AN EVALUATION:
THE FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION'S LAKE VEGETATION INDEX (LVI)

By

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
APHA	American Public Health Association
$CaCO_3$	calcium carbonate
chl	chlorophyll concentration (µg/L)
CV	coefficient of variation
D	Simpson's Diversity Index
FDEP	Florida Department of Environmental Protection
FFWCC	Florida Fish and Wildlife Conservation Commission
GPS	global positioning system
IBI	Indices of Biological Integrity
LAKEWATCH	Florida LAKEWATCH
LVI	Lake Vegetation Index
m	meters
mL	milliliters
mm	millimeters
m^2	meters squared
PLEX	Plant Lake Ecotype Index
PtCo	platinum-cobalt units
r	correlation coefficient
R^2	coefficient of determination
s	number of fish species in a transect
TL	total length
TN	total nitrogen concentration (µg/L)

TP	total phosphorus concentration (µg/L)
USEPA	United States Environmental Protection Agency
α	statistical significance level
µg/L	micrograms per liter
µS	microsiemens
º C	degrees Celsius
§	section

Abstract of Thesis Presented to the Graduate School
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The Florida Department of Environmental Protection (FDEP) developed in 2005 an ecological assessment index for Florida lakes (Fore 2005) called the Lake Vegetation Index (LVI). The index uses aquatic plant (macrophyte) species as an indicator of human disturbance to lakes. The purpose of this project was to evaluate the effectiveness of the LVI for predicting water chemistry and to determine how LVI relates to fish communities in Florida lakes. Florida LAKEWATCH, a citizen volunteer monitoring program, has extensive long-term data for water chemistry, as well as data for aquatic plant and fish communities for a diverse group of Florida lakes. It was determined, using 20 lakes sampled in 2008, that LAKEWATCH data could be used to calculate LVI scores that were comparable to scores calculated using the FDEP protocol. Weak relationships (R^2 values < 0.35) were established between LVI scores and total phosphorus, total nitrogen, chlorophyll, pH, total alkalinity, specific conductance, and color measured on the same day. The same pattern also existed for some of the long-term total phosphorus, total nitrogen, chlorophyll, and Secchi depth, surface area, and several fish community metrics (Simpson's diversity index, Simpson's evenness, Shannon-Weiner diversity index, species richness, relative sportfish

biomass, relative non-native species biomass, and non-native species presence) collected by LAKEWATCH. Based on the low R^2 values, the LVI does not seem to be a valid method for assessing ecological integrity or assessing the impact of human disturbance on Florida lakes.

CHAPTER 1
INTRODUCTION

The Clean Water Act (33 United States Congress §1251 et seq. 1972) requires protection of the biological, physical, and chemical integrity of waters in the United States to insure that those waters can support “the protection and propagation of fish, shellfish, wildlife, and recreation in and on the water.” Assessment of the integrity of aquatic systems is therefore a desirable goal for water resource managers (USEPA, 1998). Many ways of assessing the biological condition of lakes have been proposed using different biocriteria (Fore 2005, Stelzer et al. 2005, Bourdaughs et al. 2006). One biocriterium has been the use of vegetation (e.g., aquatic macrophytes) as an indicator of the ecological condition of a lake. Such indices have been proposed widely in Europe. For example, Stelzer et al. (2005) developed a macrophyte-based assessment system for use in German lakes. In their index, classification was based on macrophyte species abundance. Duigan et al. (2007) presented a Plant Lake Ecotype Index (PLEX) for use in British lakes. This index, as well as the index developed by Stelzer et al. (2005), involved estimating the abundance of macrophytes by classifying them on a 1-5 scale, ranging from rare to dominant.

In the United States, vegetation indices have been most extensively proposed for wetland integrity studies. Bourdaughs et al. (2006) reported that the “Floristic Quality Index” was a good indicator for coastal wetland ecological conditions in the Great Lakes region. Other authors have used indices in similar ways at other locations, such as northern Ohio (Andreas and Lichvar 1995), Florida (Cohen et al. 2004), and Illinois (Matthews 2003). Nichols et al. (2000), using Wisconsin lakes, proposed an index for assessing the biological quality of lakes. The components of their index included maximum depth of plant growth, percentage of littoral zone vegetated, Simpson's diversity index, relative frequencies of submersed, sensitive, and exotic species, and the number of taxa. Bachmann et al. (2002) showed, however, that there was no relationship between biomass of aquatic plants and nutrient concentrations in Florida lakes. Furthermore, they concluded that the role of macrophytes in clearing lakes may be primarily due to reduced nutrient concentrations for a given level of nutrient loading rather than nutrient concentrations controlling macrophyte abundance. Their finding suggests that indices based on aquatic macrophyte communities may not relate well to water chemistry.

The use of indices of biological integrity (IBIs) has been challenged in Florida. Schulz et al. (1999) examined an IBI that used eight metrics of fish assemblages to estimate anthropogenic impacts. In their study of 60 Florida lakes, Schulz et al. (1999) demonstrated that the IBI was unable to predict measures of anthropogenic impact. Given the results of the Schulz et al. (1999) and Bachmann et al. (2002) studies, the use of any IBIs, even those that use plant communities as metrics, should be scrutinized. However, in 2009, the Florida Department of Environmental Protection (FDEP) proposed using the lake vegetation index (LVI) to assess the ecological condition of Florida lakes and anthropogenic impact to lakes (Fore 2005). FDEP had conducted a study (Fore 2005) where candidate metrics of lake plant communities were identified, tested against independent gradients of human disturbance, and combined into the lake vegetation index. In FDEP’s statewide study, one data set, composed of 95 lakes, was used to test the candidate metrics and construct the index. A second data set, composed of 63 lakes, was used to validate the correlation between LVI and independent measures of human disturbance (Fore 2005). The four plant community metrics that were included in the index were: percent native taxa, percent invasive taxa, percent sensitive taxa, and the coefficient of conservatism score for the dominant plant species (Fore 2005). LVI scores range from 0 to 100, with lower values indicating a degraded or disturbed lake.

Bachmann et al. (2009) challenged the LVI concept and concluded that the index could not be used to determine if lakes were impaired by human disturbance. Bachmann et al. (2009) showed that the index could not separate out natural processes that determine the vegetation quality in a lake from human factors, similar to the results of Schulz et al. (1999). Florida LAKEWATCH is a citizen volunteer-based monitoring program that monitors water chemistry trends in Florida lakes. LAKEWATCH also conducts aquatic plant surveys and does long-term fish monitoring for the Florida Fish and Wildlife Conservation Commission (FFWCC). This information is public, and provides a large quantity of data regarding water chemistry, aquatic macrophyte communities, and fish communities, which can be used to test the relationship of the LVI to water quality and fish communities in a diverse group of Florida lakes. The use of this dataset also provides a way to evaluate the LVI using data collected independent of the Fore (2005) study. The primary purpose of this study was to examine the effectiveness of the LVI as an indicator of lake condition using water quality and fish community data. There were several goals for this study, including: 1) to determine if plant survey information, collected by LAKEWATCH, can be used to calculate an LVI value comparable to the FDEP LVI value for an individual lake, 2) to determine how much temporal variation is associated with a lake's LVI, 3) to determine if there is a relationship between LVI scores and concurrent (single sampling event) long-term (multiple years) water chemistry as measured by LAKEWATCH, 4) to determine if there is a relationship between LVI scores and metrics of fish communities, and, 5) to determine if there is a relationship between LVI scores and human disturbance.

CHAPTER 2
METHODS

LVI Calculations

The protocol developed by FDEP for LVI sampling involves dividing a lake into 12 sections (like the numbers on a clock), and selecting sections 1, 4, 7, and 10, sections 2, 5, 8, and 11, or sections 3, 6, 9, and 12 for sampling by rolling a die (Fore 2005). During sampling of each section (Fore 2005), a transect is set up perpendicular to the shore where a frotus plant sampling unit is deployed at least five times to sample submersed plants within 2.5 meters of both sides of the boat (to create a five-meter-wide belt transect). Then, the boat is driven parallel to the shore, where all plants that can be identified through visual observation are recorded. Plant species that cannot be identified, but can be reached from the boat are harvested for later identification. Finally, a single dominant or two co-dominant species are identified based on visual observation and recorded.

Florida LAKEWATCH has a different protocol for aquatic plant sampling (Florida LAKEWATCH 2007). The above-ground standing crop of emergent, floating-leaved, and submerged vegetation are measured along uniformly placed transects (10 to 30, depending on lake size) inside a 0.25-m^2 quadrat that is randomly placed in each plant zone (one deployment per zone per transect). Harvested plants are placed into a nylon-mesh bag, hand-spun to remove excess water, and weighed to the nearest tenth of a kilogram. The mean above-ground biomass of each plant zone is then averaged across all transects to get a lakewide value. The combined width of the emergent and floating-leaved plant zones (i.e., the distance from the outermost edge of the combined zones to shore), measured using a hand-held range finder at each transect, are then averaged for the lake. All plant species, observed during sampling, are recorded, and frequency of occurrence is determined by dividing the number of transects in which a plant species is found by the total number of transects.

To determine if plant survey information collected by LAKEWATCH can be used to calculate LVI scores, 20 lakes were sampled during the summer of 2008 for aquatic plants using the FDEP and LAKEWATCH protocols. The study lakes represented a variety of human disturbance levels and trophic states (Table 2-1). LVI scores for each lake were separately calculated using both the LAKEWATCH protocol and FDEP protocol. To calculate an LVI score using the LAKEWATCH protocol, the plant species list for all combined transects was used to calculate percent native species, percent invasive species, and percent sensitive species. The dominant plant coefficient of conservatism was determined as the coefficient of conservatism for the one or multiple species with the highest percent occurrence in the LAKEWATCH transects. If more than one species co-dominated, the average of the species coefficients of conservatism was used. One lake (Juniper, Walton County) was divided into two halves (Juniper East and Juniper West) for LAKEWATCH sampling. To account for this division, each half was scored for an LVI using the LAKEWATCH protocol, then the two LVI scores were averaged for comparison to the LVI score calculated using the FDEP protocol. Linear regression analysis was used to compare calculated LAKEWATCH and FDEP LVIs from the 20 lakes, and provided a basis for determining whether the long-term LAKEWATCH plant database could be used to calculate LVI scores for past years and other lakes where LAKEWATCH sampled plants.

LVI Variability

To examine sources of variation between LVI scores calculated using the two protocols, % agreement in recorded plant species was calculated by dividing the number of plant species identified by the total number of species discovered using the FDEP and LAKEWATCH protocols. Also, the individual metrics used to calculate the LVIs (i.e., percent native species, percent invasive species, percent sensitive species, and dominant species coefficient of conservatism) were compared using linear regression for the FDEP and LAKEWATCH protocols.

To examine the magnitude of temporal variation in calculated LVI scores, data from the 20 lakes (examined in summer 2008) were used with data from 26 additional LAKEWATCH lakes. Combined, these 46 lakes had multiple years of aquatic plant survey data, thus an LVI score was calculated for each year of available data. Coefficients of variation for individual lakes were then calculated for the time series of data by averaging the score for an individual lake across all years, then dividing the standard deviation of the LVI scores for an individual lake by the mean of the LVI scores (Krebs 1999).

LVI and Water Chemistry Comparison

At the time of plant sampling, a water sample was collected according to Florida LAKEWATCH protocol (see below) at each lake to determine concurrent water chemistry (sampled at the time of plant sampling) and water transparency was measured using a Secchi disc at an open-water location chosen randomly. The water sample was placed on ice until analyzed at the University of Florida’s Fisheries and Aquatic Sciences water quality laboratory where all LAKEWATCH samples are analyzed (see below).

To determine if there was a relationship between the calculated LVIs and long-term water chemistry in Florida lakes, water chemistry data were extracted from the long-term LAKEWATCH database for each study lake (Florida LAKEWATCH 2007). At each lake, surface water (0.5-m) samples were collected at three open-water stations. Secchi depth was also measured at each station. Water for TP and TN analyses were collected in 250-mL, acid cleaned, triple rinsed Nalgene bottles. Additional water was collected at each station in rinsed 4-L plastic milk jugs for chlorophyll analyses. To estimate algal biomass as measured by chlorophyll, a measured volume of water from these jugs was filtered through a Gelman Type A-E glass fiber filter. These filters were stored over silica gel desiccant and frozen. All samples were then transported to the laboratory for analyses by Florida LAKEWATCH. Long-term water quality values for each of the study lakes were calculated by averaging values for each sampling date, and then averaging all sampling dates for a lake to obtain a single mean value (the grand mean).

Florida LAKEWATCH sampled aquatic plants on 50 lakes in 2007 and 2008. Of the 50 lakes, 41 of these lakes had concurrent water chemistry data available at the time of plant sampling, which permitted an examination of the relationship between LVI and limited (i.e., same-day sampling) water chemistry. For lakes where samples were not taken during the plant sampling event, supplemental data were used from the next closest sampling date. These data were used to compare the LVI scores to pH, color, total alkalinity, specific conductance, TP, TN, and chl using linear regression. Finally, the LVI scores from the 50 lakes were then related to long-term (i.e., multiple dates of sampling) means of TP, TN, chl, and Secchi depth using linear regression.

Laboratory Analyses

At the laboratory, the concurrent and long-term water samples were analyzed to determine TP, TN, and chl concentrations (µg/L). Additional analyses included pH, total alkalinity (mg/L as $CaCO_3$), specific conductance (µS/cm at 25 C), and color (Pt-Co units). TP concentrations were determined using the procedures of Murphy and Riley (1962) with a persulfate digestion (Menzel and Corwin 1965). TN concentrations were determined by oxidizing water samples with persulfate and determining nitrate-nitrogen with a second derivative spectroscopy (D'Elia et al. 1977, Simal et al. 1985, Wollin 1987). Chl concentrations were determined spectophotometrically (APHA 2005) following pigment extraction with ethanol (Sartory and Grobbelaar, 1984). To determine pH, an Accumet model 10 pH meter calibrated with buffers of 4.0, 7.0, and 10.0 was used. Total alkalinity was measured by titration with 0.02 N sulfuric acid (APHA 2005). Specific conductance was measured at 25º C using a Yellow Springs Instrument Model 35 conductance meter. Color was determined by spectroscopic comparison to platinum-cobalt standard solutions based on 500 APHA color units (Bowling et al. 1986).

LVI and Fish Community Comparisons

Fish were collected by Florida LAKEWATCH using electrofishing during the fall of each year from 1999-2008 (Florida LAKEWATCH 2007). The same six uniformly spaced 10-minute transects were sampled by electrofishing on each lake each year. GPS locations were used to ensure consistent sampling of the same area throughout years. One person dipped fish on these surveys, and electrical current was constantly applied for 10 minutes. Collected fish were placed into an aerated tank until they were identified to species and measured (mm TL). Fish were released immediately after measurement. Length-weight relationships obtained by LAKEWATCH from unpublished FFWCC data (Schaeffer 2007) were used to estimate individual fish weights. From these data, LAKEWATCH calculated catch per unit effort for abundance (number of fish) and biomass (total estimated weight), relative abundance per species and biomass (weight per species), species richness, species diversity (including three forms of the Simpson's diversity index; D, 1/D, and 1-D), and Simpson's evenness (calculated as (1/D)/s, where s equals the number of species in a transect).

To examine the relationships between LVI and fish community metrics, data from 31 lakes, sampled between 2005 and 2009, were used. Twenty-five of the lakes had electrofishing and aquatic macrophyte data for the same years (Table 3-4). For the remaining six lakes, the aquatic plant data were collected within one year of the electrofishing surveys, thus the calculated LVI scores were offset by one year from the time of fish sampling. Several "lakes" connected by water (e.g., streams, canals) were considered as separate lakes for the LVI calculations. These lakes, however, were considered as a single unit by LAKEWATCH for the purpose of electrofishing effort. To account for this difference, a single mean LVI score was calculated for comparison with LAKEWATCH's electrofishing data (Ivanhoe, representing Ivanhoe East, Ivanhoe Middle, and Ivanhoe West; Conway representing Conway North and Conway South; Josephine representing Josephine East, Josephine Center, and Josephine West; and Juniper representing Juniper East and Juniper West).

LVI and Human Disturbance

Finally, LVI scores were compared to human disturbance levels using the 20 lakes sampled in summer 2008 (Table 2-1). On each of these lakes, any human disturbance (e.g. houses, artificial canals, agriculture, silviculture, etc.) was documented, and lakes were subsequently classified as: Categoty-1, low human disturbance; Category-2, intermediate human disturbance; or Category-3, high human disturbance (Table 2-1). These classifications were compared to LVI scores calculated using the FDEP protocol with an analysis of variance (ANOVA) test.

Statistical Procedures

JMP 8.0 was used in all statistical analyses. Log 10 transformations were performed on all parameters (except pH) to normalize the data. Long-term electrofishing data, dating back to 1999, were used to determine if any non-native fish species had ever been captured since 1999 on each lake. A Welch's two-tailed t-test was used to test for differences in LVI scores for lakes with and without non-native species presence. A significance level of $\alpha = 0.05$ was chosen for all analyses comparing LVIs to water chemistry and fish community metrics.

Table 2-1. List of Florida lakes sampled in summer 2008 for LVI calculations using the FDEP and LAKEWATCH protocols.

Lake	County	Surface Area (ha)	Trophic State	Human Disturbance Level**
Apopka	Orange	12412	Hypereutrophic	2
Cherry	Lake	248	Mesotrophic	3
Crescent	Putnam	6458	Eutrophic	2
Dorr	Lake	759	Mesotrophic	1
E	Miami-Dade	39	Oligotrophic	3
Eloise	Polk	469	Eutrophic	3
George	Putnam	18907	Eutrophic	1
Griffin	Lake	6679	Eutrophic	2
Harris	Lake	5579	Eutrophic	2
June	Highlands	2316	Oligotrophic	3
Juniper	Walton	271	Oligotrophic	1
Mill Dam	Marion	125	Oligotrophic	1
Minneola	Lake	764	Eutrophic	3
Sampson	Bradford	754	Mesotrophic	1
Spring	Walton	97	Oligotrophic	1
Tarpon	Pinellas	1025	Eutrophic	3
Tohopekaliga East	Osceola	5540	Mesotrophic	3
Wauberg	Alachua	149	Hypereutrophic	2
Weir	Marion	2861	Oligotrophic	3
Wildcat	Lake	142	Oligotrophic	1

* Trophic state determined using long-term TP (µg/L) means and the classification system of Forsberg and Ryding (1980).

**Human disturbance classified by visual observation as: Category-1, low human presence/disturbance, Category-2, intermediate human presence/disturbance, or Category-3, high human presence/disturbance.

CHAPTER 3
RESULTS

LVI scores calculated for the 20 Florida lakes in this study (using aquatic plant information collected using the LAKEWATCH plant sampling protocol) were significantly correlated ($r = 0.83$) to LVI scores calculated using the FDEP protocol. Linear regression analysis demonstrated that there was nearly a 1:1 slope between the two LVI scores (slope = 0.97, $p < 0.001$) (Figure 3-1). The coefficient of determination ($R^2 = 0.69$), however, indicated that there were other sources of variance associated with the relationship. For example, one of the study lakes was actually an urbanized, barrow-pit lake (E Lake, Miami-Dade County, Florida). Excluding E Lake from the analysis (Figure 3-2), yielded a 1:1 line (slope of 1.02) and an R^2 of 0.72, providing justification for excluding E Lake from other analyses where other sources of variation were identified.

Both the LAKEWATCH and the FDEP protocols identified similar numbers of plant species, and no particular plant types were routinely missed by one or the other protocols. Percent agreement between the plant species documented, however, was only about 61% (Table 3-1). Lack of complete agreement was not unexpected because some species, considered to be aquatic species by FDEP, are not recognized by LAKEWATCH as aquatic species (e.g., dog fennel, *Eupatorium leprophyllum*). Excluding these species from the analysis, however, only improved the agreement to 67%, suggesting that this discrepancy in the protocols accounted for only a small amount of the overall variance (Table 3-1). Of the 20 lakes sampled, 10 of the lakes had their percent agreement improved by 5% or less, nine improved by 6% to 10%, but one lake had its value improved by 20%, suggesting differences between the calculated LVIs for individual lakes can be substantial. A paired t-test failed to show a significant difference between percent agreement of the two methods before and after the removal of species not considered to be aquatic by Florida LAKEWATCH.

Another source(s) of variation may be related to how the individual metrics (percent native species, percent invasive species, percent sensitive species, and dominant species coefficient of conservatism) were calculated using the LAKEWATCH and FDEP protocols (Figures 3-3 through 3-6). R^2 values for percent native species, percent invasive species, percent sensitive species, and dominant species coefficient of conservatism were 0.53, 0.53, 0.66, and 0.46, respectively, again indicating methodology is not greatly influencing the overall calculation of LVI for a group of Florida lakes.

Producing statistically similar results, LVIs can be calculated using either LAKEWATCH or FDEP protocols. Analysis of LAKEWATCH's macrophyte information permitted an assessment of the magnitude of temporal variation in the LVI scores over multiple years. The mean coefficient of variation (CV) for the data was 16%, with a maximum CV was 61% (see Table 3-2). The minimum CV was 1%, the 25th quartile was 8%, and the 75th quartile was 20%.

The analysis of LVI scores (independent variable) and water chemistry (dependent variable) information (using non-transformed data), obtained concurrently with the plant sampling for the 41 Florida lakes in this study, demonstrated weak correlations between LVI and pH ($R^2 = 0.23$), total alkalinity ($R^2 = 0.07$), specific conductance ($R^2 = 0.01$), TP ($R^2 = 0.08$), TN ($R^2 = 0.04$), chl ($R^2 = 0.06$), and color ($R^2 = 0.02$). Transforming (log base 10) the data improved the statistical relationships slightly, but the relationships remained weak ($R^2 < 0.1$).

To determine if there might be a stronger relationship between LVI scores and long-term water chemistry data, information from 50 Florida lakes (Table 3-3) were analyzed. Using non-transformed data, statistically significant, but weak relationships, between the LVI scores and the primary trophic state indicators TP, TN, chl, or Secchi depth were found (Figures 3-7 to 3-10). R^2 values for the major trophic state indicators were 0.33, 0.10, 0.05, and 0.13, respectively. Transforming (log base 10) the data did not improve the relationships with TP and Secchi depth, but slightly strengthened the relationships with TN and chl (R^2 values of 0.12 and 0.11, respectively).

Analyses of fish community metrics (dependent variable) and LVI scores (independent variable) provided evidence for only weak relationships (R^2 <0.25) between the parameters (Figures 3-11 through 3-16). There were no statistically significant relationships between the LVI scores and Simpson’s D, Simpson’s Evenness, sportfish relative biomass, and non-native species relative biomass (Figures 3-11 through 3-16). The only significant relationships were between LVI scores and species richness and the Shannon-Weiner diversity index (Figures 3-15 and 3-16). The correlation coefficients for species richness and Shannon-Weiner were r = -0.5 and r = -0.37, respectively. The Welch’s two-tailed t-test showed no statistically significant differences in LVI scores for lakes with and without non-native fish present.

To assess the relationship between the LVI scores and human disturbance on the 20 lakes sampled in 2008, an ANOVA demonstrated significant differences for the LVI scores among the three human disturbance classifications used in this study (Figure 3-17). Lakes with higher LVI scores, as a group, had less human disturbance than lakes with low LVI scores. However, there was considerable overlap (LVI scores between 50 and 70) in the scores for the three human disturbance classifications (Figure 3-17).

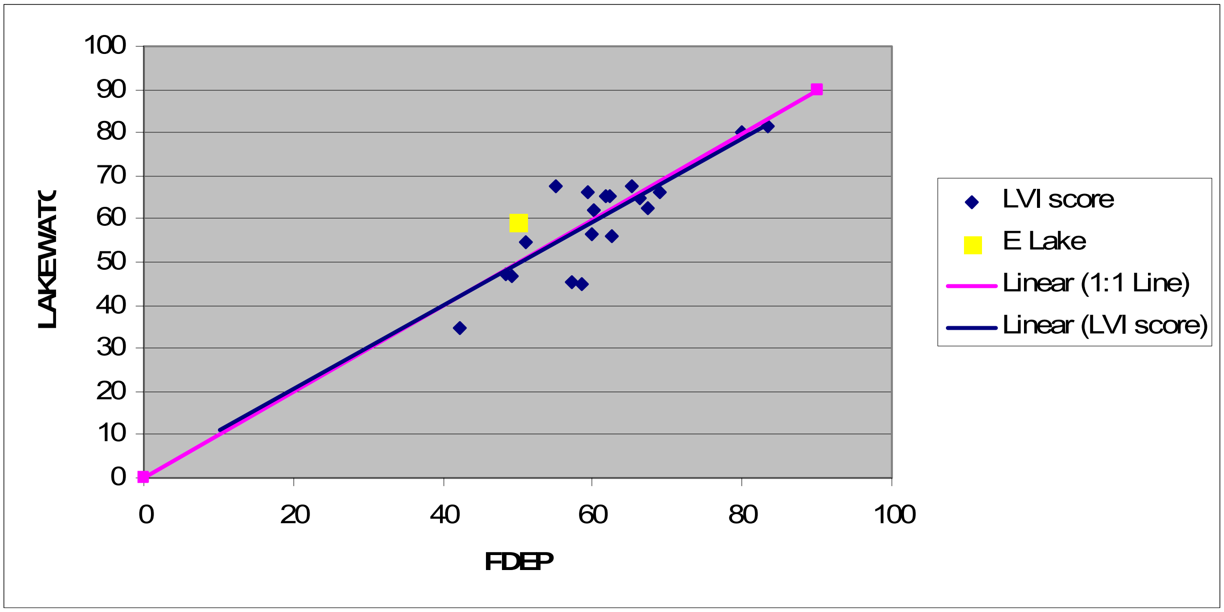

Figure 3-1. Linear regression of LAKEWATCH and FDEP calculated LVI scores with E Lake included

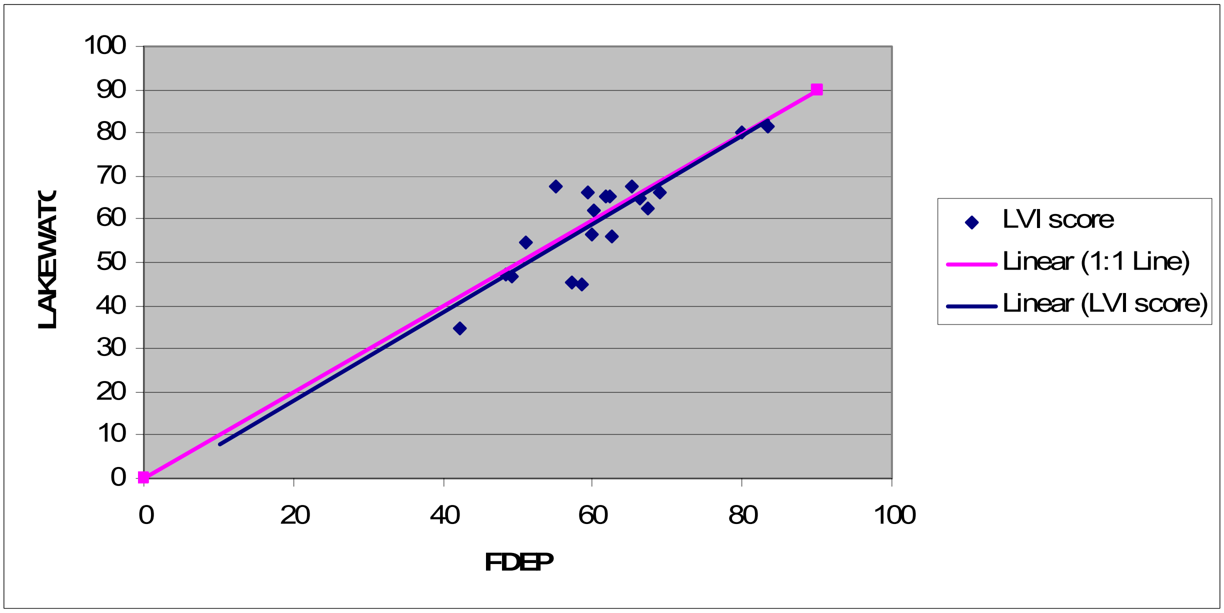

Figure 3-2. Linear regression of LAKEWATCH and FDEP calculated LVI scores with E Lake excluded.

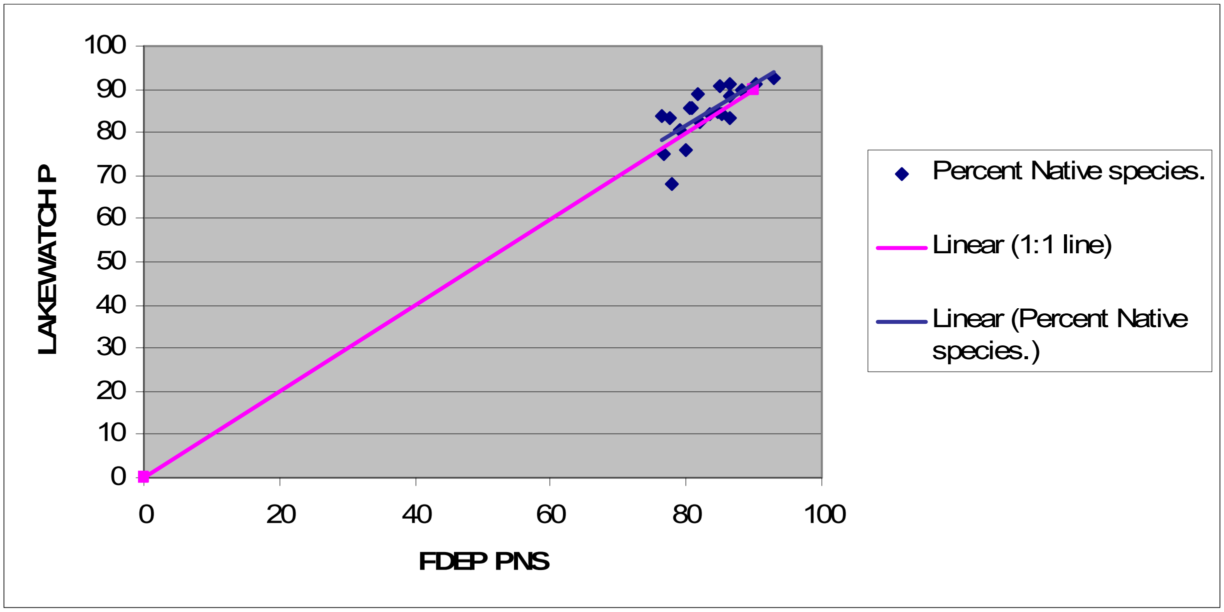

Figure 3-3. Linear regression of percent native species (PNS) as calculated by FDEP and LAKEWATCH.

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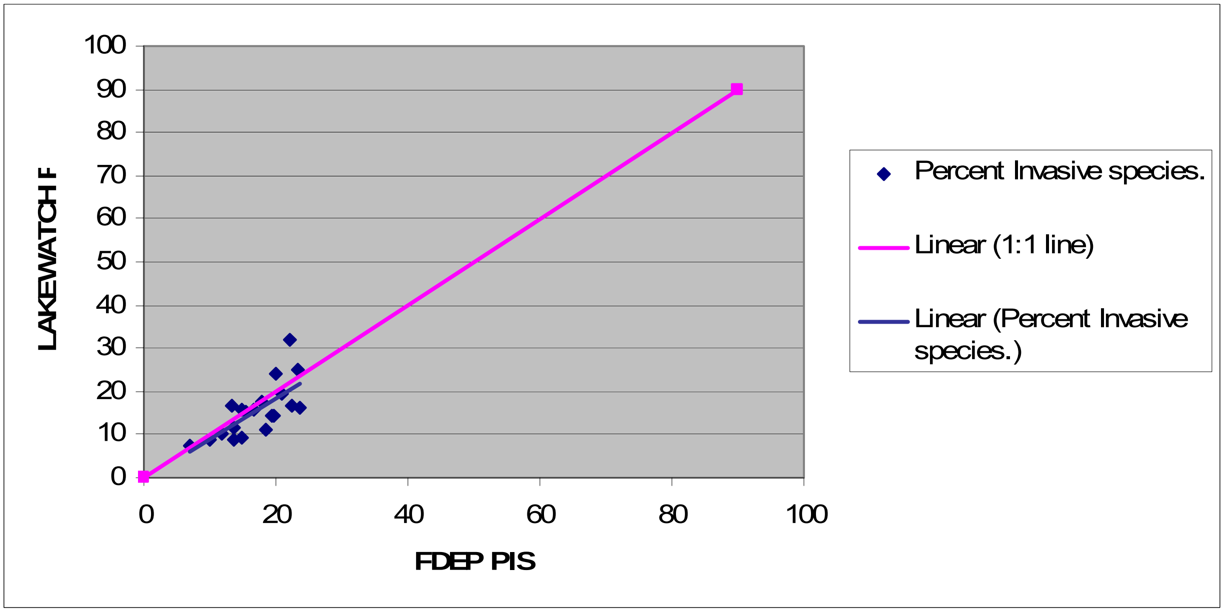

Figure 3-4. Linear regression of percent invasive species (PIS) as calculated by FDEP and LAKEWATCH

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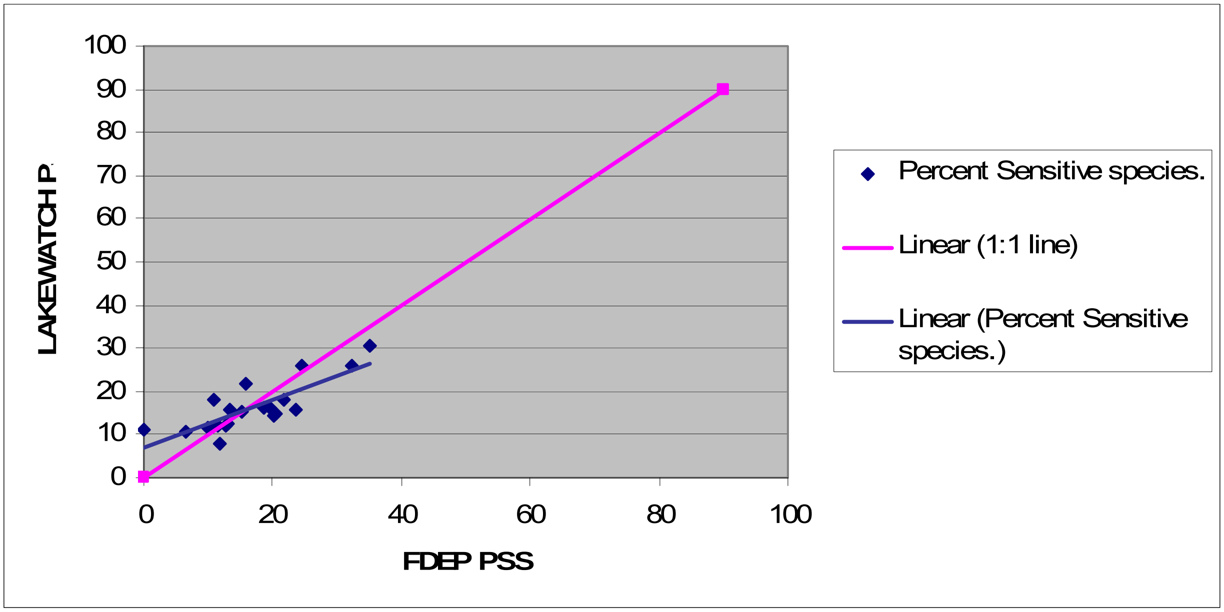

Figure 3-5. Linear regression of percent sensitive species (PSS) as calculated by FDEP and LAKEWATCH

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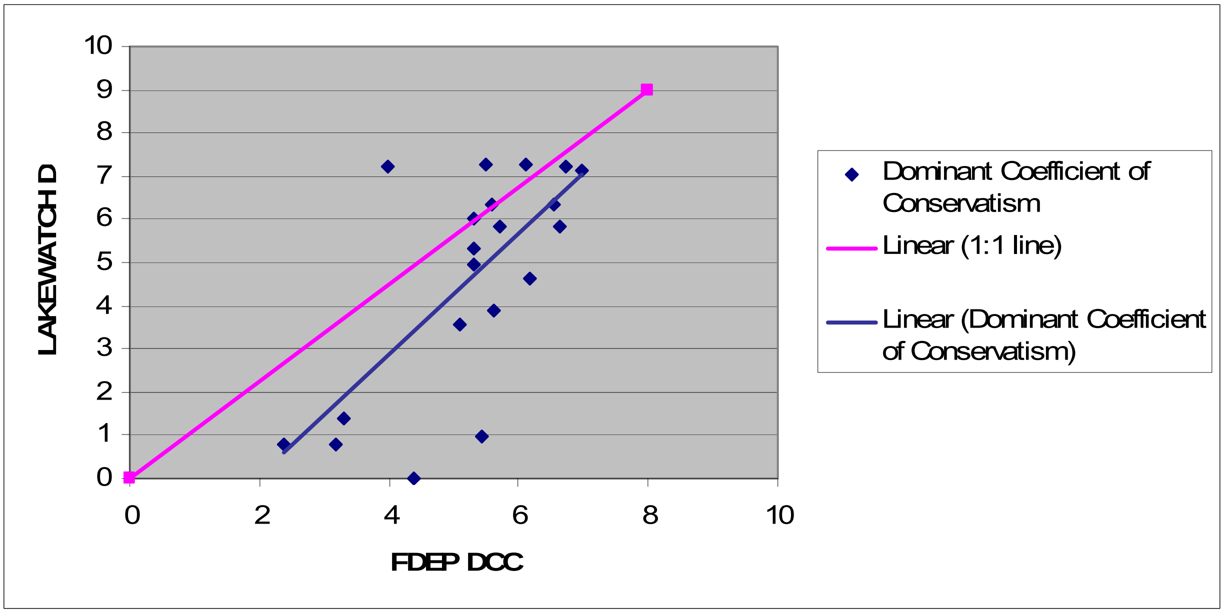

Figure 3-6. Linear regression of dominant species coefficient of conservatism (DCC) as calculated by FDEP and LAKEWATCH

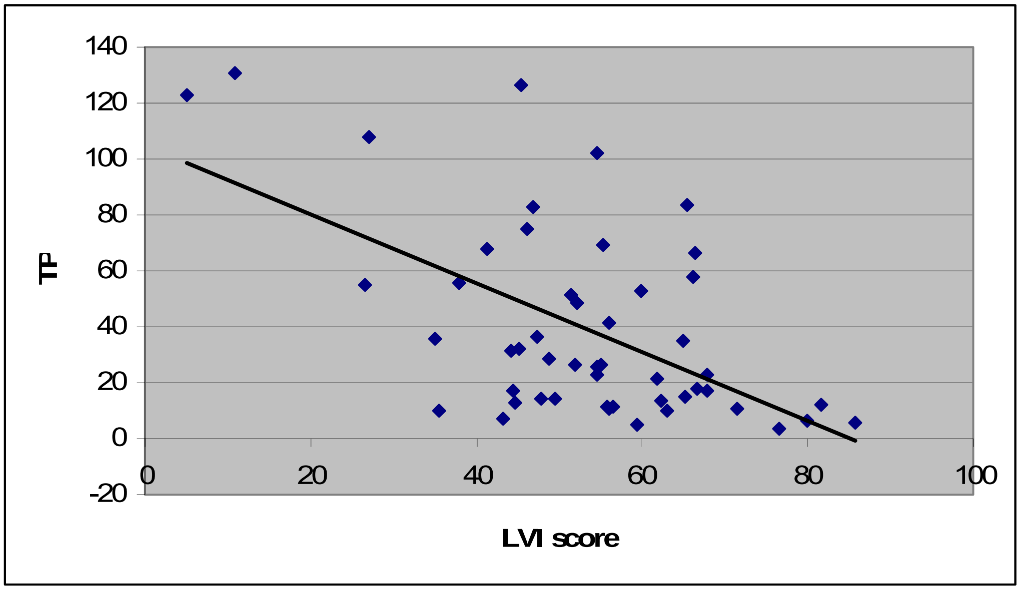

Figure 3-7. Linear regression of LAKEWATCH LVI score against long-term total phosphorus (µg/L).

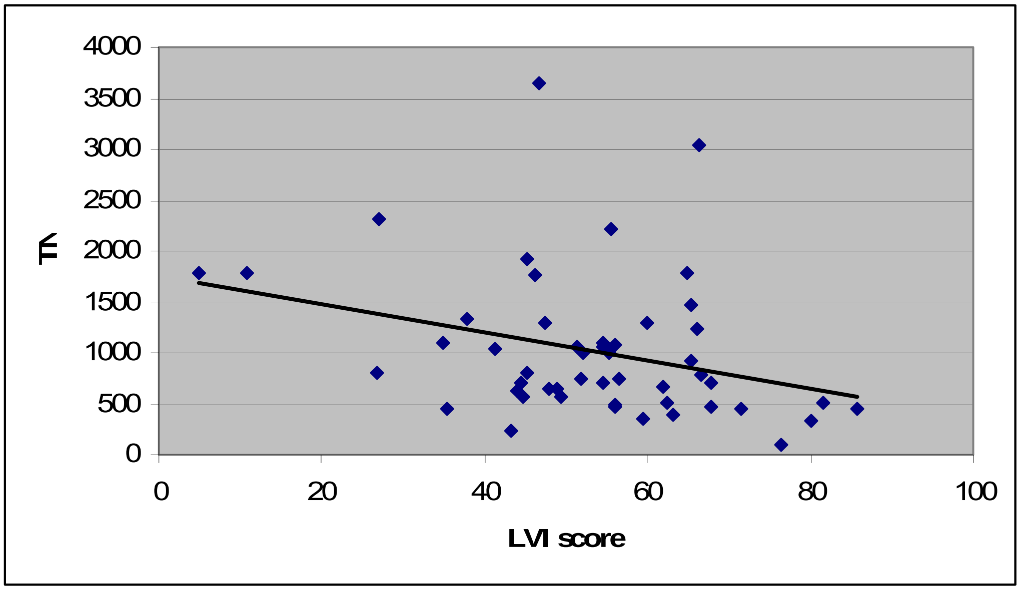

Figure 3-8. Linear regression of LAKEWATCH LVI score against long-term total nitrogen (µg/L).

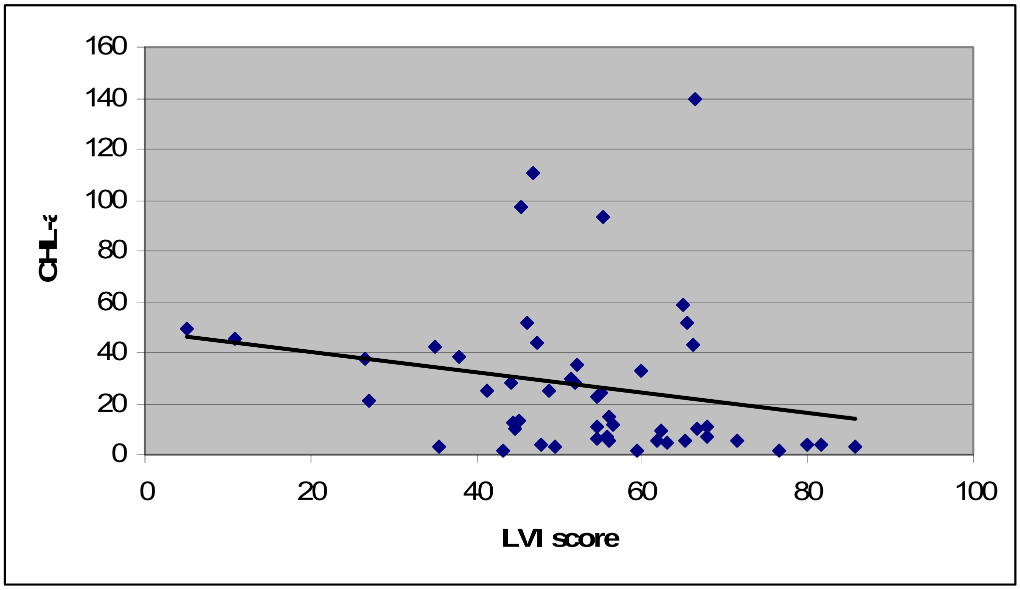

Figure 3-9. Linear regression of LAKEWATCH LVI score against long-term chlorophyll concentration (µg/L).

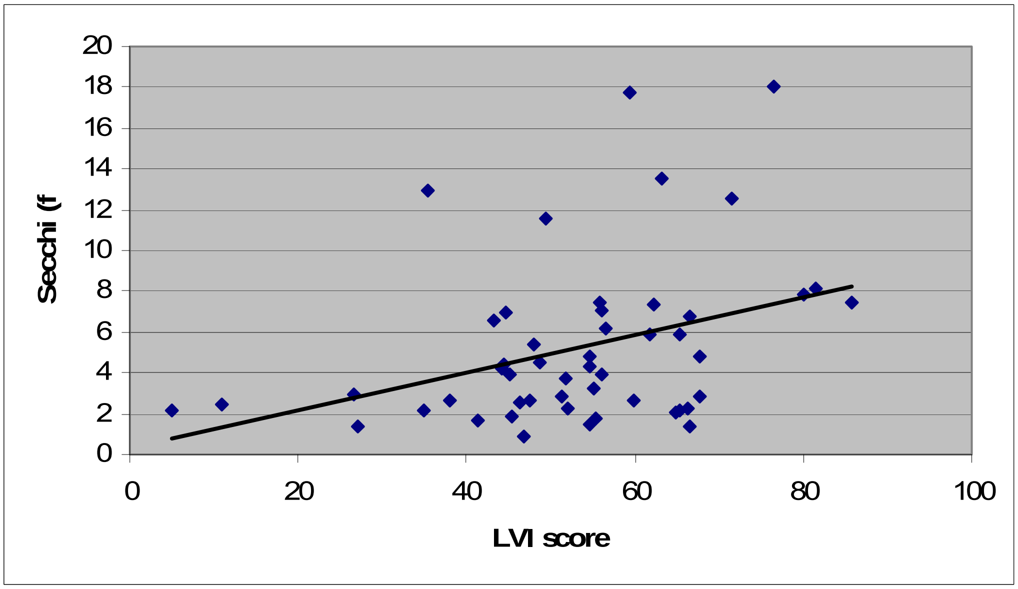

Figure 3-10. Linear regression LAKEWATCH LVI score against long-term Secchi depth (ft).

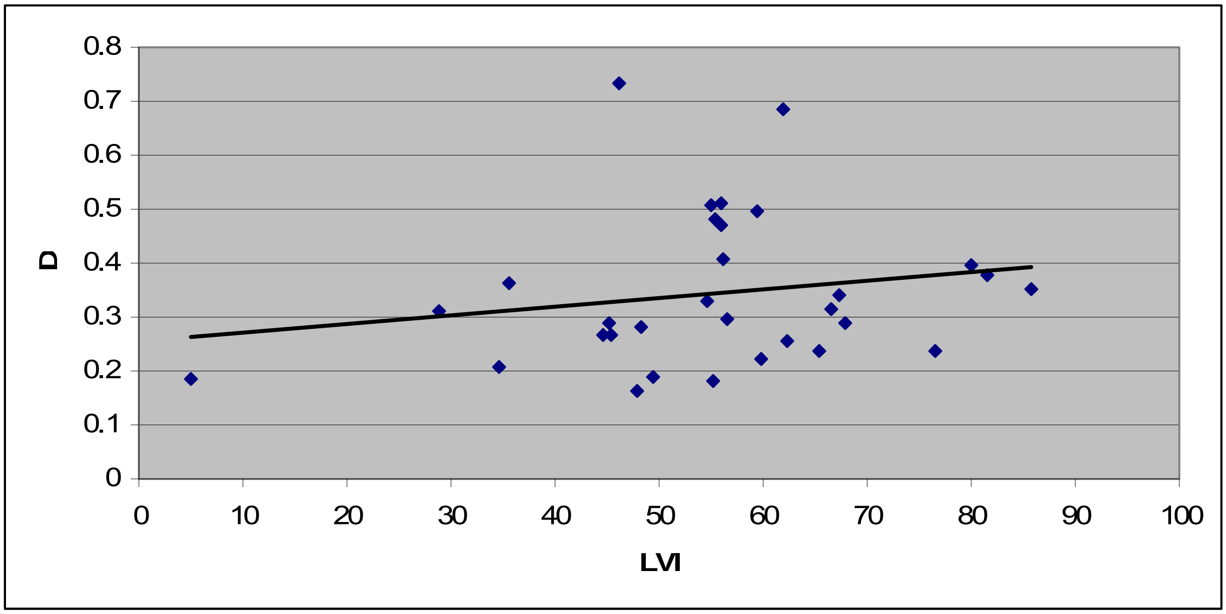

Figure 3-11. Linear regression of LVI scores against Simpson’s Diversity Index D.

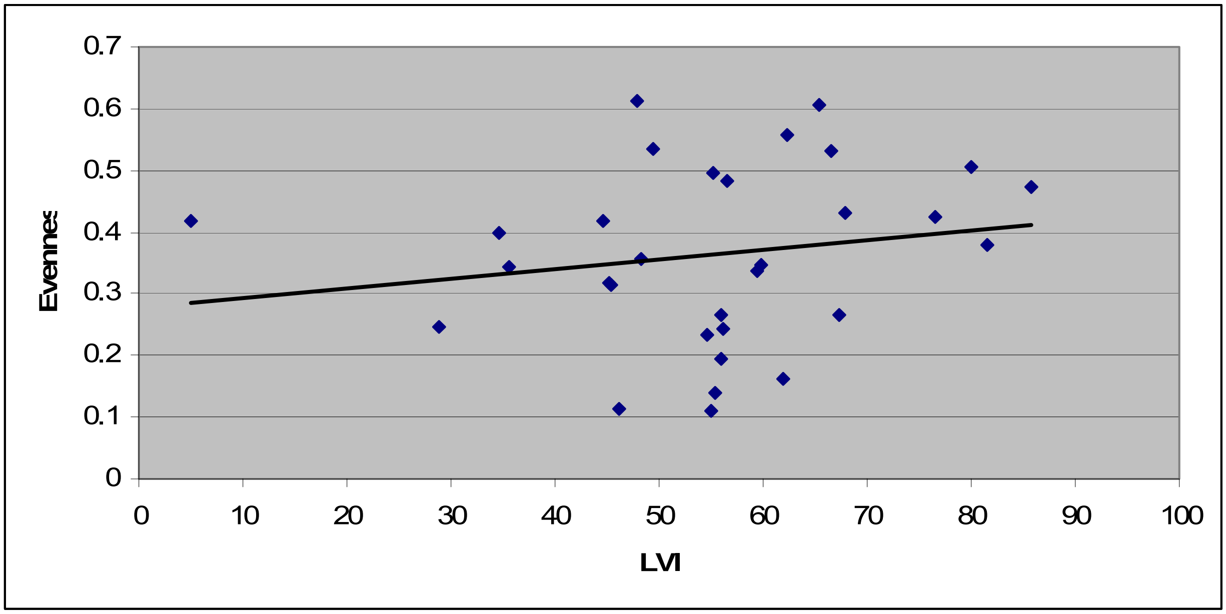

Figure 3-12. Linear regression of LVI scores against Simpson’s Evenness values.

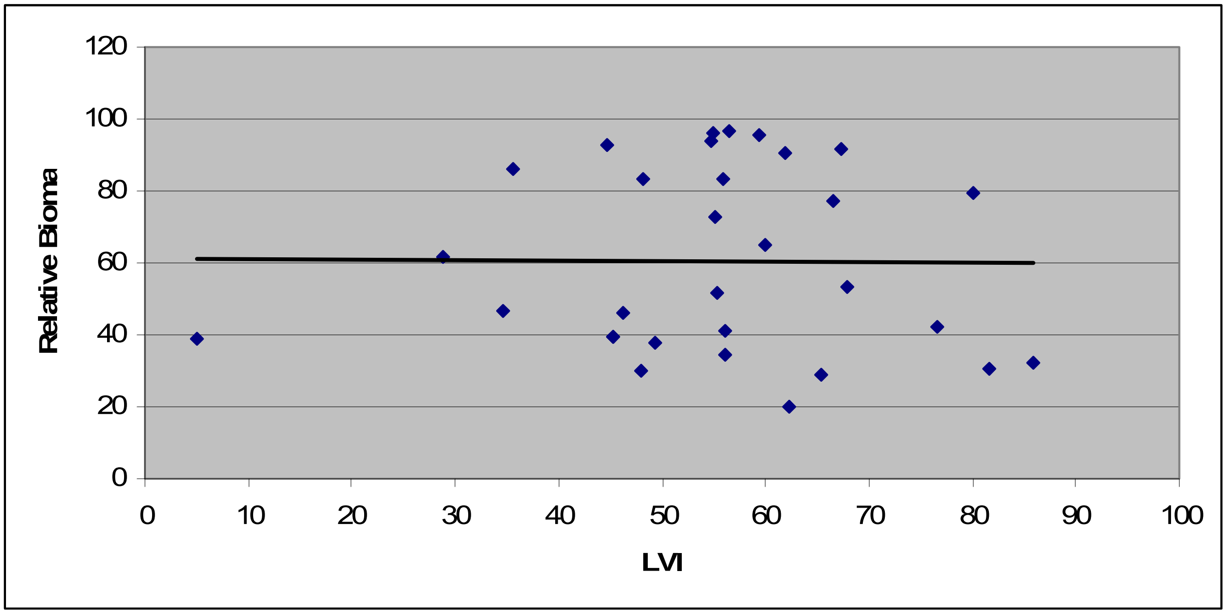

Figure 3-13. Linear regression of LVI scores against sportfish relative biomass.

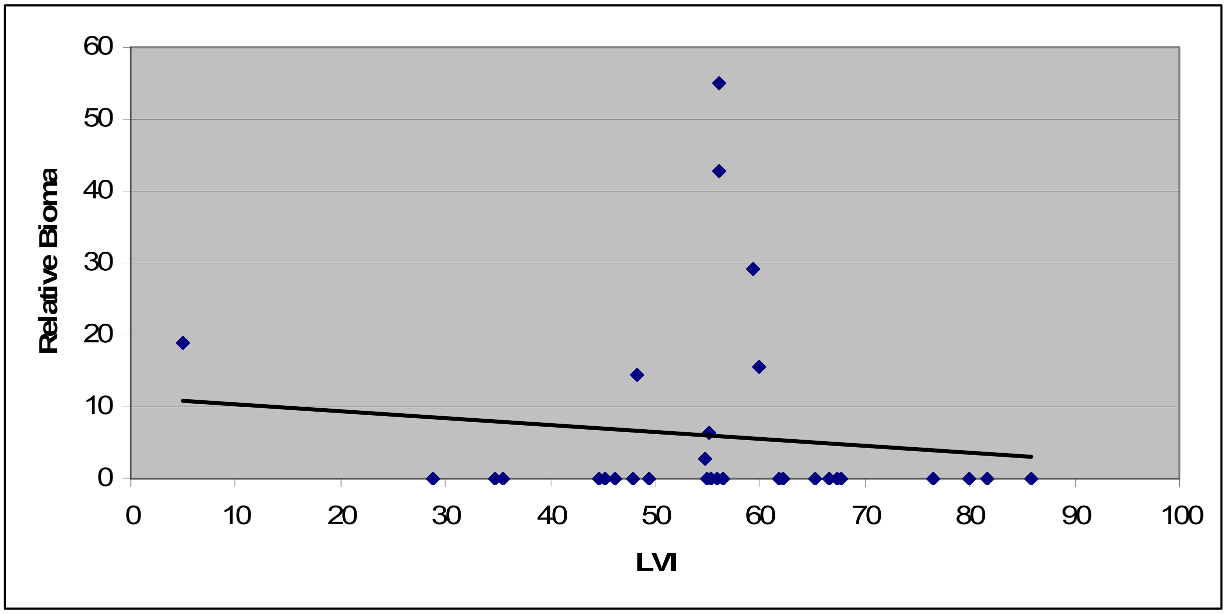

Figure 3-14. Linear regression of LVI scores against non-native species relative biomass.

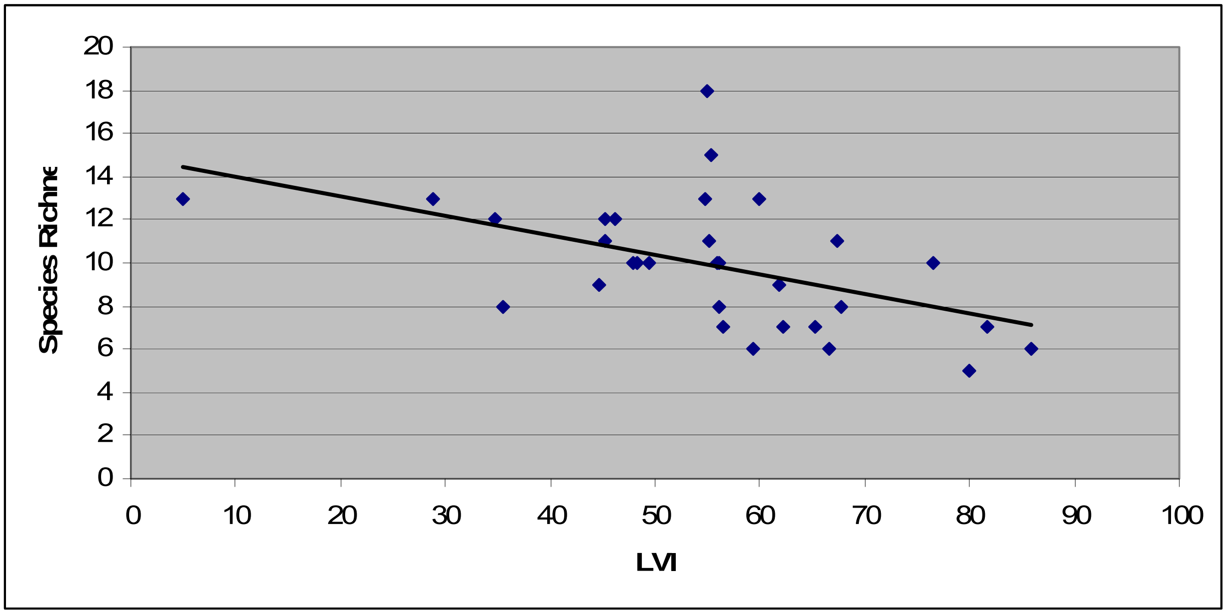

Figure 3-15. Linear regression of LVI scores against species richness.

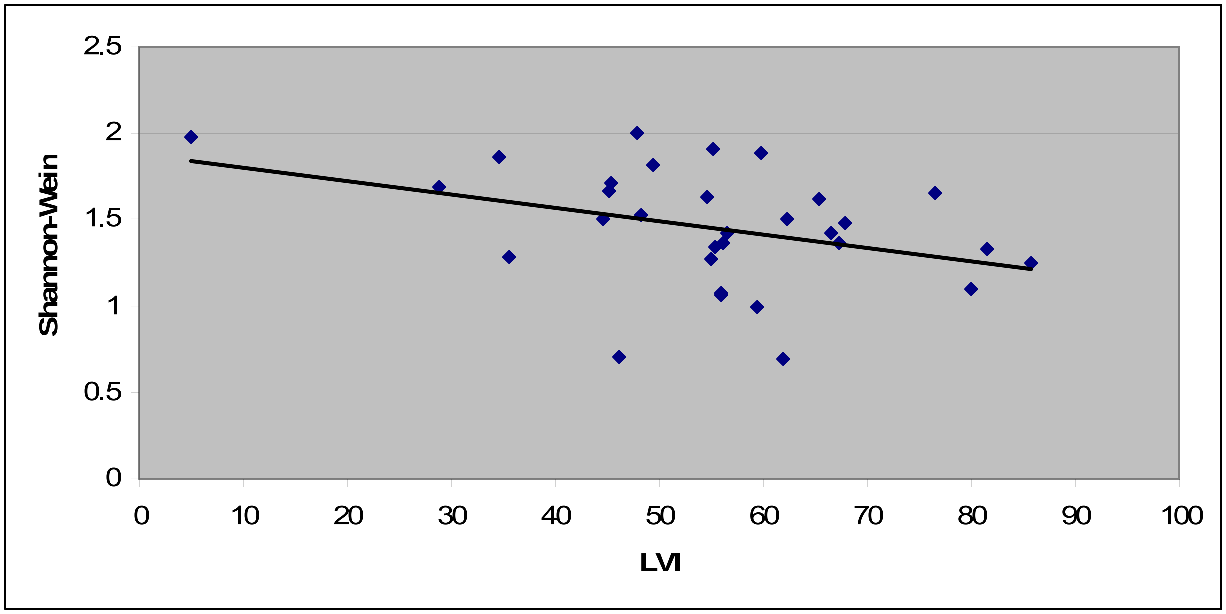

Figure 3-16. Linear regression of LVI scores against Shannon-Weiner Diversity Index values.

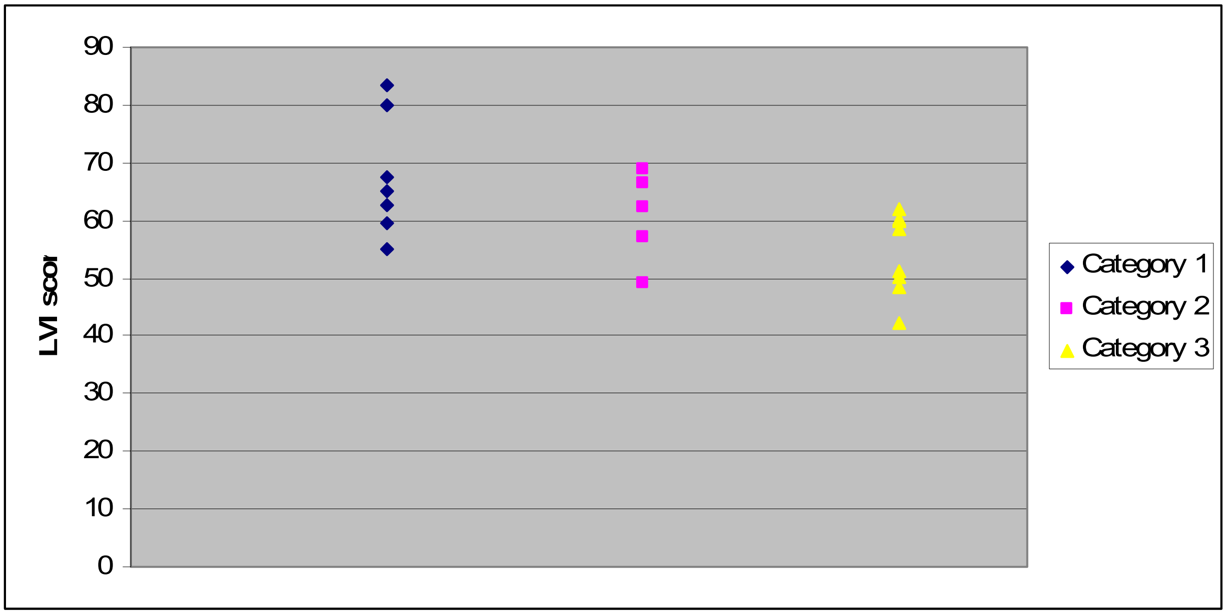

Figure 3-17. Plot of LVI scores of the various human disturbance levels.

Table 3-1. Percent agreement before and after exclusion of plants not considered by LAKEWATCH as aquatic species.

Lake	County	% agreement before	% agreement after
Apopka	Orange	73	80
Cherry	Lake	51	59
Crescent	Putnam	60	69
Dorr	Lake	68	70
Eloise	Polk	53	55
George	Putnam	59	62
Griffin	Lake	66	71
Harris	Lake	70	74
June	Highlands	63	70
Juniper	Walton	52	61
Mill Dam	Marion	61	81
Minneola	Lake	36	42
Sampson	Bradford	68	70
Spring	Walton	59	69
Tarpon	Pinellas	66	72
Tohopekaliga East	Osceola	72	75
Wauberg	Alachua	63	67
Weir	Marion	57	61
Wildcat	Lake	62	69

Table 3-2. Coefficients of variation (%) for scores calculated using the LAKEWATCH method, with number of sampling events (N) included.

Lake	County	N lakes	CV
Alligator	Osceola	3	12
Apopka	Orange	2	6
Butler	Orange	5	17
Cherry	Lake	4	6
Conway North	Orange	5	23
Conway South	Orange	5	19
Crescent	Putnam	2	8
Dexter	Polk	4	25
Dorr	Lake	3	9
E	Miami-Dade	4	15
Eloise	Polk	2	4
Farm 13	Indian River	4	51
George	Putnam	2	1
Grasshopper	Lake	4	14
Griffin	Lake	2	20
Harris	Lake	3	5
Istokpoga	Highlands	5	33
Ivanhoe East	Orange	5	25
Ivanhoe Middle	Orange	5	18
Ivanhoe West	Orange	5	13
Johns	Orange	4	25
Josephine Center	Highlands	5	26
Josephine East	Highlands	5	15
Josephine West	Highlands	5	23
June	Highlands	5	11
Juniper East	Walton	5	15
Juniper West	Walton	5	8
Kissimmee	Osceola	4	7
Lochloosa	Alachua	5	11
Mill Dam	Marion	5	10
Minneola	Lake	3	17
Orange	Alachua	3	6
Panasoffkee	Sumter	3	13
Sampson	Bradford	3	10
Santa Fe	Alachua	4	18
Sellers	Lake	4	6
Spring	Walton	5	9
Starke	Orange	5	17
Stick Marsh	Indian River	3	61
Tarpon	Pinellas	2	5
Tohopekaliga	Osceola	3	23
Tohopekaliga East	Osceola	5	8
Wauberg	Alachua	5	18
Weir	Marion	4	15
Weohyakapka	Polk	5	13
Wildcat	Lake	5	9
Wilson	Hillsborough	3	25

Table 3-3. Lakes used to compare long-term total phosphorus (TP), total nitrogen (TN), chlorophyll (chl), and Secchi depth to LVI.

Lake	County	Mean TP (µg/L)	Mean TN (µg/L)	Mean CHL (µg/L)	Mean SECCHI (ft)
Alligator	Osceola	14	639	4	5
Apopka	Orange	83	3650	111	1
Butler	Orange	14	568	3	12
Cherry	Lake	15	928	6	6
Conway North	Orange	10	444	6	13
Conway South	Orange	10	389	5	14
Crescent	Putnam	83	1468	52	2
Dead	Gulf	17	702	13	4
Deer Point	Bay	7	245	2	7
Dexter	Polk	10	445	3	13
Dorr	Lake	17	476	11	3
E	Miami-Dade	5	347	2	18
Eloise	Polk	36	1301	44	3
Farm 13	Indian River	130	1781	45	2
George	Putnam	58	1233	43	2
Grasshopper	Lake	5	459	3	7
Griffin	Lake	66	3042	140	1
Harris	Lake	35	1776	59	2
Istokpoga	Highlands	56	1325	38	3
Ivanhoe East	Orange	27	739	28	4
Ivanhoe Middle	Orange	28	640	25	5
Ivanhoe West	Orange	31	632	29	4
Johns	Orange	41	1075	15	4
Josephine Center	Highlands	68	1035	25	2
Josephine East	Highlands	49	991	35	2
Josephine West	Highlands	102	1060	23	2
June	Highlands	13	563	10	7
Juniper	Walton	11	493	6	7
Kissimmee	Osceola	53	1303	33	3
Lochloosa	Alachua	70	2209	93	2
Mill Dam	Marion	12	503	4	8
Minneola	Lake	26	1096	6	4
Orange	Alachua	75	1761	52	3
Panasoffkee	Sumter	32	798	14	4
Poinsett	Brevard	108	2319	22	1
Sampson	Bradford	23	704	7	5
Santa Fe	Alachua	11	465	7	7
Sellers	Lake	3	102	2	18
Spring	Walton	14	517	9	7
Starke	Orange	26	999	24	3
Stick Marsh	Indian River	123	1784	49	2
Talquin	Gadsden	55	811	37	3
Tarpon	Pinellas	36	1100	43	2
Tohopekaliga	Osceola	51	1065	30	3
Tohopekaliga East	Osceola	21	672	5	6
Wauberg	Alachua	126	1919	97	2

Table 3-3. cont.

Lake	County	Mean TP (µg/L)	Mean TN (µg/L)	Mean CHL (µg/L)	Mean SECCHI (ft)
Weir	Marion	11	753	11	6
Weohyakapka	Polk	23	712	11	5
Wildcat	Lake	7	326	4	8
Wilson	Hillsborough	18	792	10	7

Table 3-4. Florida lakes used to compare fish community metrics to LVI scores, along with electrofishing and LVI score years used in analysis.

County	Lake	Year of Electrofishing	Year of LVI
Osceola	Alligator	2007	2007
Orange	Butler	2007	2007
Lake	Cherry	2007	2007
Orange	Conway	2007	2007
Polk	Dexter	2008	2007
Lake	Dorr	2007	2007
Miami-Dade	E	2008	2008
Lake	Grasshopper	2007	2007
Highlands	Istokpoga	2005	2005
Orange	Ivanhoe	2007	2007
Orange	John's	2007	2007
Highlands	Josephine	2007	2007
Highlands	June	2008	2008
Walton	Juniper	2008	2008
Osceola	Kissimmee	2007	2007
Alachua	Lochloosa	2006	2007
Marion	Mill Dam	2008	2008
Alachua	Orange	2006	2007
Sumter	Panasoffkee	2007	2007
Alachua	Santa Fe	2006	2007
Lake	Sellers	2007	2007
Walton	Spring	2008	2008
Orange	Starke	2007	2007
Indian River	Stick Marsh	2006	2007
Osceola	Tohopekaliga	2005	2005
Osceola	Tohopekaliga East	2008	2008
Alachua	Wauberg	2008	2008
Marion	Weir	2008	2008
Polk	Weohyakapka	2006	2007
Lake	Wildcat	2008	2008
Hillsborough	Wilson	2007	2007

CHAPTER 4
DISCUSSION

The Clean Water Act requires protection of the biological integrity of waters in the United States; therefore development of an adaptable, robust method to assess the impact of human disturbance is needed. FDEP attempted to address the problem in Florida by developing the LVI (Fore 2005). The results from this study demonstrate that the LVI is adaptable to the extent that aquatic macrophyte information collected by another group can be used to calculate comparable LVI scores. For example, LVI scores (calculated using macrophyte data collected via the LAKEWATCH protocol) for the 20 lakes sampled in this study in the summer of 2008 were significantly correlated ($R^2 = 0.69$) to LVI scores calculated using FDEP protocol (Figure 3-1), and there was a nearly 1:1 relationship between scores calculated using each protocol. Based on this result, it can be reasonably concluded that LAKEWATCH plant sampling data can be used to calculate LVI scores that are comparable to LVI scores calculated using the FDEP protocol.

The robustness of an LVI score for an individual lake has uncertainty associated with the score. When regression analysis was used to compare LVIs calculated using LAKEWATCH and FDEP protocols, 31% of the variation could not be explained by the model. This variance was reduced by 3% when an artificial lake created by limestone mining (E Lake, Miami-Dade County) was excluded from the analysis, but excluding lake types reduces the practical use of the LVI in lake assessment.

Whenever different methodologies are used, differences can arise. Factors contributing to these differences must be considered. After examining other sources of variation for the lakes used in this study, it is evident that a user of the LVI needs to understand how the LVI is calculated before interpreting the score. For example, both the LAKEWATCH and FDEP protocols identified similar numbers of plant species, and neither protocol routinely missed a particular plant type. However, there was a lack of complete agreement (only 61%) for the plant species identified by each protocol because some species that are considered aquatic by FDEP are not considered aquatic by LAKEWATCH (e.g., dog fennel, *Eupatorium leprophyllum*). There are also methodological differences for each protocol in the calculation of the four metrics used in the LVI (percent native species, percent invasive species, percent sensitive species, and dominant species coefficient of conservatism). These differences, however, contributed little to the observed differences in LVIs calculated using the FDEP and LAKEWATCH protocols. This again suggests that LAKEWATCH plant sampling data can be used to calculate LVI scores comparable to scores calculated using the FDEP protocol.

Rather than focusing on methodology of the LVI protocol, potential users may have a greater problem associated with the temporal variation in the index. This variation can be caused by natural environmental factors or plant management activities. For the lakes used in this study, the coefficient of variation for LVI scores calculated for individual lakes was about 16%, but was as high as 60%. This type of variation is not unexpected because the index is merely a snap shot of the aquatic plant community of a lake, which varies due to climate conditions (e.g., drought) or natural disasters (hurricanes). For example, many sedges (e.g., plants in the genera *Cyperus*, *Rhynchospora*, etc.), that would not be able to establish under high water conditions could become prominent on a lake during drought, and could therefore affect the LVI score, depending on the species that establish under these conditions. Aquatic plant management practices can also change the LVI score considerably for an individual lake. For example, Lake Tohopekaliga (Osceola County, Florida) is a large lake that is the subject of intensive hydrilla management (W. Haller, University of Florida, October 2008, pers. comm.). This lake had a series of LVI scores consisting of: 55 (2000), 34 (2005), and 51 (2007). The large change between 2005 and 2007 was the result of differences in the abundance of hydrilla, an invasive aquatic plant, which was the dominant species in 2005 surveys, but not in 2007, following a major herbicide treatment. This is an example of one potential problem in the index, where management activities such as invasive plant management can drastically affect the outcome of an LVI score, thus requiring coordination among management agencies if the LVI is to be used to assess biotic integrity.

While the methodological and temporal problems call into question the practicality of the LVI, the overall utility of the LVI for assessing human impacts on Florida lakes must also be questioned. For example, eutrophication (e.g., phosphorus enrichment) has been identified as a major problem by FDEP. There, however, were only weak relationships between LVI scores and long-term water chemistry, the strongest relationship being long-term TP concentrations (R^2=0.33). However, Bachmann et al. (2009) demonstrated pH is a keystone environmental factor influencing the relationships, highlighting the problem of separating natural factors (i.e., naturally low pH causing naturally low TP concentrations) from human impacts. Other factors, not related to human disturbance, may also be influencing water chemistry. For example, internal loading was suggested to be the cause of increased TP levels in Lake

Okeechobee (Florida) by Canfield and Hoyer (1988b). Canfield and Hoyer (1988a) showed that the mineral composition and trophic states of Florida lakes are strongly related to their physiograpical region's geology, and water chemistry affected the assemblage of plant species present in a waterbody (Hoyer et al. 1996). It could therefore be inferred that since water chemistry affects the plant assemblages of lakes, it is therefore affecting the LVI scores. This suggests that the location of a lake and the chemistry of its underlying soils may be having more of an affect than human disturbance on the lake's long-term water chemistry. When taking the findings of Bachmann et al. (2009) and the effect of physiographic regions into consideration, along with the high variability associated with all of the LVI/water chemistry relationships, the practicality of the LVI is questionable.

Bachmann et al. (2009) did not, however, examine the relationship between LVI scores and biological communities (except for chlorophyll) of lakes. The Clean Water Act specifically requires the protection of the biological integrity of waters in the United States to insure that those waters can support the protection and propagation of fish. In this study, relationships between various fish community metrics and LVI scores were weak. The only statistically significant relationships were between LVI scores and species richness and Shannon-Weiner Diversity Index values. In contrast to what would be expected (i.e., reduced species richness at lower LVI scores, which supposedly indicates more human disturbance) LVI scores were inversely related to species richness ($R^2 = 0.25$). The R^2 value for the regression comparing Shannon-Weiner values to LVI scores was small ($R^2 = 0.25$), suggesting that most of the variation could not be explained by the model. Consequently, the LVI approach has little merit for assessing the impact of anthropogenic activities on fish communites.

A two-tailed t-test failed to show differences in LVI scores of lakes with and without non-native fish species. The presence of non-native fish species is generally associated with human action, so it would be expected that the LVI should show a difference between scores of lakes with and without these species. This finding and the overall inability to relate the LVI to different fish metrics should not be surprising given that Schulz, et al. (1999) found no relationship between human disturbance and an IBI that used fish assemblages as measures of human disturbance.

The LVI was developed as a different approach to gauge human disturbance (using the plant community of a lake to calculate LVI scores). Based on the available evidence for water chemistry and fish assemblages, it must be concluded that the LVI, as a management tool, shows little potential for use in Florida. The lack of relationships to water chemistry and fish communities renders it an impractical assessment or management tool. Its use as an index of human disturbance for Florida lakes, therefore, should be reconsidered by FDEP. In conclusion, the LVI is a questionable way of examining the ecological condition of Florida lakes.

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BIOGRAPHICAL SKETCH

Eric Flynt Thomas (also known as Bubba) was born in Gainesville, Florida. He was raised by his mother and stepfather, Stephen and Rebecca Parker. Thomas was raised in Lake Butler, Florida, and was heavily influenced by his uncle (Alray Harvey), his grandmother (Annie Harvey), and his grandfather (Alfred Harvey). Thomas was taught from an early age a respect for nature and learned a compassion for the outdoors that translated into his education and career. After graduating from Union County High School in 2003, Thomas attended Lake City Community College, and received an Associate in Arts degree in 2005. He then transferred to the University of Florida, where he received a bachelor's degree in wildlife ecology and conservation in 2007. He entered the University of Florida graduate school in 2007 in the Program for Fisheries and Aquatic Sciences, and completed the course requirements in May 2009. Thomas moved to Pinedale, Wyoming to work as a fisheries technician while completing his thesis, which he submitted in the fall of 2009.