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Effects of pH and specific conductance confound the use of the Florida Lake Vegetation Index to identify anthropogenic eutrophication

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Abstract

We found that the Florida Lake Vegetation Index (LVI) did not identify Florida lakes that were impaired due to excess loading of phosphorus or nitrogen from anthropogenic sources. The index is based on 4 plant metrics: the Coefficient of Conservatism of the dominant or co-dominant taxa, the percent of sensitive taxa, the percent of native taxa, and the percent of invasive exotic taxa. Our analysis of the data used by the Florida Department of Environmental Protection to establish and calibrate this biotic index found no link between nutrient concentrations and the LVI. The LVI was primarily associated with the pH and specific conductance of the lake waters, with the best scores found in acidic lakes and the poorest scores in more alkaline lakes. These variables are the result of natural gradients, not pollution, and are not included in the calculation of the LVI. Our study illustrates the importance of considering natural factors that determine the value of any index of biological integrity before it is used to indicate anthropogenic pollution.

Key words: biotic index, biotic integrity, eutrophication, Florida, lake vegetation index, macrophytes

Introduction

Since Karr (1981) proposed the use of a fish index of biological integrity as a means of determining if streams met the biological requirements of the US Clean Water Act, the US Environmental Protection Agency (USEPA) and other governmental agencies have emphasized the development of biotic indices to assess lakes and streams (USEPA 1998, Bailey et al. 2004). As a part of this effort, the Florida Department of Environmental Protection (FDEP), in collaboration with the USEPA, developed the Lake Vegetation Index (LVI; range 0–100) for Florida lakes based on the species composition of aquatic and wetland plants in freshwater lakes (Fore et al. 2007, FDEP 2011a, 2011b, 2011c). The LVI is currently being used by the FDEP to identify Florida lakes that have been subjected to increases in total phosphorus (TP) and total nitrogen (TN) due to anthropogenic loadings of these nutrients. Lakes with LVI scores <43 can be placed on a list of lakes (Verified Lakes) that need regulation of phosphorus and nitrogen inputs (Florida Administrative Code, Chapters 62-302 and 62-303).

To our knowledge, this is the first study to use a macrophyte index to identify lakes subject to cultural eutrophication, although others have explored the use of such indices. Nichols et al. (2000) proposed an aquatic plant community biotic index for Wisconsin lakes, and Rothrock et al. (2008) proposed a plant index of biotic integrity for lacustrine wetlands in northwest Indiana, but neither of these indices was directly related to the anthropogenic loading of plant nutrients. Likewise, Beck et al. (2010) discussed the development of a macrophyte-based index of biotic integrity for Minnesota lakes. While their biotic index was highly correlated ($R^2 = 0.57$) with the Carlson trophic state index (Carlson 1977), this does not prove an anthropogenic cause because Minnesota lakes demonstrate a large natural range in their trophic states (Heiskary and Wilson 2008). Mikulyuk et al. (2011)

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examined the relative roles of environmental, spatial, and land-use patterns in explaining the community composition of macrophytes in Wisconsin lakes. They found that land use alone accounted for only 0.4% of the variance in community structure. Even when they also considered the joint effects of land use with spatial and environmental factors, only an additional 9.8% of the variance was explained.

We initiated a study of the LVI because previous research on Florida lakes has shown that their macrophyte communities are relatively insensitive to the concentrations of TP and TN in the water (Bachmann et al. 2002), and the LVI has never been independently verified by publication in the peer-reviewed literature. Our objective was to test the hypothesis that the LVI identifies Florida lakes that have been impaired by anthropogenic nutrient loading. Verification of this hypothesis is critical because of the potential legal consequences now that the LVI is established in the Florida Administrative Code. Because there are no data on anthropogenic nutrient loading to the study lakes, we looked for correlations between the LVI and the concentrations of nutrients and other chemical variables in the water as well as a measure of land use around the study lakes used in the development of the index.

Methods

Florida lakes

Florida has about 7700 lakes with surface areas of 4 ha or more. Most are shallow (<5 m), and about 70% of the lakes have no surface inlets or outlets. Florida has a complex geology and physiogeography that significantly influences lake water chemistries (Canfield 1983, Canfield and Hoyer 1988), with some lakes in sandy uplands having waters with low values for pH, alkalinity, and dissolved solids. Other lakes are fed by groundwaters in contact with limestone and have waters with high values for pH, alkalinity, and dissolved solids (Baker et al. 1988, Canfield and Hoyer 1988, Griffith et al. 1997). In some lakes, groundwater inflows are in contact with deposits of phosphatic rocks, resulting in high TP concentrations (Bachmann et al. 2012). The natural trophic states of Florida lakes range from oligotrophic to hypereutrophic, with a broad range of chemical compositions (Canfield and Hoyer 1988, Griffith et al. 1997, Bachmann et al. 2012).

Calculation of the Lake Vegetation Index

The LVI is based on a structured survey of the submersed, floating, and emergent macrophyte species as well as trees and shrubs that occur up to the seasonal high water level in a Florida lake (FDEP 2011c). The calculation of the index is based on 4 plant metrics: the Coefficient of Conservatism (C of C) of the dominant or co-dominant taxa, the percent of native taxa, the percent of sensitive taxa, and the percent of invasive exotic taxa. The C of C for a plant species is a number between 0 and 10 that indicates the breadth of a taxon's ecological niche, as determined by a panel of expert botanists familiar with the Florida flora (FDEP 2011a). Exotic and ubiquitous weedy native taxa have low C of C scores, and taxa that display a fidelity to a particular community and are sensitive to disturbance have high C of C scores. The sensitive taxa, those with a C of C score ≥7, are considered to be typical of well-established communities that have sustained only minor disturbances. The native taxa are those whose natural range includes Florida. The exotic taxa are listed by the Florida Exotic Pest Plant Council as Category I invasive plants (FLEPPC 2011), exotics that are altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives. Specific details on the calculation of the LVI are given in FDEP (2011c).

Equation 1 represents the calculation of the LVI in the northern parts of Florida:

$$\mathrm{LVI}_{\mathrm{north}} = \frac{25(\mathrm{N}-62.5)}{37.5} + 25(1-\frac{\mathrm{I}}{30}) + \frac{25\mathrm{S}}{27.78} + \frac{25\mathrm{C}}{7.91}, \quad (1)$$

where $\mathrm{LVI}_{\mathrm{north}}$ is the LVI for lakes in the northern part of Florida, N is the % native taxa, I is the % invasive taxa, S is the % sensitive taxa, and C is the C of C for the dominant taxa.

Equation 2 represents the calculation of the LVI for lakes in the southern parts of Florida:

$$\mathrm{LVI}_{\mathrm{south}} = \frac{25(\mathrm{N}-66.67)}{25.89} + 25(1-\frac{\mathrm{I}}{30}) + \frac{25\mathrm{S}}{20} + \frac{25\mathrm{C}}{7}, \quad (2)$$

where $\mathrm{LVI}_{\mathrm{south}}$ is the LVI for lakes in the southern part of Florida.

Each of the 4 metrics individually accounts for 25% of the LVI score, which can range from 0 to 100. An LVI score of <43 indicates a lake that has been subjected to anthropogenic nutrient pollution (FDEP 2011a).

Examination of the factors related to the Lake Vegetation Index

In our examination of the LVI, we searched for possible relationships between the LVI and both water chemistry and possible anthropogenic stresses using 3 datasets used by the FDEP to develop the LVI (Fore et al. 2007). The first dataset, which we term the developmental dataset, consists of measurements of the LVI and water quality in

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131 lakes used by Fore et al. (2007) in developing the LVI. The second set consists of 20 lakes selected by the FDEP to represent lakes that are as close to natural conditions as they might find in Florida (FDEP 2009). While the FDEP termed these as benchmark lakes, we refer to them as reference lakes because of the way they were chosen and used. The cumulative frequency distributions of LVI values in those lakes were used to determine what scores represented nutrient impaired lakes (FDEP 2011a). The third set of 30 lakes, which we term the calibration set, was selected by the FDEP from the developmental dataset to have a gradient of LVI scores in steps of about 3 units and a range from 13 to 91 (Fore et al. 2007). These data were also used by the FDEP to determine the critical LVI score.

The FDEP provided us with the basic data. Most lakes were sampled between 2005 and 2010. In some cases lakes were sampled more than once, and we used an average value for the repeated samples. Where water quality data were incomplete on the study lakes, we used supplemental data from the USEPA STORET database (USEPA 2012) as well as data collected by the Florida LAKEWATCH program (Canfield et al. 2002). In these cases we used annual averages rather than single samples where available. In our statistical analyses, we used the common logarithms of specific conductance values and of the concentrations of TP and TN. We used total Kjeldahl nitrogen (TKN) as an approximation of TN with the developmental data because many samples did not have a measure of nitrates and/or ammonium. For those that did, the average TKN value was 94% of the TN concentration. For a quantitative measure of human disturbance, we used the values for the Landscape Development Intensity index as calculated by the FDEP for each lake. This is a Geographic Information System-based measurement of human activities within 100 m of the shoreline of a lake and was developed for watersheds of wetlands in Florida (Brown and Vilas 2005).

A probability of 0.05 was used to identify statistical significance, and the coefficient of determination (R^2) was used to show the strength of relationships. For multiple tests with the same dataset, a Bonferroni correction to the threshold probability was made (Rice 1989). In each case we obtained the same answer with or without the correction. We used stepwise multiple regressions to examine the factors related to the LVI in the developmental and reference lake datasets with probability levels of 0.25 and 0.10 for inclusion and exclusion, respectively. A probability of 0.05 was used to identify independent variables related to the LVI.

None of the datasets had information on whether the lakes had changed their trophic states due to cultural eutrophication, so our analyses of the developmental dataset (131 lakes) examined how the water quality variables pH, TP, TKN, and specific conductance as well as the Landscape Development Intensity index might be related to the LVI. Similar analyses were made on data from the 20 reference lakes used to determine the LVI score that would separate nutrient impaired from nutrient unimpaired lakes. In that case we used a t-test to compare the distribution of pH in the reference lakes with the statewide distribution of pH in 1060 Florida lakes reported by Lazzarino et al. (2009). For the 30 calibration lakes, we compared the 11 lakes with LVI scores that would place them in the impaired category with the 19 lakes that were not impaired according the LVI scores. We used t-tests to compare mean values for the Landscape Development Intensity index, pH, specific conductance, TKN, and TP.

Results

The development lakes

For the 131 lakes in the developmental dataset we found that pH explained the greatest amount of the variance in the LVI (Table 1), followed by the specific conductance and the Landscape Development Intensity index (Fig. 1). The concentrations of TP and TKN only explained a small amount of the variance in the LVI (Fig. 2). We also found that pH was related to both the specific conductance and the Landscape Development Intensity index, and that there was no relationship between the concentrations of TP and TKN and the Landscape Development Intensity index. The effect of pH was evident for each of the 4 components of the LVI, with significant negative relationships between the LVI and the C of C of the dominant taxa, the percent of sensitive taxa, and the percent of native taxa, and a positive relationship with the percent of invasive taxa (Fig. 1).

Using stepwise multiple regressions, we found the R^2 value for LVI and pH ($R^2 = 0.33$) increased to 0.40 when specific conductance was added. Next, addition of the Landscape Development Intensity index raised the R^2 value to 0.44, and then to 0.48 as the TP concentration was added.

Reference lakes

For the 20 reference lakes, pH again showed the closest relationship to the LVI (Fig. 3A) followed by TP, specific conductance and TN (Table 2). In the multiple regression, pH accounted for 68% of the variance in the LVI; none of the other variables produced a significant reduction in the R^2 value when added to pH. The test comparing the distribution of pH in the 20 reference lakes with a large sample of Florida lakes showed a statistically significant difference ($\rho < 0.001$) between the average pH of the reference lakes (6.01) and that of the large sample of Florida lakes (7.01). The reference lakes tended to be more acidic than the average Florida lakes (Fig. 3B).

Table 1. The R² values for the relationships among the LVI and pH, specific conductance (Sp Cond), Landscape Development Intensity index (LDI), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) in 131 lakes used to develop the LVI. All relationships with the LVI are negative, and all relationships among the other variables are positive. Correlations between the LDI index and nutrients TP and TKN are not statistically significant ($p > 0.05$), while all the other paired relationships are significant.

	LVI	pH	Sp Cond	LDI	TKN
pH	0.34				
Sp Cond	0.29	0.29			
LDI	0.29	0.31	0.17		
TKN	0.06	0.10	0.12	0.00	
TP	0.12	0.06	0.06	0.00	0.35

Table 2. The R² values for the relationships among the LVI and pH, specific conductance (Sp Cond), Landscape Development Intensity index (LDI), total nitrogen (TN), and total phosphorus (TP) in the 20 reference lakes used to calibrate the LVI. All relationships with the LVI are negative, and all relationships among the other variables are positive. Correlations between the LDI index and the LVI, TP, TN, and specific conductance are not statistically significant ($p > 0.05$), while all the other paired relationships are significant.

	LVI	pH	TP	Sp Cond	TN
pH	0.68				
TP	0.46	0.37			
Sp Cond	0.43	0.42	0.57		
TN	0.43	0.54	0.77	0.39	
LDI	0.00	0.11	0.04	0.00	0.03

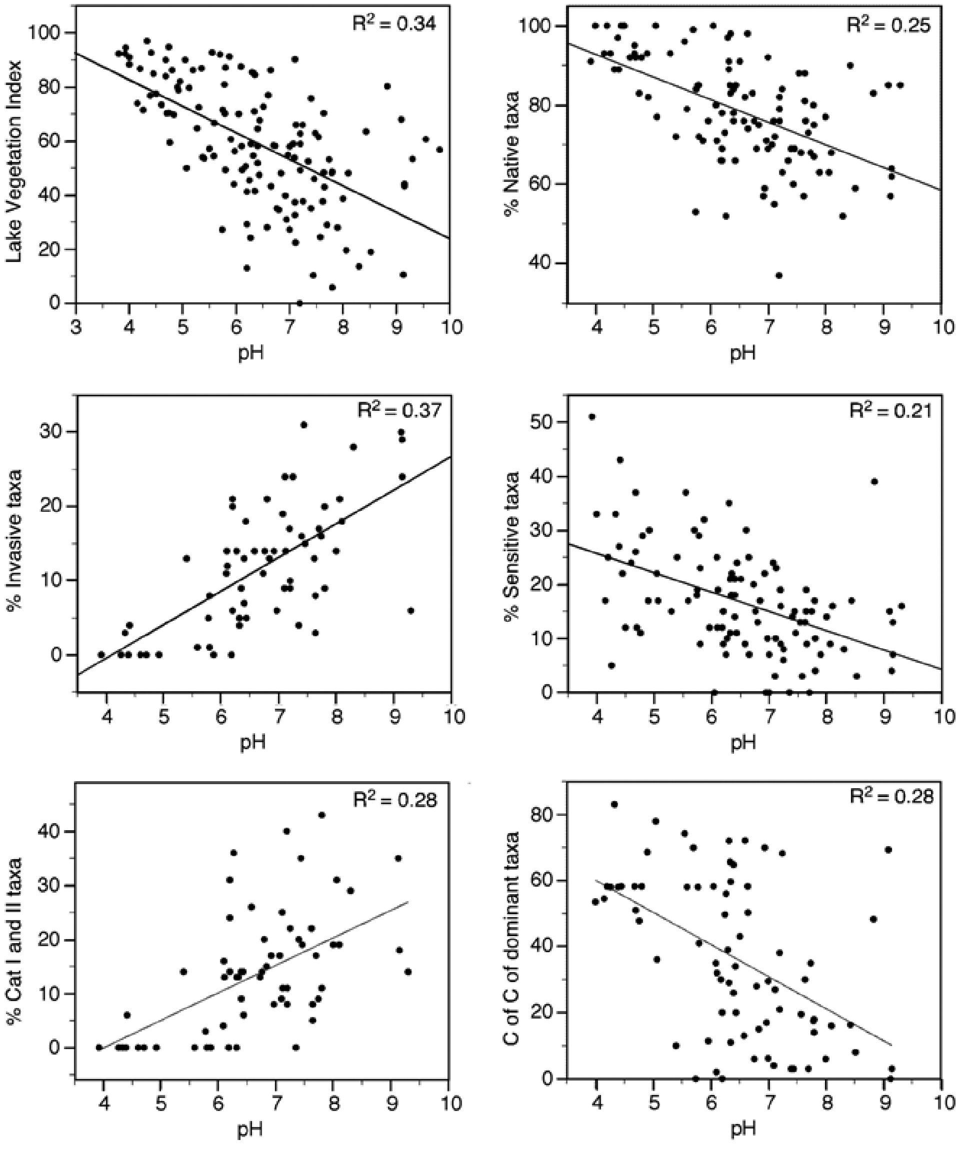

Fig. 1. Plots of the Lake Vegetation Index and several plant metrics vs. pH for the 131 lakes in the developmental dataset.

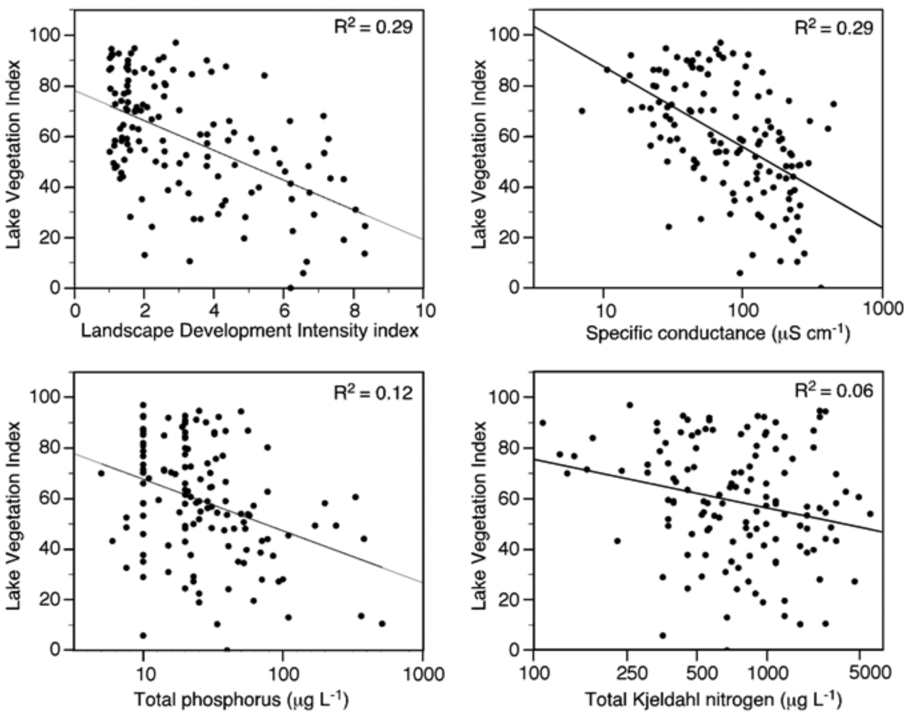

Fig. 2. Plots of the Lake Vegetation Index vs. the Landscape Development Intensity index, specific conductance, total phosphorus, and total Kjeldahl nitrogen for 131 Florida lakes.

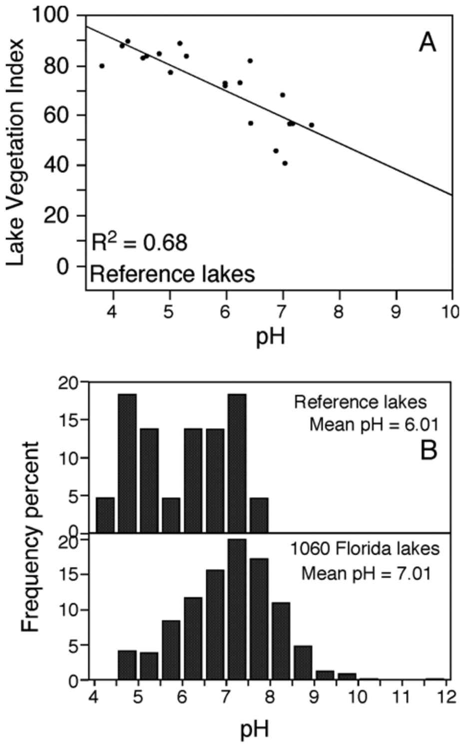

Fig. 3. A. The Lake Vegetation Index vs. pH in the 20 lakes in the reference dataset. B. Frequency distributions of pH in the 20 reference lakes and in a large statewide sample of Florida lakes from a study by Lazzarino et al. (2009).

Calibration lakes

Based on the scores of the 30 calibration lakes, 11 would be classified as nutrient impaired lakes and 19 would be classified as nonimpaired lakes. In our t-tests comparing the mean values for the Landscape Development Intensity index, pH, specific conductance, TN, and TP, only the specific conductance showed a statistically significant difference ($\rho = 0.005$) between the impaired and the nonimpaired lakes; the impaired lakes had a higher level of specific conductance than the nonimpaired lakes. These results showed no relationship between the LVI score of the lakes and measures of plant nutrients or human development in their watersheds.

Discussion

Our results did not demonstrate a reliable relationship between the Florida Lake Vegetation Index and the concentrations of phosphorus and/or nitrogen in Florida lakes. Our statistical analyses of the available data found that pH was the dominant variable associated with the LVI, with specific conductance also having a significant correlation. Lakes with lower values for pH and specific conductance had the highest LVI scores and would be considered the "healthiest," while those with the highest pH values tend to have the lowest LVI scores and would be declared impaired. Both pH and specific conductance are determined primarily by natural factors like the soils, geology, climate, and hydrology of the location where a lake is located and ordinarily are not significantly changed by anthropogenic activities. The trophic state variables TP and TN accounted for only a small portion of the variance in the LVI. While these plant nutrients can be increased by anthropogenic activities, Florida lakes have a broad range in their concentrations of TP and TN based on natural factors (Bachmann et al. 2012) such that a high nutrient concentration in itself is not sufficient to label a Florida lake as impaired by accelerated cultural eutrophication.

In the LVI developmental dataset, there was a significant relationship between the LVI and the Landscape Development Intensity index ($R^2 = 0.29$), possibly indicating that development around a lake would result in impairment with nutrients. There are 2 problems with this assumption, however. First, Fore et al. (2007) found no statistically significant correlation between water quality and the Landscape Development Intensity index in their sample of Florida lakes. Bachmann et al. (2012) also found that for a large sample of Florida lakes, the Landscape Development Intensity index was not correlated with the concentrations of TP and TN, and it only explained about 2% of the variance in chlorophyll *a* concentrations. Second, there is also a significant correlation between the pH and the Landscape Development Intensity index of individual lakes ($R^2 = 0.31$). This raises the basic question, does the development raise a lake's pH, or is there something about the geographic setting of acidic lakes that makes the surrounding lands less suitable for human development?

FDEP's use of the reference lake data removes the confounding relationship between pH and the Landscape Development Intensity index. These lakes have no or little development, but the LVI still has a strong correlation with pH. A previous study by Lazzarino et al. (2009) showed that pH has a broad range in Florida lakes under natural conditions.

Use of reference lakes

In their book on the bioassessment of freshwater ecosystems, Bailey et al. (2004) advocated that a group of unaltered reference lakes should first be used to identify which natural factors determine the distribution and abundance of the test organisms being used for a bioassessment. Predictive models would then be developed to determine what the expected species composition might be based on these models. The next step would be to compare the distribution of the organisms in a test location with that expected based on the models. If the difference between the expected and the observed values exceeded some threshold, then there would be reason to suspect anthropogenic impairment. Likewise, Irz et al. (2008) found that it was essential to control for natural variability in constructing fish-based indices of biotic integrity for lakes in the northeastern United States. For the LVI, it would be logical to first use the reference lakes to develop quantitative relationships between primarily natural factors such as pH and specific conductance with the LVI. Those relationships could then be used to determine the expected LVI score in a test lake with a given set of pH and specific conductance values. A comparison of expected and actual values could then be used as a basis for determining if there are anthropogenic factors influencing the LVI.

The reference lake approach (FDEP 2011a) used to set an LVI score of 43 as the minimum score for a nonimpaired lake did not take into consideration natural factors that were important in determining the value of the index. For example, the pH values in the group of 20 reference lakes used as reference lakes were not representative of the population of Florida lakes being examined by this index. The reference lakes on average had a lower pH than Florida lakes as a whole and did not cover the range of pH values that we might expect in Florida lakes (Fig. 3). Because pH was the dominant variable associated with the LVI scores in Florida lakes, one might expect that had the reference lakes included the full range of pH values in Florida lakes, several reference lakes would have LVI scores below 43 and the resultant threshold score would be different.

Exotic and invasive plants

Half of the LVI score is based on the presence of nonnative and exotic invasive plants. Florida has had a major problem with nonnative and exotic invasive plants since early introductions of water hyacinth (*Eichhornia crassipes*) in the 1800s (Gallagher and Haller 1990), and the list now includes plants like hydrilla (*Hydrilla verticillata*) and water lettuce (*Pistia stratiotes*; Hoyer et al. 1996). Millions of dollars are spent each year using chemical, mechanical, and biological control methods; however, nutrient control is not used for the control of invasive plants. Capers et al. (2009) also found the species richness of invasive plants in Connecticut lakes was not correlated with nutrient levels.

Role of nonnutrient factors for aquatic macrophytes

The use of the LVI as an indicator of nutrient pollution does not consider other factors that can influence the aquatic macrophyte communities of lakes, such as natural variation in the distribution of water chemistry values. Aquatic botanists have long known that pH can influence

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the distribution of aquatic plants. In his classic study of the aquatic plants of Minnesota, Moyle (1945) found that each plant species had its own pH preference, and he set up a plant classification based on the preferred pH and alkalinity for each species. Moyle (1945) pointed out that Iversen (1929) had previously shown that the distribution of aquatic plants in Danish lakes could be related to the pH of their waters. More recently, Vestergaard and Sand-Jensen (2000) found that the species compositions of macrophytes in Danish lakes were related to pH. Hoyer et al. (1996), in their study of Florida freshwater plants, surveyed the aquatic plants of more than 322 Florida lakes and noted that each species had its own range of preferred chemical conditions, including pH. These findings were in agreement with Beal (1977), who made extensive surveys of North Carolina lakes and found that the distributions of many species of aquatic plants coincided with the distributions of pH and other chemical factors. Capers et al. (2009) found the species richness of invasive plants in Connecticut lakes was most highly correlated with pH and alkalinity, with the highest richness of invasive plants in more alkaline lakes; species richness of native plants was greatest in the more acidic lakes.

The pH of lakes is generally determined by the chemical composition (balance between acidic and basic ions) of the inflows from precipitation, groundwater, and surface inlets and is closely related to the surrounding geology and soils (Stumm and Morgan 1995). In the Florida lake regions study (Griffith et al. 1997), pH differed from one lake region to another. The tendency was for lake regions in the southeast part of Florida to have higher pH values than those in the northwest regions, but there was considerable variation at the same latitude as well.

Climatic- and weather-related variables affecting macrophytes that are not related to anthropogenic nutrient loading would include periods of drought and flooding. Increases in precipitation can increase loads of humic materials from swampy areas around Florida lakes and significantly reduce water transparency, which can negatively impact submersed plant communities (Bachmann et al. 2002).

Lowered water levels during droughts can dry out littoral areas in some Florida lakes while flooding of previously dry areas during floods can likewise influence plant communities, and hence the LVI values.

Anthropogenic activities not related to nutrient pollution that can affect the LVI include planting of macrophytes in lakes as a part of lake restoration activities and the introduction of exotic plants either intentionally or accidentally. Several lake management activities on Florida lakes that can influence the LVI include sediment removal by dredging or bottom scraping, and perhaps more important, aquatic plant control activities such as water level fluctuations, herbicide use, mechanical harvesting of plants, and the addition of herbivorous fish. These factors also must be considered when explaining differences in LVI scores.

General conclusions

Our study found no basis for using the LVI to identify Florida lakes as being impacted by anthropogenic sources of nutrients because the effects of pH and specific conductance were not taken into account. Our findings also illustrate the importance of considering natural factors that determine the value of any index of biological integrity before it is used as a regulatory tool to indicate anthropogenic pollution.

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