness and distribution of aquatic macrophytes (Heegaard *et al.* 2001, Hoyer *et al.* 1996). Significant and positive correlations were found among pH, alkalinity, calcium concentration and SBI. It appears that more SAV species grow in hard-water than soft-water lakes. We also observed a correlation between Secchi depth and SBI. Since Secchi depth is a good indicator of underwater light condition, such a correlation may imply that light availability could determine the number of SAV species in freshwater lakes. Heegaard *et al.* (2001) revealed that color, alkalinity, conductivity, pH and major ions affected species number and compositions in northern Ireland lakes. They found that certain species are generalists that occurred in a wide spectrum of environmental conditions and some were restricted to a narrow range of physical and chemical gradients.

We found no significant correlation between nutrient concentrations and SBI, although increased nutrient loading is considered a mechanism leading to the decrease in plant biodiversity (Moss 1998). We speculate that within the nutrient ranges, nutrient concentration was not a limiting factor to SAV biodiversity. Bachmann *et al.* (2002) also found no significant relationships between trophic state indicators and the number of SAV species in Florida lakes. Similarly, we could not establish a close relationship between nutrient availability and SAV biomass in the study lakes. In a recent study, Bachmann *et al.* (2002) found weak correlations between SAV biomass and trophic state indicators from 319 Florida shallow lakes. However, Chambers and Kalff (1987) indicated in a controlled experiment that the biomass of a submerged *Potamogeton* species was largely determined by light availability. They also found that the biomass of an emergent species was determined by sediment nutrient concentrations. It appears that nutrient concentrations become critical only under sufficient light condition. Relationships between SAV diversity, biomass, and nutrient concentrations are complicated because many SAV species are capable of deriving nutrients from both water column and sediments. Furthermore, factors determining SAV diversity and biomass may vary with lake, species and competition with planktonic algae and periphyton.

An examination of the environmental data for each SAV gave some insights into species-specific growth habitat (Table 5). *Ceratophyllum* appeared to dominate lakes with the highest nutrient concentration among the SAV in this analysis. This agrees with findings from several previous studies. Hoyer *et al.* (1996) reported that average TP concentration (0.064 mg/L) in lakes with *Ceratophyllum* present was highest among lakes with SAV. Another study indicated that *Ceratophyllum* was typically confined to the inflow areas of a constructed wetland and experimental mesocosms where nutrient concentrations were considerably higher than other regions of these systems (Dierberg *et al.* 2001). On the other hand, some

SAV species only dominate lakes with low nutrient concentrations. In this study, *Myriophyllum* was found to occur at a maximum TP concentration of ≤0.013 mg/L. Other SAV, including *Chara* and *Utricularia*, were also present in lakes with low nutrient concentrations. For example, Lake Iamonia, an acidic, soft water lake with low TP concentrations (0.017 mg/L), was dominated by a species of *Utricularia*. Similarly, *U. purpurea* and *Chara zeylanica* were found only in the P-limited or moderately enriched area of the Everglades ecosystem (Vaithiyanathan and Richardson 1999). These results revealed species-specific preference of nutrient gradients in shallow aquatic systems. However, note that nutrient ranges for each SAV (Table 5) are restricted to our study lakes. The same species in other geographical regions may inhabit lakes with distinct nutrient conditions.

Significant SAV coverage and biomass were found in lakes with a broad areal extant ranging from only a few to thousands of hectares in size. However, no relationship between SAV unit biomass and lake surface area was found, although weak trends of SAV unit biomass to increased lake area were found in an earlier study using data from 139 lakes (Duarte *et al.* 1986) and a study of 69 Florida lakes (Canfield and Duarte 1988). Duarte *et al.* (1986) asserted that high SAV biomass coverage was inconsistent in the large lakes because these lakes tend to be deeper and have part of their basins out of the photic zone. This observation may not fully explain the lack of correlation between SAV biomass and surface area in the Florida lakes, which are often flat and shallow regardless of their size. For example, SAV areal coverage exceeded 90% for several large Florida lakes including Lake Pannassoffkee (1,780 ha), Iamonia (2,300 ha) and Istokpoga (11,000 ha). The average water depth for these lakes is <2 m (Florida LAKEWATCH 1997, O'Dell *et al.* 1995).

Light penetration is an important factor that determines the growth of SAV in aquatic systems. Duarte *et al.* (1986) indicated that SAV coverage was positively related to light intensity, which was the most important factor determining SAV biomass in their study lakes. Canfield and Duarte (1988) found similar relationships in their study of 69 Florida lakes dominated by SAV. Since light penetration decreases with increasing water depth, color and turbidity, many studies have demonstrated the importance of water depth on controlling SAV distribution and biomass (*e.g.*, Canfield *et al.* 1985, Steinman *et al.* 2002). Canfield *et al.* (1985) used Secchi depth to predict maximum water depth of macrophyte colonization in lakes. Using the regression model developed with data for Florida lakes (Canfield *et al.* 1985) and Secchi depth data for our study lakes, the predicted average maximum water depth of colonization for SAV growth in our study lakes was 3.7 m as compared to the average water depth of 2.5 m. Only 6 lakes had predicted maximum water depths of colonization less than the average water depth (Fig. 1). An examination of the data showed that these lakes had PAC and biomass values less than the averages for the study lakes. This indicates that the majority of the study lakes had shallow water depths that allow sufficient light penetration for the growth of SAV and explains why neither water depth nor Secchi depth was significantly correlated with SAV biomass. The majority of these Florida lakes are shallow, and the range in water depth and Secchi depth was not the limiting factor for the growth of SAV in these systems.

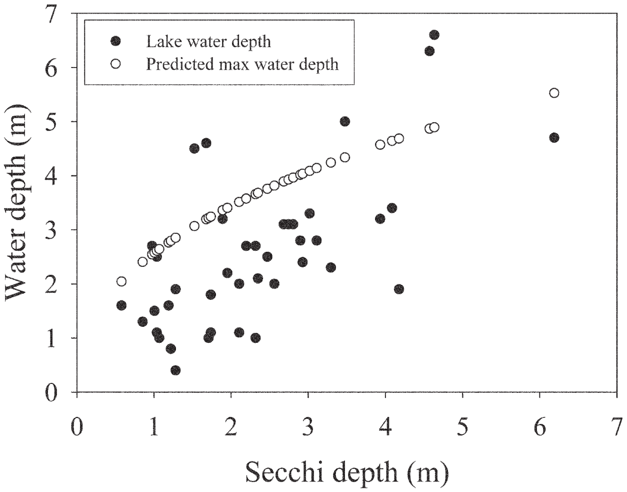

Figure 1.-Relationship between Secchi depth, mean water depth and predicted maximum water depth of SAV colonization.

High color content in aquatic systems leads to rapid extinction of light under water (Wetzel 2001). In humic and highly colored lakes, light availability is often poor and therefore would be a limiting factor in SAV growth. Surprisingly, we found a positive correlation between color and SAV biomass in our study lakes. One explanation is that the lakes selected for this analysis had a low and narrow color range from <0.1-98 Pt-Co units, and within this range, color was not high enough to hinder light penetration into the water column at these shallow depths and therefore had no significant effect on SAV growth. The positive relationship between color and SAV biomass may be a spurious correlation, and the increased color may be a result of more dissolved organic matter being released into the water column where SAV biomass was high. Knight *et al.* (2003), using a broader data base for Florida freshwaters, found no relationship between SAV coverage and water color. Bachmann *et al.* (2002) reported no SAV biomass in their study lakes with color exceeding approximately 150 Pt-Co units. An examination of their data indicated high SAV biomass in lakes with color <100 Pt-Co units.

High SAV coverage and biomass are found from poorly buffered acidic lakes to highly basic lakes, pointing to the high degree of tolerance of SAV to a range of chemical conditions. However, the positive correlation between SAV biomass and pH, alkalinity, and calcium suggests that SAV grow better in a hardwater environment where dissolved inorganic carbon is readily available for photosynthesis. Submerged plants such as *Potamogeton*, *Najas*, *Myriophyllum* and *Ceratophyllum* are capable of utilizing bicarbonate as a carbon source in hardwater lakes (Madsen and Sand-Jensen 1991). Similarly, Knight *et al.* (2003) also found a close relationship between SAV coverage and Ca and alkalinity from Florida freshwaters.

Conclusions

This analysis indicates that factors determining SAV richness and biomass in Florida lakes are multi-faceted. Although SAV species are present in lakes covering a wide spectrum of physical and chemical conditions, it appears that more SAV species and higher biomass are found in lakes with strong buffering capacity (high pH, alkalinity and calcium concentrations). Light availability is probably not an important factor in the study lakes because the majority are shallow and have sufficient light to support SAV growth. No correlations between water column nutrient concentrations and plant diversity and biomass were observed. This analysis also shows that different SAV may have unique physical and chemical boundaries within the study lakes. *Ceratophyllum demersum* is clearly identified as the SAV inhabiting in high nutrient environments while other SAV including *Chara*, *Potamogeton*, *Utricularia* and *Myriophyllum* dominate lakes with low nutrient concentrations.

Lake and wetland managers who use SAV to improve water quality or remove nutrients from inflow waters need to understand the environmental requirements for common SAV species to maximize their effectiveness. Apparently, some species grow better than others at specific ranges of nutrient concentrations and water depths. Our analysis shows that *Hydrilla* is the second most common macrophyte in the SAV lakes. Introduction of native SAV species to any aquatic system may sometimes lead to invasion of this exotic species. Finally, underwater light condition is critical to photosynthesis and nutrient uptake by SAV. During wet periods with increased water depth and lowered transparency due to high hydraulic loading, SAV growth and efficiency for nutrient removal may be reduced.

Acknowledgments

We appreciate constructive comments from Drs. Karl Havens, Jana Newman, Martha Nungesser, Michael Chimney and five anonymous reviewers.

References

Bachmann, R.W., C.A. Horsburgh, M.V. Hoyer, L.K. Mataraza and D.E. Canfield. 2002. Relations between trophic state indicators and plant biomass in Florida lakes. Hydrobiologia 470:219-234.

Barko, J.W. and W.F. James. 1998. Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation, and resuspension. P. 197-216. *In* E. Jeppesen, M. Sondergaard, M. Sondergaard and K. Christoffersen (eds.). The Structuring Role of Submerged Macrophytes in Lakes. Springer-Verlag, New York, NY.

Canfield, D.E. Jr., K.A. Langeland, S.B. Linda and W.T. Haller. 1985. Relations between transparency and maximum depth of Macrophyte colonization in lakes. J. Aquat. Plant. Manage. 23:25-28.

Canfield, D.E. Jr. and C.M. Duarte. 1988. Patterns in biomass and cover of aquatic macrophytes in lakes: A test with Florida lakes. Can. J. Fish. Aquat. Sci. 45:1976-1982.

Canfield, D.E. Jr. and M.V. Hoyer. 1992. Aquatic macrophytes and their relation to the limnology of Florida lakes. Final Report Submitted to the Bureau of Aquatic Plant Management, Florida Department of Natural Resources. 596 p.

Canfield, D.E. Jr., C.D. Brown, R.W. Bachmann and M.V. Hoyer. 2002. Volunteer lake monitoring: Testing the reliability of data collected by the Florida LAKEWATCH program. Lake and Reserv. Manage. 18:1-9.

Chambers, P.A. and J. Kalff. 1987. Light and nutrients in the control of aquatic plant community structure. I. *in situ* experiments. J. Ecol. 75:611-619.

Dierberg, F.E., T.A. DeBusk, S.D. Jackson, M.J. Chimney and K. Pietro. 2001. Submerged aquatic vegetation-based treatment wetlands for removing phosphorus from agricultural runoff: response to hydraulic and nutrient loading. Water Res. 36:1409-1422.

Dierberg, F., T. DeBusk, J. Potts and B. Gu. 2002. Biological uptake vs. coprecipitation of soluble reactive phosphorus by 'P-enriched' and 'P-deficient' *Najas guadalupensis* in hard and soft waters. Verh. Internat. Verein. Limnol. 28:1865–1870.

Duarte, C.M., J. Kalff and R.H. Peters. 1986. Patterns in biomass and cover of aquatic macrophytes in lakes. Can. J. Fish. Aquat. Sci. 43:1900-1908.

Florida LAKEWATCH. 1997. Florida LAKEWATCH Data 1986-1996. Department of Fisheries and Aquatic Sciences. University of Florida/Institute of Food and Agricultural Sciences. University of Florida, Gainesville, Florida. 1108 p.

Gu, B., T. DeBusk, F.E. Dierberg, M. Chimney, K. Pietro and T. Aziz. 2001. Phosphorus removal from Everglades agricultural area runoff by submerged aquatic vegetation/limerock treatment technology: An overview of research. Water Sci. Tech. 44:101-108.

Heegaard, E., H.H. Birks, C.E. Gibson, S.J. Smith and S. Wolfe-Murphy. 2001. Species-environmental relationship of aquatic macrophytes in northern Ireland. Aquat. Bot. 70:175-223.

Hoyer, M.V., D.E. Canfield, Jr., C.A. Horsburgh and K. Brown. 1996. Florida freshwater plants, a handbook of common aquatic plants in Florida lakes. University of Florida, Institute of Food and Agricultural Sciences. SP 189. 264 p.

Knight, R.L., B. Gu, R.A. Clark and J.M. Newman. 2003. Long-term phosphorus removal in Florida aquatic systems dominated by submerged aquatic vegetation. Ecol. Eng. 20:45-63.

Maceina, M.J. and J.V. Shireman. 1980. The use of a recording fathometer for the determination of distribution and biomass of hydrilla. J. Aquat. Plant Manag. 18:34-49.

Madsen, T.V. and K. Sand-Jensen. 1991. Photosynthetic carbon assimilation in aquatic macrophytes. Aquat. Bot. 41:5-40.

Moss, B. 1998. The E numbers of eutrophication – errors, ecosystem effects, economics, eventualities, and environment and education. Water Sci. Tech. 37:75-84.

Murphy, T., K. Hall and I. Yesaki. 1983. Co-precipitation of phosphate and calcite in a naturally eutrophic lake. Limnol. Oceanogr. 28:58-67.

O'Dell, K.M., J. VanArman, B.H. Welch, and S.D. Hill. 1995. Changes in water chemistry in a macrophyte-dominated lake before and after herbicide treatment. Lake and Reserv. Manage. 11:311-316.

SAS Institute, Inc. 2001. SAS JMP User's Manual. SAS Institute, Inc., Cary, NC.

Steinman, A.D., K.E. Havens, A. Rodusky, B. Sharfstein, R. Thomas and M.C. Harwell. 2002. The influence of environmental variables and a managed water recession on the growth of charaphytes in a large, subtropical lake. Aqua. Bot. 72:297-313.

Vaithiyanathan, P. and C.J. Richardson. 1999. Macrophyte species changes in the Everglades: Examination along a eutrophic gradient. J. Environ. Qual. 28:1347-1358.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, 3rd Edition. Academic Press, San Diego, CA. 1006 p.