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Analysis of the Relationship Between Submerged Aquatic Vegetation (SAV) and Water Trophic Status of Lakes Clustered in Northwestern Hillsborough County, Florida

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Abstract This study examined the relationship between abundance of submerged aquatic vegetation (SAV) and the water trophic status of a group of lakes located in northwestern Hillsborough county. SAV abundance was expressed by the percent of lake volume infested with SAV (PVI) and the percent of lake area covered with SAV (PAC). The group of lakes was divided into two subgroups based on SAV abundance less than 20 PVI (PVI<20) and lakes with more than 20 PVI (PVI>20). Mean concentrations of total phosphorus (TP), total nitrogen (TN), and chlorophyll-α in lake water were used as indicators of trophic status, with the concentration of each nutrient in one group of lakes compared to its corresponding concentration in the other group. Lakes with PVI<20 had a mean concentration of TP and chlorophyll-α of 28 and 11 μg/l, respectively, while those with a PVI>20 had a mean concentration of 18 and 4 μg/l for the same parameters, respectively. The results of a *t* test and one-way ANOVA performed at the 95% confidence level indicated that the differences were significant for the concentrations of TP and chlorophyll-α but not for TN, the last of which had a mean lake water concentration of 0.8 and 0.7 mg/l for the PVI<20 and PVI>20 subgroups, respectively.

Keywords Total phosphorus · Total nitrogen · Chlorophyll-α · Phytoplankton · Relationship · Water quality · PVI · PAC · Macrophytes

1 Introduction

The results of several studies have suggested that submerged aquatic vegetation (SAV) plays an important role in regulating the concentration of lake water nutrients (Bachmann et al. 2002, 2004; Brenner et al. 1999; Knight et al. 2003) and lake phytoplankton (Canfield and Hoyer 1992; Canfield et al. 1984; Scheffer 2004). These relationships, however, are complex and have not yet been identified as clearly as has the strong link between water nutrient concentration and phytoplankton biomass (Bachmann et al. 2002; Canfield 1983). It appears possible that water nutrient concentration could control SAV by regulating phytoplankton biomass and consequent penetration of photosynthetically active radiation into the lake bottom. In Florida lakes, although there have been indications

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that the concentration of SAV may be reduced by the concentration of nutrients in the water column in waters with only the highest nutrient concentrations, no clear relationship has yet been indicated between the abundance of SAV and the concentration of nutrients in lakes with lower concentrations (Bachmann et al. 2002).

Studies conducted in other geographic areas appear even more conflicting in terms of clarifying the nature of this relationship. Increased water nutrient concentration has been found to trigger SAV growth (Ozimek 1978, as quoted by Duarte and Kalff 1986), to have no clear effect (Carpenter and Adams 1979), and to decrease SAV growth (Duarte 1995), especially when the phosphorus level greatly increases (Graneli and Solander 1988) due to light attenuation caused by the triggered phytoplankton (Duarte 1995; Graneli and Solander 1988). The literature has reported that lakes have changed from a clear water state to a turbid water state (i.e., with a higher concentration of nutrients and suspended solids), when SAV was removed by herbicide treatment (O'Dell et al. 1995) or the action of hurricanes (Bachmann et al. 1999). Likewise, lakes have been reported to transition from a turbid to clear water state when planktivorous fish were removed, triggering SAV growth (Ozimek et al. 1990).

Much research is needed to further clarify the relationship between SAV and lake water trophic state variables. In this study, data collected from a group of 34 lakes clustered in northwestern Hillsborough County, Florida, were examined for a possible relationship between the abundance of SAV and the concentration of total phosphorus (TP), total nitrogen (TN), and chlorophyll-α in lake water. This paper analyzed for this group of lakes the relationship suggested in the literature. On a broader scale, the knowledge of such a relationship, if one exists, would assist surface water managers and community stakeholders in their efforts to engage in sustainable development.

2 Methods

2.1 Data Description

This study examined data collected from 34 urban and suburban lakes distributed over an area with mixed land use (residential, recreational, and agricultural) in the northwestern portion of Hillsborough County (Fig. 1). The lakes are located within the Tampa Bay watershed and distributed over the three lake regions of Keystone Lakes, Land-o-Lakes, and the Tampa Plain, in accordance with the classification system of Griffith et al. (1997). The study used existing data on the trophic state indicators of lake water TP, TN, and chlorophyll-α concentrations and the SAV indicators of the percentage of lake volume infested with SAV (PVI) and percentage of lake area covered with SAV (PAC). The data for the variables for each lake correspond to only one measurement performed in 2006 or 2007 (depending on the lake) at one point in time and therefore may not reflect their concentrations at all points in time. The data were collected by biologists at the Florida Center for Community Design and Research at the University of South Florida (Koenig and Eilers 2007) and were made available by the Water Atlas (2007). Data availability was the determining factor in the inclusion of the 34 lakes in this analysis.

Samples taken to determine TP, TN, and chlorophyll-α concentrations were analyzed by the Hillsborough County Environmental Protection Commission laboratory, a National Environmental Laboratory Accreditation Program (NELAP)-certified laboratory. Analysis was conducted using a combination of EPA and APHA Standard Methods, following QA/QC guidelines from both methodologies and all NELAP QA/QC rules. TP concentration was determined by EPA 365.4; TN concentration by the sum of total Kjeldahl nitrogen (TKN) and nitrate/nitrite nitrogen, where TKN was determined by EPA 351.2; nitrate/nitrite nitrogen concentration by SM 4500 NO3 F (Clescerl et al. 1998); and chlorophyll-α concentration was determined by SM 10200 H (Clescerl et al. 1998).

The abundance of SAV was expressed by PVI and PAC, which were estimated from a recording of soft (depth of vegetation or muck return) and hard bottom (lake depth) returns conducted with a Lowrance recording fathometer (LCX-28CHD) on 100 randomly selected points. The Lowrance software allows measurements of the vertical view based on the return data and the creation of a bathymetry trace record of the lake. About 10 points per lake were verified by direct observations made by divers when sites were quantitatively assessed for SAV abundance. This assessment

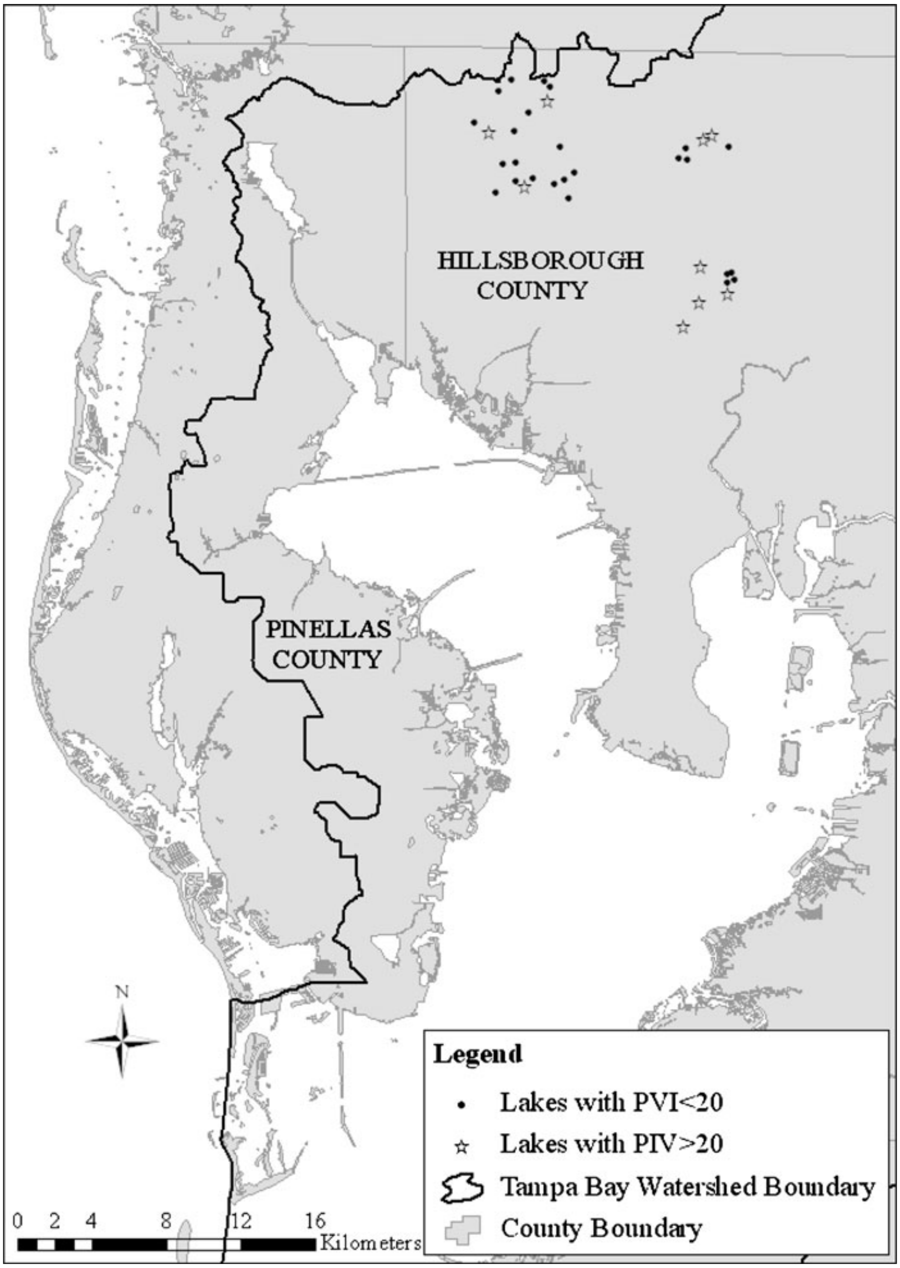

Fig. 1 Location of lakes examined in this study

included the collection and weighing of SAV biomass and the estimation of the littoral area where SAV was present. These data, together with the knowledge regarding lake depth and the depth at which light penetrates (based on Secchi Depth), were factors determining the presence or absence of SAV. Because the abundance of SAV less than 16 cm in height could not be determined accurately with a fathometer, it was estimated using the decision process described above. Once the presence of SAV had been determined, PAC was estimated by expressing the results in terms of percentage, and PVI was estimated as shown in Eq. 1. For points where no vegetation existed, the numerator was zero and was therefore considered zero.

$$\frac{\sum_0^{100}\left(\frac{(\text{Lake depth}-\text{Depth of vegetation})}{\text{Lake depth}}\right)}{100}=\text{PVI} \quad (1)$$

2.2 Statistical Analysis

To detect any possible level of TP, TN, and/or chlorophyll-α presumably associated with the presence of SAV, the lakes were separated into two groups, those with an SAV abundance of less than 20 PVI (the PVI<20 group) and those with an SAV abundance greater than 20 PVI (the PVI>20 group). Using PVI as the separation criterion accorded with a similar method used by Bachmann et al. (2002) in a study of a larger group of Florida lakes, in which they considered lakes with a PVI<20 as having low abundance of SAV and being phytoplankton-dominated and lakes with a PVI>80 as having high abundance of SAV and being macrophyte-dominated.

None of the 34 lakes in the present study had a PVI>80 (the limit for lakes with high abundance of SAV), and all were below or above PVI<20 (the limit for lakes with low abundance of SAV). Therefore, a PVI of 20 was set as the threshold for the separation of the two groups, with 25 of the 34 lakes having a PVI<20 and the remaining nine having a PVI>20. A *t* test assuming unequal variances was performed to determine if the means of both groups of lakes were significantly different for each of the three variables considered (TP, TN, and chlorophyll-α), and a one-way analysis of variance (ANOVA) performed to confirm the results, with both tests performed at the 95% confidence level (α=0.05). Bachmann et al. (2002) conducted similar analysis, performing a one-way ANOVA to determine differences between the means of two groups of lakes regarding their trophic state variables.

3 Results and Discussion

The 25 lakes classified as having a PVI<20 were found to have a mean PVI and PAC of 9.7 and 25.9, respectively, and the nine lakes having been classified as PVI>20 were found to have a mean PVI and PAC of 34.1 and 74.4, respectively. For more information regarding the SAV statistics regarding both groups of lakes, refer to Table 1.

The TP concentration of the PVI<20 group ranged from 10 to 50 µg/l, with a mean and median of 27.6 and 26.0 µg/l, respectively, while that of the PVI>20 group ranged from 3 to 31 µg/l, with a mean and median of 18.4 and 19.0 µg/l, respectively (Fig. 2).

Table 1 Summary statistics of SAV abundance (PVI and PAC) for Northwestern Hillsborough lakes examined in this study

	PVI<20		PVI>20	
	PVI	PAC	PVI	PAC
N	25.0	25.0	9.0	9.0
Median	10.0	30.0	33.0	76.0
Mean	9.7	25.9	34.1	74.4
SD	5.4	17.8	8.4	7.6
Minimum	0.5	2.0	23.0	63.0
Maximum	19.0	56.0	47.0	85.0

According to the Trophic State Classification System of Forsberg and Ryding (1980), based on their levels of phosphorus, several lakes from both groups could be classified as oligotrophic ([TP] <15 µg/l), mesotrophic (15<[TP] <25 µg/l), and eutrophic ([TP] >25 µg/l) lakes, but no lake could be classified as a hypereutrophic ([TP] >100 µg/l) lake.

The chlorophyll-α concentration for the PVI<20 group ranged from 3.6 to 44.6 µg/l, with a mean and median of 10.9 and 8.8 µg/l, respectively, while that of the PVI>20 group ranged from 1.2 to 6.9 µg/l, with a mean and median of 3.6 and 3.8 µg/l, respectively (Fig. 3). These results indicate that, at low abundance of SAV, the concentration of phytoplanktonic chlorophyll-α can be low or high, but at higher abundance of SAV, the phytoplanktonic chlorophyll-α concentration is always low. Because the ranges overlap for both lake groups regarding both variables, no accurate prediction of water quality could be done based only on SAV prevalence.

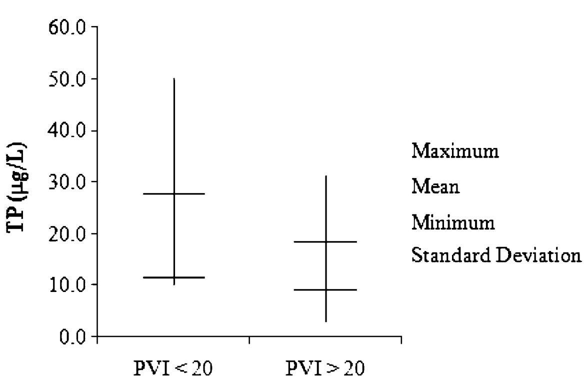

Fig. 2 Lake water TP concentration in both groups of lakes studied

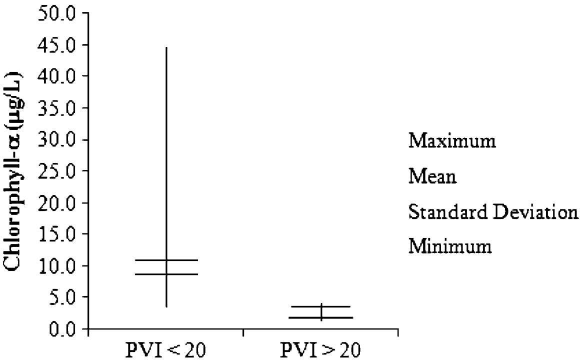

Fig. 3 Lake water chlorophyll-α concentration in both groups of lakes studied

Despite the overlap, the results of a *t* test indicated a significant difference between the groups of lakes for both TP and chlorophyll-α concentration ($p=0.0002$ and <0.0001, respectively), both being higher for lakes with a PVI<20 (low SAV) as compared to those with a PVI>20 (high SAV; Figs. 2 and 3). This difference was confirmed by the results of a one-way ANOVA that analyzed the same parameters ($p=0.036$ and 0.017, respectively). Such results suggest a strong relationship between SAV abundance and lake water concentration of TP and chlorophyll-α and support the results of Bachmann et al. (2002), who proposed an effect of SAV on reducing lake water nutrient concentrations. These results also align with literature that indicates the capacity of SAV to remove nutrients from the water column (Dierberg et al. 2002; Gu et al. 2001; Knight et al. 2003). The findings of an additional study by these authors analyzing several of the lakes from both groups in this study suggested an overall increase in the lake water concentration of TP and chlorophyll-α and a corresponding decrease in the ratio of TN to TP concentration from 1990 to 2007 (Moreno and Poor 2010).

Among the mechanisms by which SAV may facilitate the reduction of nutrient concentration in the water column may be the inhibition of water turbulence and the consequent suppression of sediment resuspension and nutrient recycling (Hamilton and Mitchell 1996; Scheffer 2004). This would favor the accumulation of nutrients in the sediments. Nutrient uptake may be another important mechanism in nutrient reduction, as SAV can uptake nutrients from both the water column and sediments (Graneli and Solander 1988). SAV, as well as emergent aquatic vegetation, provides substrate surfaces for epiphytes and periphyton (Cattaneo and Kalff 1980; Dierberg et al. 2002), which can remove phosphorus directly from the water column (Dierberg et al. 2002; Scinto and Reddy 2003). Because the nutrients taken up by aquatic vegetation and periphyton are contained in their biomass, they could eventually be released back into the water column or added to the sediment if the vegetation disappears (Canfield et al. 1983). Similarly, in the absence of SAV and other aquatic vegetation, bottom sediments would be exposed to turbulence, which may cause the release of nutrients from the sediments back into the water column, thereby increasing the water nutrient concentration. The results of a study conducted in the Everglades suggested that, under alkaline conditions, the intense photosynthesis of SAV and associated periphyton may be able to increase the pH, leading to coprecipitation of phosphorus with calcium carbonate (Dierberg et al. 2002).

The strong relationship between lake water nutrient concentration and chlorophyll-α concentration results in an indirect relationship between SAV abundance and chlorophyll-α concentration in lake water. Additionally, SAV may further control chlorophyll-α levels by providing shelter from fish to zooplankton that graze on phytoplankton (Scheffer 2004; Scheffer et al. 2001). As mentioned earlier, the absence of planktivorous fish has been associated with a reduction in chlorophyll-α levels.

No significant difference was found between the groups of lakes regarding the concentration of TN (*t* test, $p=0.071$; ANOVA, $p=0.326$; Fig. 4). This result partially aligns with that of Bachmann et al. (2002), who found no significant association between lake water TN concentration and SAV abundance when the latter was expressed by PVI but found a

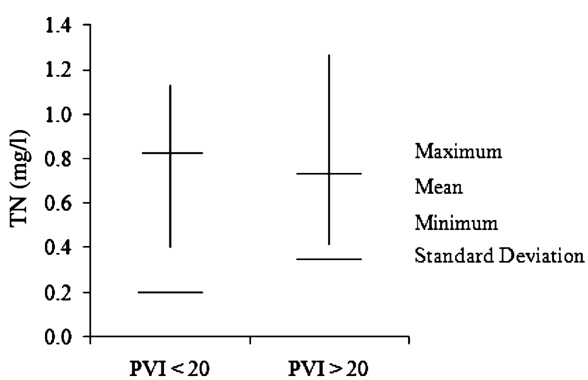

Fig. 4 Lake water TN concentration in both groups of lakes studied

weak though significant relationship when SAV was expressed by PAC. In this study, the mean and median lake water TN concentrations in lakes with a PVI<20 were 0.8 and 0.9 mg/l, respectively, and ranged from 0.4 to 1.1 mg/l, respectively. The mean and median lake water TN concentrations in lakes with a PVI>20 were 0.7 and 0.6 mg/l, respectively (Fig. 4), and ranged from 0.4 to 1.3 mg/l. As expected from the *t* test and ANOVA analysis, the overlap for both groups of lakes regarding this parameter was much greater; in fact, the range of the lakes with a PVI<20 was entirely included within the range of those with a PVI>20.

4 Conclusions

The results of *t* test and one-way ANOVA performed in this study indicate that, as a group, lakes with a PVI<20 have a significantly higher mean lake water concentration of TP and chlorophyll-α compared to lakes with a PVI>20 but that there is no significant difference between the groups of lakes in regard to TN concentration. The results also indicate considerable overlap regarding the ranges of individual lakes for the three water trophic indicators considered. Whereas the concentration of phytoplanktonic chlorophyll-α could be low or high for lakes with PVI<20, the concentration was low for all lakes with a PVI>20. These results align with the suggested association between increased SAV abundance and reduced phytoplanktonic chlorophyll-α and TP concentration in lake water reported in the literature.

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Appendix

Table 2

Table 2 One-time values of variables of lakes with PVI<20

Lake	PVI	PAC	TP µg/l	TN mg/l	Chlorophy. µg/l	Latitude	Longitude	Lake region
Horse	19	46	21	0.9	4	28.11056	−82.5789	Keystone Lakes
Pine	18	44	40	1.0	9	28.06056	−82.4722	Land-o-Lakes
Round	17	56	21	0.5	4	28.12056	−82.5	Land-o-Lakes
Cypress	16	56	10	0.5	4	28.12556	−82.5644	Keystone Lakes
Noreast	14	40	27	0.7	10	28.0625	−82.4686	Land-o-Lakes
Rogers	13	44	17	1.0	14	28.10889	−82.5886	Keystone Lakes
Taylor	13	30	12	0.6	6	28.13667	−82.6119	Keystone Lakes
Dead Lady	13	34	50	0.9	7	28.155	−82.5706	Keystone Lakes
Island Ford	12	38	25	0.9	9	28.15222	−82.5989	Keystone Lakes
Keystone	12	38	25	1.1	4	28.13306	−82.59	Keystone Lakes
Armistead	12	7	45	1.1	21	28.10111	−82.5597	Tampa Plain
Crescent	10	35	35	0.9	45	28.15806	−82.5919	Keystone Lakes
Elizabeth	10	30	24	0.9	6	28.15722	−82.5733	Keystone Lakes
Juanita	10	21	10	1.0	11	28.1175	−82.5889	Keystone Lakes
Calm	9	39	22	0.4	4	28.14222	−82.5817	Keystone Lakes
Rainbow	9	26	10	0.8	8	28.11667	−82.5961	Keystone Lakes
Saddleback	9	3	27	1.1	11	28.12028	−82.4947	Land-o-Lakes

Table 2 (continued)

Lake	PVI	PAC	TP µg/l	TN mg/l	Chlorophy. µg/l	Latitude	Longitude	Lake region
Crenshaw	8	20	22	0.8	11	28.12583	−82.4958	Land-o-Lakes
Cedar East	5	8	33	0.6	7	28.06556	−82.4703	Land-o-Lakes
Church	5	15	26	0.5	6	28.10306	−82.5994	Keystone Lakes
Rock	4	6	35	0.9	22	28.11333	−82.5567	Tampa Plain
Cedar West	2	3	41	0.8	17	28.06528	−82.4725	Land-o-Lakes
Pretty	1	2	33	1.0	12	28.1075	−82.5678	Tampa Plain
Josephine	1	2	44	0.9	12	28.10972	−82.5619	Tampa Plain
Brant	1	5	35	0.9	9	28.12639	−82.4722	Land-o-Lakes

Table 3 One-time values of variables of lakes with PVI >20

Lake	PVI	PAC	TP µg/l	TN mg/l	Chlorophy. µg/l	Latitude	Longitude	Lake region
Magdalene	47	76	14	1.1	4	28.13194	−82.4819	Land-o-Lakes
White Trout	44	77	14	0.6	3	28.03917	−82.4961	Land-o-Lakes
Alice	41	85	19	0.4	1	28.13222	−82.6039	Keystone Lakes
Carroll	35	85	23	0.5	1	28.05111	−82.4875	Land-o-Lakes
George	33	63	31	0.5	4	28.06861	−82.4872	Land-o-Lakes
Mound	32	69	20	0.5	3	28.1475	−82.5719	Keystone Lakes
Eckles	27	71	30	1.3	5	28.05528	−82.4719	Land-o-Lakes
Reinheimer	25	77	12	1.2	4	28.13	−82.4867	Land-o-Lakes
Raleigh	23	67	3	0.6	7	28.10583	−82.5839	Keystone Lakes

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