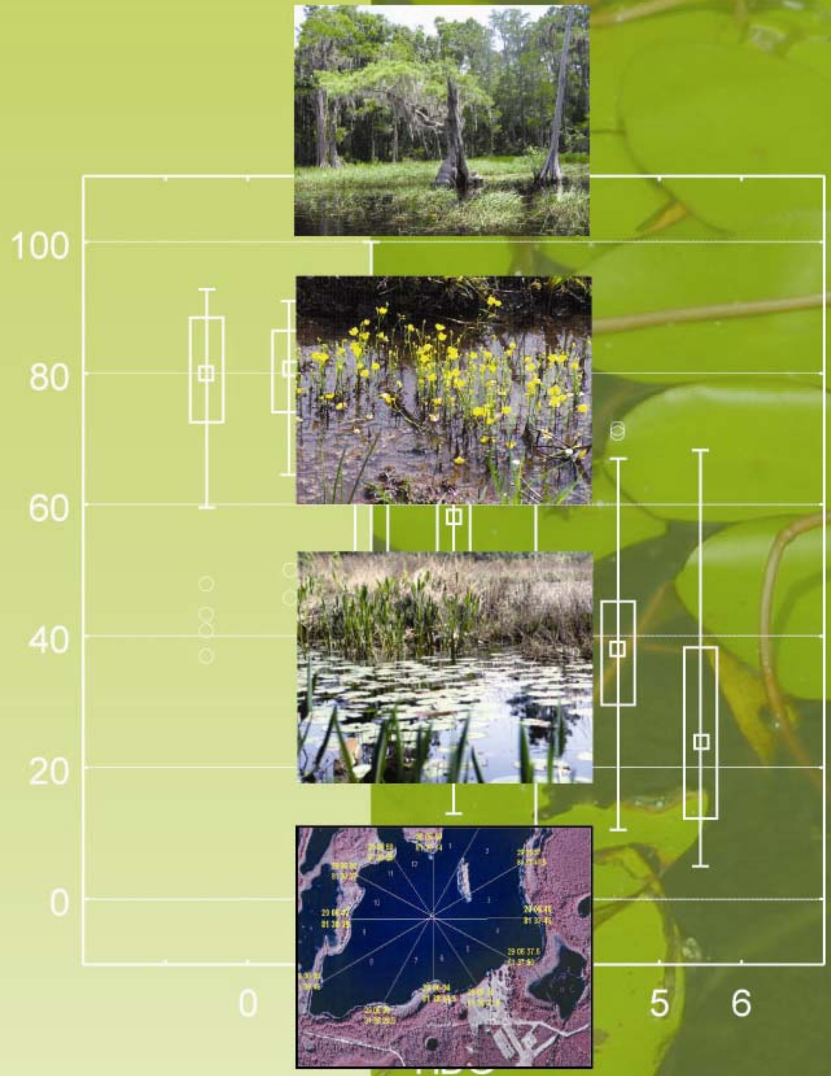
Assessing the Biological Condition of Florida Lakes: Development of the Lake Vegetation Index (LVI)



DEPARTMENT OF ENVIRONMENTAL PROTECTION
FLORIDA

Nonpoint Source Bioassessment Program

Assessing the Biological Condition of Florida Lakes: Development of the Lake Vegetation Index (LVI)

Final Report

Prepared for:

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FOREWORD

The original version of this document was completed in 2005. Two appendices were added in 2007 that respond specifically to recommendations made in the 2005 version of this report. Appendix 6 provides additional validation of the association between the biological condition of lake macrophytes and independent measures of human disturbance using data collected in 2005–2006. Scoring rules for combining metrics in the lake vegetation index (LVI) were also amended slightly for this more recent, larger data set. In addition, new estimates of variance for the LVI were calculated for multiple years of sampling. Appendix 7 describes the development of biological criteria as part of Florida's water quality standards for lakes. Recent guidance from the U.S. Environmental Protection Agency was used to define thresholds for impaired and exceptional lake condition based on the advice of a panel of regional experts.

ABSTRACT

The Florida Department of Environmental Protection (DEP) is required under the Clean Water Act to assess the biological condition of its streams, rivers and lakes. We developed a multimetric index, the Lake Vegetation Index (LVI), to assess the biological condition of aquatic plant communities in Florida lakes. For the development and testing of the LVI, aquatic plants in 95 lakes were sampled by boat during 2000–03. To validate the results for the LVI, data from an additional 63 lakes were collected in 2004; these data included 15 lakes with repeat visits for spring and summer. A total of 48 candidate metrics based on measures of community structure, taxa richness, and percent of total taxa were calculated and tested against independent measures of human disturbance. An additional 17 metrics derived from plant information from a national database were also evaluated. To test metrics, we developed a human disturbance gradient (HDG) that summarized measures of water chemistry, habitat condition, intensity of land use in a 100 m buffer around the lake, and hydrologic modifications. A total of 10 metrics met the targeted values for correlation with HDG; of these ten, four were not redundant with each other and were included in the LVI: percent native taxa, percent invasive taxa, percent sensitive taxa, and the average tolerance value of the taxon present over the largest area.

Tolerant and sensitive taxa were defined based on designations made by 10 expert botanists working independently to define coefficient of conservatism (CC) scores for wetland (not lake) plants in Florida. Metrics derived from CC scores were highly correlated with HDG. In contrast, relatively few individual taxa were significantly associated with HDG: only 29 out of 404 taxa showed significant preferences. Rare taxa were partially to blame for weak results, more than half of the taxa were found in less than 5 lakes.

Lakes were divied into 12 pie-shaped sections. Plant data were collected from each section and taxa lists from the 12 sections were kept separate. Using the replicate data, we compared the ability of different sampling protocols to detect differences in lake condition. Based on LVI calculated and averaged from four lake sections, LVI could detect five categories of biological condition.

LVI was highly correlated with HDG and other independent measures of human disturbance for both the development and the validation data sets (-0.68 and -0.72, Spearman's *r*). For the 15 lakes with repeat visits, LVI values for repeat visits within the year were more variable than for repeat visits on the same-day; however, neither spring nor summer LVI values were consistently higher across lakes. We conclude that LVI is a reliable indicator of lake condition and has sufficient statistical precision to detect multiple levels of biological condition. Given the relatively small data sets available for this study (<200 site-visits), we recommend that future studies be designed to evaluate the influence of season on metric values, to determine whether regional adjustments are needed to metric scoring, and to assess the annual variability of LVI.

INTRODUCTION

A primary objective of the federal Clean Water Act (CWA) is “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters.” Under the CWA, each state must develop water quality standards for all its surface waters. Water quality standards include designated uses assigned to a water body, water quality criteria to protect the uses, and an antidegradation policy (Ransel, 1995; Karr et al., 2000). Until the late 1980s, most states used primarily chemical criteria to assess surface waters. A shift occurred when resource managers realized that chemical criteria alone often fail to protect aquatic life uses (Karr and Chu, 1999). At that time, EPA recommended that states adopt biological criteria for the protection of water resources (Karr, 1991).

The state of Florida recognizes the importance of biological monitoring of water resources and has developed sampling protocols to assess the condition of streams, lakes, and wetlands based on their biological assemblages (Barbour et al., 1996; Gerritsen and White, 1997; McCarron and Frydenborg, 1997; Fore, 2004; Lane et al., 2004; Reiss and Brown, 2005). Florida Department of Environmental Protection (DEP) uses bioassessments derived from these protocols to define acceptable conditions for the support of aquatic life uses. Within the context of the CWA, bioassessments can be used to define impairment, evaluate best management practices, develop targets for management plans or restoration, or identify exceptional resources for protection (Yoder and Rankin, 1998; Karr and Yoder, 2004).

Compared to rivers, streams, and wetlands, relatively less work has been done to develop biological monitoring tools for lakes (USEPA, 2002a, 2002b; but see Whittier et al., 2002 and Harig and Bain, 1998 for lake indicator development). While most states have biological assessment programs in place for rivers and streams, Florida is one of only nine states with lake or reservoir bioassessment programs in place and one of only three that is developing numeric biocriteria for lakes (Gerritsen and White, 1997; USEPA, 2003). In many states, lakes may represent a smaller proportion of surface waters; however, with more than 7700 lakes greater than 10 acres in size, lakes represent a significant natural resource in Florida.

Although lakes are not wetlands, they share many of the same habitats and taxa within a particular region. The U.S. Environmental Protection Agency (EPA) has recently supported numerous research efforts related to the development of bioassessment and biocriteria for wetlands (USEPA, 2002b). Resources developed for wetland assessment were borrowed and applied for this study of lakes. For example, extensive literature surveys have documented the current science for wetland monitoring at the national level (Adamus et al., 2001) and specifically for Florida (Doherty et al., 2000). Documents published by EPA summarize the aquatic plant metrics that have been successfully applied in wetlands throughout the U.S., and this information was very helpful in identifying potential metrics for this study (USEPA, 2002c). Similar lists of candidate metrics for aquatic plants in lakes have not been developed (Gerritsen et al., 1998). Another source for potential metrics was Ohio EPA which has tested several types of plant metrics for inclusion in their vegetation IBIs for wetlands (Mack, 2004). Within Florida, the multimetric indices developed for isolated depressional herbaceous wetlands by Lane et al. (2004) and for isolated depressional forested wetlands by Reiss and Brown (2005) included additional metrics that were tested in this study for lakes. Finally, a study by Cohen et al. (2004) used the professional experience of ten botanists to define aquatic plant tolerance and sensitivity to disturbance in wetlands. We used these designations to define sensitive and tolerant plant taxa.

The purpose of this study was to develop a monitoring and assessment tool for lakes based on aquatic plant sampling. Though used extensively in wetland monitoring, aquatic plants are rarely selected as indicators of lake condition (but see Nichols et al., 2000 for a Wisconsin index). Aquatic plants provide an effective endpoint for monitoring lake condition for several reasons: 1) a wide array of plants with a variety of life history strategies are represented in Florida lakes, 2) much is known about the specific preferences and tolerances of many of these plants, and 3) collecting and identifying plants in the field is relatively straightforward, which means that laboratory costs are minimal. The goals of this study were to identify potential metrics for aquatic plants, test them against an independent gradient of human disturbance, combine the metrics into a lake vegetation index (LVI), and determine the most efficient method for collecting plant data to calculate the index.

METHODS

Study area

The state of Florida can be divided into three geographic regions based on watershed drainage patterns: the northern panhandle, the southern peninsula, and a transition region known as the northeast. These three regions were used to develop and test a multimetric index for invertebrates because different species assemblages were associated with these three geographic areas (Barbour et al., 1996; Fore, 2004). Sufficient data did not exist for lake plants to perform a similar test for associations between geographic areas and plant species assemblages; consequently, we used the geographic areas derived from watershed drainage patterns to test for regional differences in metric values.

The middle and lower Suwannee basin provides a natural demarcation between the panhandle and peninsula, with the northeast region straddling the upper Suwannee northeast of the Cody escarpment (White, 1970). Terrestrial vegetation communities in the panhandle generally consist of mixed pine/oak/hickory forests (*Pinus* spp., *Quercus* spp., *Carya* spp.), longleaf pine forests (*Pinus palustris*), hardwood forests with beech/magnolia climax community (*Fagus grandiflora*/*Magnolia grandiflora*), and swamp hardwood forests of cypress (*Taxodium* spp.) or tupelo (*Nyssa* spp.), interspersed by a mosaic of pine plantations, cropland (e.g., corn, soy beans, peanuts), and pasture (SWCS, 1989; Fernald and Purdum, 1992). The panhandle is less densely populated by humans than the other areas.

The peninsula has a sandy highland ridge extending down its center almost to Lake Okeechobee. The elevation of the central ridge is approximately 150 to 200 ft. Terrestrial vegetation communities on the ridge of the peninsula consist of longleaf pine/turkey oak forests (*Pinus palustris/Quercus laevis*), on flat areas are slash pine (*Pinus eliottii*) or loblolly pine (*Pinus teada*) with palmetto/gallberry understory (*Serenoa repens/Ilex glabra*), and in depressional areas are marsh/wet prairies (maidencane, pickerel weed), and hardwood wetlands of sweetbay (*Magnolia virginiana*), cypress (*Taxodium* spp.), and ash (*Fraxinus* spp.; SWCS, 1989). The dominant land use is pasture, cropland (e.g., watermelons, nursery products, tomatoes), and urban areas (Fernald and Purdum, 1992). Dense population centers are located at Tampa and Orlando.

The northeast region includes portions of the Okeefenokee Swamp, parts of the upper Suwannee drainage, the Black Creek drainage, and the Sea Island flatwoods. Plant communities consist of longleaf pine/turkey oak (*Pinus palustris/Quercus laevi)* on the sandy uplands, hardwood wetlands of cypress (*Taxodium* spp.), tupelo (*Nyssa* spp.), and loblolly bay (*Gordonia lasianthus*), pine flatwoods, and marsh (FNAI, 1990). Jacksonville is the only major population center.

Lake sampling

For this study, lakes were defined as fresh water bodies with >= 2 acres of open water of sufficient depth and size to require a boat for sampling. Two different data sets were used to develop and validate the LVI. The first data set included data from 95 lakes that were selected to represent a broad range of site conditions and human influence across the state. These lakes were used to test metrics and develop the LVI. Lakes were sampled by Florida DEP during August–November, 2000–2003. Of the 95 lakes, 17 were located in the panhandle region, 74 in the peninsula, and 4 in the northeast. Lake surface area was known for 80 lakes and ranged from 8–3500 acres, with a mean area of 343 acres. Lakes were not selected randomly, nor were they selected to ensure coverage in all ecoregions. Consequently some geographic areas were not included.

The second data set included data from 63 additional lakes, and these data were used to validate the correlation between LVI and independent measures of human disturbance. These lakes were sampled during March–September, 2004; 34 lakes were located in the panhandle and 29 in the peninsula. Of these lakes, 15 small lakes from the panhandle were sampled during spring and summer and were used to test for seasonal differences in LVI.

Aquatic macrophytes include aquatic plants large enough to be easily seen by the unaided eye, as well as some larger algae such as *Nitella* and *Chara*. Aquatic macrophytes grow in water or wet areas and may be rooted in the sediment or floating on the water's surface. Most aquatic macrophytes are vascular plants and include herbaceous species as well as trees and shrubs.

Each lake was sampled 12 times by dividing the lake into 12 approximately wedge-shaped sections, depending on the shape of the lake (Figure 1). Within each section, two methods were used to identify plants: 1) from the boat, plants were identified, using either binoculars or the unaided eye, while boating slowly along the shore, and 2) plants were also identified within a 5 m belt transect. The transect was perpendicular to the shore, from the mean high water mark towards the center of the lake. For the belt transect, visible plants were identified and submersed plants were also sampled with a standard frotus, a device used to collect underwater plants. The frotus was deployed 5 times along each 5 m belt transect (Figure 2). Lakes sampled before the fall of 2003 used only the drive-by method (35 of the 95 lakes in the development data set), while lakes sampled during or after fall 2003 used both methods. Plants identified using the two above methods were combined into a single taxa list, one for each of the 12 sections.

The plant judged to have the greatest areal extent, determined visually, within each of the 12 lake sections was denoted as "dominant," while all others were recorded as "present." If two taxa were more abundant than the other plants present, they were noted as "co-dominant." If the degree of dominance was not readily determined, all plants in the sampling unit would simply be marked "present." Plants were identified to the lowest taxonomic level possible, typically species. Unknown species were placed on ice and sent to an expert for identification.

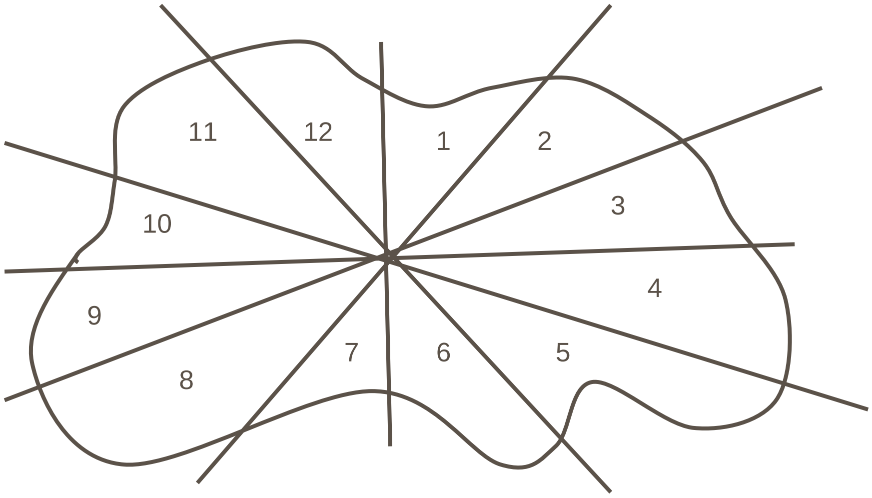

Figure 1. Diagram showing the method used to divide a typical lake into 12 sections for replicate sampling.

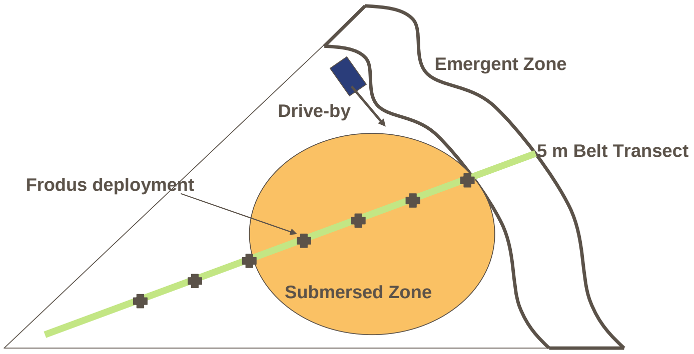

Figure 2. Detail of sampling methods used to identify plant taxa within a lake section.

Quantifying human disturbance

Karr and colleagues describe five factors to summarize the ways in which humans alter and degrade rivers and streams (Karr et al., 1986; Karr et al., 2000). The five factors are flow regime, physical habitat structure, water quality, energy source, and biological interactions. For this study data were available to evaluate three of these factors (water quality, physical habitat structure, and flow regime), as well as human disturbance at the watershed scale.

To evaluate lake water chemistry, DEP biologists measured conductivity, total Kjeldahl nitrogen (TKN), nitrites/nitrates (NO_x), total phosphorus (TP), and algal growth potential (AGP). We summarized information from these five measures into a water quality (WQ) index by converting values for each measure into unit-less scores and then averaging the scores. To convert to unit-less scores, we used the percentiles from a statewide data set (Integrated Water Resource Monitoring [IWRM] Cycle 1, 2000-2003) to define expectations. For the IWRM Cycle 1 study, water chemistry data were collected from ~1100 randomly chosen lakes. If the observed value from the LVI index development data set was less than the 10th percentile value observed for the statewide IWRM data set, the lake-visit received a score of 1 for that chemistry measure; if less than the 20th percentile the lake-visit scored a 2; and so on. We repeated this process for each of the five chemical measures. After scoring each of the measures, we averaged the unit-less scores (ignoring missing data) for all the chemical measures to define the water quality (WQ) index. For the 95 lakes in the index development data set, 10–25 had missing values for one or more of the chemical measures. To test whether missing values contributed to the correlation (or lack of correlation) between the WQ index and other measures of disturbance, correlation was also tested for sites without missing data.

For each lake, Florida DEP biologists also evaluated habitat condition by assigning numeric scores to qualitative descriptions of vegetation quality, stormwater inputs, bottom substrate, lakeside human alterations, upland buffer zone, and watershed land use (DEP protocol FT-3200). These scores are summed to yield a single value, the habitat index. Sufficient information was not available to develop a similar index for hydrologic condition. Instead, each lake was assigned a score of 0 if no hydrologic modification was observed or 1 if the lake was impounded or its hydrology artificially controlled.

Human land use around each lake was derived from aerial photos of 1995 land use coverages and a 100 m buffer area around the lake defined. Land use within a 100 m buffer area around the lake was summarized using an index developed to estimate the intensity of human land use based on nonrenewable energy flow (Brown and Vivas, 2004). The landscape development intensity (LDI) index was calculated as the percentage area within the catchment of a particular type of land use multiplied by the coefficient of energy use associated with that land use, summed over all land use types found in the catchment (Table 1).

$$LDI = \sum \left(LDI_i * \%LU_i \right).$$

Where,

LDI_i = the nonrenewable energy land use for land use *i*, and

$\%LU_i$ = the percentage of land area in the catchment with land use *i*.

To define the human disturbance gradient (HDG), we converted the four measures of human disturbance (the water quality index, the habitat index, the measure of hydrologic condition, and the LDI) to unit-less scores and summed the scores to define HDG values for each lake-visit. Three of the measures had scores of 0, 1, or 2 indicating low, moderate or high levels of human influence. One measure, hydrologic condition, only had scores of 0 or 1 (Table 2). HDG ranged from the minimum value of 0 to the maximum of 7 for the 95 lakes in the development data set. Each of the eight categories of HDG was represented by 6–18 lakes with the extreme values (HDG = 0, 6, or 7) having the fewest lakes.

Table 1. Description of land use and the coefficient value used to calculate the LDI. Higher values indicate greater intensity of human land use.

Land use	LDI value
Natural Open water	1.00
Pine Plantation	1.58
Woodland Pasture	2.02
Pasture	2.77
Recreational / Open Space (Low-intensity)	2.77
Low Intensity Pasture (with livestock)	3.41
Citrus	3.68
High Intensity Pasture (with livestock)	3.74
Row crops	4.54
Single Family Residential (Low-density)	6.79
Recreational / Open Space (High-intensity)	6.92
High Intensity Agriculture	7.00
Single Family Residential (Med-density)	7.47
Single Family Residential (High-density)	7.55
Low Intensity Highway	7.81
Low Intensity Commercial	8.00
Institutional	8.07
High Intensity Highway	8.28
Industrial	8.32
Low Intensity Multi-family residential	8.66
High intensity commercial	9.18
High Intensity Multi-family residential	9.19
Low Intensity Central Business District	9.42
High Intensity Central Business District	10.00

Table 2. Scoring rules for measures used to calculate the human disturbance gradient (HDG). HDG is the sum of the scores.

Measure	0	1	2
WQ index	<3.5	3.5–5.9	>=6
Habitat index	>65	45–65	<45
Hydrologic condition	Not impounded	Impounded	—
LDI	<2	2–4	>4

Metric development and testing

Candidate metrics in six general categories were tested for correlation with HDG using only the data from the development data set of 95 lakes. Only taxa presence was recorded within each lake section; therefore, no information regarding extent of cover was collected. One exception to this was the designation of one or two plants as “dominant” or “codominant” if they had the greatest areal cover. Only 64 of the 95 lakes had information on dominant plants in at least one lake section; thus, 31 lakes lacked sufficient information to calculate metrics related to dominance.

For this initial phase of index development, taxa lists from all 12 sections were combined to create a single composite plant sample for each lake. Aquatic plant metrics were calculated from the combined data with one value for each metric per lake. Data were combined from the 12 sections to ensure the strongest signal for metric testing. After metrics were selected, alternative sampling protocols based on varying numbers of lake sections were compared using the final index (see “LVI development and testing” below). Most metrics were calculated as both the total number of taxa representing a specific group (e.g., native plants) and the percentage of total taxa that the taxa of interest represented (e.g., number of native taxa/total number of taxa).

Coefficient of conservatism scores (CC) were used to calculate several metrics. CC scores were defined by a panel of 10 expert botanists working independently, and CC scores from each expert were averaged to derive a single CC score for each taxon. The CC scores were developed for depressional marshes in Florida, not for lakes (Cohen et al., 2004).

Community structure – The total number of taxa found is expected to decline as human disturbance eliminates habitat, changes water chemistry, and interrupts the natural hydroperiod. Although some studies have documented a decline in the number of wetland taxa as disturbance increases (Findlay and Houlahan,1997; Lopez et al., 2002), this metric is not typically chosen for wetland monitoring (USEPA, 2002c). The number of plant guilds summarized the number of different types of plants present at a lake, e.g., forb/herb, graminoid, shrub, tree, or vine. The number of plant guilds is expected to decline with disturbance. We expect more tolerant plants to dominate the assemblage as disturbance increases. Dominant C of C was defined as the CC score for the one or two plants that covered the greatest area.

Nativity – Native taxa are those whose natural range included Florida at the time of European contact (1500 AD). Exotic taxa are species introduced to Florida from a natural range outside of Florida. Definitions of invasive taxa were taken from lists developed by the Florida Exotic Pest Plant Council (FLEPPC). FLEPPC defines Category I invasives as “exotics that are altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives” (FLEPPC, 2003). Category II invasives are defined as “exotics that have increased in abundance or frequency but have not yet altered Florida plant communities to the extent shown by Category I species.” For 95 lakes in the development data set, 17 taxa were listed as Category I and 7 as Category II. (See Appendix 1 for plant attributes.)

Threatened and endangered species – Four endangered species (*Xyris isoetifolia*, *Hypericum lissophloeus*, *Salix eriocephala,* and *S. floridana*) and one threatened species were found (*Drosera intermedia*). Five species did not provide enough range of values to define a metric and no metric was tested for this attribute.

Tolerance/Sensitivity – Coefficient of conservatism (CC) scores were available for 240 of the 404 taxa found. CC scores are most typically used to calculate a ‘floristic quality index (FQI)’ (Lopez and Fennessy, 2002). FQI was calculated as the average CC value multiplied by the square root of the total number of plant taxa. The simple mean of the CC scores has also been reported and was tested here. Lane et al. (2004) found that mean CC score was significantly correlated with LDI for herbaceous wetlands in Florida. We calculated the total number of sensitive and tolerant taxa by defining taxa with a CC score > 7 to be sensitive and CC < 3 to be tolerant (Table 3). Percent sensitive and tolerant taxa were selected as metrics for both the herbaceous and forested wetland indices in Florida (Lane et al., 2004; Reiss and Brown, 2005).

Duration – Lakes with less human disturbance are expected to have a greater number of perennial taxa or a higher relative proportion of perennial taxa than annual taxa. Annual taxa represent more opportunistic taxa which tend to be associated with human disturbance. Ohio EPA uses the ratio of annual to perennial taxa in several of its vegetation indices for wetlands (Mack, 2004).

Table 3. Coefficient of conservatism (CC) scoring criteria (after Cohen et at., 2004; Andreas 1995) and designations used to define a plant as tolerant or sensitive for this study.

CC score	Sensitive or Tolerant	Criteria
0	T	Alien taxa and native taxa that are opportunistic invaders
1–3	T	Widespread taxa that are found in a variety of communities, including disturbed sites
4–6	Neither	Taxa that display fidelity to a particular community, but tolerate moderate disturbance
7–8	S	Taxa that are typical of well-established communities, which have sustained only minor disturbances
9–10	S	Taxa that exhibit high degrees of fidelity to a narrow set of ecological conditions

Wetland status – Although all sampling locations were defined as lakes and not wetlands, we tested metrics related to wetland status because extensive lists have been developed for many plants and because wetland status may provide an indicator of hydrologic alteration or other types of human disturbance in lakes (USEPA, 2002c). Species defined as ‘obligate wetland’ or ‘facultative wetland’ plants are considered to be adapted to life in anaerobic soils (USACE, 1987); facultative species are equally likely to occur in wetlands or non-wetlands; and upland species are expected not to occur in wetlands.

Growth form – This category included several aspects of plant growth. Metrics were calculated for herbaceous and woody taxa and for emergent, floating, and submersed taxa. Fern and gymnosperm taxa were also summarized. The previous metrics were also calculated for native taxa only. In addition, candidate metrics based on native forbs+herbs, graminoids, nonvascular plants, vines, shrubs, subshrubs and trees were tested. Nichols et al. (2000) suggest that the relative frequency of submersed taxa may be greater than floating or emergent taxa when water quality is degraded. Emergent species may also tolerate greater wave action. Other studies suggest that emergent species may increase with an increase in nutrients, while submersed taxa decline (Doherty et al., 2000).

Dicot/monocot – Flowering plants (angiosperms) are divided into two groups depending on the number of cotyledons found in the embryo. The cotyledons are the seed leaves produced by the embryo. In Ohio, native dicots decline with increasing disturbance, and this metric is included in four out of five Ohio wetland indices (Mack, 2004).

Additional metrics derived from the national wetland database – In addition, several metrics were derived from a national database of plant characteristics developed for wetland plants (Adamus and Gonyaw, 2000). Information in this database was derived from published, peer-reviewed studies. Development of this database was funded by EPA in response to requests from state agencies involved in monitoring wetlands. The attributes were derived from literature surveys for each taxon and summarized information regarding general sensitivity or tolerance, tolerance to nutrients, nitrogen or phosphorus, and sensitivity or tolerance to flooding, sediment, and salinity (Appendix 2). Of the 404 taxa found in the 95 lakes, 137 were listed in the EPA database.

Sensitive and tolerant taxa evaluation

We tested the association of individual plant taxa with the HDG using a 2 x 2 contingency table analysis (χ^2, Yates correction, $\alpha = 0.05$). Lakes with an HDG of 0, 1, or 2 were defined as 'good' lakes (N = 36), and the remaining 59 lakes with HDG from 3–7 as the 'poor' lakes. An HDG < 3 meant that a lake could have moderate disturbance indicated for two measures or high disturbance for a single indicator. This statistical approach tests whether occurrence of an individual plant taxon depended on the level of human disturbance.

We also calculated the average HDG value for all the lakes at which a particular taxon was found and compared this empirical value for sensitivity (or tolerance) to the CC values derived from expert judgment. This approach was not intended as a potential metric, but as a test of the CC scores for the lakes data set.

Lake Vegetation Index (LVI) development and testing

Candidate metrics were considered for inclusion in the LVI if they were significantly correlated with the HDG (Spearman's *r* >= 0.4 or <= –0.4), the correlation was in the predicted direction, and the metric was not redundant with another metric.

After selecting metrics to be included in the LVI, additional tasks remained before finalizing the details of index calculation. First, we tested for correlation between LVI and lake surface area, latitude and longitude. Second, we used data from the 12 lake sections to compare alternative sampling protocols in order to determine the most efficient method for collecting plant data from a lake. From that analysis we defined the final protocol for the LVI to be based on the average of 4 replicate LVI values from 4 lake sections. Using this version of the LVI, we tested that the patterns of correlation observed in the original 95 lakes were valid, using an independent data set of 63 lakes to test for correlation between LVI and HDG. Finally, we evaluated seasonal differences for 15 lakes with LVI sampling during both spring and summer.

There were numerous choices in how to calculate the LVI from the 12 taxa lists for each lake visit. We used three versions of the LVI for different aspects of index testing and development and denoted the different versions with suffixes. The three versions of LVI were calculated as:

> LVI_1x – one sample from each of 12 sections, N = 12 per lake-visit,
>
> LVI_2x – one sample equals the combination of data from two sections from opposite sides of the lake, N = 6 per lake-visit, and
>
> LVI_12x – one sample per lake derived from the combination of data from all 12 lake sections, N = 1 per lake-visit.

Additional versions of the index could be calculated, for example, by combining data from 3 or 4 lake sections. We did not pursue these other combinations because results for these three versions were so similar. Furthermore, we were interested in the smallest amount of sampling in order to minimize field effort.

For all three versions of the LVI, the index was calculated by first transforming metrics into unit-less scores on the basis of their 5th and 95th percentiles. Leaving out the upper and lower 5% of metric values eliminates extremely high or low values that may not be typical of minimally or extremely disturbed sites. The 95th percentile value was assigned a score of 10 (for metrics that declined with disturbance such as percent native taxa) and the 5th percentile value was assigned a score of 0. For metrics that increased with disturbance, the scores were reversed for the 5th and 95th percentiles. After transformation, metric scores ranged from 0–10. The LVI was the sum of the four metrics multiplied by a constant to adjust the range of LVI to a 0–100 scale. A scale from 0–100 was selected for convenience with the intention of keeping the same scale for all Florida multimetric indices (Hughes et al., 1998).

We used non-parametric correlation to test association between LVI_12x and lake surface area, latitude, and longitude. Because LVI_12X was significantly correlated with latitude as well as HDG, we used multiple regression to evaluate the relationship between LVI_12x and these independent variables. After confirming that human disturbance was the primary correlate for both LVI_12x and its component metrics, we next addressed the question of how many lake sections should be sampled. We evaluated the different versions of the index using two criteria: 1) LVI correlation with human disturbance and 2) the number of categories of biological condition that each version of the index could detect.

We estimated within-lake variability of the different versions of LVI using an ANOVA model. We used lake as the main factor and repeat samples within each lake were defined as replicates and used to calculate the mean squared error (MSE). This estimate of variance was used to calculate a 90% confidence interval for different versions of LVI (Zar, 1984). The confidence interval was calculated as:

$$\mathrm{LVI} \pm \left(\sqrt{\frac{s^2}{n}} * 1.645 \right),$$

where s^2 = variance estimated from ANOVA (mean squared error), and
n = number of samples taken from the lake.

The number of categories of biological condition that LVI can reliably detect was obtained by dividing the possible range of the index (0–100) by the confidence interval. Thus, the confidence interval defined the level of precision of the index by representing how different LVI would have to be during a subsequent lake-visit to conclude that a statistically significant change had occurred in lake condition. That confidence interval was also used to define how many non-overlapping categories of biological condition could be defined over the potential range of LVI. To compare the different versions of LVI, we looked at the number of categories of biological condition each version could reliably detect for different numbers of replicate samples.

We used *z*-values from the normal distribution to calculate 90% confidence limits for LVI for two reasons. First, the distribution of multimetric indices are known to approximate the normal distribution in that they are unimodal and symmetric (Fore et al., 1994). Second, for small sample sizes, the *t*-distribution is appropriate for calculating confidence limits because variance may be underestimated; however, for large sample sizes (df > 30) the two distributions converge. For this data set, data from 95 lakes provided an adequate sample size to apply the normal distribution. An additional concern when estimating variance is that the full range of expected values are represented. LVI values for this data set ranged from 0–100, which included all possible values for the index.

To validate the results based on the development data set of 95 lakes, an additional 63 lakes were sampled in 2004. LVI, HDG, the WQ index, the habitat index and LDI were calculated for these additional lakes and tested for correlation. Fifteen of these lakes were sampled twice during 2004, once during spring (March–April) and again during the summer (July–August).

Expectations for statistical correlation

The statistical significance of a correlation coefficient (*r*) is a function of the sample size, such that for larger sample sizes a smaller correlation coefficient will be significant. For large data sets, e.g., N = 100, a correlation coefficient of 0.17 will be statistically significant (alpha = 0.05, 1-sided test). Such a small correlation coefficient may be statistically significant but biologically not very meaningful. Consequently, before correlation testing is complete, a scientist should consider the underlying meaning of correlation coefficients and what values represent biological significance.

Based on these considerations, we selected specific values for correlation coefficients that would represent a meaningful association depending on which relationship was being tested. We used a correlation coefficient for metrics > 0.4 to define a significant relationship with HDG, then further evaluated each metric by looking at scatter plots. Thus, for metric selection, a higher standard was set than simple statistical significance. For metric correlation with the HDG, we anticipated that the variability associated with HDG and the inherent difficulty involved in fully assessing human influence would mean that high correlation coefficients (e.g., > 0.7) would be unlikely. On the other hand, correlation coefficients < 0.4, though they may be statistically significant, tend to be unconvincing when graphed.

Using graphs, we tested to be sure that the lack of correlation was not due to good metric values in sites where human disturbance was known to be high. In contrast, we tolerated poor metric values in sites with no known disturbance because the HDG does not include many potential sources of degradation (e.g., herbicides).

To test for metric redundancy, we first screened metrics to determine whether a metric pair's correlation was greater than 0.8. We expected metrics to be highly correlated with each other because they were initially selected for their correlation with the same underlying measure, the HDG. When selecting metrics for the LVI, we wanted to be sure that the metrics were not redundant in that they were derived from the same information (species). If a metric pair was highly correlated, we evaluated the metrics to determine whether the same taxa were used in calculation of both metrics. When metrics were derived from redundant information, one metric in each pair (or group) was selected on the basis of its correlation with HDG, biological meaning, and sensitivity to degradation.

When testing for correlation between biological measures (LVI and its component metrics) and physical measures (lake surface area, latitude, and longitude), we were less tolerant of correlation. For this analysis, any statistical significant correlation was considered because we were concerned that underlying natural features or processes could bias the biological assessment of LVI. We wanted to be sure that smaller lakes, for example, did not consistently score lower for LVI for the same level of human disturbance. Thus, in different testing situations, different values for the correlation coefficient were selected to indicate a significant association *before testing*.

RESULTS

A total of 404 taxa were identified from the 95 lakes in the index development data set. Most plants were identified to species, in some cases plants were identified to genus (e.g., *Bidens*, *Cyperus*, *Ludwigia*, *Panicum*, *Xyris*), and in a very few cases to family. The number of taxa identified in a lake based on the combination of data from all 12 sections ranged from 13–57, with an average of 34 taxa. The number of taxa found in a single lake section (1 of 12) ranged from 1–44 with an average of 15 taxa (Kell-Air and Karick Lakes had the lowest value of one taxon in a section and Lake Juliana had 44 taxa in one section).

Human disturbance gradient

The HDG was highly correlated with its component measures, indicating that HDG effectively integrated site condition for all three component measures (Table 4). Overall, each individual measure of human disturbance was more highly correlated with the HDG than with other measures, suggesting that the HDG was a better measure of general human disturbance. Hydrologic condition was not tested for correlation because it had only two possible values. The WQ and habitat indices were also highly correlated with each other, as were the habitat index and the LDI. In contrast, the WQ index was not significantly correlated with LDI, indicating that land use was not a good predictor of water quality condition for this data set. When only sites with no missing values for water quality variables were tested for correlation, values for the correlation coefficient changed little (< 0.04).

Table 4. Correlation for measures of human disturbance and the HDG, only significant correlations are shown (Spearman's *r*, p < 0.01). Index values were tested for correlation using their original values, not the scores (0, 1, 2) used to calculate the HDG.

	HDG	**WQ index**	**Habitat index**	**LDI**
HDG		0.62	-0.87	0.73
WQ index	0.62		-0.46	
Habitat index	-0.87	-0.46		-0.69
LDI	0.73		-0.69	

Because the WQ index and LDI were not highly correlated, we tested whether soil type could explain the lack of correlation (Florida GIS coverage STATSGO soils). Some soils are more porous than others and for lakes in porous soils, chemicals or pollutants may run into the soil rather than run off the surface and into the lake. Lakes surrounded by non-porous soils may have higher levels of chemicals. We used a nonparametric two-sample test to check for differences in the WQ index, conductivity, NH_3, TKN, NO_x, TP, orthophosphates (OP), chloride, and sulfate. Conductivity, TP, and TKN were significantly higher in lakes with non-porous soils (Mann-Whitney U test, 1-sided, $p < 0.05$; Table 5). NO_x was significant, but not in the direction predicted, values were lower in lakes with non-porous soil. Though statistically significant, the differences between levels of chemical measures in porous and non-porous soils were probably not large enough to explain the lack of correlation between the WQ index and LDI.

Table 5. Water quality measure, and statistics from Mann-Whitney U test including rank sums for non-porous (NP) and porous (P) soils, U-statistic, z-statistic, sample size (N), and p-value. Significantly different measures are marked with an *.

WQ measure	**Rank Sum NP**	**Rank Sum P**	**U**	**Z**	**N (NP)**	**N (P)**	***p***
WQ index	1901.0	2285.0	959.0	0.49	40	51	0.31
* Conductivity	2070.5	2024.5	749.5	2.03	40	50	0.02
* TKN	1662.0	1824.0	648.0	1.77	35	48	0.04
NOX	1294.0	2361.0	591.0	-2.63	37	48	0.00
* TP	1972.5	1855.5	630.5	2.57	38	49	0.01
AGP	1273.5	1576.5	678.5	-0.20	34	41	0.42
OP	564.0	517.0	264.0	0.00	24	22	0.50
NH3_N	1624.5	2203.5	883.5	-0.41	38	49	0.34
Chloride	371.0	532.0	181.0	0.70	16	26	0.24
Sulfate	390.0	513.0	162.0	1.19	16	26	0.12

Metric selection

Many candidate metrics were tested and relatively few were strongly correlated with HDG or consistently correlated with the other measures of human disturbance. Of the 65 metrics tested for correlation with HDG, only 10 had an *r*-value > 0.4 (or < –0.4; Table 6). Because many of these metrics were redundant, a total of four metrics were selected for the final multimetric index. In general, if a candidate metric was correlated with HDG when calculated as number of taxa, it was also correlated with HDG when calculated as percentage of total taxa. In addition, if a candidate metric was correlated with HDG, it was typically correlated with at least two of the other measures of disturbance.

Overall, the metrics that measured the numbers of native and exotic taxa and metrics derived from CC values were the most consistently associated with human disturbance. Within specific metric categories, results for individual metrics tended to be similar. Of the three metrics related to community structure, only dominant C of C (defined as the CC score for the one or two plants that covered the greatest area) was significantly correlated with HDG and was included in the index. A total of 63 taxa were identified as dominant in at least one lake section. Of these 63 taxa, about 1/3 were identified only once and about 1/3 were identified >10 times as dominant (Table 7). Total number of taxa and the total number of growth forms were not correlated with HDG.

Of the four metrics related to nativity, all were significantly correlated with HDG, but the three based on exotic taxa were redundant. Category I and II invasives represented a subset of the exotic taxa. We retained percent invasive taxa for the LVI because invasive taxa represent a significant economic concern and an objective threat to native plant assemblages. We calculated this metric as a *percentage* of total taxa rather than total number of taxa because this form of the metric was less affected by geographic factors such as latitude. We also included percent native taxa in the index, which was only significantly associated with HDG when calculated as a percentage of total taxa.

Table 6. Candidate plant metrics and their correlation with HDG, the WQ index, LDI, and the habitat index. Only Spearman's correlations >0.40 are shown ($p < 0.001$). The sample size is shown for all metrics except dominant C of C for which N ranged from 57–65. Most metrics were calculated as both the total number of taxa and the percentage of total taxa (left vs. right side of table); exceptions to this were metrics in the category "Community structure" which could only be calculated in one way. The source of information for each metric is listed. Similar metrics calculated from the national EPA database are also shown (Adamus and Gonyaw, 2000). Metrics selected for the final index are marked ("*").

	Number of taxa				**Percent of total taxa**				
	HDG	**WQ**	**LDI**	**Habitat**	**HDG**	**WQ**	**LDI**	**Habitat**	**Source**
N =	**95**	**95**	**93**	**90**	**95**	**95**	**93**	**90**	
Community structure									
Total taxa					–	–	–	–	FDEP
No. of plant guilds					–	–	–	–	FDEP
* Dominant C of C	-0.52	-0.43		0.49	–	–	–	–	FDEP
Nativity									
* Native					-0.56	-0.46	-0.53	0.64	FDEP
Exotic	0.55	0.50	0.45	-0.48	0.63	0.51	0.61	-0.65	FDEP
Category 1	0.56	0.44	0.48	-0.50	0.58	0.43	0.58	-0.58	FLEPPC
* Categories 1 & 2	0.59	0.51	0.49	-0.53	0.62	0.48	0.60	-0.62	FLEPPC
Tolerance									
FQI Score	-0.52	-0.32	-0.54	0.57	–	–	–	–	FDEP
Average CC	-0.67	-0.49	-0.59	0.63	–	–	–	–	CC
* Sensitive (CC > 7)	-0.40		-0.41	0.46	-0.49	-0.44	-0.41	0.48	CC
Tolerant (CC < 3)	0.48				0.67	0.42	0.60	-0.59	CC
V. Tolerant (CC < 2)	0.51	0.40		-0.40	0.65	0.41	0.59	-0.59	CC
Duration									
Perennial									FDEP
Annual									FDEP
Annual:Perennial ratio									FDEP
Native A:P ratio									FDEP
Native perennials									FDEP
Native annuals									FDEP
Wetland status									
Obligate wetland									FDEP
Obligate + facultative									FDEP
Upland									FDEP
Native obligate wetland									FDEP
Native facult. wetland									FDEP
Native upland									FDEP
Growth form									
Herbaceous									FDEP
Woody									FDEP
Emergent									FDEP
Floating									FDEP
Submersed									FDEP
Fern									FDEP
Gymnosperm									FDEP

	Number of taxa				Percent of total taxa				
	HDG	**WQ**	**LDI**	**Habitat**	**HDG**	**WQ**	**LDI**	**Habitat**	**Source**
N =	**95**	**95**	**93**	**90**	**95**	**95**	**93**	**90**	
Native herbaceous									FDEP
Native woody			-0.48						FDEP
Native emergent									FDEP
Native floating									FDEP
Native submersed									FDEP
Native fern									FDEP
Native gymnosperm									FDEP
Native forbs + herbs									FDEP
Native graminoids									FDEP
Native vines									FDEP
Native shrubs	-0.44		-0.52	0.48			-0.41		FDEP
Native subshrubs									FDEP
Native tree									FDEP
Dicot/monocot									
Dicot									FDEP
Monocot									FDEP
Native dicot			-0.40						FDEP
Native monocot									FDEP
EPA database									
Sensitive									EPA
Tolerant									EPA
V. Tolerant									EPA
Nutrient tolerant									EPA
V. Nutrient tolerant									EPA
N tolerant									EPA
P sensitive									EPA
P tolerant								-0.41	EPA
Flood sensitive			-0.40						EPA
Flood tolerant								-0.43	EPA
V. Flood tolerant									EPA
Sediment sensitive	*0.40*								EPA
Sediment tolerant	*-0.40*			*0.43*	*-0.41*		*-0.40*	*0.41*	EPA
V. Sediment tolerant									EPA
Salinity sensitive									EPA
Salinity tolerant									EPA
V. salinity tolerant									EPA

Table 7. List of plant taxa that were most frequently identified as the dominant (or co-dominant) taxon in a lake section. Shown are the number of times the taxon was named dominant (or co-dominant) out of 786 occasions when dominant taxa were noted and CC score for that taxon.

Taxon	**Number of times**	**CC score**
Panicum repens	169	0
Panicum hemitomon	164	5.82
Typha domingensis	37	0.59
Nuphar luteum	32	4.64
Typha latifolia	32	1.6
Mayaca fluviatilis	27	8.45
Hydrilla verticillata	26	0
Panicum	20	
Taxodium ascendens	19	7.21
Ludwigia octovalvis	17	4.09
Nymphaea odorata	17	7.18
Vallisneria americana	17	7.28
Eichhornia crassipes	16	0
Cladium jamaicense	12	9.04
Fuirena scirpoidea	12	6.5
Hypericum fasciculatum	12	7.27
Hypericum lissophloeus	11	

Of the five metrics related to tolerance and sensitivity, all were significantly correlated with HDG. FQI score and average CC represented a general measure of overall tolerance, while the number (or percentage) of tolerant or sensitive taxa represented opposite ends of the spectrum. The general metrics that summarized sensitivity (or tolerance) of the entire plant assemblage were redundant with the more specific metrics that measured either tolerance or sensitivity. Of these, we selected the more specific metric, percentage sensitive taxa, for inclusion in the index. Other studies have found that metrics related to sensitive or intolerant taxa are the first to register changes in an assemblage when human disturbance is introduced into new locations (Karr and Chu, 1999). We did not include percent tolerant taxa in the index because many of the same plant taxa were also included in the invasive or exotic metrics.

Other candidate metrics related to duration of life cycle, wetland status, and number of cotyledons were not correlated with HDG. Similarly, candidate metrics based on growth form or type were not correlated with HDG, with the exception of one metric, number of native shrub taxa, which was significantly correlated with HDG, LDI and the habitat index. This metric was not included in the final index for two reasons. First, very few shrub taxa are typically found at a lake and, second, of these few, some are indicators of disturbed conditions (e.g., *Baccharis* and *Sambucus*).

The candidate metrics derived from the EPA database failed to correlate predictably or consistently with HDG or other measures of disturbance. The sediment sensitive and sediment tolerant metrics were significantly correlated with HDG but in the opposite direction predicted, and so were not retained for the index.

Of the metrics correlated with HDG, *r*-values were generally higher when calculated as percentage of total taxa rather than as number of taxa, probably because the total number of taxa varied as a function of other natural features and calculation based on a percentage of total taxa controlled for that source of variability.

The four metrics included in the LVI were all significantly correlated with each other, as expected, but correlation coefficients were not high enough to warrant concerns regarding redundancy of metrics. Correlation coefficients were < 0.8 (or > -0.8) for all metrics. More importantly, the metrics were based on different sets of taxa with minimal overlap.

The four metrics selected for inclusion in the LVI, percent native taxa, percent invasive taxa, percent sensitive taxa and dominant C of C, were correlated with HDG and its component measures (Figures 3–6). Both percent invasive taxa and dominant C of C showed regional differences in the panhandle and peninsula, and metric scores were adjusted for percent invasive taxa by calculating the 5th and 95th percentiles separately for each region. Metric scoring for dominant C of C was not adjusted for region, but should be reconsidered as more data become available. Dominant C of C had three lakes with values that were outliers, that is, dominant C of C was high in three lakes that also had high values for HDG. For these lakes, dominant plants with high CC scores were *Panicum hemitomon* (CC = 5.82) and *Vallisneria americana* (CC = 7.28).

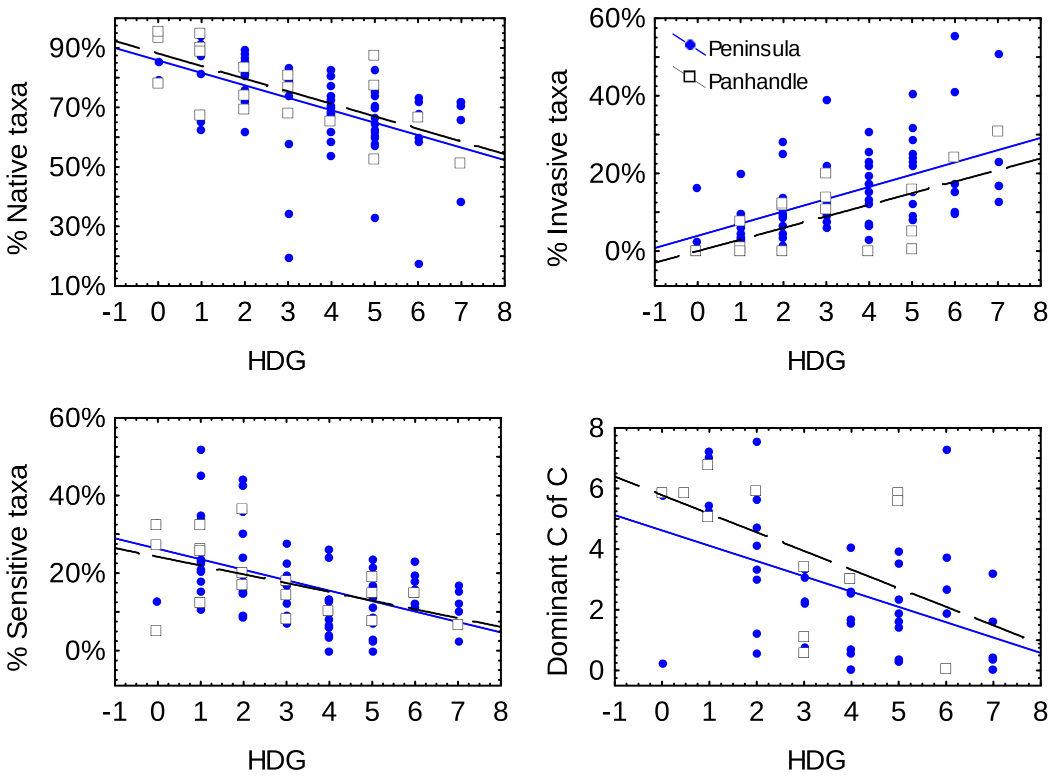

Figure 3. Metrics selected as components of LVI were strongly correlated with the human disturbance gradient (HDG). Percent invasive taxa and dominant C of C differed slightly in the peninsula and panhandle for the same values of HDG. Each point represents a single lake; lines are least fit regression lines for each geographic area. Four lakes from the NE region are not shown.

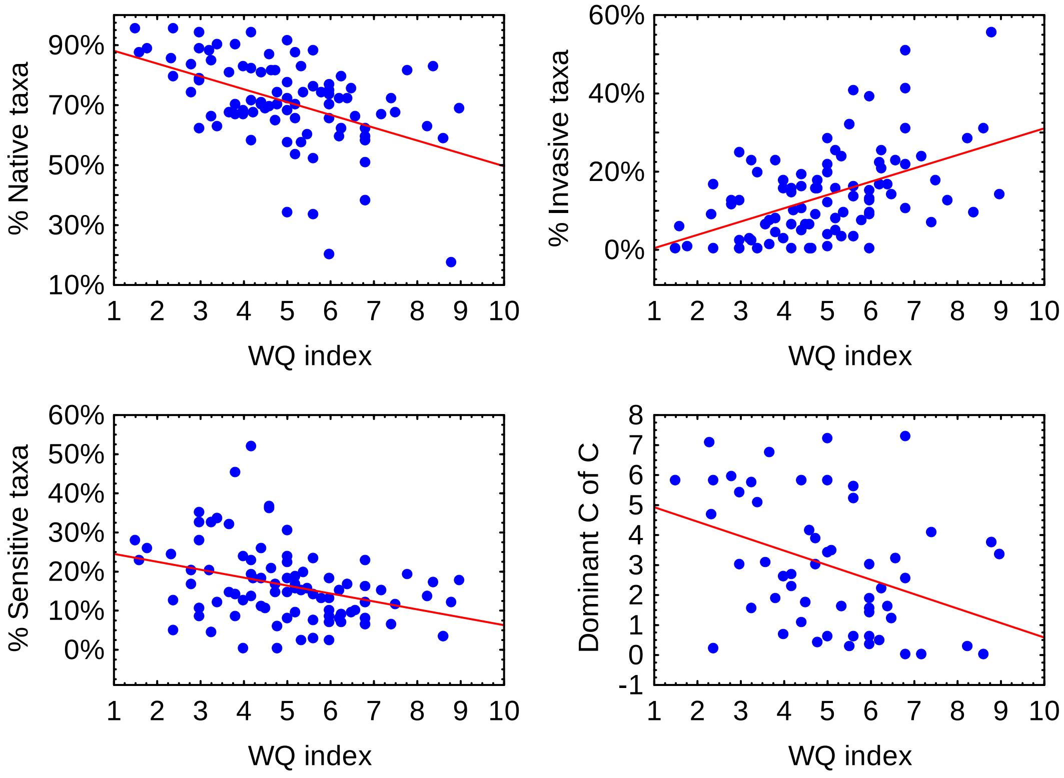

Figure 4. LVI metrics were highly correlated with the water quality index. Each point represents a single lake.

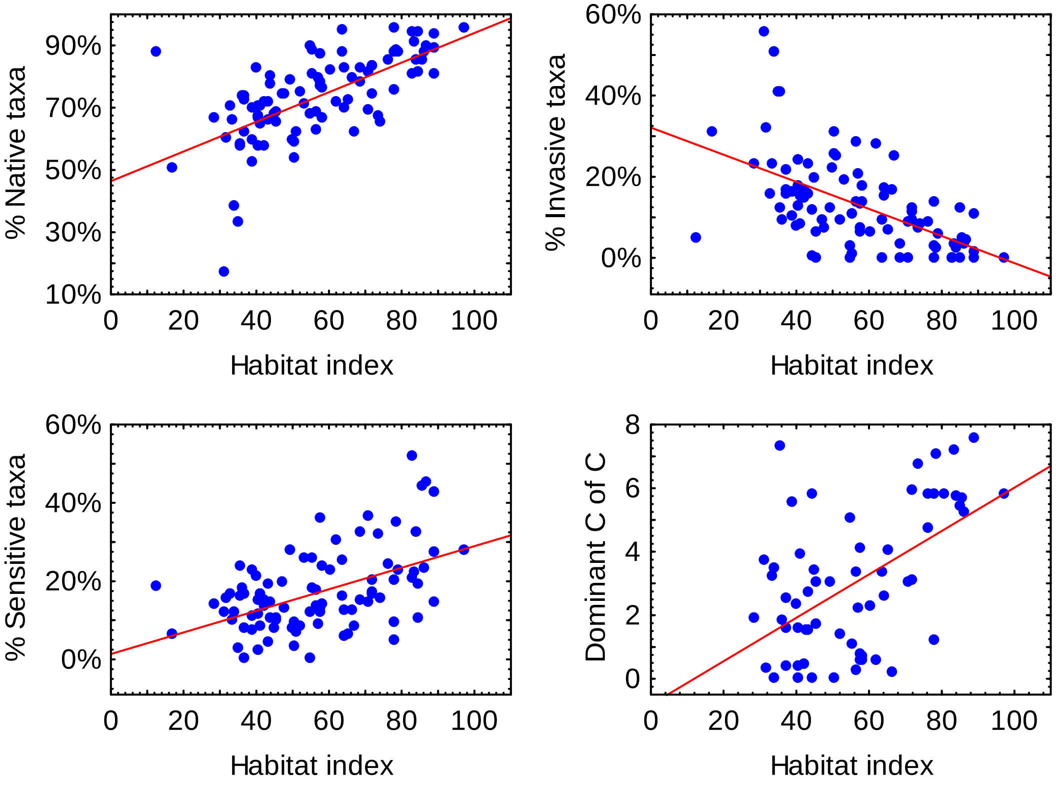

Figure 5. LVI metrics were highly correlated with the habitat index. Each point represents a single lake.

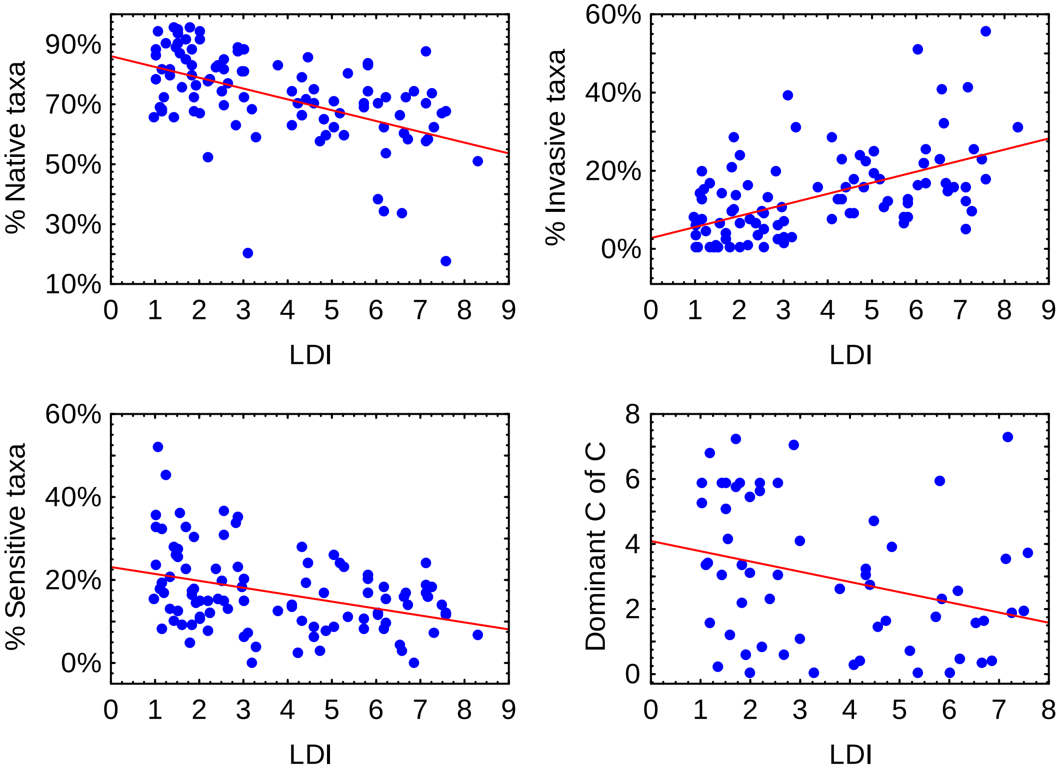

Figure 6. LVI metrics were highly correlated with the LDI index. Each point represents a single lake.

Sensitive and tolerant taxa

Of the 404 taxa found in 95 lakes, 62 were defined as sensitive (CC score > 7) and 47 as tolerant (CC < 3) based on professional judgment (Cohen et al., 2004). Not all these assignments could be tested using the data from 95 lakes because so many taxa were rare. More than half of the taxa occurred in < 5 lakes (248 out of 404, or 61%). Of the 62 taxa defined as sensitive, 35 (56%) occurred in < 5 lakes; of the 47 tolerant taxa, 19 (40%) occurred in < 5 lakes. These taxa occurred in too few lakes to be tested for their association with HDG.

Of the taxa that occurred frequently enough to test, relatively few (29 of 404, or 7%) showed an association with HDG that was statistically significant (χ^2, $p < 0.05$). Nine sensitive taxa and 11 tolerant taxa were significantly associated with disturbance (Table 8; see Appendix 3 for all taxa). One species, *Vallisneria americana*, was defined as sensitive on the basis of its CC score, but was significantly associated with more disturbed lakes for this data set indicating that this taxon may be incorrectly defined for lakes. In general, most of the other taxa that showed a statistically significant association with HDG agreed with their CC scores in terms of their preference for undisturbed or disturbed conditions.

Although statistically significant, the preferences for ‘good’ or ‘poor’ lakes were not strong in several cases. For example, *Cephalanthus occidentalis* showed a significant preference with 25 out of 51 occurrences in ‘good’ sites although the preference represented only 49% of its occurrences. From a statistical point of view, the association may be better than chance (which was equal to 38% of occurrences at good sites); however, from a biological point of view, 51% of its occurrences in ‘poor’ sites does not indicate a sensitive species. For this reason, a similar analysis of macroinvertebrates in streams set the criteria for defining sensitive taxa much higher (87% of occurrences in good sites) than statistical significance (Fore, 2004).

We continued to use the sensitive and tolerant taxa lists derived from the panel of expert botanists rather than define a list based on the results of this statistical analysis for two reasons. First, most of the taxa were too rare to test with these data. In addition, the statistical analysis for these data yielded too few taxa to define reliable metrics for sensitive or tolerant taxa.

Table 8. Taxa that were significantly associated with low or high HDG (χ^2, $p < 0.05$). Shown are taxon name, CC value, whether the taxon was identified as sensitive or tolerant based on CC value, number of lakes in which taxon was found out of 95 lakes, number of occurrences in 'good' lakes (HDG < 3) and 'bad' lakes (HDG >= 3), proportion of total occurrences in good lakes, and whether the direction of taxon preference agreed with the CC value.

Taxon	**CC**	**Sens/Tol**	**# Occur**	**# Good**	**# Bad**	**%Good**	**Agree**
Vallisneria americana	7.28	S	18	2	16	0.11	**no**
Cephalanthus occidentalis	7.27	S	51	25	26	0.49	yes
Cladium jamaicense	9.04	S	22	15	7	0.68	yes
Decodon verticillatus	7.8	S	12	10	2	0.83	yes
Hypericum fasciculatum	7.27	S	13	10	3	0.77	yes
Lyonia lucida	7.06	S	8	7	1	0.88	yes
Mayaca fluviatilis	8.45	S	19	12	7	0.63	yes
Nymphaea odorata	7.18	S	43	22	21	0.51	yes
Triadenum virginicum	8.16	S	17	11	6	0.65	yes
Alternanthera philoxeroides	0	T	49	10	39	0.20	yes
Brachiaria mutica	0	T	18	2	16	0.11	yes
Colocasia esculenta	0	T	40	7	33	0.18	yes
Cyperus surinamensis	2.03	T	14	1	13	0.07	yes
Hydrilla verticillata	0	T	19	1	18	0.05	yes
Ludwigia peruviana	0.62	T	42	10	32	0.24	yes
Mikania scandens	1.95	T	65	16	49	0.25	yes
Panicum repens	0	T	73	23	50	0.32	yes
Pistia stratiotes	0	T	15	1	14	0.07	yes
Sapium sebiferum	0	T	21	3	18	0.14	yes
Schinus terebinthifolius	0	T	34	6	28	0.18	yes
Ludwigia alata	5.85		4	4	0	1.00	unk
Nymphoides aquatica	6.09		17	13	4	0.76	unk
Utricularia purpurea	6.5		7	6	1	0.86	unk
Cabomba caroliniana	5.07		9	7	2	0.78	unk
Cyperus odoratus	4.25		27	3	24	0.11	unk
Lachnanthes caroliana	3.76		24	16	8	0.67	unk
Scirpus cyperinus	na		4	4	0	1.00	unk
Solidago	na		17	12	5	0.71	unk
Utricularia	na		18	11	7	0.61	unk

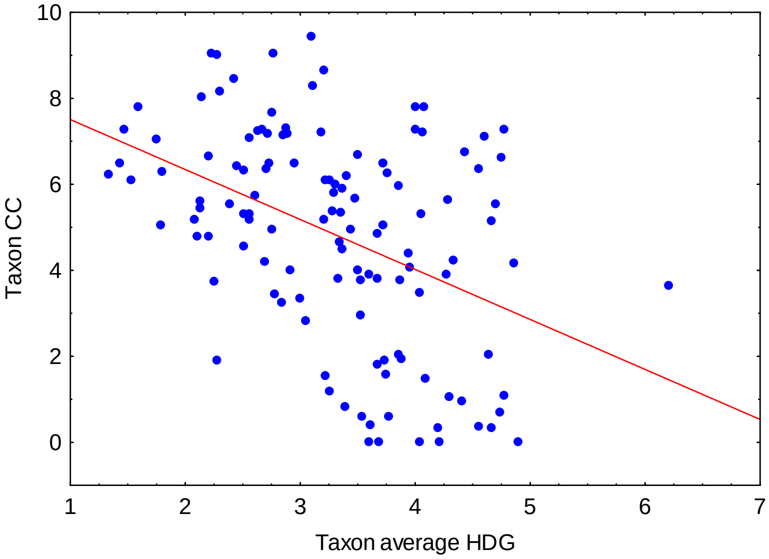

Figure 7. Plant CC value declined as the average HDG for the lakes at which a taxon was found increased (Spearman's r = -0.42, $r^2 = 0.18$, $p < 0.01$, N = 123 taxa). Shown are results for taxa with >4 occurrences in 95 lakes.

Cohen et al. (2004) describe another approach for comparing field data with CC scores. For each taxon, they calculated the average LDI value for all the sites at which the taxon was found. We followed their approach using HDG instead of LDI. We averaged the HDG values for each lake in which a particular taxon was found. We compared the average HDG values for each taxon with the CC score for each taxon and found that they were significantly correlated (Spearman's r = –0.42, N = 123 taxa, $p < 0.01$). Although statistically significant, the agreement between the CC values based on expert opinion and the average HDG value at all sites in which a taxon was found was not close ($r^2 = 0.18$; Figure 7).

Evaluation of the Lake Vegetation Index (LVI)

The following sections describe results for 1) correlation analysis of LVI with human disturbance and other natural geographic features; 2) selection of the most efficient lake sampling protocol; 3) validation of LVI using an independent data set; 4) description of lakes with higher or lower LVI values than predicted by the HDG (outliers); and 5) a comparison of

LVI values for lakes sampled during spring and summer. We compared different versions of LVI using different numbers of lake sections and selected a final protocol based on LVI calculated from 4 lake sections from opposite sides of the lake.

Correlation of LVI with human disturbance and natural features

For this initial testing of LVI, plant data from all lake sections were combined to obtain a single LVI for each lake (LVI_12x). We anticipated that correlations with natural features might be subtle and our goal was to use the most accurate LVI for this testing. (Subsequent analyses based on smaller numbers of lake sections revealed index values differed little according to the number of sections used in calculations.) LVI_12x was highly correlated with HDG and was more highly correlated with HDG than other measures of human disturbance indicating the value of the HDG as an integrated measure of disparate types of human disturbance (Table 9; Appendix 4). LVI_12x was not correlated with lake size (surface area), which meant that adjustments to metric scoring based on lake size were not necessary. LVI_12x was not significantly correlated with longitude, but was correlated with latitude, probably because the HDG was also correlated with latitude.

Table 9. Correlation coefficients for LVI_12x and measures of human disturbance, lake area, latitude and longitude. Non-significant correlations indicated by parentheses (Spearman's *r*, $p < 0.01$).

	HDG	WQ index	Habitat index	LDI	Area	Latitude	Longitude
N =	95	87	90	93	76	95	95
LVI_12x	-0.68	-0.46	0.69	-0.62	(0.03)	0.35	(0.06)

The significant correlation between LVI_12x and latitude triggered a more detailed analysis between these variables to ensure that human disturbance was the primary cause of changes in LVI values and not spurious correlation with other natural features. We used multiple regression to test for significant associations between LVI_12x and HDG, lake surface area, and latitude (the independent variables) simultaneously. We also tested each of LVI's component metrics separately for association with the same independent measures to identify any confounding relationships among the metrics.

LVI_12x was significantly correlated with HDG but not with area or latitude when all three were included in a multiple regression model. Of the four metrics, only percent invasive taxa was significantly associated with both latitude and HDG; the other three were only significantly associated with HDG (Table 10). Adjustments to the metric scoring for panhandle and peninsula areas helped to resolve the underlying correlation with geographic location for the final LVI.

Multiple regression assumes that the independent variables (area, latitude, and longitude) are independent and not correlated. For this analysis, HDG and latitude were significantly correlated (Pearson's $r = 0.3$, $p < 0.01$). Correlation among independent variables in a multiple regression model can result in unstable solutions or inconsistent results. Correlation among independent variables is difficult to avoid in regional surveys such as these because human land use typically follows geographic gradients. Nonetheless, the consistent high correlation between LVI_12x and its component metrics with HDG and consistent exclusion of latitude and area from the model solution supports the conclusion that HDG was the primary source of variance in LVI.

Table 10. Standardized regression coefficients from multiple regression. Each row represents a different statistical test for each biological measure. Column variables were entered in each model and only coefficients for significant predictors are shown. Only 76 lakes had information for lake surface area.

Biological measure	N	HDG	Latitude	Area
LVI_12x	76	-0.68		
% Native taxa	76	-0.50		
% Invasive taxa	76	0.49	-0.28	
% Sensitive taxa	76	-0.50		
Dominant C of C	50	-0.62		

Variability analysis of alternative lake sampling protocols

As expected, the total number of species increased as the number of lake sections increased from 1–12 (Figure 8). The percentage of the total taxa collected increased steadily, but an obvious asymptote was not achieved. About half the taxa found in all 12 sections were found within a single section when results were averaged across all 100 lake-visits (95 lakes with 5 lakes visited twice; Table 11). For eight sections, 92% of the taxa (on average) were found. Results from this analysis of species accumulation failed to identify an obvious asymptote for a particular number of sections that could be used to define the minimum sampling effort for lake assessment and LVI calculation. Therefore, we looked at the variability of LVI derived from different sampling protocols to define how many lake sections should be sampled during each visit.

Table 11. The cumulative number of sections sampled per lake-visit, the proportion of the total taxa found for a given number of sections (averaged across all lake-visits), and the number of lake-visits that attained the maximum number of taxa found in all 12 sections for each number of sections sampled.

Number of sections	1	2	3	4	5	6	7	8	9	10	11	12
Mean of prop. of taxa	0.49	0.62	0.70	0.76	0.81	0.86	0.89	0.92	0.95	0.96	0.98	1.00
Number achieve max	0	0	0	2	5	6	9	13	21	41	62	100

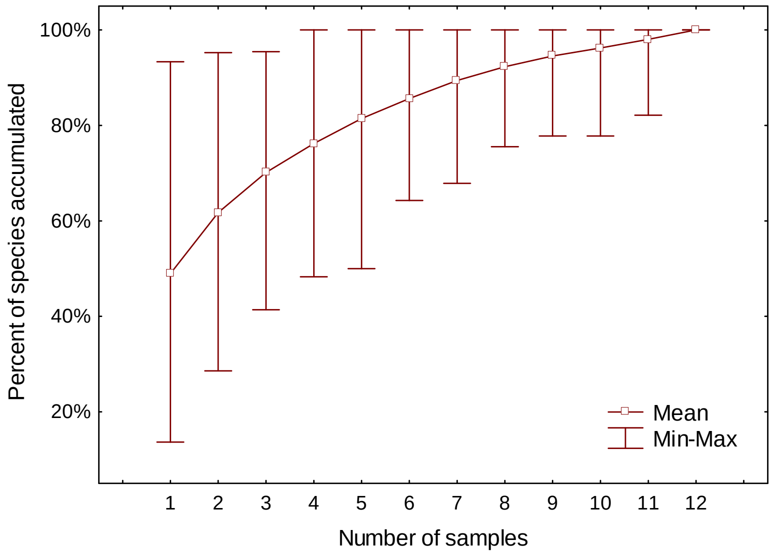

Figure 8. Number of species increased as the number of lake sections sampled increased from 1–12. Averaged across all lakes, 49% of the taxa found in all 12 sections were found in one section. For two sections, 62% of the total taxa were collected.

Variance estimates for LVI were derived from ANOVA with lake as the main factor and replicate samples in a lake used to calculate the within-lake variability (mean squared error). We calculated variance for two versions of the LVI: 1) treating each of the 12 lake sections as individual replicates (LVI_1x), and 2) combining data from two lake sections on opposite sides of the lake, which yielded a total of 6 replicates per lake (LVI_2x). Within lake variance for LVI_1x was ~50% greater than variance calculated for LVI_2x (Table 12). We used the variance estimates for both versions of LVI to calculate confidence intervals. We divided the possible range of the LVI (0–100) by the confidence interval to obtain the number of categories of biological condition that each version of the index could detect.

If data were collected from a single lake section and LVI_1x calculated, 2.9 categories of biological condition could be detected. If two replicate samples of this type were collected, 4.1 categories could be detected. For LVI_2x, if a single sample were collected (representing a composite of data from two lake sections), 3.6 categories could be detected; if two samples of this type were collected, 5.1 categories of condition could be detected. The two different sampling approaches yielded similar levels of precision for an equivalent number of lake sections (Figure 9). Two composite samples equals four single samples in terms of field effort, and the two field methods yielded a similar number of categories: 5.7 vs. 5.1 (for LVI_1x vs. LVI_2x).

Table 12. Two versions of the LVI, their variance estimates (MSE) for within lake sampling, and the number of categories of biological condition that could be detected for 1–6 replicate samples. Results are shown for two versions of the LVI calculated for 1) single section samples (LVI_1x) and 2) composite samples derived from two lake sections (LVI_2x).

Index version	**Variance**	**Number of replicate samples**					
		1	**2**	**3**	**4**	**5**	**6**
LVI_1x	112.33	2.87	4.06	4.97	5.74	6.41	7.02
LVI_2x	70.20	3.63	5.14	6.29	7.27	8.12	8.90

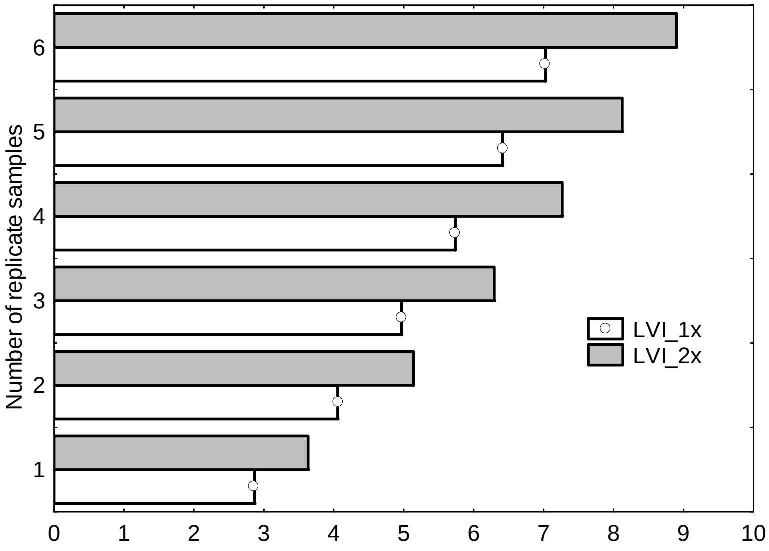

Figure 9. The number of categories of biological condition that can be reliably detected increased as the number of replicate samples within each lake increased from 1 to 6. Shown are results for two versions of the LVI based on samples from a single section (LVI_1x) and composite samples composed of two lake sections (LVI_2x).

In addition to evaluating the statistical precision, we also tested whether LVI derived from more lake sections was more highly correlated with HDG. In fact, correlation coefficients were very similar for the three versions of LVI and for its component metrics (Table 13). Thus, correlation with HDG did not improve with larger sample sizes (i.e., greater field effort), even though the single sections had only half as many taxa as the composite samples based on data from 12 lake sections. These results demonstrate that an exhaustive sample of all the plants in the lake is not needed and that a consistent sample of a small subset of the plants present will provide a reliable assessment of the plant assemblage. Based on these results, we selected the LVI_1x version of the index for lake assessment. LVI_1x had a unimodal and fairly symmetric distribution for the lakes in this data set (Figure 10).

Table 13. Correlation with HDG for LVI and its component metrics for three different sampling methods (Spearman's *r*, $p < 0.01$).

Sampling method	LVI	% Native taxa	% Invasive taxa	% Sensitive taxa	Dominant C of C
N =	**95**	**95**	**95**	**95**	**62**
1x	-0.70	-0.62	0.60	-0.49	-0.48
2x	-0.70	-0.59	0.61	-0.48	-0.48
12x	-0.68	-0.56	0.62	-0.49	-0.48

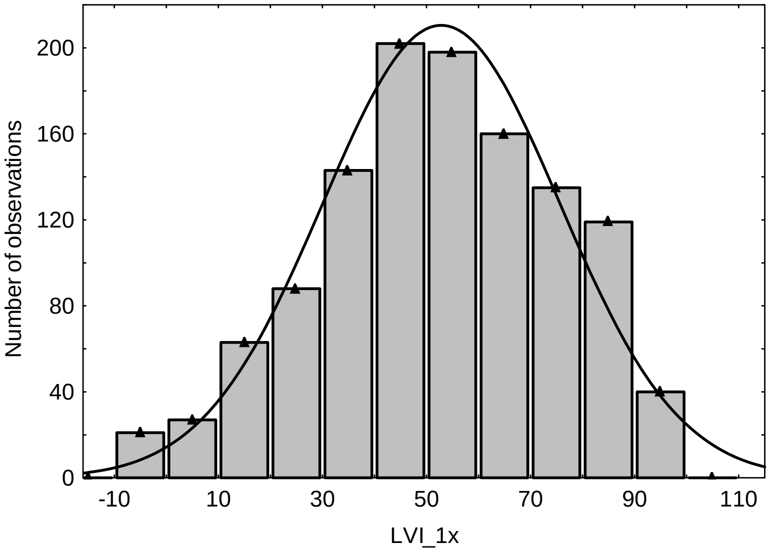

Figure 10. Distribution of LVI_1x for 12 replicate samples from 95 lakes. Curved line represents the normal distribution.

We used replicate samples of LVI_1x to test whether index values were more variable in larger lakes than smaller lakes and found that they were not. In contrast, within-lake variance of LVI_1x was higher in lakes with more human disturbance as measured by HDG (Spearman's *r* = 0.38).

We also tested whether replicate sampling improved the accuracy of the lake assessment for LVI_1x by averaging different numbers of lake replicates and correlating the average index values with measures of human disturbance. The greatest improvement in correlation occurred for one vs. two lake sections; improvements were incrementally smaller as more lake sections were added to calculate the average LVI (Table 14). These results indicate that four replicate samples of LVI_1x were sufficient to reliably assess a lake.

Table 14. Correlation between LVI_1x and measures of disturbance for different numbers of replicate samples within each lake (Spearman's *r*, N = 95, $p < 0.01$).

Number of reps	HDG	WQ index	Habitat index	LDI
1	-0.60	-0.45	0.65	-0.40
2	-0.65	-0.46	0.70	-0.49
3	-0.66	-0.44	0.70	-0.53
4	-0.67	-0.46	0.69	-0.54
5	-0.66	-0.46	0.69	-0.54
6	-0.66	-0.48	0.68	-0.54
7	-0.67	-0.48	0.68	-0.55
8	-0.68	-0.49	0.68	-0.57
9	-0.69	-0.49	0.68	-0.58
10	-0.69	-0.50	0.68	-0.58
11	-0.70	-0.50	0.69	-0.59
12	-0.69	-0.51	0.68	-0.58

Metric scoring for the LVI

Percent invasive taxa differed slightly in metric values for similar values of HDG in the peninsula and panhandle regions of the state. Metric scores were adjusted to ensure that an equivalent level of human disturbance would translate into a similar LVI value independent of location in the state (Table 15; see also Appendix 6). Several lakes had no information available to calculate dominant C of C. For those lakes, we used the average of three (rather than four) metric scores to calculate LVI.

Table 15. Metric scoring rules derived from the 5th and 95th percentiles. For percentage of taxa metrics, N = 1196 (12 sections in 100 lake-visits – 4 missing sections), but for Dominant C of C, N = 551. For dominant C of C, lakes in the northeast were scored as panhandle lakes. (See Appendix 6 for more recent scoring rules.)

Metric	5th %tile	95th %tile	Scoring rule
% Native taxa	43%	95%	(x – 43)/52
% Invasive taxa	0%	39%	
Panhandle	0%	27%	1 – (x/27)
Peninsula	0%	40%	1 – (x/40)
% Sensitive taxa	0%	41%	x/41
Dominant C of C	0	7.8	x/7.8

Validation of the LVI with independent data

LVI_1x calculated for the 63 independent lakes in the validation data set was highly correlated with HDG (Table 16). Lakes in this data set provided a good test of the LVI because the lakes represented a broad range of site conditions and included all possible values of HDG from 0–7 (Figure 11). LVI was also highly correlated with the habitat index and LDI; correlation was not as high with the WQ index. These results were similar to those observed for the development data set (see Table 9 above; see App. 6 for more recent validation).

The distribution of LVI values vs. HDG does not clearly illustrate the 5 non-overlapping categories of biological condition that the variance analysis predicted. The 5 categories of biological condition represent detectable levels of change for an individual lake. Figure 11 plots LVI values from different lakes with similar values for HDG. In other words, the figure introduces additional sources of variability for LVI associated with the type of disturbance or the intensity of disturbance at a particular lake. Because the “true” value of human disturbance cannot be accurately measured, lakes with *approximately* the same level of disturbance are combined for similar values of HDG.

Table 16. Correlation between LVI_1x and HDG, WQ index, habitat index, and LDI for the validation data set. All correlations were significant (Spearman's *r*, p < 0.01, N = 63).

	HDG	WQ index	Habitat index	LDI
LVI_1x (average of 4 reps)	-0.72	-0.34	0.59	-0.78

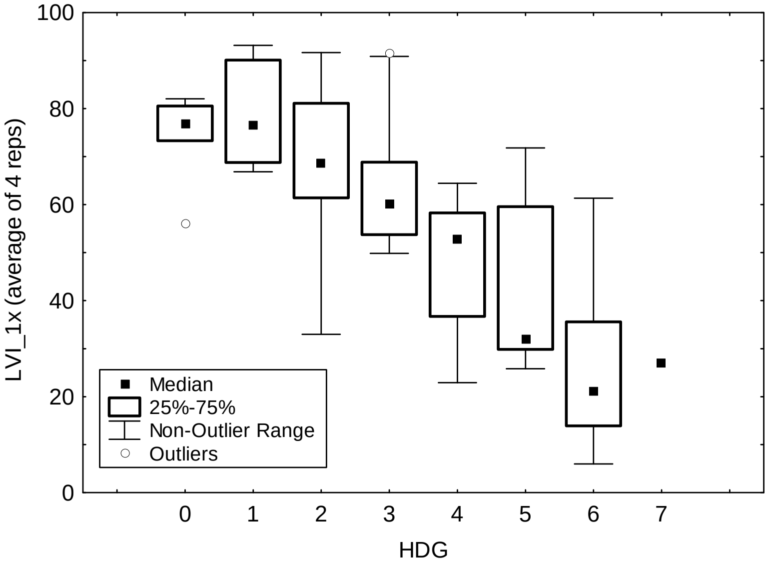

Figure 11. For the validation data set, LVI declined significantly as human disturbance increased (Spearman's r = -0.73, p << 0.01 N = 63). LVI for each lake was calculated as the average LVI from four lake sections.

Description of outliers

Six lakes in the index development data set of 95 lakes had lower LVI values than predicted on the basis of their association with HDG and three lakes had a higher LVI value (Figure 12). For the six lakes that fell below the 90% confidence bound, HDG ranged from 0–5, which represented almost the entire range of possible values (Table 17). These lakes may have other causes of degradation not captured in the HDG used for this study. They may also share some natural feature that lowers the expectation for LVI; several of these lakes were located in the southernmost part of the state. Two of the three lakes with higher LVI than expected were located in the northeast district.

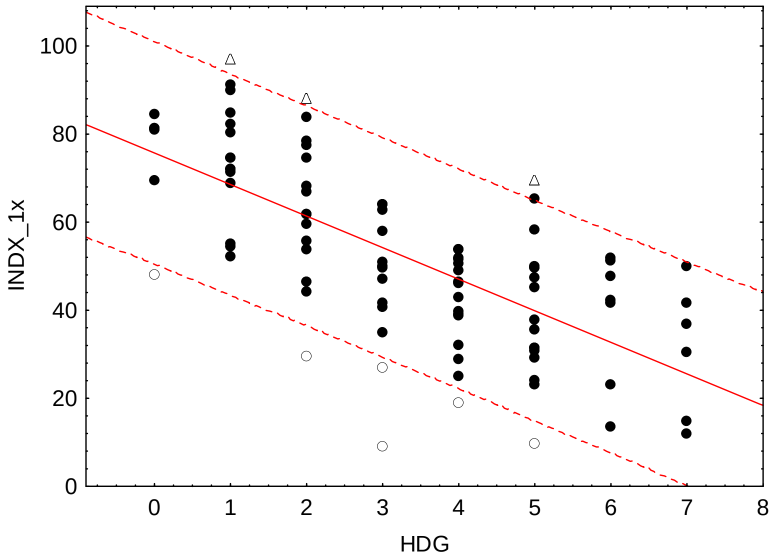

Figure 12. LVI declined as human disturbance increased. The regression line (solid) and the 90% confidence bounds (dotted) are shown, each point represents one lake (N = 95 lakes). Six lakes had lower LVI values than predicted by the HDG (open circles) and three lakes had an LVI slightly higher than predicted (open triangles).

Table 17. Lakes with higher or lower LVI values than expected based on HDG. Shown are the nickname, STORET, observed difference from expectation, region, district, LVI, HDG, WQ index, LDI and habitat index for each lake.

Nickname	STORET	Diff	Region	District	LVI	HDG	WQ index	Hab index	LDI
L84-BANANA	27584418154127	Lower	Peninsula	SW	18.7	4	8.6	50.7	3.3
LKLECLARE	28063598232193	Lower	Peninsula	SW	29.3	2	3.0	67.1	5.1
L51PEAST	24040806	Lower	Peninsula	SW	26.8	3	5.0		6.2
FRANTST	21020056	Higher	Panhandle East	NE	69.4	5	5.2	12.9	7.2
LKHALPATOK	28010594	Lower	Peninsula	SE	47.9	0	2.4	66.4	1.4
LAKEIDA	28010500	Lower	Everglades	SE	9.6	5	5.6	35.0	6.6
LITTLE REF	26010636	Higher	Peninsula	S	87.8	2		89.3	
TANKLAKE	20030151	Higher	Peninsula	NE	96.8	1	4.2	82.9	1.1
L52PWALDEN	24040170	Lower	Peninsula	SW	9.1	3	6.0		3.1

Comparison of spring and summer LVI values

Some lakes had different LVI values in spring vs. summer, but higher LVI values were not consistently associated with one season. LVI for five lakes were higher in spring, five lakes were higher in summer, and five lakes were similar during both seasons (Figure 13). Because LVI was higher in some lakes in spring and lower in others, no consistent seasonal association could be identified and corrected. We could not discern from these data why some lakes were higher in spring and others lower.

The observed differences may have occurred because some plants are easier to identify in the spring due to the presence of flowers or seeds. Looking at the complete list of taxa for all 15 lakes, the number of individual plants that were not identified beyond genus was 8% during the spring vs. 11% during the summer, a relatively small difference. Data from such a small data set may be difficult to interpret; for example, 5 of the 15 sites had no invasive taxa recorded for either season.

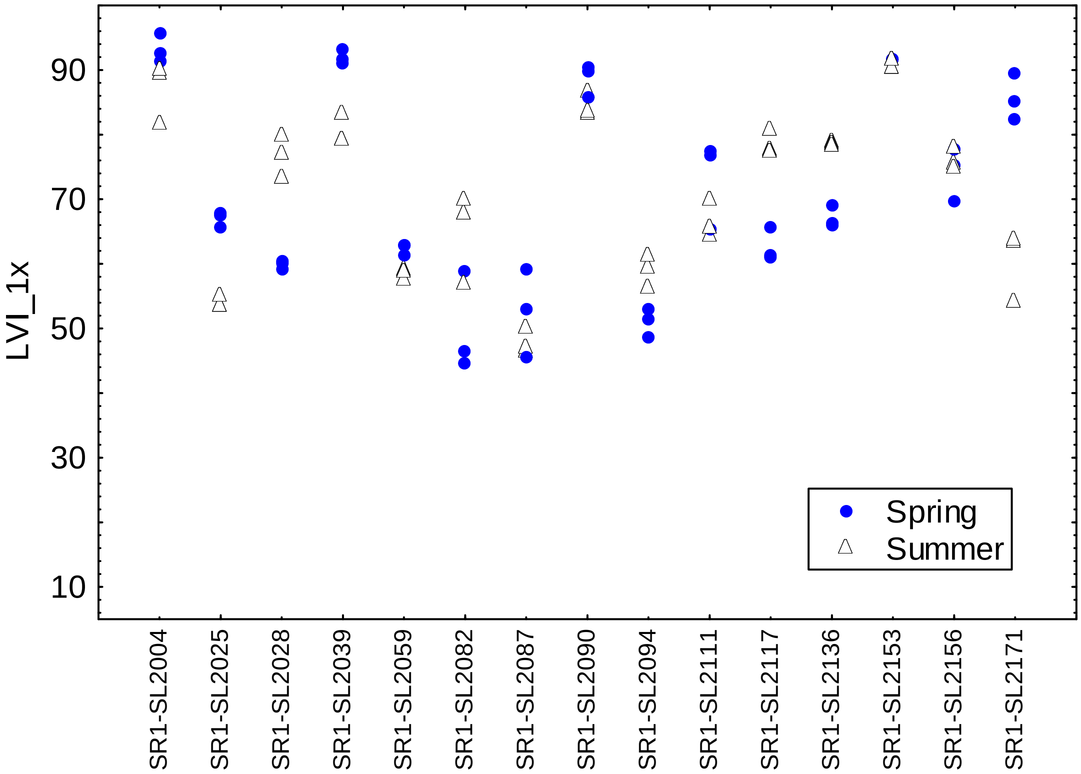

Figure 13. LVI for repeat visits to 15 lakes during the spring (closed circles) and summer (open triangles) of 2004. Each point represents the average LVI from four lake sections. Each lake-visit had three replicate samples of four sections each (4 x 3 = 12 lake sections).

DISCUSSION

When selecting biological measures as indicators of water body condition, two criteria must be considered. First, the indicator must show a consistent and meaningful association with an independent measure of human disturbance (Karr and Chu, 1999). Second, the indicator must be sufficiently precise to detect changes in site condition should a change occur in order to be protective of the resource (Fore, 2003). Metric selection for the LVI was relatively straightforward because so few candidate metrics were reliably correlated with HDG. Those metrics were also highly correlated with the other independent measures of disturbance. The LVI was also precise enough to reliably detect five categories of biological condition based on sampling 4 of 12 possible lake sections.

The LVI was highly correlated with HDG, more so than its component metrics, which illustrates one of the advantages of a multimetric index: the index provides a more integrative assessment of biological condition than a single metric. For multimetric indices, precision typically increases with more metrics, and 7–10 metrics are preferred. Nonetheless, the precision for LVI was quite high with only four metrics. LVI derived from four replicate lake sections had sufficient statistical precision to reliably detect five categories of biological condition. Thus, the LVI was both highly correlated with an independent measure of human disturbance and was very precise for detecting changes in lake condition.

Human disturbance gradient

Human activities influence and degrade aquatic systems in multiple ways including the addition of chemicals and nutrients to the water, destruction and loss of habitat, alteration of natural flow patterns, changes in the way energy moves through the system, and addition or loss of species that change how species interact (Karr et al., 1986; Karr and Chu, 1999; Karr et al., 2000). Information was available from routine lake sampling to characterize water chemistry, habitat condition, hydrologic alteration, and the intensity of human land use around the lake. When developing a human disturbance gradient, the hope is that different measures of human disturbance will be highly correlated and contribute equally to the final HDG.

For this study, only the WQ index and LDI failed to correlate with each other, although both were highly correlated with the final HDG. To test whether the lack of correlation was associated with different types of soils, we compared the WQ index for lakes surrounded by porous soils to those with non-porous soils. The expectation was that porous soils would have lower WQ index values because nutrients and chemicals would percolate through the soil and become trapped before reaching the lake. The WQ index values did not differ according to soil type although three of the five component measures included in the WQ index were higher in non-porous soils. Conductivity, total phosphorus, and total Kjeldahl nitrogen were significantly higher in non-porous soils; however, the differences in values for the two soil types were relatively small and likely could not explain the lack of correlation between LDI and the WQ index. An alternative explanation for the lack of correlation between these two measures of disturbance may be that different types of human activity influence water chemistry in different ways. For example, agriculture may increase nutrients while urban development does not.

The primary benefit derived from using the HDG to test metrics was the opportunity to select metrics that showed a consistent change across a broad range of possible site conditions. An added benefit associated with the HDG was in setting consistent metric expectations for different areas of the state. By adjusting metric scores by region according to HDG, the final LVI had the same relative meaning independent of geographic location.

Biological indicators

Sampling and analysis methods for lake bioassessment are less mature than those for streams or wetlands; consequently, a short list of best metrics has yet to be defined for aquatic plants. Therefore, we approached metric testing as a somewhat exploratory exercise and identified a long list of potential metrics. Although the list of metrics was long, 48 metrics plus an additional 17 metrics derived from the national database (Adamus and Gonyaw, 2000), surprisingly few correlated with HDG. In fact, from a similar long list of candidate metrics tested for wetlands, most of the same metrics were selected based on their correlation with LDI (Lane et al., 2004; Reiss and Brown, 2005).

For LVI, percent native taxa, percent invasive taxa, FQI, percent sensitive taxa, and percent tolerant taxa were highly correlated with HDG. Similarly for forested wetlands, native perennial, exotic, FQI, sensitive, and tolerant species were all highly correlated with LDI and selected for the wetland condition index (WCI, Reiss and Brown, 2005). For herbaceous wetlands, nearly identical metrics were selected for the WCI: percent exotic taxa, average CC, percent sensitive taxa, and percent tolerant taxa (Lane et al., 2004). All of these metrics were also significantly associated with disturbance in lakes for this study. One additional metric, annual/perennial ratio, was significant for wetlands but not for lakes. Lane et al. (2004) noted that although the species composition of wetlands varied between regions, the metrics that were significantly correlated with LDI did not. Results were similar for lakes in this study, and the same metrics were consistently correlated with HDG across the state.

Metric selection for LVI was simple because metrics that were correlated with HDG were also highly correlated with the WQ index, the habitat index, and LDI. Most other candidate metrics failed to correlate with HDG or its component metrics. Thus, the patterns of metric correlation were easy to interpret.

One goal of this study was to test the plant CC designations based on professional experience with field data and the HDG. A fair assessment of the expert designations of plant taxa could not be done with this data set, primarily because plants tended to be rare (61% of the plants occurred in < 5 lakes). Only 29 taxa (7%) were significantly associated with HDG. Because the data were sparse for so many taxa and the lists of sensitive and tolerant taxa derived from the analysis were also very short, we elected to retain the current designations as sensitive or tolerant based on expert definitions of CC values. Empirical data did support the CC designations; average HDG values for the lakes in which each taxon occurred were highly correlated with CC values, indicating that professional judgment was supported by field data.

Statistical precision of the Lake Vegetation Index (LVI)

The most important characteristic of a biological indicator should be its correlation with an independent measure of human disturbance; second in importance is its statistical precision. A statistically precise indicator that fails to indicate disturbance is meaningless for assessment. A third important characteristic of an indicator is the cost associated with sampling, that is, the level of sampling effort needed to obtain a reasonably precise measure of resource condition.

We expected that correlation with HDG would be higher for LVI derived from all 12 lake sections combined (LVI_12x) rather than for LVI based on smaller samples of one or two sections (LVI_1x, 2x), particularly because the percentage of the plants found in a single lake section was only about half the number found in all 12 sections. In fact, correlation with HDG was very similar for the different versions of LVI. These results indicated that a smaller sampling effort (i.e., fewer lake sections) would not sacrifice the accuracy of LVI for assessing lake condition. In addition, these results illustrated the fact that it is not necessary to sample all the taxa present in order to obtain a reliable assessment of site condition.

In contrast, the number of sampling sections used to calculate LVI had a large influence on the variability of LVI. One goal of this study was to identify a less intensive sampling protocol (i.e., less than 12 sections) in order to reduce the time required for routine field assessments. We compared the statistical precision of LVI based on single lake sections and LVI based on the composite of two lake sections. We summarized the relative statistical precision of the different methods in terms of the number of categories of biological condition that each version of the index could reliably detect. We found that collecting plant information from 12 lake sections was not necessary because data from four replicate samples (using data from 4 of the 12 sections) could detect five categories of biological condition.

Land use can vary in both type and intensity around a lake’s perimeter. In order to capture this difference, we defined the lake sampling protocol to be based on samples from four sides of the lake. To avoid bias in choosing which lake sections to sample, the starting section is randomly selected and the subsequent three sections located in each quadrant around the lake.

RECOMMENDATIONS

- *Define a minimum, standard sampling effort to consist of LVI calculated from four quadrants of a lake.*

For the development data set, lakes were "oversampled" in order to determine the appropriate sampling effort needed to characterize a lake's aquatic plant assemblage. Rather than collecting data from 12 separate sections of a lake, data from four lake sections was adequate to detect five categories of biological condition. This represents approximately one-third of the current sampling effort.

To avoid bias in lake sampling, the first replicate sample should be randomly selected from sections 1, 2, or 3. Section 1 is designated as the first section located clockwise from the north, and subsequent sections are numbered in a clockwise direction. If section 1 is randomly selected, the three additional replicates would form a cross-pattern as seen in Figure 14.

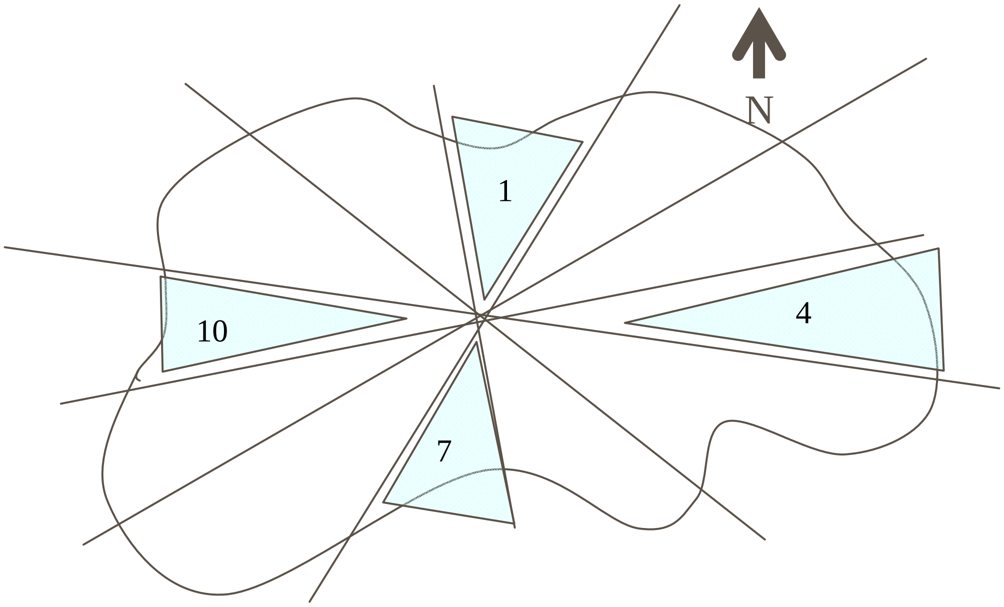

Figure 14. Diagram showing 12 lake sections and locations for the four replicate samples (marked with triangles).

- *Develop guidelines to identify the dominant taxon within a lake section.*

Data for several lakes did not include information on dominant taxon. Because dominant C of C is needed to calculate LVI, each lake sample should include this information. Criteria should be specified for defining dominance and co-dominance and future lake training should emphasize the best way to estimate this metric. LVI based on 3 metrics was somewhat more variable than the index based on 4 metrics; therefore, simply excluding this metric when dominance is difficult to determine would not be the preferred solution.

Data from different seasons indicate that the dominant taxon can change during the year even in the absence of changes in human influence. When different taxa dominate on opposite sides of the lake, simple averaging is the best approach for calculating this metric.

- *Evaluate other sources of temporal variability for LVI.*

Estimates of the number of categories of biological condition that the LVI can detect were based on same-day sampling. Data were not available to estimate the influence of annual variability. Thus, the variance may be underestimated and the number of categories of biological condition exaggerated because not all sources of natural variability (e.g., annual or seasonal differences) could be adequately assessed or included for LVI. (See Appendix 6 for more recent estimates of annual variability.)

To estimate annual variability, a subset of 20–30 lakes should be resampled. Lakes selected for resampling should represent a range of conditions (from low to high HDG values). In addition, lakes should be selected for which *little or no change* in human influence is expected between sampling visits. Human influence may be high, but it should be consistent from one year to the next so that natural variability can be measured. Estimates of annual variance are needed to define the sampling design for trend monitoring and to determine the amount of change that can be detected over time (Larsen et al., 1995; Urquhart et al., 1998).

Repeat lake visits for 15 lakes sampled during the same year indicated that LVI differed according to season for some lakes, but the direction of the difference was not consistent across lakes. One approach to avoid differences associated with seasons would be to restrict sampling to a single season, e.g., spring, when many taxa are blooming and more easily identifiable.

However, for the LVI to be adopted as a useful management tool, it must be available for much of the year. Consequently, a better approach would be to continue to carefully evaluate the influence of seasonal differences on LVI values, particularly for the peninsula which had no repeat visits in this data set.

- *Evaluate metric scoring rules as more data become available.*

Metric scoring for percent invasive taxa was adjusted to reflect lower metric values in the peninsula region of the state. For the northeast region, metric differences could not be evaluated because only four lakes were sampled. The three state regions were based on riverine drainage patterns, and other variables, e.g., latitude or freeze-line, may be more appropriate for setting metric expectations for plants in lakes. For this study, lakes in the far southern section of the state (26–27° latitude) had somewhat lower LVI values than predicted by HDG and lakes in this area should be assessed for consistency as more data become available.

- *Reevaluate sensitive and tolerant designations of plant taxa.*

For this study, 95 lakes did not provide sufficient data to define a list of sensitive and tolerant taxa for lake plants, primarily because most plants were somewhat rare (61% of taxa occurred in < 5 lakes). Consequently, we used sensitive and tolerant designations based on the CC values derived from expert opinion. One concern is that these values were developed for wetlands, not specifically for lakes.

For wetlands, expert opinion and field data showed a stronger correlation than for lakes. When CC values were compared to the average HDG for lakes (LDI for wetlands) in which each taxon was found, agreement was much better for wetlands than lakes ($r^2 = 0.18$ for lakes vs. 0.54 for wetlands; Cohen et al., 2004). Although the percent sensitive and tolerant taxa metrics were highly correlated with HDG as currently defined, a larger data set (~300–400 lakes), would allow a better list of sensitive and tolerant taxa to be defined specifically for lakes.

CONCLUSIONS

The different types of plants found in Florida lakes were strongly associated with lake condition and the level of human disturbance observed around the lake perimeter. Ten metrics were highly correlated with independent measures of human disturbance, and four were selected for inclusion in the final Lake Vegetation Index (% native taxa, % invasive taxa, % sensitive taxa, and dominant C of C). Based on an independent set of lakes not used for the original development or testing of metrics, the LVI was highly correlated with measures of disturbance related to water chemistry, habitat condition and land use intensity. LVI values derived from repeat samples within a lake varied little, and four replicate samples within a lake would be sufficient to detect five categories of biological condition.

Additional work remains to be done as more lake data become available, but changes to the LVI will be minimal. Tolerant and sensitive taxa designations based on professional judgment need to be confirmed for specific taxa using field data and some designations for individual taxa may change. Small adjustments in the metric scoring rules may be needed for southern and northeastern lakes. Better estimates of within-year and annual variability of LVI values are also needed to define the sensitivity of LVI through time.

The primary goal of this study was to test the feasibility of using plants as biological indicators. Results reported here confirm that simple measures of the plant assemblage can provide a reliable and meaningful biological assessment of lake condition.

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APPENDIX 1. AQUATIC PLANT ATTRIBUTES

Shown are lake plant taxa names sorted alphabetically by phylum, class, and order (not shown), taxonomic family, whether the species is listed as a category 1 or 2 invasive by the Florida Exotic Pest Plant Council, whether the plant is herbaceous or woody, growth form (GR_1: F/H = forb/herb, G = graminoid, NV = nonvascular, SH = shrub, SSH = subshrub, T = tree, V = vine; GR_2: E = emergent, F = floating, O = other, S = submersed), whether the plant is listed as threatened or endangered, reproductive group, wetland status, duration of life cycle (A = annual, B = biennial, P = perennial), nativity, and CC score.

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Acer rubrum	Aceraceae		W	T	O		A_dicot	FACW	P	N	4.65
Agalinis filifolia	Scrophulariaceae		H	F/H	E		A_dicot	Upland	A	N	6.69
Agalinis linifolia	Scrophulariaceae		H	F/H	E		A_dicot	OBL	P	N	7.04
Agarista populifolia	Ericaceae		W	SH	O		A_dicot	OBL	P	N	
Alternanthera philoxeroides	Amaranthaceae	Cat2	H	F/H	E		A_dicot	OBL	P	E	0
Amorpha fruticosa	Leguminosae		H	SH	O		A_dicot	FACW	P	N	
Ampelopsis arborea	Vitaceae		W	V	O		A_dicot	FAC	P	N	3.25
Amphicarpum muhlenbergianum	Poaceae		H	G	E		A_Mono	FACW	P	N	5.7
Andropogon	Poaceae		H	G	E		A_Mono		P	N	
Andropogon glomeratus	Poaceae		H	G	E		A_Mono	FACW	P	N	3.9
Andropogon gyrans stenophyllus	Poaceae		H	G	E		A_Mono	FAC	P	N	
Andropogon virginicus	Poaceae		H	G	E		A_Mono	FAC	P	N	3.44
Annona glabra	Annonaceae		W	T	O		A_dicot	OBL	P	N	
Arundinaria	Poaceae		W	SSH	E		A_Mono	FACW	P	N	
Arundinaria gigantea	Poaceae		W	SSH	E		A_Mono	FACW	P	N	
Arundo donax	Poaceae		H	SSH	E		A_Mono	FAC	P	E	
Aster	Asteraceae						A_dicot			N	
Aster carolinianus	Asteraceae		H	SSH	E		A_dicot	OBL	P	N	
Aster elliottii	Asteraceae		H	F/H	E		A_dicot	OBL	P	N	6.76
Aster pilosus	Asteraceae		H	F/H	E		A_dicot	FAC	P	N	
Aster subulatus	Asteraceae		H	F/H	E		A_dicot	OBL	P	N	5.74
Aster tortifolius	Asteraceae		H	F/H			A_dicot		P	N	
Axonopus	Poaceae		H	G	E		A_Mono				
Azolla caroliniana	Azollaceae		H	F/H	F		Fern	OBL	A	N	1.81
Baccharis	Asteraceae						A_dicot		P	N	
Baccharis angustifolia	Asteraceae			SH	O		A_dicot	OBL	P	N	

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Baccharis glomeruliflora	Asteraceae		W	SH	O		A_dicot	FAC	P	N	6.12
Baccharis halimifolia	Asteraceae		W	SH	O		A_dicot	FAC	P	N	2.53
Bacopa caroliniana	Scrophulariaceae		H	F/H	E		A_dicot	OBL	P	N	5.31
Bacopa monnieri	Scrophulariaceae		H	F/H	E		A_dicot	OBL	P	N	4.49
Bambusa	Poaceae		W				A_Mono			E	
Bidens	Asteraceae		H	F/H	E		A_dicot				
Bidens alba	Asteraceae		H	F/H	E		A_dicot	FAC	AP	N	
Bidens laevis	Asteraceae		H	F/H	E		A_dicot	OBL	AP	N	7.19
Bidens mitis	Asteraceae		H	F/H	E		A_dicot	OBL	A	N	6.31
Bidens pilosa	Asteraceae		H	F/H	E		A_dicot	FACW	A	E	
Blechnum	Blechnaceae				E		Fern				
Blechnum serrulatum	Blechnaceae		H	F/H	E		Fern	FACW	P	N	7.15
Boehmeria cylindrica	Urticaceae		H	F/H	E		A_dicot	OBL	P	N	5.91
Brachiaria	Poaceae		H	G	E		A_Mono	FACW			
Brachiaria mutica	Poaceae	Cat1	H	G	E		A_Mono	FACW	P	E	0
Brasenia schreberi	Nymphaeaceae		H	F/H	F		A_dicot	OBL	P	N	8.79
Cabomba caroliniana	Cabombaceae		H	F/H	S		A_dicot	OBL	P	N	5.07
Callistemon viminale	Myrtaceae		W	SH	O		A_dicot			E	
Callitriche	Callitrichaceae						A_dicot				
Canna	Cannaceae				E		A_Mono				
Canna flaccida	Cannaceae		H	F/H	E		A_Mono	OBL	P	N	6.75
Carex	Cyperaceae		H	G	E		A_Mono				
Carya aquatica	Juglandaceae		W	T	O		A_dicot	OBL	P	N	
Cassia	Leguminosae		H	F/H	E		A_dicot				1.46
Casuarina	Casuarinaceae		W				A_dicot				
Casuarina equisetifolia	Casuarinaceae	Cat1	W	T	O		A_dicot	Upland	P	E	0
Catalpa	Bignoniaceae						A_dicot				
Centella asiatica	Umbelliferae		H	F/H	E		A_dicot	FACW	P	N	1.92
Cephalanthus occidentalis	Rubiaceae		W	SH	O		A_dicot	OBL	P	N	7.27
Ceratophyllum demersum	Ceratophyllaceae		H	F/H	S		A_dicot	OBL	P	N	4.16
Ceratopteris thalictroides	Parkeriaceae		H	F/H	E		Fern	OBL	AP	E	2.93
Chamaecyparis thyoides	Cupressaceae		W	T	O		Gymno	OBL	P	N	
Chara	Characeae			NV	S		Algae			N	3.9
Chasmanthium laxum	Poaceae		H	G	E		A_Mono	FACW	P	N	7.37
Cicuta maculata	Umbelliferae		H	F/H	E		A_dicot	OBL	PB	N	
Cinnamomum camphora	Lauraceae	Cat1	W	T	O		A_dicot	Upland	P	E	0

Taxon	**Family**	**FLEPPC**	**H/W**	**GR_1**	**GR_2**	**T&E**	**Repro**	**Wetland**	**Duration**	**Nativity**	**C of C**
Cladium jamaicense	Cyperaceae		H	G	E		A_Mono	OBL	P	N	9.04
Coelorachis	Poaceae										
Colocasia esculenta	Araceae	Cat1	H	F/H	E		A_Mono	OBL	P	E	0
Commelina	Commelinaceae		H	F/H	E		A_Mono	FACW			
Commelina diffusa	Commelinaceae		H	F/H	E		A_Mono	FACW	AP	E	2.02
Commelina erecta	Commelinaceae		H	F/H	E		A_Mono	FACW	P	N	
Conoclinium coelestinum	Asteraceae		H	F/H	E		A_dicot	FAC	P	N	4.37
Coreopsis gladiata	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	
Cortaderia selloana	Poaceae			G			A_Mono		P	E	
Crinum americanum	Liliaceae		H	F/H	E		A_Mono	OBL	P	N	8.67
Crotalaria pallida	Fabaceae		W	SSH	E		A_dicot		P	E	
Crotalaria spectabilis	Fabaceae			F/H	E		A_dicot		A	E	
Cyperaceae	Cyperaceae										
Cyperus	Cyperaceae		H	G	E		A_Mono				
Cyperus alternifolius	Cyperaceae	Cat2	H	G	E		A_Mono	OBL	P	E	1.11
Cyperus articulatus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.64
Cyperus croceus	Cyperaceae		H	G	E		A_Mono	FAC	AP	N	1.3
Cyperus difformis	Cyperaceae		H	G	E		A_Mono	OBL	A	E	
Cyperus distinctus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	5
Cyperus erythrorhizos	Cyperaceae		H	G	E		A_Mono	OBL	AP	N	
Cyperus esculentus	Cyperaceae		H	G	E		A_Mono	FAC	P	E	
Cyperus haspan	Cyperaceae		H	G	E		A_Mono	OBL	P	N	5.68
Cyperus lecontei	Cyperaceae		H	G	E		A_Mono	FACW	P	N	
Cyperus ligularis	Cyperaceae		H	G	E		A_Mono	FACW	P	N	
Cyperus odoratus	Cyperaceae		H	G	E		A_Mono	FACW	AP	N	4.25
Cyperus papyrus	Cyperaceae		H	G	E		A_Mono	OBL	P	E	
Cyperus polystachyos	Cyperaceae		H	G	E		A_Mono	FACW	AP	N	1.56
Cyperus retrorsus	Cyperaceae		H	G	E		A_Mono	FAC	P	N	1.79
Cyperus rotundus	Cyperaceae		H	G	E		A_Mono	FAC	P	E	
Cyperus surinamensis	Cyperaceae		H	G	E		A_Mono	FACW	P	N	2.03
Cyrilla racemiflora	Cyrillaceae		W	T	O		A_dicot	FAC	P	N	5.2
Decodon verticillatus	Lythraceae		W	SH	O		A_dicot	OBL	P	N	7.8
Dichromena colorata	Cyperaceae		H	G	E		A_Mono	FACW	P	N	6.18
Diodia virginiana	Rubiaceae		H	F/H	E		A_dicot	FACW	AP	N	4.96
Dioscorea bulbifera	Dioscoreaceae	Cat1		V	O		A_Mono		P	E	0
Diospyros virginiana	Ebenaceae		W	T	O		A_dicot	FAC	P	N	5.76

Taxon	**Family**	**FLEPPC**	**H/W**	**GR_1**	**GR_2**	**T&E**	**Repro**	**Wetland**	**Duration**	**Nativity**	**C of C**
Drosera	Droseraceae		H				A_dicot				
Drosera capillaris	Droseraceae		H	F/H	E		A_dicot	FACW	AP	N	7.09
Drosera intermedia	Droseraceae		H	F/H	E	T	A_dicot	OBL	P	N	8.23
Echinochloa	Poaceae		H				A_Mono				
Echinochloa crusgalli	Poaceae		H	G	E		A_Mono	FACW	A	E	0.22
Echinochloa walteri	Poaceae		H	G	E		A_Mono	FACW	A	N	3.36
Eclipta prostrata	Asteraceae		H	F/H	E		A_dicot	FACW	AP	N	3.22
Eichhornia crassipes	Pontederiaceae	Cat1	H	F/H	F		A_Mono	OBL	P	E	0
Eleocharis	Cyperaceae		H	G	E		A_Mono	OBL		N	
Eleocharis baldwinii	Cyperaceae		H	G	E		A_Mono	OBL	P	N	2.82
Eleocharis cellulosa	Cyperaceae		H	G	E		A_Mono	OBL	P	N	7.8
Eleocharis elongata	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.97
Eleocharis equisetoides	Cyperaceae		H	G	E		A_Mono	OBL	P	N	9.1
Eleocharis flavescens	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Eleocharis interstincta	Cyperaceae		H	G	E		A_Mono	OBL	P	N	7.8
Eleocharis montana	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Eleocharis robbinsii	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Eleocharis vivipara	Cyperaceae		H	G	E		A_Mono	OBL	A	N	3.81
Eragrostis	Poaceae				E		A_Mono				
Erechtites hieracifolia	Asteraceae		H	F/H	E		A_dicot	FAC	A	N	1.37
Erianthus giganteus	Poaceae		H	G	E		A_Mono	OBL	P	N	6.34
Erigeron quercifolius	Asteraceae		H	F/H	E		A_dicot	FAC	A	N	3.31
Eriocaulon	Eriocaulaceae		H	F/H	E		A_Mono	OBL	PB	N	
Eriocaulon decangulare	Eriocaulaceae		H	F/H	E		A_Mono	OBL	P	N	7.5
Eupatorium	Asteraceae		H	F/H	E		A_dicot		P	N	
Eupatorium capillifolium	Asteraceae		H	F/H	E		A_dicot	Upland	P	N	0.83
Eupatorium leptophyllum	Asteraceae		H	F/H	E		A_dicot	OBL	P	N	4.94
Eupatorium mikanioides	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	
Eustachys petraea	Poaceae		H	G	E		A_Mono	FAC	P	N	
Euthamia tenuifolia tenuifolia	Asteraceae		H	F/H	E		A_dicot	FAC	P	N	
Ficus aurea	Moraceae		W	V	O		A_dicot	FAC	P	N	3.38
Fimbristylis castanea	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Fraxinus americana	Oleaceae		W	T	O		A_dicot	Upland	P	N	
Fraxinus caroliniana	Oleaceae		W	T	O		A_dicot	OBL	P	N	
Froelichia floridana	Amaranthaceae		H	F/H	O		A_dicot		A	N	
Fuirena	Cyperaceae		H	G	E		A_Mono				

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Fuirena breviseta	Cyperaceae		H	G	E		A_Mono	OBL	P	N	7.6
Fuirena pumila	Cyperaceae		H	G	E		A_Mono	OBL	A	N	5.92
Fuirena scirpoidea	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.5
Fuirena squarrosa	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Gleditsia triacanthus	Fabaceae		W	T	O		A_dicot	FACW	P	N	
Gordonia lasianthus	Theaceae		W	T	O		A_dicot	FACW	P	N	9.03
Habenaria repens	Orchidaceae		H	F/H	E		A_Mono	FACW	P	N	4.58
Hedyotis	Rubiaceae										
Hibiscus coccineus	Malvaceae		H	F/H	E		A_dicot	OBL	P	N	
Hibiscus furcellatus	Malvaceae			SSH	E		A_dicot		P	N	
Hibiscus grandiflorus	Malvaceae		H	F/H	O		A_dicot	OBL	P	N	6.86
Hydrilla verticillata	Hydrocharitaceae	Cat1	H	F/H	S		A_Mono	OBL	P	E	0
Hydrocotyle	Umbelliferae						A_dicot				
Hydrocotyle umbellata	Umbelliferae		H	F/H	E		A_dicot	FACW	P	N	1.92
Hydrolea corymbosa	Hydrophyllaceae		H	F/H	E		A_dicot	OBL	P	N	5.85
Hydrolea quadrivalvis	Hydrophyllaceae		H	F/H	E		A_dicot	OBL	P	N	
Hypericum	Clusiaceae						A_dicot			N	
Hypericum cistifolium	Clusiaceae		W	SH	O		A_dicot	FACW	P	N	6.32
Hypericum fasciculatum	Clusiaceae		W	SH	O		A_dicot	OBL	P	N	7.27
Hypericum hypericoides	Clusiaceae		W	SH	O		A_dicot	FAC	P	N	5.44
Hypericum lissophloeus	Clusiaceae		W	SH	O	E	A_dicot	OBL	P	N	
Hyptis alata	Lamiaceae		H	F/H	E		A_dicot	FACW	P	N	4.58
Ilex cassine	Aquifoliaceae		W	T	O		A_dicot	OBL	P	N	7.66
Ilex coriacea	Aquifoliaceae		W	T	O		A_dicot	FACW	P	N	
Ilex glabra	Aquifoliaceae		W	SH	O		A_dicot	FACW	P	N	5.85
Ilex myrtifolia	Aquifoliaceae		W	SH	O		A_dicot	OBL	P	N	
Ilex vomitoria	Aquifoliaceae		W	T	O		A_dicot	FAC	P	N	
Indigofera hirsuta	Leguminosae		H	F/H	E		A_dicot		A	E	
Ipomoea sagittata	Convolvulaceae		H	V	O		A_dicot		P	N	6.42
Iris hexagona	Iridaceae		H	F/H	E		A_Mono	OBL	P	N	6.97
Iris virginica	Iridaceae		H	F/H	E		A_Mono	OBL	P	N	
Itea virginica	Saxifragaceae		W	SH	O		A_dicot	OBL	P	N	7.09
Iva microcephala	Asteraceae		H	F/H	E		A_dicot	FACW	A	N	4.68
Juncus	Juncaceae		H	G			A_Mono			N	
Juncus effusus	Juncaceae		H	G	E		A_Mono	OBL	P	N	3.25
Juncus marginatus	Juncaceae		H	G	E		A_Mono	FACW	P	N	3.65

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Juncus megacephalus	Juncaceae		H	G	E		A_Mono	OBL	P	N	5.7
Juncus scirpoides	Juncaceae		H	G	E		A_Mono	OBL	P	N	4.33
Justicia	Acanthaceae						A_dicot				
Kosteletzkya	Malvaceae						A_dicot				
Kosteletzkya virginica	Malvaceae		H	F/H	E		A_dicot	OBL	P	N	7.49
Lachnanthes caroliana	Haemodoraceae		H	F/H	E		A_Mono	FAC	P	N	3.76
Lachnocaulon anceps	Eriocaulaceae		H	F/H	E		A_Mono	FACW	P	N	7.15
Lachnocaulon minus	Eriocaulaceae		H	F/H	E		A_Mono	OBL	P	N	7.97
Leersia hexandra	Poaceae		H	G	E		A_Mono	OBL	P	N	5.61
Lemna	Lemnaceae		H	F/H	F		A_Mono	OBL			
Lemna minor	Lemnaceae		H	F/H	F		A_Mono	OBL	P	N	3.77
Leucothoe racemosa	Ericaceae		W	SH	O		A_dicot	FACW	P	N	9.44
Liatris	Asteraceae										
Ligustrum sinense	Oleaceae	Cat1	W	SH	O		A_dicot	FAC	P	E	0
Limnobium spongia	Hydrocharitaceae		H	F/H	F		A_Mono	OBL	P	N	4.79
Limnophila sessiliflora	Scrophulariaceae	Cat2	H	F/H	E		A_dicot	OBL	P	E	0
Lindernia	Scrophulariaceae						A_dicot				
Liquidambar styraciflua	Hamamelidaceae		W	T	O		A_dicot	FACW	P	N	5.56
Liriodendron tulipifera	Magnoliaceae		W	T	O		A_dicot	FAC	P	N	
Ludwigia	Onagraceae		H	F/H	E		A_dicot				
Ludwigia alata	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	5.85
Ludwigia alternifolia	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	6.24
Ludwigia arcuata	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	5.32
Ludwigia decurrens	Onagraceae		H	F/H	E		A_dicot	OBL	AP	N	6.76
Ludwigia grandiflora	Onagraceae		H	SSH	E		A_dicot	OBL	P	E	
Ludwigia leptocarpa	Onagraceae		H	F/H	E		A_dicot	OBL	AP	N	3.47
Ludwigia linifolia	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	7.04
Ludwigia octovalvis	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	4.09
Ludwigia peruviana	Onagraceae		H	F/H	E		A_dicot	OBL	P	E	0.62
Ludwigia repens	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	5.2
Ludwigia sphaerocarpa	Onagraceae		H	F/H	E		A_dicot	OBL	P	N	
Ludwigia suffruticosa	Onagraceae		H	F/H	E		A_dicot	FACW	P	N	6.23
Luziola fluitans	Poaceae		H	G	E		A_Mono	OBL	P	N	4.79
Lycopodiella alopecuroides	Lycopodiaceae		W	SSH	E		Fern	OBL	P	N	
Lycopus	Lamiaceae		H	F/H	E		A_dicot		P	N	
Lycopus amplectens	Lamiaceae		H	F/H	E		A_dicot	OBL	P	N	

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Lycopus virginicus	Lamiaceae		H	F/H	E		A_dicot	OBL	P	N	
Lygodium microphyllum	Schizaeaceae	Cat1	H	V	O		Fern		P	E	0
Lyonia	Ericaceae						A_dicot				
Lyonia lucida	Ericaceae		W	SH	O		A_dicot	FACW	P	N	7.06
Magnolia grandiflora	Magnoliaceae		W	T	O		A_dicot	FAC	P	N	
Magnolia virginiana	Magnoliaceae		W	T	O		A_dicot	FACW	P	N	9.44
Mayaca fluviatilis	Mayacaceae		H	F/H	S		A_Mono	OBL	P	N	8.45
Melaleuca	Myrtaceae		W	T	O		A_dicot				
Melaleuca quinquenervia	Myrtaceae	Cat1	W	T	O		A_dicot	FAC	P	E	0
Melia azedarach	Meliaceae	Cat1	W	T	O		A_dicot		P	E	0
Micranthemum glomeratum	Scrophulariaceae		H	F/H	E		A_dicot	OBL	P	N	5.85
Micranthemum umbrosum	Scrophulariaceae		H	F/H	E		A_dicot	OBL	AP	N	5.66
Mikania scandens	Asteraceae		H	V	O		A_dicot	FACW	P	N	1.95
Mimosa pigra	Leguminosae	Cat1	W	T	O		A_dicot	FAC	P	E	0
Muhlenbergia capillaris	Poaceae		H	G	E		A_Mono	Upland	P	N	
Musa	Musaceae				E		A_Mono				
Musa sapientum	Musaceae			T	O		A_Mono	Upland	P	E	
Myrica cerifera	Myricaceae		W	SH	O		A_dicot	FAC	P	N	3.82
Myriophyllum	Haloragaceae		H	F/H	S		A_dicot	OBL	P		
Myriophyllum aquaticum	Haloragaceae		H	F/H	S		A_dicot	OBL	P	E	0.98
Myriophyllum heterophyllum	Haloragaceae		H	F/H	S		A_dicot	OBL	P	N	4.77
Najas gracillima	Najadaceae		H	F/H	S		A_Mono	OBL	A	N	
Najas guadalupensis	Najadaceae		H	F/H	S		A_Mono	OBL	A	N	5.07
Najas minor	Najadaceae		H	F/H	S		A_Mono	OBL	A	E	3.64
Nelumbo	Nelumbonaceae		H				A_dicot				
Nelumbo lutea	Nelumbonaceae		H	F/H	F		A_dicot	OBL	P	N	6.26
Nephrolepis	Polypodiaceae										
Nitella	Characeae			NV	S		Algae			N	7.28
Nuphar luteum	Nymphaeaceae		H	F/H	F		A_dicot	OBL	P	N	4.64
Nymphaea	Nymphaeaceae		H				A_dicot				
Nymphaea mexicana	Nymphaeaceae		H	F/H	F		A_dicot	OBL	P	N	8.61
Nymphaea odorata	Nymphaeaceae		H	F/H	F		A_dicot	OBL	P	N	7.18
Nymphoides aquatica	Menyanthaceae		H	F/H	F		A_dicot	OBL	P	N	6.09
Nyssa sylvatica biflora	Cornaceae		W	T	O		A_dicot	OBL	P	N	9.04
Osmunda	Osmundaceae				E		Fern				
Osmunda cinnamomea	Osmundaceae		H	F/H	E		Fern	FACW	P	N	6.44

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Osmunda regalis	Osmundaceae		H	F/H	E		Fern	OBL	P	N	8.04
Ostrya virginiana	Betulaceae		W	T	O		A_dicot	Upland	P	N	
Panicum	Poaceae		H	G	E		A_Mono				
Panicum dichotomiflorum	Poaceae		H	G	E		A_Mono	FACW	A	N	4.96
Panicum hemitomon	Poaceae		H	G	E		A_Mono	OBL	P	N	5.82
Panicum repens	Poaceae	Cat1	H	G	E		A_Mono	FACW	P	E	0
Panicum rigidulum	Poaceae		H	G	E		A_Mono	FACW	P	N	5.47
Panicum rigidulum pubesens	Poaceae		H	G	E		A_Mono	OBL	P	N	
Panicum scabriusculum	Poaceae		H	G	E		A_Mono	OBL	P	N	7.15
Panicum tenerum	Poaceae		H	G	E		A_Mono	OBL	P	N	8.67
Panicum virgatum	Poaceae		H	G	E		A_Mono	FACW	P	N	5.44
Paspalidium geminatum	Poaceae		H	G	E		A_Mono	OBL	P	N	6.36
Paspalum	Poaceae		H	G	E		A_Mono				
Paspalum distichum	Poaceae		H	G	E		A_Mono	OBL	P	N	5.54
Paspalum floridanum	Poaceae		H	G	E		A_Mono	FACW	P	N	6.11
Paspalum repens	Poaceae		H	G	E		A_Mono	OBL	A	N	6.69
Paspalum urvillei	Poaceae		H	G	E		A_Mono	FAC	P	E	0
Peltandra	Araceae		H	F/H	E		A_Mono	OBL	P	N	7.31
Peltandra virginica	Araceae		H	F/H	E		A_Mono	OBL	P	N	7.31
Pennisetum purpureum	Poaceae	Cat1	H	G	E		A_Mono	FAC	P	E	0
Persea borbonia	Lauraceae		W	T	O		A_dicot	FACW	P	N	8.02
Persea borbonia humilis	Lauraceae		W	SH	O		A_dicot		P	N	
Persea palustris	Lauraceae		W	T	O		A_dicot	OBL	P	N	8.31
Phanopyrum gymnocarpon	Poaceae		H	G			A_Mono	OBL	P	N	
Phragmites australis	Poaceae		H	F/H	E		A_Mono	OBL	P	E	4.39
Phyla nodiflora	Verbenaceae		H	F/H	E		A_dicot	FAC	P	N	1.92
Pinus	Pinaceae		W	T	O		Gymno				
Pinus clausa	Pinaceae		W	T	O		Gymno	FACW	P	N	
Pinus elliottii	Pinaceae		W	T	O		Gymno		P	N	4.21
Pinus palustris	Pinaceae		W	T	O		Gymno		P	N	4.77
Pistia stratiotes	Araceae	Cat1	H	F/H	F		A_Mono	OBL	P	E	0
Pluchea	Asteraceae		H	F/H	E		A_dicot	FACW		N	
Pluchea foetida	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	6.65
Pluchea odorata	Asteraceae		H	F/H	E		A_dicot	FACW	AP	N	4.96
Pluchea rosea	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	5.45
Poaceae	Poaceae										

Taxon	**Family**	**FLEPPC**	**H/W**	**GR_1**	**GR_2**	**T&E**	**Repro**	**Wetland**	**Duration**	**Nativity**	**C of C**
Polygonum	Polygonaceae		H	F/H	E		A_dicot				
Polygonum densiflorum	Polygonaceae		H	F/H	E		A_dicot	OBL	AP	N	5.32
Polygonum hydropiperoides	Polygonaceae		H	F/H	E		A_dicot	OBL	P	N	4.02
Polygonum punctatum	Polygonaceae		H	F/H	E		A_dicot	OBL	AP	N	4.02
Polypogon monspeliensis	Poaceae		H	G	E		A_Mono	FAC	A	E	
Pontederia cordata	Pontederiaceae		H	F/H	E		A_Mono	OBL	P	N	5.38
Pontederia rotundifolia	Pontederiaceae		H	F/H	E		A_Mono		P	E	
Potamogeton diversifolius	Potamogetonaceae		H	F/H	S		A_Mono	OBL	P	N	7.15
Potamogeton illinoensis	Potamogetonaceae		H	F/H	S		A_Mono	OBL	P	N	6.64
Potamogeton pectinatus	Potamogetonaceae		H	F/H	S		A_Mono	OBL	P	N	7.8
Potamogeton pusillus	Potamogetonaceae		H	F/H	S		A_Mono	OBL	P	N	7.8
Quercus	Fagaceae		W	T	O		A_dicot		P	N	
Quercus laurifolia	Fagaceae		W	T	O		A_dicot	FACW	P	N	5.14
Quercus nigra	Fagaceae		W	T	O		A_dicot	FACW	P	N	4.14
Rhexia	Melastomataceae		H	F/H	E		A_dicot	FACW	P	N	
Rhexia cubensis	Melastomataceae		H	F/H	E		A_dicot	FACW	P	N	7.22
Rhexia mariana	Melastomataceae		H	F/H	E		A_dicot	FACW	P	N	5.5
Rhexia nashii	Melastomataceae		H	F/H	E		A_dicot	FACW	P	N	7.8
Rhexia virginica	Melastomataceae		H	F/H	E		A_dicot	FACW	P	N	
Rhus copallinum	Anacardiaceae		W	SH	O		A_dicot		P	N	3.65
Rhynchospora	Cyperaceae		H	G	E		A_Mono			N	
Rhynchospora baldwinii	Cyperaceae		H	G	E		A_Mono	OBL	AP	N	
Rhynchospora cephalantha	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.19
Rhynchospora fascicularis	Cyperaceae		H	G	E		A_Mono	FACW	P	N	5.92
Rhynchospora globularis	Cyperaceae		H	G	E		A_Mono	FACW	AP	N	
Rhynchospora inundata	Cyperaceae		H	G	E		A_Mono	OBL	P	N	7.25
Rhynchospora microcarpa	Cyperaceae		H	G	E		A_Mono	OBL	P	N	5.29
Rhynchospora microcephala	Cyperaceae		H	G	E		A_Mono	FACW	P	N	6.5
Rhynchospora nitens	Cyperaceae		H	G	E		A_Mono	OBL	AP	N	5.2
Rhynchospora scirpoides	Cyperaceae		H	G	E		A_Mono	OBL	A	N	
Rhynchospora tracyi	Cyperaceae		H	G	E		A_Mono	OBL	P	N	9.03
Rubus	Rosaceae		H	SH	O		A_dicot		P	N	
Rubus argutus	Rosaceae		H	SH	O		A_dicot	FAC	P	N	3.56
Rubus trivialis	Rosaceae		H	SH	O		A_dicot	FAC	P	N	2.6
Sabal palmetto	Palmae		W	T	O		A_Mono	FAC	P	N	4.85
Sabatia grandiflora	Gentianaceae		H	F/H	E		A_dicot	FACW	A	N	7.09

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Saccharum	Poaceae		H	G	E		A_Mono				
Sacciolepis striata	Poaceae		H	G	E		A_Mono	OBL	P	N	5.35
Sagittaria	Alismataceae		H	F/H			A_Mono	OBL	P	N	
Sagittaria graminea	Alismataceae		H	F/H	E		A_Mono	OBL	P	N	5.53
Sagittaria kurziana	Alismataceae		H	F/H	S		A_Mono	OBL	P	N	9.75
Sagittaria lancifolia	Alismataceae		H	F/H	E		A_Mono	OBL	P	N	4.96
Sagittaria latifolia	Alismataceae		H	F/H	E		A_Mono	OBL	P	N	6.5
Sagittaria subulata	Alismataceae		H	F/H	E		A_Mono	OBL	P	N	
Salix	Salicaceae		W				A_dicot				
Salix babylonica	Salicaceae		W	T	O		A_dicot	OBL	P	E	
Salix caroliniana	Salicaceae		W	T	O		A_dicot	OBL	P	N	2.95
Salix eriocephala	Salicaceae		W	T	O	E	A_dicot	FACW	P	N	
Salix floridana	Salicaceae		W	T	O	E	A_dicot	FACW	P	N	
Salvinia minima	Salviniaceae		H	F/H	F		Fern	OBL	AP	E	2.03
Sambucus	Caprifoliaceae						A_dicot				
Sambucus canadensis	Caprifoliaceae		W	SH	O		A_dicot	FAC	P	N	1.48
Sapium sebiferum	Euphorbiaceae	Cat1	W	T	O		A_dicot	FAC	P	E	0
Sarcostemma clausum	Asclepiadaceae		H	V	O		A_dicot	FACW	P	N	3.81
Saururus cernuus	Saururaceae		H	F/H	E		A_dicot	OBL	P	N	7.33
Schinus terebinthifolius	Anacardiaceae	Cat1	W	T	O		A_dicot	FAC	P	E	0
Schizachyrium	Poaceae						A_Mono				
Scirpus	Cyperaceae		H	G	E		A_Mono	OBL	P		
Scirpus americanus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.5
Scirpus californicus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	6.01
Scirpus cubensis	Cyperaceae		H	G	E		A_Mono	OBL	P	E	3.77
Scirpus cyperinus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Scirpus pungens	Cyperaceae		H	G	E		A_Mono	OBL	P	N	
Scirpus validus	Cyperaceae		H	G	E		A_Mono	OBL	P	N	5.55
Scleria	Cyperaceae		H	G	E		A_Mono				
Serenoa repens	Palmae		W	SH	O		A_Mono	Upland	P	N	7.03
Sesbania	Fabaceae						A_dicot				
Sesbania herbacea	Fabaceae		H	F/H	E		A_dicot	FAC	A	N	1.5
Sesbania punicea	Fabaceae	Cat2	W	SH	O		A_dicot	FAC	P	E	0
Setaria magna	Poaceae		H	G	E		A_Mono	FACW	A	N	
Setaria parviflora	Poaceae		H	G	E		A_Mono	FAC	P	N	3.4
Smilax	Smilacaceae			V	O		A_Mono		P	N	

Taxon	Family	FLEPPC	H/W	GR_1	GR_2	T&E	Repro	Wetland	Duration	Nativity	C of C
Smilax laurifolia	Smilacaceae			V	O		A_Mono	FACW	P	N	
Smilax pumila	Smilacaceae			V	O		A_Mono		P	N	6.01
Solidago	Asteraceae		H	F/H	E		A_dicot		P	N	
Solidago fistulosa	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	4.49
Solidago leavenworthii	Asteraceae		H	F/H	E		A_dicot	FAC	P	N	
Solidago stricta	Asteraceae		H	F/H	E		A_dicot	FACW	P	N	5.49
Spartina alterniflora	Poaceae		H	G	E		A_Mono	OBL	P	N	7.94
Spartina bakeri	Poaceae		H	G	E		A_Mono	FACW	P	N	5.98
Spirodela polyrhiza	Lemnaceae		H	F/H	F		A_Mono	OBL	P	N	2.95
Taxodium ascendens	Taxodiaceae		W	T	O		Gymno	OBL	P	N	7.21
Taxodium distichum	Taxodiaceae		W	T	O		Gymno	OBL	P	N	7.21
Thalia geniculata	Marantaceae		H	F/H	E		A_Mono	OBL	P	N	7.12
Thelypteris	Polypodiaceae				E		Fern				
Thelypteris interrupta	Polypodiaceae		H	F/H	E		Fern	FACW	P	N	6.74
Toxicodendron	Anacardiaceae						A_dicot				
Toxicodendron radicans	Anacardiaceae		H	V	O		A_dicot	FAC	P	N	1.44
Toxicodendron vernix	Anacardiaceae		W	T	O		A_dicot	OBL	P	N	
Tradescantia ohiensis	Commelinaceae		H	F/H	E		A_Mono	FAC	P	N	
Triadenum virginicum	Clusiaceae		H	F/H	E		A_dicot	OBL	P	N	8.16
Typha	Typhaceae		H		E		A_Mono		P	N	
Typha domingensis	Typhaceae		H	F/H	E		A_Mono	OBL	P	N	0.59
Typha latifolia	Typhaceae		H	F/H	E		A_Mono	OBL	P	N	1.6
Ulmus americana	Ulmaceae		W	T	O		A_dicot	FACW	P	N	7.68
Urena lobata	Malvaceae	Cat2	H	SSH	O		A_dicot	Upland	P	E	0
Utricularia	Lentibulariaceae		H		S						
Utricularia cornuta	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	7.46
Utricularia floridana	Lentibulariaceae		H	F/H	S		A_dicot	OBL	P	N	6.34
Utricularia foliosa	Lentibulariaceae		H	F/H	S		A_dicot	OBL	P	N	6.44
Utricularia gibba	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	6.37
Utricularia inflata	Lentibulariaceae		H	F/H	S		A_dicot	OBL	P	N	5.85
Utricularia olivacea	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	
Utricularia purpurea	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	6.5
Utricularia radiata	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	6.01
Utricularia subulata	Lentibulariaceae		H	F/H	S		A_dicot	OBL	AP	N	7.23
Vallisneria americana	Hydrocharitaceae		H	F/H	S		A_Mono	OBL	P	N	7.28
Verbena bonariensis	Verbenaceae		H	F/H	E		A_dicot	FAC	APB	E	0.56

Taxon	**Family**	**FLEPPC**	**H/W**	**GR_1**	**GR_2**	**T&E**	**Repro**	**Wetland**	**Duration**	**Nativity**	**C of C**
Vigna luteola	Fabaceae		W	V	O		A_dicot	FACW	P	N	
Vitaceae	Vitaceae										
Vitis	Vitaceae		H	V	O		A_dicot				
Vitis rotundifolia	Vitaceae		H	V	O		A_dicot	FAC	P	N	1.18
Websteria confervoides	Cyperaceae		H	G	S		A_Mono	OBL	P	N	
Wedelia trilobata	Asteraceae	Cat2	H	F/H	E		A_dicot	FAC	AP	E	0
Wolffiella	Lemnaceae		H	F/H	F		A_Mono	OBL	P	N	4.37
Woodwardia areolata	Polypodiaceae		H	F/H	E		Fern	OBL	P	N	7.68
Woodwardia virginica	Polypodiaceae		H	F/H	E		Fern	FACW	P	N	6.5
Xanthosoma sagittifolium	Araceae	Cat2	H	F/H	E		A_Mono	FACW	P	E	0
Xyris	Xyridaceae		H	F/H	E		A_Mono	OBL	P	N	
Xyris baldwiniana	Xyridaceae		H	F/H	E		A_Mono	OBL	P	N	6.97
Xyris fimbriata	Xyridaceae		H	F/H	E		A_Mono	OBL	P	N	7.08
Xyris isoetifolia	Xyridaceae		H	F/H	E	E	A_Mono	OBL	P	N	
Xyris smalliana	Xyridaceae		H	F/H	E		A_Mono	OBL	P	N	7.8
Zanthoxylum	Rutaceae										
Zizania aquatica	Poaceae		H	G	E		A_Mono	OBL	A	N	6.69
Zizaniopsis miliacea	Poaceae		H	G	E		A_Mono	OBL	P	N	6.21

APPENDIX 2. EPA’S WETLAND PLANT ATTRIBUTES

Florida taxon name, the taxon’s general tolerance to pollution, nutrients, N, P, flooding, sediment, or salinity based on a national wetland database (Adamus and Gonyaw, 2000) (T = tolerant, M = moderately tolerant, V = very tolerant, S = sensitive).

Taxon	**GenPoll**	**Nutrients**	**N**	**P**	**Flooding**	**Sediment**	**Salinity**
Acer rubrum	T	M	T	T	T		S
Amorpha fruticosa	M						
Andropogon virginicus	T	M			M		S
Andropogon		M					
Arundinaria gigantea		M			M		S
Aster pilosus	T	M			M		S
Aster					S		
Baccharis halimifolia		M			M		T
Bacopa monnieri	T						
Bidens laevis		M			M		M
Bidens					T		
Boehmeria cylindrica	M	M			M		S
Brasenia schreberi	M	M			M		S
Callitriche		T			T		S
Carex			T	T	S	S	
Carya aquatica					T		
Catalpa					M		
Cephalanthus occidentalis	M	M			T		S
Ceratophyllum demersum	M	M	T	T	VT		S
Chamaecyparis thyoides		T			M		S
Chara				S	T		
Cicuta maculata	T	M			M		S
Cladium jamaicense		T	T	T			
Conoclinium coelestinum		M			M		S
Cyperus erythrorhizos	M						
Cyperus esculentus	T	M			M		S
Cyperus odoratus	M						
Cyperus rotundus	T						
Decodon verticillatus	M	M			M		S
Diospyros virginiana	T	M			T	T	S
Drosera intermedia							S
Echinochloa crusgalli	T	M			M		S
Echinochloa walteri	M						
Eichhornia crassipes		M	T	T	VT		S
Eleocharis elongata					T		
Eleocharis interstincta			T	T	T		
Eleocharis robbinsii		M			T		
Eleocharis				T		M	
Erechtites hieracifolia		M			M		S
Eupatorium					S		
Fraxinus americana	M	M			M		S

Taxon	**GenPoll**	**Nutrients**	**N**	**P**	**Flooding**	**Sediment**	**Salinity**
Fraxinus caroliniana					T		
Gordonia lasianthus					M		
Hydrilla verticillata				T		S	
Hydrocotyle umbellata	S	M			M		S
Hypericum		T			S		
Ilex glabra		M			M		S
Iris virginica	M						
Itea virginica		M			M		S
Juncus effusus	T	M			M		M
Juncus marginatus	M	M			M		S
Juncus					S		
Leersia hexandra					T		
Lemna minor	M	M	T	T	T		S
Lemna	T	M			T		
Leucothoe racemosa		M			M		S
Liquidambar styraciflua		M			T		S
Liriodendron tulipifera	M	M			T		S
Ludwigia alternifolia	M	M			M		S
Lycopus virginicus	M	M			M		S
Lyonia lucida		M			M		S
Magnolia grandiflora					M		
Magnolia virginiana		M			M		S
Melaleuca quinquenervia					T		
Mikania scandens		M			T		S
Mimosa pigra	T						
Myrica cerifera		M			M		S
Myriophyllum aquaticum	VT		T	T		S	
Myriophyllum heterophyllum	S				T		
Najas gracillima	M						
Najas guadalupensis	M						
Najas minor	VT	M			T		S
Nelumbo lutea		T			M		S
Nuphar luteum	M				T		
Nymphaea odorata	M	M			M		S
Osmunda cinnamomea	M	M			M		S
Osmunda regalis	M	M			M		S
Ostrya virginiana	M	M			M		S
Panicum dichotomiflorum	M						
Panicum hemitomon					T		
Panicum virgatum	M	M			M		M
Panicum				T	S		
Peltandra virginica	M	M	T	T	M		S
Persea borbonia					M		
Phragmites australis	T	VT	T		M	S	M
Pinus elliottii					S		
Polygonum densiflorum					VT		
Polygonum hydropiperoides	M	M			T		S

Taxon	GenPoll	Nutrients	N	P	Flooding	Sediment	Salinity
Polygonum punctatum	M	M			M		M
Pontederia cordata	M	M			M		S
Potamogeton diversifolius	M						
Potamogeton pectinatus	T	T	T	T	T		T
Potamogeton pusillus	T						
Quercus laurifolia					M		
Quercus nigra	T	M	T				S
Rhexia mariana		M			M		S
Rhexia virginica	M	M					S
Rhus copallinum						S	
Rhynchospora inundata		M			M		S
Rubus						S	
Sagittaria graminea	M						
Sagittaria lancifolia		T			T		
Sagittaria latifolia	M	M			M		S
Sagittaria		M			M		S
Salix babylonica	VT	M			M		S
Salix eriocephala	M						
Salix					VT		
Sambucus canadensis	M	M			M	S	S
Sapium sebiferum					VT		
Saururus cernuus	M	M			M		S
Scirpus americanus	M	M			T		T
Scirpus cyperinus	M	M			M		S
Scirpus pungens	M						
Scirpus validus		M			T		M
Solidago						M	
Spartina alterniflora		M	T	T			T
Spirodela polyrhiza	T	M			T		S
Taxodium distichum		M			T		S
Toxicodendron vernix		M			M		S
Tradescantia ohiensis	M						
Triadenum virginicum	M	M				M	S
Typha domingensis			T	T	T		
Typha latifolia	T	M	T	T	T		S
Typha		M	T	T	M	S	
Ulmus americana	M	M			T		S
Utricularia cornuta		T			M		S
Utricularia gibba	M						
Utricularia inflata		M			T		S
Utricularia purpurea		M			T		S
Utricularia subulata					T		
Vallisneria americana	M	M			T	S	S
Vitis rotundifolia		M			M		S
Woodwardia areolata	M	M			M		S
Woodwardia virginica	S	M			M		S
Xyris smalliana					T		
Xyris					S		
Zizania aquatica	M	M			T		S

APPENDIX 3. RESULTS OF TESTING FOR TOLERANCE AND SENSITIVITY

List of lake taxa that occurred in >= 4 lakes (out of 95). Shown for each taxon are CC value, whether the taxon was defined as a sensitive or tolerant taxa on the basis of CC scores, number of lakes in which taxon was found, number of occurrences that were in minimally disturbed lakes (HDG < 3), whether the association with HDG was significant (χ^2, * p < 0.05, * * p < 0.01), and whether the association was in the direction predicted.

Taxon	CC	Tol/Sens	# Occur	# Good	Significant	Correct
Bidens laevis	7.19	S	7	5		
Blechnum serrulatum	7.15	S	13	6		
Cephalanthus occidentalis	7.27	S	51	25	*	yes
Cladium jamaicense	9.04	S	22	15	* *	yes
Crinum americanum	8.67	S	5	2		
Decodon verticillatus	7.80	S	12	10	* *	yes
Eleocharis cellulosa	7.80	S	13	3		
Eleocharis interstincta	7.80	S	14	4		
Gordonia lasianthus	9.03	S	11	7		
Hypericum fasciculatum	7.27	S	13	10	* *	yes
Ilex cassine	7.66	S	37	18		
Itea virginica	7.09	S	9	6		
Lyonia lucida	7.06	S	8	7	* *	yes
Magnolia virginiana	9.44	S	42	18		
Mayaca fluviatilis	8.45	S	19	12	*	yes
Nitella	7.28	S	11	2		
Nymphaea odorata	7.18	S	43	22	*	yes
Nyssa sylvatica biflora	9.04	S	30	13		
Osmunda regalis	8.04	S	7	4		
Persea palustris	8.31	S	10	4		
Potamogeton diversifolius	7.15	S	4	1		
Rhynchospora inundata	7.25	S	8	5		
Saururus cernuus	7.33	S	8	4		
Serenoa repens	7.03	S	4	3		
Taxodium ascendens	7.21	S	39	17		
Taxodium distichum	7.21	S	34	9		
Thalia geniculata	7.12	S	5	1		
Triadenum virginicum	8.16	S	17	11	*	yes
Vallisneria americana	7.28	S	18	2	*	no
Woodwardia areolata	7.68	S	4	3		
Alternanthera philoxeroides	0.00	T	49	10	* *	yes
Azolla caroliniana	1.81	T	6	2		
Brachiaria mutica	0	T	18	2	*	yes
Centella asiatica	1.92	T	11	6		
Colocasia esculenta	0	T	40	7	* *	yes
Cyperus alternifolius	1.11	T	9	1		
Cyperus polystachyos	1.56	T	9	3		
Cyperus surinamensis	2.03	T	14	1	*	yes

Taxon	**CC**	**Tol/Sens**	**# Occur**	**# Good**	**Significant**	**Correct**
Eichhornia crassipes	0.00	T	25	10		
Eleocharis baldwinii	2.82	T	50	23		
Eupatorium capillifolium	0.83	T	59	20		
Hydrilla verticillata	0.00	T	19	1	* *	yes
Hydrocotyle umbellata	1.92	T	62	20		
Ludwigia peruviana	0.62	T	42	10	*	yes
Melaleuca quinquenervia	0.00	T	20	6		
Mikania scandens	1.95	T	65	16	* *	yes
Myriophyllum aquaticum	0.98	T	5	0		
Panicum repens	0	T	73	23	*	yes
Pistia stratiotes	0	T	15	1	*	yes
Salix caroliniana	2.95	T	61	19		
Salvinia minima	2.03	T	34	9		
Sambucus canadensis	1.48	T	12	1		
Sapium sebiferum	0	T	21	3	*	yes
Schinus terebinthifolius	0.00	T	34	6	* *	yes
Typha domingensis	0.59	T	15	4		
Typha latifolia	1.60	T	55	16		
Vitis rotundifolia	1.18	T	16	6		
Wedelia trilobata	0	T	9	1		
Acer rubrum	4.65		67	24		
Andropogon	na		11	7		
Andropogon glomeratus	3.90		20	8		
Andropogon virginicus	3.44		9	5		
Aster	na		4	2		
Aster carolinianus	na		6	2		
Aster subulatus	5.74		5	3		
Baccharis	na		6	2		
Baccharis glomeruliflora	6.12		16	6		
Bacopa caroliniana	5.31		9	6		
Bacopa monnieri	4.49		11	3		
Bidens	na		25	10		
Bidens mitis	6.31		5	4		
Blechnum	na		7	2		
Boehmeria cylindrica	5.91		19	8		
Cabomba caroliniana	5.07		9	7	*	unknown
Canna flaccida	6.75		7	1		
Casuarina equisetifolia	0		4	0		
Ceratophyllum demersum	4.16		7	1		
Chara	3.90		15	2		
Cicuta maculata	na		5	2		
Cyperus	na		23	5		
Cyperus haspan	5.68		17	7		
Cyperus lecontei	na		8	3		
Cyperus odoratus	4.25		27	3	* *	unknown
Cyrilla racemiflora	5.20		14	8		
Echinochloa	na		5	0		
Echinochloa walteri	3.36		5	3		
Eleocharis	na		9	3		

Taxon	**CC**	**Tol/Sens**	**# Occur**	**# Good**	**Significant**	**Correct**
Eriocaulon	na		7	5		
Eupatorium	na		14	6		
Eupatorium leptophyllum	4.94		4	2		
Fuirena	na		7	2		
Fuirena scirpoidea	6.50		21	9		
Habenaria repens	4.58		6	4		
Hydrocotyle	na		17	5		
Hypericum	na		6	5		
Juncus	na		7	5		
Juncus effusus	3.25		12	6		
Juncus marginatus	3.65		5	0		
Juncus megacephalus	5.70		4	3		
Lachnanthes caroliana	3.76		24	16	* *	unknown
Leersia hexandra	5.61		8	5		
Lemna minor	3.77		19	6		
Limnobium spongia	4.79		5	3		
Liquidambar styraciflua	5.56		13	7		
Ludwigia	na		25	10		
Ludwigia alata	5.85		4	4	*	yes
Ludwigia arcuata	5.32		6	3		
Ludwigia grandiflora	na		7	2		
Ludwigia leptocarpa	3.47		25	5		
Ludwigia octovalvis	4.09		39	10		
Ludwigia repens	5.20		9	4		
Ludwigia suffruticosa	6.23		6	5		
Luziola fluitans	4.79		10	6		
Lycopus	na		4	2		
Lycopus virginicus	na		5	3		
Magnolia grandiflora	na		8	6		
Melaleuca	na		7	0		
Micranthemum umbrosum	5.66		7	2		
Musa	na		5	0		
Myrica cerifera	3.82		76	28		
Myriophyllum heterophyllum	4.77		4	3		
Najas guadalupensis	5.07		7	2		
Nelumbo lutea	6.26		8	3		
Nuphar luteum	4.64		63	25		
Nymphoides aquatica	6.09		17	13	* *	yes
Osmunda cinnamomea	6.44		9	4		
Panicum	na		5	3		
Panicum hemitomon	5.82		70	28		
Paspalidium geminatum	6.36		9	1		
Paspalum	na		4	2		
Paspalum repens	6.69		6	1		
Phragmites australis	4.39		15	4		
Pinus elliottii	4.21		26	13		
Pluchea	na		7	2		
Pluchea foetida	6.65		5	3		
Pluchea odorata	4.96		8	3		

Taxon	CC	Tol/Sens	# Occur	# Good	Significant	Correct
Pluchea rosea	5.45		8	5		
Polygonum	na		12	4		
Polygonum densiflorum	5.32		21	5		
Polygonum hydropiperoides	4.02		23	9		
Polygonum punctatum	4.02		6	2		
Pontederia cordata	5.38		64	25		
Potamogeton illinoensis	6.64		8	1		
Quercus laurifolia	5.14		9	1		
Quercus nigra	4.14		4	1		
Rhynchospora	na		10	5		
Rhynchospora nitens	5.20		5	2		
Rubus	na		4	3		
Sabal palmetto	4.85		9	2		
Sacciolepis striata	5.35		40	15		
Sagittaria lancifolia	4.96		44	16		
Sagittaria latifolia	6.50		14	4		
Sagittaria subulata	na		4	2		
Salix	na		10	3		
Sambucus	na		7	1		
Sarcostemma clausum	3.81		9	2		
Scirpus californicus	6.01		10	3		
Scirpus cubensis	3.77		15	3		
Scirpus cyperinus	na		4	4	*	unknown
Scirpus validus	5.55		10	1		
Sesbania	na		5	2		
Solidago	na		17	12	* *	unknown
Spartina bakeri	5.98		7	2		
Thelypteris	na		4	3		
Typha	na		9	3		
Utricularia	na		18	11	*	unknown
Utricularia floridana	6.34		6	3		
Utricularia gibba	6.37		10	4		
Utricularia purpurea	6.50		7	6	*	yes
Vitis	na		4	2		
Woodwardia virginica	6.50		11	6		
Xyris	na		26	13		
Zizaniopsis miliacea	6.21		5	2		

APPENDIX 4. LVI VALUES BY DISTRICT

Lake district, water body name, nick name, county, HDG, and LVI (average of 12 replicates) for the 95 lakes used to develop and test the LVI.

District	Waterbody name	Nick name	County	STORET	HDG	LVI_1x
Central	Russell Lake	OSCEO78	Osceola	26010239	2	61.81
Central	Holden Lake	ORANG159	Orange	26010884	5	23.07
Central	Lake Barton	LakeBarton	Orange	20010890	5	35.50
Central	Lake Rexford	REXFORDUNK	Orange	26010012	5	47.16
Central	Downey Lake	ORANG44	Orange	20010319	3	63.91
Central	Halfmoon Lake	HALFMN*REF	Marion	20020463	1	74.47
Central	Winona Lake	LKWINONA	Lake	20020470	4	32.05
Central	Davis Lake	LKDAVIS	Lake	20030148	3	62.69
Central	Lake Norris	LKNORRIS	Lake	20010355	3	64.00
Central	Hammond Lake	HAMMONDREF	Lake	20020014	1	80.22
Central	Sellers Lake	SELLCTREF	Lake	20020496	0	84.42
Central	Grasshopper Lake	GRAHOP*REF	Lake	20030913	1	90.97
Northeast	Butler Lake	UNION8	Union	21030015	2	59.52
Northeast	Swift Creek Pond	SFPNDCTREF	Union	21030066	0	81.17
Northeast	Louise Lake	SUWAN4	Suwannee	21020016	3	46.97
Northeast	Lake Ida	LKIDA	Putnam	20020116	4	42.71
Northeast	Lake Fanny	LKFANNY	Putnam	20020100	1	74.08
Northeast	Lake Fanny	LKFANNY	Putnam	20020100	1	89.79
Northeast	Cherry Lake	CHERYNEUNK	Madison	21010039	2	53.57
Northeast	Cherry Lake	CHERYNEUNK	Madison	21010039	2	61.60
Northeast	Francis Lake	FRANTST	Madison	21020056	5	69.36
Northeast	Lake Mystic	MYSTICREF	Madison	22040025	1	82.11
Northeast	Dead Lake	CRESTUDY4	Flagler	20030461	3	49.76
Northeast	Gore Lake	GOREREF	Flagler	20030339	2	74.60
Northeast	Tank Lake	TANKLAKE	Flagler	20030151	1	96.84
Northeast	Watertown Lake	WATERTWNLK	Columbia	21010206	3	49.65
Northeast	Magnolia Lake	MAGNOLREF	Clay	20030545	1	72.00
Northeast	Rowell Lake	ROWELLCT	Bradford	21030110	4	38.97
Northeast	Lake Altho	LKALTHO	Alachua	21030047	2	77.47
Northwest	Rattlesnake Lake	RSNAKEREF	Washington	32030099	0	69.45
Northwest	Porter Lake	PORTERREF	Washington	32030097	0	82.83
Northwest	Porter Lake	PORTERREF	Washington	32030097	1	84.80
Northwest	Otter Lake	OTTER*REF	Wakulla	22020090	1	68.79
Northwest	Bear Lake	BEARTST	Santa Rosa	33030057	4	51.47
Northwest	Kell-Air Lake	KELLALK	Okaloosa	32010050	7	14.63
Northwest	Karick Lake	KARICKTST	Okaloosa	33040042	5	65.32
Northwest	Lake Munson	LKMUNSON	Leon	23010165	6	22.98
Northwest	Lake Victor	LKVICTOR	Holmes	32010085	5	37.78
Northwest	Sand Hammock Pond	SANDPOND	Holmes	32010038	2	78.47
Northwest	Lake Cassidy	CASSCTREF	Holmes	32020104	0	80.73
Northwest	Stone Lake	LKSTONE	Escambia	33020097	3	34.99
Northwest	Court Martial Lake	CORTMARREF	Bay	32030098	1	71.78

District	Waterbody name	Nick name	County	STORET	HDG	LVI_1x
South	Lake Verona	LKVERONMID	Highlands	26010339FTM	4	28.75
South	Lake Pioneer	LKPIONEER	Highlands	26010651FTM	7	30.48
South	Lake Tulane	LKTULANMID	Highlands	26010340FTM	5	31.25
South	Lake Carrie	LKCARRIE	Highlands	26010585	7	36.78
South	Lake Denton	LKDENTON	Highlands	26010648	4	39.52
South	Lake Viola	VIOLCTREF	Highlands	26010605	7	41.41
South	June In Winter Lake	HIGHL73	Highlands	26010559	6	47.56
South	Lake Placid	LKPLACIDNO	Highlands	26010650FTM	4	48.91
South	Wolf Lake	WOLFCTREF	Highlands	26010613	4	50.55
South	Lake Little Bonnet	LTLBONNET	Highlands	26010326	3	50.95
South	Lake Olivia	LKOLIVIA	Highlands	26010652FTM	6	51.05
South	Red Beach Lake	REDBCHREF	Highlands	26010638	4	53.63
South	Lake Apthorpe	APTHORPREF	Highlands	26010630	3	57.85
South	Persimmon Lake	HIGHL11	Highlands	26010303	5	58.12
South	Annie Lake	ANNMIDREF	Highlands	26010310	0	81.23
South	Submarine Lake	SUBMARIREF	Highlands	26010640	2	83.72
South	Little Lake	LITTLE REF	Highlands	26010636	2	87.82
South	Lake Yellowhammer	LKYELHAM	Charlotte	25010080FTM	3	41.53
South	Lake Webb	LKWEBB	Charlotte	25010079	2	61.66
Southeast	Lake At Tozour Rd.	LKTOZOUR	St Lucie	28010596	4	38.79
Southeast	Lake Eden	LKEDEN	St Lucie	28010595	1	52.13
Southeast	Lake Ida Pb	LAKEIDA	Palmbeach	28010500	5	9.61
Southeast	Lake Osborne	LKOSBORNE	Palmbeach	28010500	7	11.82
Southeast	Lake Clark	LKCLARK	Palmbeach	28010400	6	13.43
Southeast	Wellington Lake	LKWELNGTON	Palmbeach	28010600	6	41.58
Southeast	Lake Halpatioke	LKHALPATOK	Martin	28010594	0	47.91
Southeast	Quiet Waters Lake N	LKQUIETH2O	Broward	28030600	2	46.49
Southwest	Lake Deaton	L58P	Sumter	UNKNOWNL58P	1	54.21
Southwest	Banana Lake	L84-BANANA	Polk	27584418154127	4	18.74
Southwest	Lake Conine	CONINETST	Polk	25020131	5	31.26
Southwest	Lake Lena	L74-LENA	Polk	28040038148367	6	42.36
Southwest	Lake Mattie	MATTIE1REF	Polk	23010406	2	43.98
Southwest	Lake Elbert	LKELBERT	Polk	28013598142314	5	44.95
Southwest	Lake Rochelle	SWDLL1027	Polk	14580	4	46.00
Southwest	Lake Daisy	LKDAISY	Polk	27594708139333	5	49.41
Southwest	Lake Juliana	JULIANREF	Polk	23010427	5	49.47
Southwest	Lake Martha	LKMARTHA	Polk	25020198	5	49.71
Southwest	Lake Shipp	LKSHIPP	Polk	25020355	7	49.99
Southwest	Lake Martha	LKMARTHA	Polk	25020198	5	51.62
Southwest	Lake Easy	L53PEASY	Polk	25023002	1	54.88
Southwest	Lake Annie	LAKE ANNIE	Polk	27594380813618	2	55.66
Southwest	East Lake	L51PEAST	Pasco	24040806	3	26.78
Southwest	Lake Como	L61PCOMO	Pasco	24040805	6	51.83
Southwest	Lake Walden	L52PWALDEN	Hillsborough	24040170	3	9.12
Southwest	Lake Weeks	WEEKSREF	Hillsborough	24030082	5	23.96
Southwest	Lake Norbert	LKNORBERT	Hillsborough	28091278228372	4	25.04
Southwest	Lake Bellows	LKBELLOS	Hillsborough	24030127	5	29.08
Southwest	Lake Le Clare	LKLECLARE	Hillsborough	28063598232193	2	29.33
Southwest	Thonotosassa Lake	THONOTST	Hillsborough	24030022	5	30.55

District	Waterbody name	Nick name	County	STORET	HDG	LVI_1x
Southwest	White Trout Lake	L62P	Hillsborough	UNKNOWNL62P	3	40.48
Southwest	Lake Williams	LKWILLIAMS	Hillsborough	28055458236093	4	51.66
Southwest	Lake Brooker	L59PBRKR	Hillsborough	24040172	4	53.85
Southwest	Lake Alice	ALICEPREF	Hillsborough	24040019	2	68.19
Southwest	Lake Rogers	L63P	Hillsborough	UNKNOWNL63P	1	71.24
Southwest	Spring Lake	L65P	Hernando	UNKNOWNL65P	4	46.37
Southwest	Lake Lindsey	LKLINDSY	Hernando	23010439	2	66.78
Southwest	Lake Tooke	TOOKEPREF	Hernando	24040015	2	67.21
Southwest	Lake Tooke	TOOKEPREF	Hernando	24040015	1	74.54

APPENDIX 5. ADDITIONAL TABLES

App. Table 5.1. Details for Table 4 including N, Spearman's r, and associated p level.

Disturbance measures	N	r	p-level
HDG & WQ index	91	0.62	0.00
HDG & LDI	98	0.73	0.00
HDG & Habitat index	95	-0.87	0.00
WQ index & HDG	91	0.62	0.00
WQ index & LDI	91	0.19	0.07
WQ index & Habitat index	87	-0.46	0.00
LDI & HDG	98	0.73	0.00
LDI & WQ index	91	0.19	0.07
LDI & Habitat index	93	-0.69	0.00
Habitat index & HDG	95	-0.87	0.00
Habitat index & WQ index	87	-0.46	0.00
Habitat index & LDI	93	-0.69	0.00

App. Table 5.2. Candidate plant metrics and their correlation with HDG, the WQ index, LDI, and the habitat index, detail from Table 6. The sample size is shown for all metrics except dominant C of C for which N ranged from 57–65. Most metrics were calculated as both the total number of taxa and the percentage of total taxa (left vs. right side of table); exceptions to this were metrics in the category “Community structure” which could only be calculated in one way.

	Number of taxa				**Percent of total taxa**			
	HDG	**WQ**	**LDI**	**Hab**	**HDG**	**WQ**	**LDI**	**Hab**
N =	**95**	**95**	**93**	**90**	**95**	**95**	**93**	**90**
Community structure								
Total taxa	-0.05	0.04	-0.17	0.16	-	-	-	-
No. of plant guilds	0.25	0.15	0.07	-0.15	-	-	-	-
Dominant C of C	-0.52	-0.43		0.49	-	-	-	-
Nativity								
Native	-0.24	-0.13	-0.31	0.35	-0.56	-0.46	-0.53	0.64
Invasive	0.55	0.50	0.45	-0.48	0.63	0.51	0.61	-0.65
Category 1	0.56	0.44	0.48	-0.50	0.58	0.43	0.58	-0.58
Categories 1 & 2	0.59	0.51	0.49	-0.53	0.62	0.48	0.60	-0.62
Tolerance								
FQI SCORE	-0.52	-0.32	-0.54	0.57	-	-	-	-
Average C of C	-0.67	-0.49	-0.59	0.63	-	-	-	-
Sensitive (CC>7)	-0.40	-0.31	-0.41	0.46	-0.49	-0.44	-0.41	0.48
Tolerant (CC<3)	0.48	0.39	0.35	-0.37	0.67	0.42	0.60	-0.59
V. Tolerant (CC<2)	0.51	0.40	0.38	-0.40	0.65	0.41	0.59	-0.59
Duration								
Perennial	-0.07	-0.01	-0.16	0.18	-0.08	-0.15	-0.01	0.15
Annual	-0.15	0.12	-0.31	0.26	-0.16	0.09	-0.32	0.25
Annual:Perennial ratio	0.11	0.18	0.10	0.02	-0.12	0.14	-0.27	0.21
Native perennials	-0.24	-0.16	-0.32	0.35	-0.07	-0.07	-0.08	0.07
Native annuals	0.00	0.16	-0.05	0.14	0.16	0.24	0.14	-0.04
Wetland status								
Obligate wetland	-0.06	0.11	-0.15	0.17	-0.02	0.23	0.00	0.04
Obl. & Facult.	-0.03	0.08	-0.14	0.17	0.07	0.20	0.00	0.07
Upland	0.07	-0.10	0.01	0.04	0.09	-0.14	0.04	-0.01
Native obl. Wetland	-0.20	-0.03	-0.26	0.31	0.01	0.23	0.09	-0.06
Native facult wetland	-0.03	-0.09	-0.11	0.17	0.23	-0.01	0.15	-0.12
Native upland	0.00	-0.15	-0.08	0.13	0.12	-0.11	0.04	-0.02
Growth form								
Herbaceous	0.02	0.09	-0.07	0.12	0.14	0.18	0.24	-0.11
Woody	-0.18	-0.11	-0.31	0.21	-0.18	-0.21	-0.25	0.15
Emergent	0.01	0.07	-0.09	0.14	0.18	0.15	0.14	-0.09
Floating	-0.04	0.20	-0.05	0.04	-0.03	0.18	0.06	-0.03
Submersed	0.05	-0.18	0.19	-0.07	0.05	-0.19	0.23	-0.09
Fern	-0.08	0.16	-0.27	0.21	-0.06	0.14	-0.23	0.19
Gymnosperm	0.07	-0.06	0.01	0.00	0.06	-0.12	0.05	-0.03
Native herbaceous	-0.14	-0.07	-0.17	0.29	0.13	0.11	0.29	-0.10
Native woody	-0.32	-0.14	-0.48	0.37	-0.13	-0.08	-0.29	0.13
Native emergent	-0.14	-0.03	-0.21	0.31	0.11	0.17	0.14	-0.02
Native floating	-0.28	-0.16	-0.14	0.19	-0.22	-0.17	-0.02	0.09

	Number of taxa				**Percent of total taxa**			
	HDG	**WQ**	**LDI**	**Hab**	**HDG**	**WQ**	**LDI**	**Hab**
N =	**95**	**95**	**93**	**90**	**95**	**95**	**93**	**90**
Native submersed	0.01	-0.28	0.25	-0.03	0.09	-0.21	0.36	-0.13
Native fern	-0.25	-0.07	-0.38	0.34	-0.22	-0.08	-0.35	0.31
Native gymnosperm	0.06	-0.07	0.02	0.02	0.16	-0.01	0.14	-0.14
Native forbs & herbs	-0.17	-0.08	-0.17	0.27	0.02	0.06	0.24	-0.07
Native graminoids	-0.13	-0.12	-0.14	0.29	-0.01	-0.07	0.00	0.13
Native vines	0.23	0.11	0.11	-0.10	0.37	0.17	0.27	-0.26
Native shrubs	-0.44	-0.31	-0.52	0.48	-0.37	-0.30	-0.41	0.34
Native subshrubs	-0.14	0.19	-0.37	0.16	-0.13	0.19	-0.36	0.14
Native tree	-0.18	-0.03	-0.37	0.21	0.01	0.05	-0.17	-0.03
Dicot/Monocot								
Annual dicot	-0.17	-0.02	-0.28	0.25	-0.30	-0.19	-0.29	0.24
Monocot	0.14	0.13	0.05	-0.01	0.32	0.22	0.35	-0.28
Native annual dicot	-0.31	-0.15	-0.40	0.39	-0.16	-0.06	-0.20	0.16
Native annual monocot	-0.10	-0.07	-0.13	0.21	0.13	0.09	0.18	-0.13
EPA database								
Sensitive	0.15	0.05	0.12	0.02	0.24	0.03	0.25	-0.08
Tolerant	-0.02	0.09	-0.15	0.11	0.01	0.15	-0.05	-0.03
V. Tolerant	0.17	0.22	-0.10	-0.08	0.24	0.23	0.04	-0.21
Nutrient tolerant	-0.08	0.06	-0.25	0.17	-0.14	-0.01	-0.24	0.09
V. Nutrient tolerant	-0.10	-0.09	-0.12	0.03	-0.07	-0.07	-0.06	-0.06
N tolerant	0.18	0.26	-0.09	-0.17	0.28	0.29	0.08	-0.38
P sensitive	0.20	-0.02	0.28	-0.14	0.20	-0.03	0.29	-0.14
P tolerant	0.21	0.32	-0.04	-0.21	0.29	0.36	0.09	-0.41
Flood sensitive	-0.33	-0.31	-0.40	0.32	-0.31	-0.33	-0.35	0.30
Flood tolerant	0.19	0.18	0.12	-0.11	0.38	0.22	0.39	-0.43
V. Flood tolerant	0.28	0.38	0.23	-0.28	0.31	0.36	0.32	-0.38
Sediment senstive	0.40	0.24	0.28	-0.34	0.37	0.22	0.28	-0.34
Sediment tolerant	-0.40	-0.27	-0.39	0.43	-0.41	-0.30	-0.40	0.41
V. Sediment tolerant	-0.13	0.23	-0.28	0.20	-0.13	0.23	-0.28	0.20
Salinity sensitive	-0.04	0.07	-0.20	0.13	-0.07	0.01	-0.16	0.08
Salinity tolerant	0.16	0.14	-0.03	-0.04	0.19	0.17	0.03	-0.10
V. salinity tolerant	0.07	0.14	-0.08	-0.03	0.08	0.14	-0.07	-0.04

App. Table 5.3. Spearman's correlation coefficients for plant metrics included in LVI. Shown are correlations for metric values calculated from the combined data from all 12 lake sections. N = 95 for % native taxa, % invasive taxa and % sensitive taxa; N = 62 for dominant C of C.

	% Native taxa	% Invasive taxa	% Sensitive taxa	Dominant C of C
% Native taxa		-0.72	0.46	0.40
% Invasive taxa	-0.72		-0.48	-0.48
% Sensitive taxa	0.46	-0.48		0.43
Dominant C of C	0.40	-0.48	0.43	

APPENDIX 6. LVI VALIDATION AND CALIBRATION FOR 2005–2006 SAMPLING

LVI was initially developed from data collected during 2000–2003. The association between measures of macrophyte condition and human disturbance was validated with additional data collected in 2004. The final report from that study was completed in 2005. This appendix used data collected during 2005–2006 to document the association between LVI and human disturbance for a new data set, calibrate metric scoring for regional differences, and evaluate the annual variability of LVI.

Methods

Data set

During 2005–2006, 167 lakes were sampled and some were visited more than once. For validation testing, only the most recent visits were used from each lake. For metric calibration, metric values from the most recent visits to the 167 lakes were used as well as data from 88 of the original lakes sampled in 2002–2003 (10 lakes sampled in 2000 were excluded because sampling methods changed). For variability analysis, 31 lakes had 2–3 repeat visits during 2005–2006. Some lakes had visits before 2005, but protocols for defining and calculating some of the metrics changed during that time; therefore, earlier LVI values were not entirely comparable. Of the 31 lakes, 11 lakes had two visits during 2005 and one visit during 2006; the remaining lakes had two visits either during one year (2005) or during both years.

Data collected during 2005-2006 included three modifications to metric calculation: C of C scores were added for some species that were missing during the initial calibration; native status was added for plants identified to genus, where appropriate; and *Cephalanthus occidentalis*, *Nymphaea odorata*, and *Vallisneria americana* were removed from the list of sensitive taxa based on the original analysis (see Table 8 main document).

Data analysis

The WQ index and habitat index were calculated as described in the main document but two changes were made to the calculation of HDG. Information related to hydrology was not included in the HDG because impoundment was difficult to measure reliably and, even when known, failed to influence metric values as predicted. The second change related to treatment of missing values for the WQ and habitat indexes (all lakes had LDI values). Previously, missing values were assumed to show no impairment and scored as 0. For the analysis described here, when only two of the three components of HDG were available, the sum of the scored values was multiplied by 3/2 to make values more comparable to lakes for which all three component values of the HDG were available. In this way the value for the third, missing component was inferred from the other two. If both the WQ and habitat indices were missing, HDG was not calculated. Four lakes were excluded from HDG comparisons due to missing data.

For all lake visits, four of 12 lake sections were measured. For 75% of the visits in 2005, sections from opposite sides of the lake were combined before calculating metrics and LVI. For all other visits, the four lake sections were kept separate, and metrics and LVI were calculated for all four. The final LVI value for a lake-visit was the average of the LVI values for the sections. All comparisons and analyses of both LVI and its component metrics used the average value for each lake-visit.

Metric scoring rules were derived (as previously) from the 5th and 95th percentiles. The original analysis had relatively few lakes from the southern part of the state; consequently, ecological differences in metric values due to latitude could not be fully evaluated. The new data had more southern sites and scoring rules for metrics were updated to make LVI values more comparable across the state. Northern and southern lakes were divided according to climatological zones defined by the U.S. Department of Agriculture (Fernald and Purdum, 1998; Lane, 2000). The line between the USDA’s north central and south central divisions falls near 28.2° latitude and approximates the frost line. Along this line, Pasco, Sumter, Lake, and Orange counties are in the northern region, Pinellas, Hillsborough, Polk, and Osceola counties are in the southern region, while Brevard county is divided by the 28.35° latitude line.

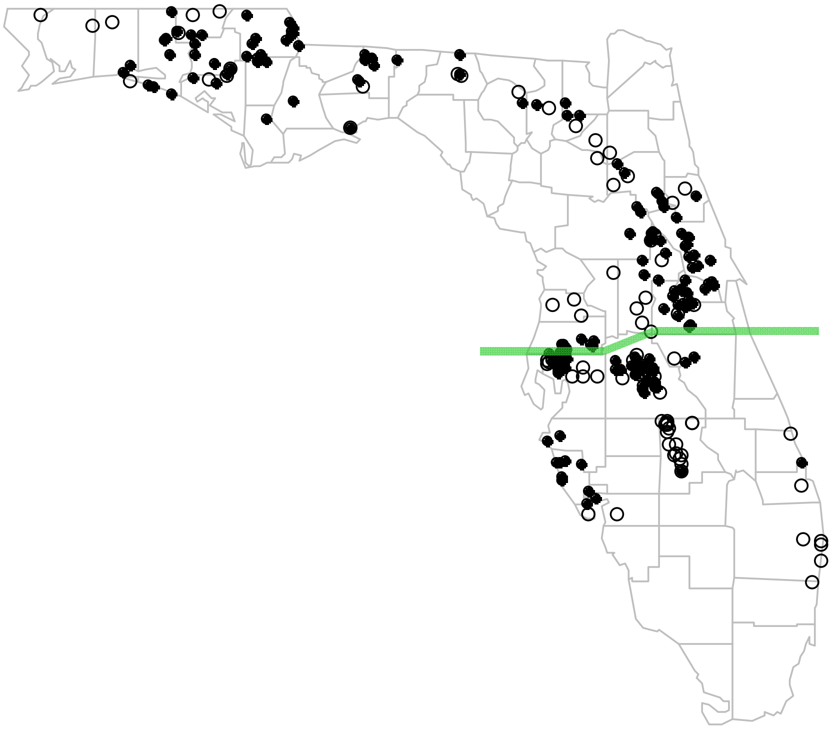
Variance of LVI was evaluated in two ways. To compare sources of variance, a balanced ANOVA design is preferred, that is, a design for which all year and lake combinations have an LVI value. For this analysis, only 11 lakes had the same pattern of visits (2 visits in 2005 and 1 in 2006), and these lakes were used. In contrast, to estimate variance of LVI, a larger sample size was preferred; therefore, all the lakes visits during 2005–2006 were used.

Components of variance analysis was used to partition the variance of LVI and its four metrics according to different sources of variability. Sources of variance included different lakes, different visits within a year, different years, and lake x year interaction (additional differences that cannot be explained by lake and year alone). An ANOVA model was used to derive estimates of variance, one model each for LVI and the four metrics. The relative percentages for each source of variance were compared to identify which source contributed the greatest portion to the overall variability of LVI; a similar comparison was done for each of the four metrics.

In the original analysis, variance of LVI was calculated for repeat visits on the same day. For this study, repeat visits during 2005 and 2006 to 31 lakes were used to estimate variance of LVI. With lake as the main factor, all repeat visits were used to calculate the mean squared error (MSE). In other words, different years were not treated as a factor. The estimate of variance was used to calculate a 90% confidence interval as:

$$\text{LVI} \pm \left(\sqrt{\frac{s^2}{n}} * 1.645 \right),$$

where s^2 = variance estimated from ANOVA (mean squared error), and
n = number of lake visits.

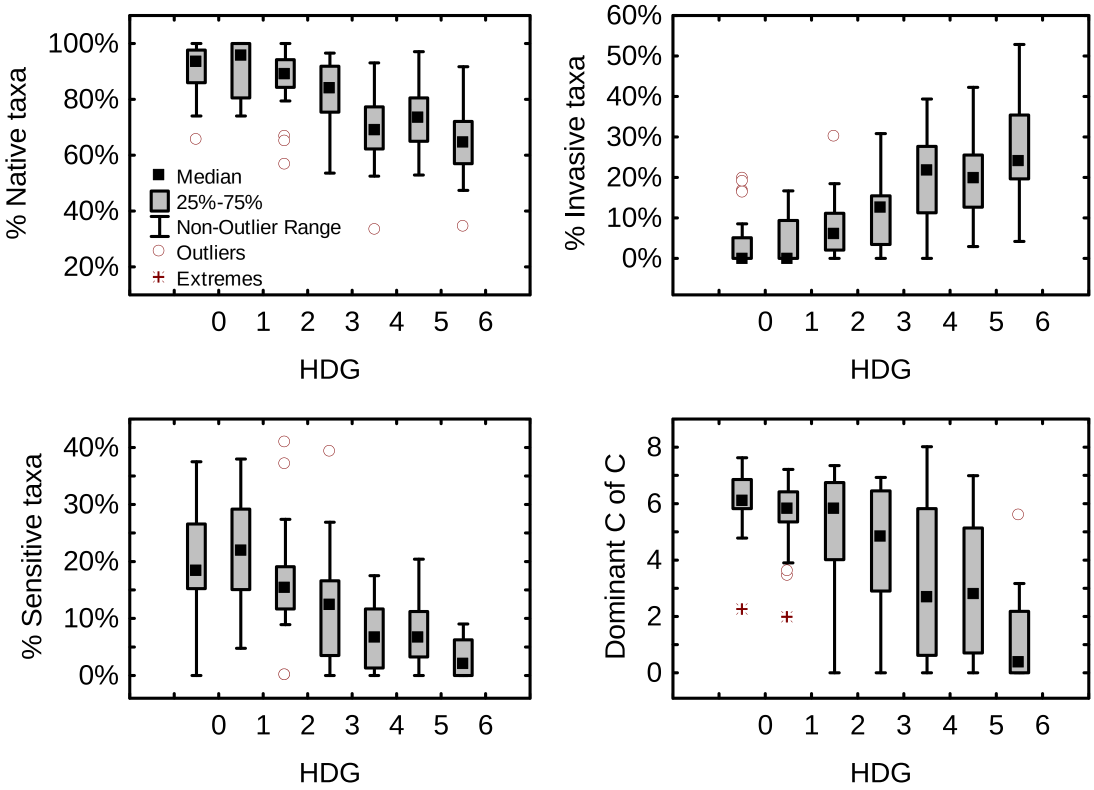


App. Figure 6.1. Lake locations for the original data collected in 2000–2003 (open circles) and the more recent data used here that were collected in 2005–2006 (closed circles). The line dividing northern and southern lakes is shown.

Results

Validation testing

LVI and its component metrics were, again, highly correlated with HDG, the WQ index, and the habitat index (App. Table 6.1). Correlation values for metrics were slightly higher for the more recent data set, perhaps due to the adjustment made to the HDG scoring for missing values or adjustments made to metric calculations. Correlation between LVI and HDG was nearly identical to earlier results for the 2004 validation testing (Spearman's *r* = –0.71 vs. –0.70 (development data set; Table 13 main document) and –0.72 (first validation data set; Table 16). Correlation between LVI and the WQ index was higher for this data set (–0.58 vs. –0.34) but lower for LDI (–0.60 vs. –0.78).



App. Figure 6.2. Percent native and sensitive taxa and dominant C of C declined as human disturbance increased. Percent invasive taxa increased with disturbance (N = 164 except for dominant C of C for which N = 118).

As seen in the original analysis (see Table 4 main document), all measures of human disturbance were significantly correlated with each other (App. Table 6.2). LDI and the WQ index again had the weakest association.

App. Table 6.1. Spearman's correlation values for LVI (original version developed in 2005 and with modified 2007 scoring described below) and its metrics (2005–2006 data) with measures of disturbance. All values significant (*p* < 0.01). N represents most recent lake visit; number of lakes for dominant C of C lower due to missing data. Last column shows correlation values from the original analysis (see Table 13).

	HDG	**N**	**LDI**	**N**	**Habitat index (%)**	**N**	**WQ index**	**N**	**HDG (original analysis)**
LVI (2005)	-0.71	164	-0.60	167	0.70	98	-0.58	162	-0.70
LVI (2007)	-0.72	164	-0.60	167	0.72	98	-0.58	162	
% Native taxa	-0.68	164	-0.54	167	0.74	98	-0.58	162	-0.59
% Invasive taxa	0.70	164	0.60	167	-0.70	98	0.58	162	0.61
% Sensitive taxa	-0.61	164	-0.52	167	0.51	98	-0.47	162	-0.48
Dominant C of C	-0.53	118	-0.41	121	0.55	86	-0.44	116	-0.48

App. Table 6.2. Spearman's correlation of disturbance measures. All values significant (*p* < 0.01). N varied from 96-164. For comparison, correlation values from the original analysis are shown below (see Table 4).

	HDG	**N**	**LDI**	**N**	**Habitat index (%)**	**N**
LDI	0.84	164				
Habitat index (%)	-0.89	98	-0.75	98		
WQ index	0.64	162	0.33	162	-0.59	96

Original analysis:

	HDG	**LDI**	**Habitat index (%)**
LDI	0.73		
Habitat index (%)	-0.87	-0.69	
WQ index	0.62		-0.46

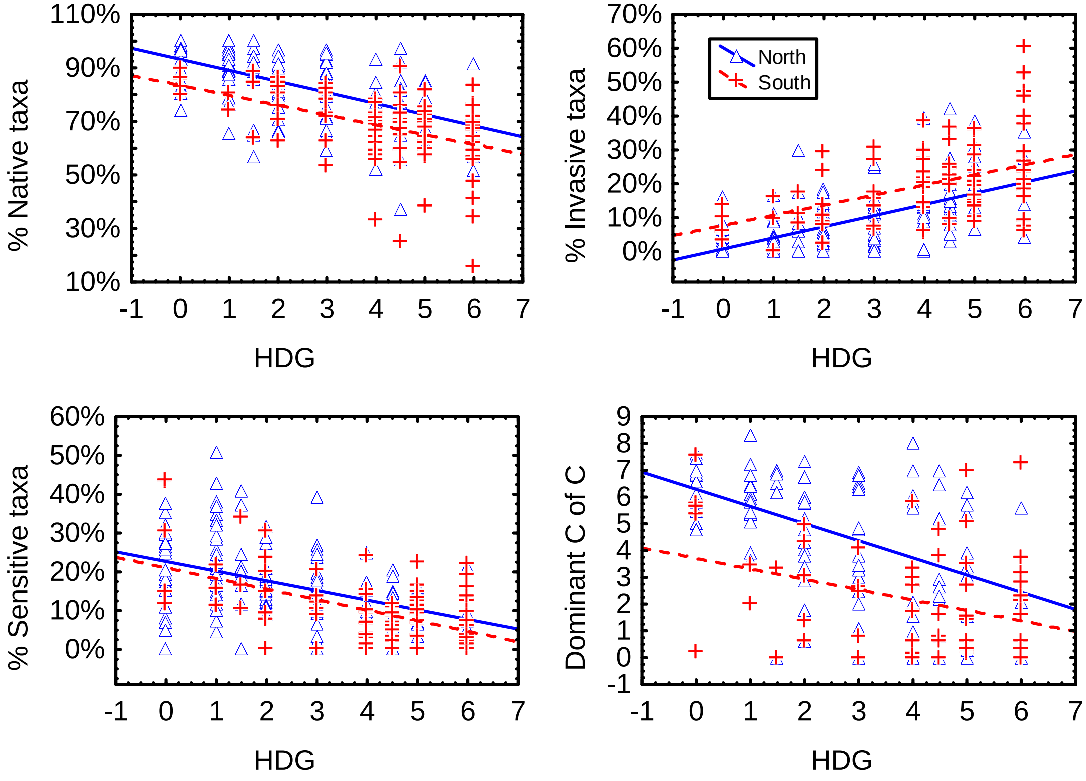
Regional adjustment of metric scoring

All four metrics showed regional differences in that northern lakes had values indicating better biological condition than southern lakes for the same level of human disturbance (App. Figure 6.3). Dominant C of C showed the greatest difference between regions. Two metrics, percent sensitive taxa and dominant C of C, were adjusted for regional differences by using separate scoring rules for lakes in the north and south (App. Table 6.3). Percent native and invasive taxa were not adjusted because the differences in these metric values represent real differences in biological condition. Lower values for these two metrics are expected in southern lakes because many invasive exotic plants are from tropical climates and are able to persist and displace native plants in the absence of freezing temperatures. Thus, southern lakes are more vulnerable to this type of biological change associated with human disturbance.

These adjustments to metric scoring had only a small effect on the LVI, and the two versions were very similar in their correlation with disturbance measures (see App. Table 6.1 above).

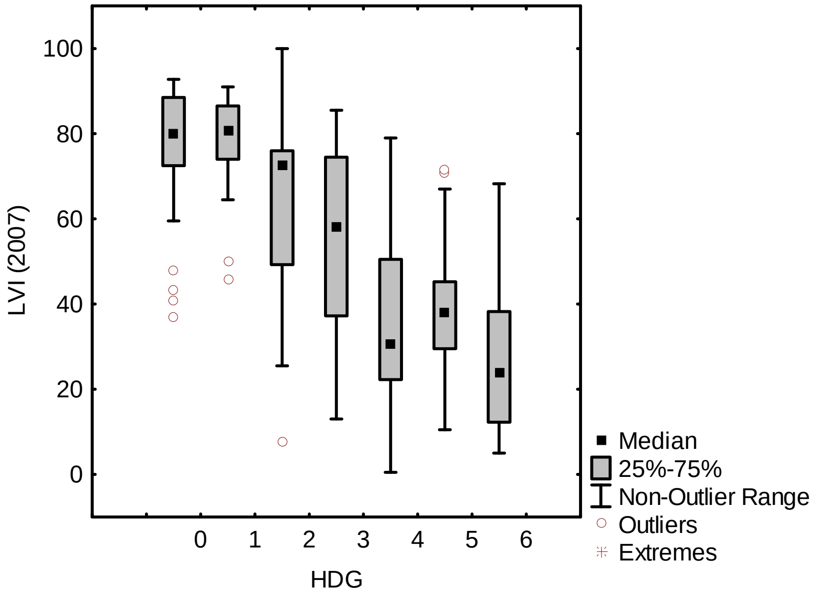
App. Table 6.3. Metric scoring rules derived from the 5th and 95th percentiles using the most recent visit from each lake including lakes from the original development data set. Metric scores less than 0 are set equal to 0; scores greater than 1 are set equal to 1.

Metric	N	5th %tile	95th %tile	Scoring rule
% Native taxa	256	54%	98%	(x – 54)/44
% Invasive taxa	256	0%	36%	1 – (x/36)
% Sensitive taxa				
North	154	0%	37%	x/37
South	102	0%	24%	x/24
Dominant C of C				
North	111	0	7.2	x/7.2
South	67	0	5.8	x/5.8



App. Figure 6.3. LVI metrics plotted against the HDG with northern and southern lakes distinguished. Regression lines are shown for each group of lakes (N=252 for all except dominant C of C for which N=178).

Overall, the LVI declined consistently as human disturbance increased (App. Figure 6.4). Much of the overlap in categories defined by HDG was due to the inaccuracy of measurements of human disturbance; therefore, this method was not used to define the number of categories of biological condition that LVI could detect. Instead, repeat visits to the same lake were used to determine the natural variability of LVI values and estimate precision of the index.



App. Figure 6.4. LVI declined as human disturbance increased for lakes sampled in 2005–2006 (Spearman's $r = 0.72$, $p < 0.01$). N: 164 (total), 23 (HDG = 0), 30 (HDG = 1), 14 (HDG = 2), 22 (HDG = 3), 47 (HDG = 4), 13 (HDG = 5), and 15 (HDG = 6).

Variability analysis

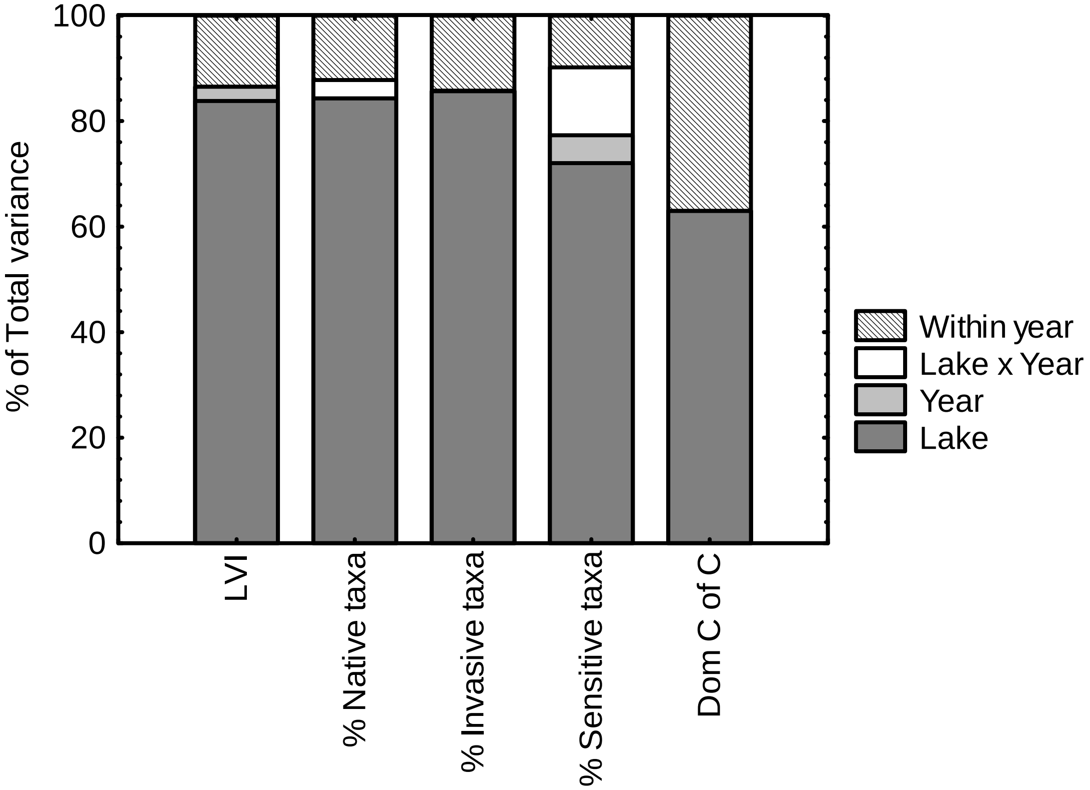
Repeat visits to 11 lakes were used to evaluate the precision of LVI. Comparisons through time assumed that the influence of human disturbance at each lake changed very little during the sampling period and that differences in LVI values were due to natural variability. LVI values for the 11 lakes ranged from 25–94. Excluding the LVI variance due to differences in lakes (which is the type of variance we hope to detect), within year variability represented the largest component of variance for most of the indicators (App. Figure 6.5). Differences associated with annual variability were much smaller in comparison. The most variable metric continued to be dominant C of C even though the metric value was missing for only one lake-visit.

The variance, 90% confidence interval, and number of categories of biological condition that LVI could detect were derived from same-day repeat visits in the original analysis. For an LVI value calculated as the average of values from four lake sections, the variance would be equal to the within-lake variance divided by four, or 28.0 (=112.33/4; see Table 12, main document). The 90% confidence interval derived from that estimate of variance was 17.4 (LVI +/- 8.7). Dividing the confidence interval into 100 (the range of values possible for LVI) yielded an estimate of 5.7 categories of biological condition for a single lake visit.

LVI variance derived from repeat visits in 2005 and 2006 was 53.7 (App. Table 6.4), approximately twice the estimate observed for same-day sampling (28.0). This estimate of variance also includes differences associated with sampling crews because the same-day sampling of sections was done by a single field crew while the repeat visits in 2005 and 2006 could have been done by different field crews. The 90% confidence interval for this variance estimate was 24.1 (LVI +/- 12) for a single lake visit (n = 1). Dividing into 100 yielded an estimate of 4.2 categories of biological condition for repeat visits across years. For two visits, variance decreased to 14.0 (=28/2) and the 90% confidence interval was 17.0 (LVI +/- 8.5), which yielded 5.9 categories of biological condition.

App. Table 6.4. ANOVA results for LVI for repeat visits to lakes (STORET sites).

	Effect	df	MS	df	MS	F	p
STORET	Random	33	1020.8	41	53.663	19.02209	0.00



App. Figure 6.5. Relative contributions of different sources of variance for LVI and its four metrics. Differences associated with lakes represented the greatest percentage of total variance for LVI and all four metrics. Repeat visits within a year accounted for the next largest percentage of variance for LVI and three metrics (lake x year interaction was next greatest for % sensitive taxa). Variability due to differences in years contributed a relatively small percentage of the total variance for LVI and its four metrics.

Conclusions

Recent data for macrophyte metrics and the LVI show a very similar pattern to earlier testing: LVI and its component metrics were highly correlated with independent measures of human disturbance, including landscape level disturbance (LDI), measures of water chemistry (WQ index), and physical habitat condition (habitat index).

Differences in metric values were associated with climatological differences in location. Southern lakes are more vulnerable to invasion by exotics from tropical climates. Lack of freezing temperatures allows these plants to obtain a firmer foothold. For this reason percent native and percent exotic taxa were not adjusted during the metric scoring process. Percent sensitive taxa and dominant C of C were adjusted because many of the sensitive plants with high C of C values are not found in southern lakes; therefore, expectations for these metrics should be lower and are now reflected in the scoring rules for these metrics.

The variance estimate of LVI derived from repeat visits to the same lake during two years was approximately twice the variance estimate derived from same-day repeat visits for the original analysis. Although variance estimates derived from different data sets should be compared cautiously, results suggest that about the half the variability observed for LVI was due to natural differences associated with different lake sections and half was due to changes through time. Precision could be increased by increasing the number of lake visits, but for the current sampling protocol the LVI is capable of detecting approximately 4 levels of biological condition. Two repeat visits to a lake would increase the precision of LVI and support the distinction of 6 levels of biological condition. Managers can use the LVI to distinguish lakes with exceptional macrophyte communities as well as those whose degraded condition fails to support the expected assemblage of plants.

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APPENDIX 7: BIOLOGICAL CONDITION GRADIENT TO DEFINE BIOCRITERIA FOR LVI

Background

The regulatory context for the management of surface waters is derived from the Clean Water Act (CWA; EPA, 2005; Davies and Jackson, 2006). Within this framework, states and tribes must adopt water quality standards to protect their waters. Water quality standards (WQS) include three parts: 1) designated uses, 2) numeric and narrative criteria that protect the uses, and 3) antidegradation policies to prevent deterioration of high-quality waters. WQS define the water quality goals for a water body by designating the use(s) and setting criteria necessary to protect the use(s). States are required to report to Congress the water bodies that are failing to support their designated uses.

Florida DEP intends to use biological criteria along with physical and chemical criteria to determine whether lakes are meeting their designated uses, particularly uses related to aquatic life support. Designated aquatic life uses represent a state's biological goals for its water bodies. In 2001, the National Research Council recommended *tiering* designated uses to improve the decision-making related to setting water quality standards (NRC, 2001). The NRC found the CWA's goals to be too broad to provide the operational definition of designated uses needed to support aquatic life. For example, rather than stating that a water body needs to be "fishable," the designated use should specifically describe the expected fish assemblage (e.g., cold water fishery, warm water fishery, or salmon, trout, bass, etc.). In response to the NRC's recommendations, EPA has developed guidance for developing *tiered aquatic life uses* (TALUs), which are bioassessment-based statements of expected biological condition in specific water bodies that allow more precise and measurable definitions of designated aquatic life uses. Thus, the TALU approach is designed to support the implementation of biocriteria, and the scientific knowledge of aquatic ecology that they represent, into state water quality standards. Because FDEP's intends ultimately to adopt criteria based on this tiered aquatic life use concept, three categories are proposed for the LVI. Subject to future rule making decisions, those three categories may be conceptually interpreted as “exceptional” (Category 1), “healthy” (Category 2), and “impaired” (Category 3). The approach described here for defining biocriteria for lakes closely parallels the methods used to define biocriteria for macroinvertebrate assemblages in streams (Fore et al., 2007)

Biological Condition Gradient

Within the context of defining TALUs for surface waters, EPA recommends that states use a Biological Condition Gradient (BCG) to illustrate how ecological attributes change in response to increasing levels of human disturbance (Davies and Jackson, 2006). The BCG is a conceptual model that assigns the relative health of aquatic communities into one of six categories. The BCG is based on fundamental ecological principles and has been extensively tested and verified by aquatic biologists throughout the U.S.

The BCG utilizes ten biological attributes of aquatic systems that respond predictably to increasing pollution and human disturbance:

I. Historically documented, sensitive, long-lived or regionally endemic taxa
II. Sensitive and rare taxa
III. Sensitive but ubiquitous taxa
IV. Taxa of intermediate tolerance
V. Tolerant taxa
VI. Non-native taxa
VII. Organism condition
VIII. Ecosystem functions
IX. Spatial and temporal extent of detrimental effects
X. Ecosystem connectance.

The gradient represented by the BCG is divided into six levels (tiers) of condition that were defined during a series of national workshops with experienced aquatic biologists from across the U.S. (Davies and Jackson, 2006). The six tiers are described as:

1. Natural or native condition
2. Minimal changes in structure of the biotic community and minimal changes in ecosystem function
3. Evident changes in structure of the biotic community and minimal changes in ecosystem function

4. Moderate changes in structure of the biotic community with minimal changes in ecosystem function
5. Major changes in structure of the biotic community and moderate changes in ecosystem function
6. Severe changes in structure of the biotic community and major loss of ecosystem function.

Davies and Jackson (2006) recommend that regional biological experts adapt the conceptual tiers described by the BCG to local conditions using data from a regional monitoring program. This was the approach adopted by Florida DEP to define biocriteria for the LVI.

Methods

A panel of 20 experienced plant ecologists, all with more than five years of experience, was convened as part of a workshop to develop a BCG for Florida lakes (App. Table 7.1). Participants were asked to apply and calibrate the general BCG model to macrophyte data collected from Florida lakes. Results from the workshop were used to define biological thresholds (biocriteria) for the LVI.

Prior to the workshop, experts were provided with background literature on the BCG concept (Davies and Jackson, 2006; Stoddard et al., 2006) and a description from DEP of the workshop process and the LVI sampling method. Experts were informed that they would be asked during the workshop to review macrophyte data from individual lakes and assign each sample a score from 1 (best) to 6 (worst), signifying their assessment of the biological condition represented by the plant assemblage.

The experts were given taxa lists and metric values for each lake. Data were provided for 15 lakes in the north and 15 in the south; experts were told whether lakes were located in the north or south. Experts were not given LVI index values or any physical, chemical, or habitat descriptions of the sites.

Lake visits were selected primarily from the 2005-2006 data, with additional lake visits from the southern region as needed. Within each region, the samples with LVI scores closest to the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th percentiles of LVI scores for that region were chosen (nine visits; “LVI %iles” in App. Table 7.2). Then one lake visit was randomly selected from each of HDG levels 1-6 for each region (six visits; “HDG cat” in App. Table 7.2).

During the workshop, experts were given the opportunity to discuss their rationale for scoring a lake, and, if they desired, to change their score for a lake based on their assessment from the discussions (Delphi method). Scoring sheets were provided to each expert for recording both initial and final BCG scores. Experts were requested to indicate what relevance they ascribed to their BCG scores. More specifically, they were asked to record the maximum BCG score that they believed did not meet the interim goals of the Clean Water Act (impaired site; does not meet designated use). In other words, lakes below a selected tier score would be considered “impaired.” Experts were also asked to record the minimum score they believed represented an exceptional condition.

Before the TALU guidance was developed, many states used an approach based on reference site condition to develop biocriteria (EPA, 2006). Typically percentiles of index values for references sites are used to define thresholds. A buffer derived from the variability of reference site index values may also be used to define the lowest index value that indicates departure from reference condition, or impairment. Although not used to define thresholds for the LVI, LVI statistics for reference lakes are reported here because this method has been widely used before the more recent recommendations from EPA to use the BCG approach.

App. Table 7.1. Workshop participants, their affiliation and years of experience working with plants. Three participants had <5 years of experience and their scores were not included in threshold calculations.

Expert	Affiliation	Years of Experience
Loran Anderson	FSU Emeritus	>60
Erica Anderson	DEP - Bureau Aquatic Plant Management	>5
David Hall	Independent consultant	47
Jess Van Dyke	DEP - Bureau Aquatic Plant Management	37
Joe Hinkle	DEP - Bureau Aquatic Plant Management	33
Jeff Schardt	DEP - Bureau Aquatic Plant Management	31
John Rodgers	DEP - Tampa	30
Jackie Smith	DEP - Bureau Aquatic Plant Management	25
Robbie Lovesrand	DEP - Floral City	20
Ed Harris	DEP - Orlando	20
Katherine Gilbert	DEP - Tallahassee	20
John Tobe	ERC, Inc	20
Terry Sullivan	DEP - Floral City	20
Jeff Holland	Reedy Creek Improvement District	17
David Demmi	DEP - Bureau Aquatic Plant Management	15
Christine Keenan	DEP - Tallahassee	15
Nathalie Visscher	DEP - Orlando	8
Peggy Morgan	DEP - Tampa	5
Julie Espy	City of Tallahassee	5
Dana Denson	DEP - Orlando	5
Kelli Gladding	DEP - Orlando	4
Danielle Sobczak	DEP - Bartow	2
Marissa Rodriguez	DEP - Orlando	1.5

App. Table 7.2. Lake visits used in the BCG workshop. Shown are station nickname, STORET number, macrophyte ID, date of sampling, LVI, HDG, LDI and the method used to select the lake.

BCG ID	Station Nickname	STORET	Macro ID	Date	LVI	HDG	LDI	Selection method
N01	LKTHOMAS	24040132	3861	10/27/2005	48	2	3.8	LVI %iles
N02	PETTYGULF	22020129	4867	10/20/2005	33	4	4.4	HDG cat
N03	CHERYNEUNK	21010039	5123	10/13/2005	69	3	5.9	HDG cat
N04	PALSTCTREF	19010044	5201	10/11/2005	94	1	1.0	HDG cat
N05	ORANG161	26010887	5282	11/2/2005	41	5	6.4	LVI %iles
N06	LKSAUNDERS	20020166	5341	10/27/2005	63	5	4.6	HDG cat
N07	MARINERLK	20020165	5361	10/25/2005	82	2	3.8	HDG cat
N08	RSNAKEREF	32030099	5381	11/10/2005	82	0	1.7	LVI %iles
N09	LKSTANLEY	33040029	5383	10/26/2005	85	3	7.1	LVI %iles
N10	NW3SL2065	29664	6061	7/26/2006	78	2	2.6	LVI %iles
N11	LKSTANLEY	33040029	6241	11/6/2006	68	3	7.1	LVI %iles
N12	HIAWATHA	22020042	6364	10/19/2006	85	1	2.2	LVI %iles
N13	LONG POND	32020131	6409	10/16/2006	60	3	2.7	LVI %iles
N14	LKFRANCES	21020123	6410	11/15/2006	68	6	7.0	HDG cat
N15	BAKER15	21010011	6419	11/1/2006	87	1	2.0	LVI %iles
S01	LKYELHAM	25010080FTM	502	8/13/2002	38	3	1.9	HDG cat
S02	LKPLACIDNO	26010650FTM	546	8/20/2002	54	3	3.8	LVI %iles
S03	LKVERONMID	26010339FTM	921	10/27/2003	36	4	6.6	LVI %iles
S04	CYPRESSLK1	26010075	5621	5/10/2006	41	0	1.8	LVI %iles
S05	SAR616NL	SAR616NL	6322	11/1/2006	63	2	1.1	HDG cat
S06	LKHUNTER	24030148	6323	10/19/2006	63	5	6.8	HDG cat
S07	HIL540NL	HIL540NL	6324	9/28/2006	49	1.5	1.9	LVI %iles
S08	SW3SL2006	30724	6367	8/8/2006	22	4	4.2	HDG cat
S09	GENTNEREF	26010988	6373	10/16/2006	66	1	1.9	HDG cat
S10	SW3SL2013	30726	6376	9/5/2006	18	6	7.3	HDG cat
S11	SW3SL2082	30736	6392	8/22/2006	31	4	5.5	LVI %iles
S12	SW3SL2114	30745	6400	8/15/2006	72	4.5	3.3	LVI %iles
S13	SW3SL2170	30748	6401	9/6/2006	12	6	8.2	LVI %iles
S14	SW3SL2102	30741	6403	8/24/2006	41	5	7.7	LVI %iles
S15	LKEDEN	28010595	6426	11/8/2006	42	2	1.0	LVI %iles

Results

Each expert assigned a BCG to all of the 30 lakes (App. Table 7.3). After reviewing the data, most experts selected tiers 1 and 2 as exceptional aquatic life use (16 out of 19; 1 with no response; App. Table 7.4). Most experts agreed that tiers 5 and 6 indicated impairment or failure to support aquatic life use (13 out of 20). Seven experts thought the line for impairment should be higher: two identified tier 3 and five identified tier 4 as failing to support aquatic life use.

BCG scores from the experts were averaged to define thresholds for LVI. For the definition of the impairment line, an average of 4.6 was calculated from the experts' definitions. We rounded this value to the nearest half category (4.5) because BCG scores were not considered in increments of 0.1, and a value of 4.6 implied an accuracy that was not supported by the discussion. For the definition of the exceptional category, a value of 2.0 was calculated from the experts definitions. To translate these thresholds into LVI values, a regression equation was used (App. Figure 7.1).

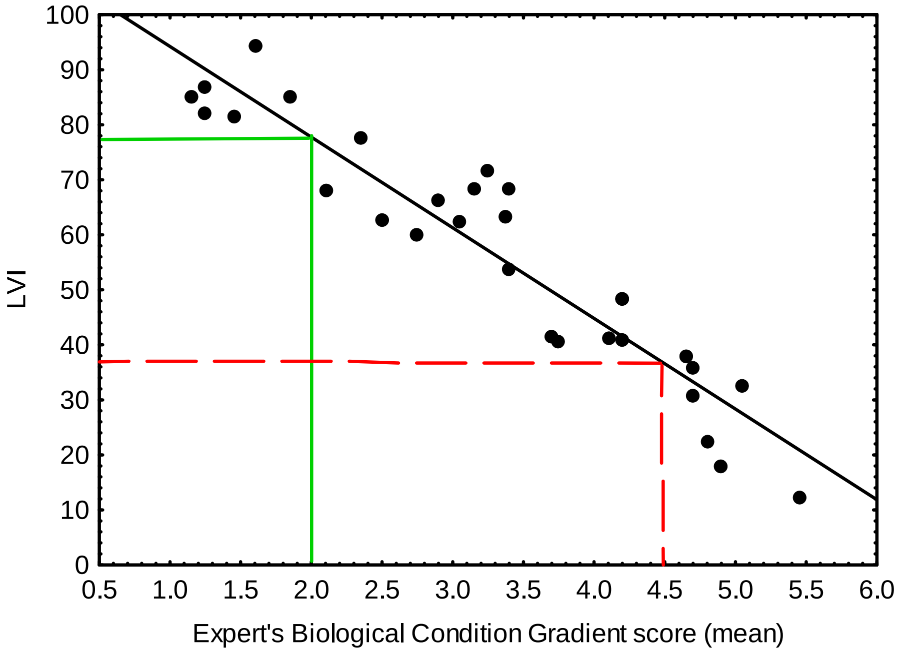
A BCG score of 4.5 corresponded to an LVI value of 37 as the impairment threshold. Thus, based on the recommendations of 20 regional experts, LVI values from 0-37 are proposed as Category 3 (provisionally interpreted as “impaired”). A BCG score of 2.0 corresponded to an LVI value of 78 as the threshold between Categories 2 and 1 (provisionally interpreted as “healthy” and “exceptional”).

App. Table 7.3. Lake visit, BCG scores for each expert, median BCG for each lake, and LVI.

Lake	E01	E02	E03	E04	E05	E06	E07	E09	E10	E12	E13	E14	E15	E17	E18	E19	E20	E21	E22	E23	Mean BCG	Median BCG	LVI
N01	4	4	4	4	5	5	4	3	5	3	4	5	5	4	4	4	5	4	4	4	4.2	4	48
N02	3	5	6	5	6	5	5	5	5	5	5	5	6	5	5	5	5	5	5	5	5.1	5	33
N03	4	3	3	3	3	3	3	3	4	3	3	4	4	3	3	3	4	1	3	3	3.2	3	69
N04	1	1	1	1	1	2	1	1	1	2	1	4	2	2	2	1	2	2	2	2	1.6	2	94
N05	5	5	5	4	4	4	4	3	4	4	4	2	4	3	3	4	4	3	3	3	3.8	4	41
N06	3	3	4	3	4	4	4	3	3	3	4	3	4	3	3	3		3	4	3	3.4	3	63
N07	2	1	1	1	1	2	1	1	1	1	1	3	1	1	2	1	4	2	1	1	1.5	1	82
N08	2	1	1	3	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1.3	1	82
N09	2	2	1	2	2	2	2	1	2	2	2	2	2	2	2	2	1	2	2	2	1.9	2	85
N10	3	2	2	2	2	3	2	2	2	3	2	2	3	2	3	2	3	2	2	3	2.4	2	78
N11	3	2	1	2	2	2	2	2	2	2	2	2	2	2	3	2	3	2	2	2	2.1	2	68
N12	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1.2	1	85
N13	2	3	2	3	2	3	3	4	3	3	3	3	3	2	3	3	1	3	3	3	2.8	3	60
N14	3	4	3	4	3	4	4	3	4	3	3	3	4	3	4	3	3	4	3	3	3.4	3	68
N15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	4	2	1	1	1.3	1	87
S01	5	5	5	5	5	5	5	4	5	5	5	4	5	5	5	4	2	5	4	5	4.7	5	38
S02	3	3	3	4	3	3	3	4	3	3	4	3	3	4	4	3	5	3	4	3	3.4	3	54
S03	5	5	4	5	5	5	5	5	5	5	5	4	4	5	5	5	4	4	4	5	4.7	5	36
S04	4	3	4	4	4	4	4	5	5	5	4	5	5	4	4	5	5	2	4	4	4.2	4	41
S05	3	3	3	2	2	3	3	2	2	2	3	2	2	2	2	3	5	2	2	2	2.5	2	63
S06	3	3	3	4	2	4	4	3	3	3	4	3	3	3	3	3	2	3	2	3	3.1	3	63
S07	4	3	4	4	4	4	4	5	4	5	4	4	6	5	4	5	3	3	5	4	4.2	4	49
S08	5	5	5	5	5	5	5	4	5	4	5	5	4	5	5	5	5	5	5	4	4.8	5	22
S09	3	2	3	2	3	2	3	4	3	3	3	2	3	3	3	3	5	2	3	3	2.9	3	66
S10	5	6	6	5	5	5	5	3	6	5	5	5	5	4	5	5	5	5	4	4	4.9	5	18
S11	5	5	6	4	5	5	5	5	4	4	5	5	5	5	5	5	4	4	4	4	4.7	5	31
S12	4	3	3	3	3	3	4	3	3	4	3	3	4	4	3	3	3	4	2	3	3.3	3	72
S13	5	6	6	5	5	5	5	6	5	6	5	6	6	6	6	5	5	5	5	6	5.5	5	12
S14	4	4	4	4	4	4	4	5	4	4	4	4	4	4	4	4	5	4	4	4	4.1	4	41
S15	3	4	4	3	4	3	4	4	4	4	3	3	3	4	4	3	5	4	5	3	3.7	4	42

App. Table 7.4: Experts' selection of threshold values of BCG that indicate exceptional condition and impaired condition.

Expert	Exceptional	Impaired/ Does Not Meet
E01	1	5
E02	2	5
E03	2	5
E04	1	4
E05	2	5
E06	1	4
E07	2	5
E09	2	5
E10	3	5
E12	2	3
E13	2	3
E14	3	6
E15	2	4
E17	ND	5
E18	2	4
E19	2	5
E20	2	5
E21	2	4
E22	2	5
E23	3	5
MEDIAN =	**2**	**5**
AVERAGE =	**2**	**4.6**



App. Figure 7.1. LVI values were highly correlated with the BCG scores assigned by the experts (Pearson's *r* = 0.89). Shown are the regression line (solid black) and threshold values for impaired lakes (LVI = 37; red dashed lines) and exceptional lakes (LVI=78; green solid line).

Reference sites

Initially, 37 reference lakes with HDG = 0 were identified from the 2005–2006 validation data set. Recall that HDG = 0 does not mean no human disturbance, but minimal human disturbance. This initial list of lakes was evaluated by biologists who had sampled the lakes and were familiar with local conditions. If any lake could not be confidently labeled as "minimally disturbed," it was excluded from the reference set based on the best professional judgment of the biologist. This process yielded a total of 22 reference lakes for calculating statistics for the LVI (App. Table 7.5). Notably, only two reference lakes could be identified for the southern section of the state.

Paralleling an approach used by other states, a buffer of LVI values below the 10th percentile was used to represent the natural variability associated with field sampling that could be due to water level fluctuation, weather, or time of sampling. Half the 90% confidence interval

(12.0) was subtracted from the 10th percentile of LVI as: 66–12.0 = 54 (App. Table 7.6; Appendix 6). Values below 54 would be considered impaired using this approach. This value (LVI = 54) for the impairment line is 17 points higher than the threshold derived from the BCG approach (LVI = 37).

In contrast, the higher threshold for the LVI value (dividing "exceptional" from "healthy" lakes) based on the reference site approach was very close to the value from the BCG workshop. Subtracting half the 90% confidence interval from the 90th percentile for LVI as: 92–12.0 = 80, yielded a value only 2 points higher than the LVI threshold derived from the BCG workshop.

App. Table 7.5. Reference lake STORET, nickname, region, date of sampling LVI, and LDI.

STORET	Station Nickname	Region	Date	LVI	LDI
26010301	NONAREF	North	11/1/2005	93	1.6
27144	SJ6SL2036	North	9/16/2005	92	1.0
29671	NW3SL2086	North	8/1/2006	92	1.1
27141	SJ6SL2020	North	9/2/2005	92	1.0
27150	SJ6SL2052	North	9/2/2005	91	1.1
32020104	CASSCTREF	North	11/1/2006	89	1.0
32010045	DUNFORDREF	North	10/12/2005	86	1.0
26010300	MUDTST	North	12/7/2005	85	1.2
26762	NW2SL2126	North	8/4/2005	84	1.8
14441	NWC-LL1002	North	10/26/2005	83	1.6
20020496	SELLCTREF	North	10/18/2006	82	1.8
26742	NW2SL2025	North	7/7/2005	79	1.4
32030097	PORTERREF	North	11/1/2005	78	1.5
26010310	ANNMIDREF	South	11/3/2005	78	1.7
26753	NW2SL2086	North	7/28/2005	75	1.6
27166	SJ6SL2098	North	9/1/2005	74	1.7
20010080	BUCKLKONF	North	6/1/2005	73	2.0
32030099	RSNAKEREF	North	10/31/2006	70	1.7
26769	NW2SL2158	North	7/27/2005	67	1.6
26010988	GENTNEREF	South	10/16/2006	66	1.9
22100	NW1-LL2007	North	11/2/2006	60	1.4
29655	NW3SL2045	North	7/11/2006	43	1.3

Biocriteria for Lakes

The above analyses support the establishment of three categories of aquatic life use for Florida lakes based on macrophyte sampling. The categories of biological condition were described as Category 1 (“exceptional”, with LVI = 78–100), Category 2 (“healthy”, with LVI = 38–77), and Category 3 (“impaired”, with LVI = 0–37). Narrative descriptions of these categories were derived from the ranges of metric values associated with each LVI category (App. Table 7.7)

For regulatory decisions, two separate, temporally independent site-visits resulting in a Category 3 evaluation are recommended to list a lake as failing to support aquatic life use. If two lake visits were routine, the precision of LVI would support the designation of additional categories.

App. Table 7.6. Statistics and percentile values for LVI reference sites.

Statistic	Value
N	22
Standard deviation	12.3
Minimum	43
10th percentile	66
25th percentile	73
Mean	79
Median	80
75th percentile	89
90th percentile	92
Maximum	93

App. Table 7.7. Proposed aquatic life use categories, corresponding LVI values, and narrative descriptions of biological conditions typically found for that category.

Aquatic life use category	LVI Range	Description
Category 1	78–100	Nearly every macrophyte present is a species native to Florida, invasive taxa typically not found. About 30% of taxa present are identified as sensitive to disturbance and most taxa have C of C values >5.
Category 2	38–77	About 85% of macrophyte taxa are native to Florida; invasive taxa present. Sensitive taxa have declined to about 15% and dominant C of C values average about 5.
Category 3	0–37	About 70% of macrophyte taxa are native to Florida. Invasive taxa may represent up to 1/3 of total taxa. Less that 10% of the taxa are sensitive and C of C values of most taxa are <4.

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