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ABSTRACT: *A Pearson correlation analysis was conducted on a database containing eight limnological variables of 34 lakes located in northwestern Hillsborough County. Lake water concentrations of total phosphorus (TP), total nitrogen (TN), and chlorophyll-α; submerged aquatic vegetation (SAV) as measured by percentage of area covered with vegetation (PAC) and percentage of volume infested with vegetation (PVI); and mean depth, lake surface area, and lake volume were examined. The purpose of this study was to examine the theory by Bachmann and co-workers (2002) that SAV may reduce nutrients in the water column.*

The stronger statistically significant inverse correlations were found between chlorophyll-α and SAV as represented by PVI and PAC ($r = -0.45$ and -0.41, respectively), and between lake water TP and PAC and PVI ($r = -0.49$ and -0.35, respectively). Weaker but also significant were the inverse correlations found between TP and mean depth ($r = -0.33$) as well as that between TN and PAC ($r = -0.31$). Statistically significant direct correlations were found between chlorophyll-α and TN and TP ($r = 0.38$ and 0.32, respectively), and weaker but still significant, between mean depth and PVI and PAC ($r = 0.31$ and 0.30, respectively). In conclusion the examined theory is supported.

Key Words: Submerged aquatic vegetation, eutrophication, indicators, parameters

AQUATIC vegetation can contain an important proportion of the total nutrient content of a lake, and should be considered when assessing the potential concentration of nutrients in the lake water column (Canfield et al., 1983). Aquatic vegetation and especially submerged aquatic vegetation (SAV) may act to reduce nutrient concentrations in the water column of shallow lakes (Bachmann et al., 2002; Dierberg et al., 2002).

Canfield and co-workers (1984) and Brown and co-workers (2000) have documented for Florida lakes a strong positive association between phytoplankton as measured by chlorophyll-α and dissolved nutrients. A negative association between SAV and phytoplankton productivity, however, is less clear (Landers, 1982; Canfield et al., 1984; Canfield and Hoyer, 1992). This study looks at the correlations between trophic state variables, SAV, and lake size in a group of 34 northwestern Hillsborough County lakes. The study database contains information on eight limnological variables: (1) SAV variables: percentage of area covered with vegetation (PAC) and percentage of

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volume infested with vegetation (PVI); (2) trophic state variables: lake water concentrations of TP, TN, and chlorophyll-α; and (3) lake size variables: area, depth, and volume. Correlations between variables are examined and discussed with results from previous studies.

METHODS—*Data sampling program*—The 34 urban and suburban lakes examined are located in an area with mixed land use: residential, recreational, and agricultural, in the northern and western portions of Hillsborough County (Table 1). The lakes are located within the Tampa Bay watershed and distributed over three lake regions according to the classification system of Griffith and co-workers (1997): Keystone Lakes, Land-o-Lakes, and Tampa Plain. Data for trophic state and SAV variables were collected by biologists of the Florida Center for Community Design and Research at the University of South Florida (Koenig and Eilers, 2007) and made available through the Water Atlas (2008). Data availability was the determining factor for inclusion of the 34 lakes in this analysis.

Concentrations of water column TP, TN, and chlorophyll-α were estimated from a single mid-lake sample collected on the same day as measurements were made for lake vegetation coverage. Samples taken to determine TP, TN, and chlorophyll-α 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, and following QA/QC guidelines from both methodologies and all NELAP QA/QC rules. TP was determined by EPA 365.4. TN was the sum of Total Kjeldahl Nitrogen (TKN) and nitrate/nitrite nitrogen, where Total Kjeldahl Nitrogen (TKN) was determined by EPA 351.2 and nitrate/nitrite nitrogen by SM 4500 NO3 F (Clesceri et al., 1998). Chlorophyll-α was determined by SM 10200 H (Clesceri et al., 1998).

On a single visit to a lake, PAC and PVI were determined by boat-mounted fathometer measurements at 100 randomly-ordered lake bathymetric points (Griffin, 2007). The fathometer used was a Lowrance LCX-28CHD with dual frequency 200 kHz/50 kHz. PAC was calculated from soft return fathometer data and PVI was calculated as shown in Eqn (1) by measuring the depth of the soft returns (top of vegetation) and the depth of the hard returns (lake bottom) at each bathymetric point. For points where no vegetation existed, the numerator was zero and that point was counted as zero. About 10 points per lake were verified by direct observations made by divers.

$$\frac{\sum_{0}^{100}\left(\frac{(Lake\ Depth - Depth\ of\ \ Vegetation)}{Lake\ Depth}\right)}{100} = \mathrm{PVI} \tag{1}$$

Additional information for the lake physical parameters (lake size): lake surface area, mean depth, and lake volume were available through the Water Atlas (2008).

Statistical analysis—A Kolmogorov-Smirnov test at the 95% confidence level was conducted with SAS 9.2 to test for normality. Variables that were not normally distributed (PAC, TP, TN, and depth) were log transformed. Analyses of Pearson product moment correlation coefficients were used to determine significant associations between the trophic state indicators lake water TP, TN, and chlorophyll-α concentration and indicators of SAV, lake area, depth, and volume. This analysis was conducted using EXCEL Statistical package, version 2003.

RESULTS—Summary statistics for physical and chemical variables analyzed in this study are presented in Table 2. The lakes had an average mean depth of 2.5 m, ranging from 0.9 to 4 m. Scheffer (2004) defined a shallow lake as a lake with a depth of 3 m or less. Lake surface area ranged from 1.2 to 174.4 ha with a mean of 25.4 ha. The average volume was 713,300 m^3 with a minimum of 2,087 and maximum of 5,714,000 m^3.

TABLE 1. Limnological variables and location of lakes examined in this study.

Lake	PAC	PVI	TP µg/L	TN µg/L	Chl. µg/L	Area Hs	Depth m	Volume m^3	Latitude	Longitude	Lake region
Alice	85	41	19	370	1	37.2	2.7	941847	28.1322	−82.6039	Keystone Lakes
Carroll	85	35	23	450	1	81.7	2.4	2044183	28.0511	−82.4875	Land-o-Lakes
Reinheimer	77	25	12	600	4	8.1	1.8	236600	28.1300	−82.4867	Land-o-Lakes
White Trout	77	44	14	1196	3	30.4	3.4	1011391	28.0392	−82.4961	Land-o-Lakes
Magdalene	76	47	14	1070	4	83.4	2.4	2385713	28.1319	−82.4819	Land-o-Lakes
Eckles	71	27	30	1268	5	11.3	2.1	256854	28.0553	−82.4719	Land-o-Lakes
Mound	69	32	20	520	3	30.4	4.0	1280673	28.1475	−82.5719	Keystone Lakes
Raleigh	67	23	3	602	7	9.7	2.7	378654	28.1058	−82.5839	Keystone Lakes
George	63	33	31	500	4	10.9	3.7	378654	28.0686	−82.4872	Land-o-Lakes
Cypress	56	16	10	542	4	6.5	3.7	225021	28.1256	−82.5644	Keystone Lakes
Round	56	17	21	450	4	4	2.7	99847	28.1206	−82.5000	Land-o-Lakes
Horse	46	19	21	889	4	10.9	2.1	146282	28.1106	−82.5789	Keystone Lakes
Rogers	44	13	17	950	14	38	2.4	746805	28.1089	−82.5886	Keystone Lakes
Pine	44	18	40	987	9	3.2	2.4	555292	28.0606	−82.4722	Land-o-Lakes
Noreast	40	14	27	718	10	3.2	1.5	87071	28.0625	−82.4686	Land-o-Lakes
Calm	39	9	22	410	4	46.5	3.4	1477849	28.1422	−82.5817	Keystone Lakes
Island Ford	38	12	25	870	9	36	3.0	1131957	28.1522	−82.5989	Keystone Lakes
Keystone	38	12	25	1130	4	174.4	3.4	5714176	28.1331	−82.5900	Keystone Lakes
Crescent	35	10	35	940	45	18.2	2.7	553353	28.1581	−82.5919	Keystone Lakes
Dead Lady	34	13	50	937	7	1.2	0.9	2087	28.1550	−82.5706	Keystone Lakes
Elizabeth	30	10	24	860	6	7.7	3.7	272512	28.1572	−82.5733	Keystone Lakes
Taylor	30	13	12	640	6	19	2.7	543649	28.1367	−82.6119	Keystone Lakes
Rainbow	26	9	10	770	8	19	2.7	544936	28.1167	−82.5961	Keystone Lakes
Juanita	21	10	10	989	11	9.7	2.7	246887	28.1175	−82.5889	Keystone Lakes
Crenshaw	20	8	22	833	11	12.1	1.5	42304	28.12583	−82.4958	Land-o-Lakes
Church	15	5	26	519	6	25.1	1.2	138039	28.10306	−82.5994	Keystone Lakes
Cedar East	8	5	33	611	7	1.2	1.5	33639	28.06556	−82.4703	Land-o-Lakes
Armistead	7	12	45	1090	21	13.8	2.7	347739	28.10111	−82.5597	Tampa Plain

TABLE 1. Continued.

Lake	PAC	PVI	TP µg/L	TN µg/L	Chl. µg/L	Area Hs	Depth m	Volume m^3	Latitude	Longitude	Lake region
Rock	6	4	35	910	22	21.4	2.1	431011	28.11333	−82.5567	Tampa Plain
Brant	5	1	35	927	9	22.3	1.8	18916	28.12639	−82.4722	Land-o-Lakes
Saddleback	3	9	27	1079	11	12.5	1.5	226065	28.12028	−82.4947	Land-o-Lakes
Cedar West	3	2	41	780	17	2.0	1.8	18916	28.06528	−82.4725	Land-o-Lakes
Pretty	2	1	33	950	12	32.8	3.4	1068395	28.1075	−82.5678	Tampa Plain
Josephine	2	1	44	850	12	20.2	2.1	422013	28.10972	−82.5619	Tampa Plain

TABLE 2. Summary statistics of limnological variables for 34 northwestern Hillsborough lakes.

	N	Median	Mean	SD	Minimum	Maximum
PAC (%)	34	38	39	27	2.0	85
PVI (%)	34	13	16	13	0.5	47
Volume (m^3)	34	381700	713300	1050000	2087	5714000
Area (ha)	34	16.0	25.4	32.8	1.20	174
Mean Depth (m)	34	2.6	2.5	0.8	0.9	4.0
TN ($\mu g\ L^{-1}$)	34	855	800	244	370	1270
TP ($\mu g\ L^{-1}$)	34	24.5	25.2	11.4	3.00	50.0
Chlorophyll-α ($\mu g\ L^{-1}$)	34	6.6	9.0	8.1	1.2	45

According to the Trophic State Classification System of Forsberg and Ryding (1980), the lakes ranged from oligotrophic to eutrophic based on TP concentrations. Mean values were 24.5 $\mu g\ L^{-1}$, 800 $\mu g\ L^{-1}$, and 9 $\mu g\ L^{-1}$ for TP, TN, and chlorophyll-α concentrations, respectively. Ranges for these concentrations were: 3 to 50 $\mu g\ L^{-1}$ for TP, 370 to 1268 $\mu g\ L^{-1}$ for TN, and 1.2 to 45 $\mu g\ L^{-1}$ for chlorophyll-α. The average PAC was 39%, with a minimum and maximum of 2 and 85%, respectively. On average, PVI was 16% and ranged between 0.5 and 47% (Table 2).

Correlations (r) greater than $|\pm 0.30|$ were statistically significant at a 95% of confidence level ($p \leq 0.05$). We found a significant inverse correlation between chlorophyll-α and both measures of SAV: PAC and PVI, with $r = -0.41$ and -0.45, respectively. Chlorophyll-α was positively correlated with TN, $r = 0.38$; and TP, $r = 0.32$. TP was inversely correlated with both forms of SAV, $r = -0.49$ and -0.35 for PAC and PVI, respectively, and additionally with mean depth, $r = -0.33$. TN was inversely correlated with PAC, $r = -0.31$.

Mean depth was weakly but significantly correlated with both forms of SAV: PAC and PVI, with r = 0.30 and 0.31, respectively. As anticipated, mean depth was correlated with lake volume, $r = 0.38$. There was a strong correlation, $r = 0.98$, between surface area and lake volume as was expected for a shallow lake, but both indicators had insignificant correlations with the rest of variables examined that were not size indicators. Since PAC and PVI are both expressions of the same variable, SAV, they were consequently highly correlated, $r = 0.75$. Non-significant relationships are not mentioned.

DISCUSSION—The stronger negative correlation found between chlorophyll-α and both measures of SAV (PAC and PVI) as compared with the weaker positive correlation between chlorophyll-α and TP and TN may suggest that SAV rather than TP and TN might be the factor most associated with phytoplankton productivity. If this is the case, this result suggests that SAV may be associated with chlorophyll-α also through some other additional way not involving TP and TN.

Mechanisms by which SAV reduces nutrient concentrations (and indirectly chlorophyll-α concentrations) in lake water include (1) up-take of nutrients from the water column by SAV (Denny, 1972; Graneli and Solander, 1988); (2) by attenuating water turbulence, which results in less re-suspension and recycling of nutrients back into the water column (Hamilton and Mitchell, 1996; Bachmann et al., 2004; Scheffer, 2004); (3) by providing substrate surface for periphyton that up-take nutrients from the water column (Cattaneo and Kalff, 1980; Bachmann et al., 2004); and (4) by influencing ion exchange reactions via regulation of dissolved oxygen and pH (Graneli and Solander, 1988). Additionally, SAV may affect phytoplankton directly by sheltering from predatory fish the zooplankton that graze on phytoplankton (Scheffer, 2004).

Unlike findings from this study, Bachmann and co-workers (2002) reported for a much larger group of Florida lakes a weaker negative correlation between chlorophyll-α and SAV ($r = -0.29$) as compared to those between chlorophyll-α and TP ($r = 0.82$), and chlorophyll-α and TN ($r = 0.70$). Other authors also reported a strong association between chlorophyll-α and TP and TN (Canfield et al., 1984; Brown et al., 2000). The results of this study support the theory of Bachmann and co-workers (2002) that when SAV is present at some level, SAV may reduce nutrients in the water column and consequently may reduce phytoplankton productivity as measured by chlorophyll-α.

The inverse correlation between TP and mean depth may be due to the greater distance between the source of re-suspended organic matter in the bottom sediments and the superior layers of the water column. For deeper lakes, stronger turbulence would be required to re-suspend phosphorus through the entire water column (Bachmann et al., 2000). The positive correlation found between depth and both forms of SAV may seem to be unexpected since light penetration is reduced with depth (Hemminga and Duarte, 2000); however, considering that all the lakes studied were shallow, light penetration may not be an issue for photosynthesis on SAV. In fact, shallower depths might favor dominance of emergent aquatic vegetation over SAV, allowing deeper depths to favor SAV as long as the depth does not exceed that of light penetration.

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