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An Index of Biotic Integrity: A Test with Limnological and Fish Data from Sixty Florida Lakes

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Abstract.—An index of biotic integrity (IBI) that used eight fish assemblage metrics was examined for effectiveness in estimating anthropogenic impacts to 60 Florida lakes ranging in size from 2 ha to more than 12,400 ha. The lakes ranged in trophic status from oligotrophic to hypereutrophic and had aquatic macrophyte abundances (percent lake volume infested) ranging from less than 1% to 100%. Fish species were classified by trophic feeding guild and tolerance to increases in turbidity or warming and decreases in dissolved oxygen concentration. Fish assemblage metrics tested were as follows: number of fish species, number of native fish species, number of *Lepomis* species, number of piscivorous species, number of generalist species, number of invertivore species, number of species intolerant of increased turbidity or warming and decreased dissolved oxygen concentration, and number of species tolerant of increased turbidity or warming and decreased dissolved oxygen concentration. The total IBI scores and the data used to calculate individual metrics were unable to accurately predict the degree of anthropogenic impact to 60 Florida lakes, as estimated by personal observations of local limnologists, lake chloride concentrations, and road densities in the watersheds. Lake surface area and lake trophic status have a dominant influence on the fish assemblage metrics tested in this study. Thus, the IBI approach may be of limited usefulness for predicting anthropogenic impact in lake data sets that have wide ranges of surface areas and trophic status classifications.

Indexes of biotic integrity (IBIs) are models comprising attributes of fish species assemblages, termed metrics, that are used as measures of human disturbances (Fausch et al. 1984; Karr et al. 1986). Some studies in streams have successfully correlated IBI scores with human activities, including sewage effluent (Karr et al. 1986), mining activities (Leonard and Orth 1986), and urbanization and riparian zone destruction (Steedman 1988). There are natural variations in fish species assemblages, however, that need to be considered before IBIs are used to imply environmental degradation (Bramblett and Fausch 1991). For example, the location of a stream within a drainage basin, ecoregion boundary, and zoogeographic region can naturally influence the species richness of fish communities (Gilbert 1987; Keller and Crisman 1990; Maret et al. 1997). Although IBIs were originally developed and used on stream systems, they are now being examined for use in lakes and reservoirs (Minns et al. 1994; Hickman and McDonough 1996).

The Environmental Monitoring and Assessment Program–Surface Waters 1991 Pilot Project (hereafter, the 1991 Pilot Project) conducted by the U.S. Environmental Protection Agency (USEPA) tested the ability of experimental biotic assemblage metrics to estimate the impact of human activity and condition of 19 lakes in the northeastern region of the United States (USEPA 1993). These lakes had been subjected to various types and degrees of anthropogenic impacts and watershed disturbances, including agriculture, silviculture, residential development, nutrient enrichment, and fish stocking. As was done in streams, fish assemblage metrics were included for testing as candidate estimators of lake condition because fish represent many feeding guilds (e.g., piscivores, omnivores, herbivores, invertivores, etc.) and, being sensitive to multiple environmental stressors, integrate those stressors over long time periods and over multiple habitats (USEPA 1993). Fish assemblages seem to be responsive to the broad array of environmental stressors (Karr et al. 1986; Miller et al. 1988; Williams et al. 1989; Nehlsen et al. 1991; Hughes and Noss 1992).

The USEPA (1993) tested the ability of five fish assemblage metrics to estimate lake condition: number of fish species, number of native fish species, percent piscivorous species, percent omnivorous species, and percent generally intolerant species. These metrics were based on fish species presence–absence data, the use of which is currently being emphasized for studies examining ecological integrity (Jackson and Harvey 1997).

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The preliminary results indicated that these five metrics were "roughly comparable in their ability to distinguish the effects of watershed disturbances and fishery management practices" (USEPA 1993). However, the 1991 Pilot Project also stated that studies in other regions are needed before fish assemblage metrics are selected for nationwide monitoring.

Hickman and McDonough (1996) examined the potential of using the IBI approach for assessing the condition of reservoirs in the Tennessee River valley. They modified Karr's (1981) 12 original stream-based metrics to accommodate fish species assemblages characteristic of reservoirs. Minns et al. (1994) also modified Karr's metrics in developing an IBI for the littoral zone in areas of concern in the Great Lakes.

The major objective of this study was to calculate total IBI scores from eight fish assemblage metrics that were modified from Hickman and McDonough (1996) and USEPA (1993) and to test their ability to estimate the condition of 60 Florida lakes subjected to varying degrees of anthropogenic impact and watershed disturbance. Data used to assign IBI scores for the individual metrics were also examined to determine the ability of each metric to estimate the degree of anthropogenic impact and watershed disturbance. In addition, the relations between data collected for these eight fish assemblage metrics and lake surface area, lake trophic status, and aquatic macrophyte abundance, which are three naturally varying factors that affect fish assemblages (Ware and Gasaway 1978; Bachmann et al. 1996; Hoyer and Canfield 1996), were examined.

Methods

This study uses lake trophic state, water chemistry, aquatic macrophyte abundance, physical lake attributes, and fish assemblage data from 60 Florida lakes sampled between 1986 and 1990 by Canfield and Hoyer (1992). Canfield and Hoyer (1992) selected the study lakes to include a wide range of lake trophic states (oligotrophic to hypereutrophic) and, within each trophic state, a wide range of aquatic macrophyte abundances. Eight of the 60 Florida lakes had been stocked with grass carp *Ctenopharyngodon idella* 10–15 years before the study, and the fish virtually eliminated all aquatic vegetation from these lakes for that time period.

The 1991 Pilot Project (USEPA 1993) stratified lake habitat type into littoral and open-water zones and then sampled fish populations by means of random placement of the appropriate habitat-selective gear. This method was proposed as an objective way of obtaining lakewide estimates of fish species assemblages. Canfield and Hoyer (1992) also sampled fish in littoral and open-water habitats between May and November using rotenone and block nets, experimental gill nets, and electrofishing. Depending on lake size, 4–12 0.08-ha block nets were randomly placed in littoral (with one side being the shore) and limnetic habitats. The majority of the lakes were sampled with six block nets (three littoral and three limnetic), but lakes with surface areas less than 5 ha received 4 block nets and lakes with surface areas greater than 2,000 ha received 12 block nets. Block-net areas were treated with rotenone (5% active ingredient, Noxfish) at 2.0 mg/L, and fish were collected for 3 d.

Fish in open-water areas were also sampled with experimental gill nets. Depending on lake size, three to six experimental gill nets were set once in each lake for 24 h. Three gill nets were set in the majority of lakes, but six were set in lakes with surface areas greater than 2,000 ha. Gill nets were 50 m × 2.4 m, and each gill net had five 10-m panels of different mesh size (bar mesh sizes: 19, 25, 38, 51, and 76 mm).

Fish in littoral areas were also sampled with electrofishing. Two to 10 electrofishing transects were sampled at each lake. Six transects were sampled at the majority of the lakes, but only two transects were sampled in lakes with surface areas less than 5 ha, and 10 transects were sampled in lakes with surface areas greater than 2,000 ha. Electrofishing transects were spaced evenly around each lake. Each transect was electrofished for 10 min with continuous current, and approximately 150 m of shoreline was covered.

Following the reasoning of Jackson and Harvey (1997), we evaluated the effectiveness of block nets to determine species richness, defined as the number of different fish species collected in a lake. First, we examined the cumulative number of fish species encountered in each lake as fishing effort increased to assess the likelihood that more sampling would add additional species. For all 60 lakes, we constructed curves showing the cumulative number of fish species obtained as progressively more block nets were fished. For each species in each lake, we used our catch records to determine the number of nets in which the species was found versus the number of nets set. We then determined the probability that a species would be encountered for the first time in the first, second, third, or additional net sets, following the basic laws of probability (Dietrich and Kearns 1986). The expected frequencies for each species for each net were then summed to derive a curve of species found versus sampling effort.

In each case, the greatest increase in the number of species captured was in the first few nets; there was relatively little increase in the number of species captured as the last net was fished. As a measure of the flatness of the right-hand portion of the curve, the number of species collected after the next to last net was fished was expressed as a percentage of the number of species collected after the last net was fished. For 41 of the 60 lakes, 95–100% of the species collected in all nets were captured by the next-to-last net, and in only three lakes, was the value less than 90%. In addition to block nets, fish were also collected by using gill nets and electrofishing to capture species that may have been missed by block nets.

Jackson and Harvey (1997) reported that estimates of relative abundance and patterns of covariation for fish species captured with a variety of sampling gears differed greatly among the gears and provided contradictory results about fish species' relative abundance. They also concluded that attempts to integrate catches from gears to provide an overall estimate of species abundances in communities across lakes are compromised because of the inconsistency in estimates of abundance and covariation. Therefore, only fish species presence–absence data, as proposed by Jackson and Harvey (1997), were used to examine the following fish assemblage metrics as indicators of anthropogenic impact and watershed development in 60 Florida lakes: number of fish species (TFS), number of native fish species (NFS), number of *Lepomis* species (LEP), number of piscivorous species (PIS), number of generalist species (GEN), number of invertivore species (INV), number of species intolerant to increased turbidity or warming and decreased dissolved oxygen concentration (INT), and number of species tolerant to increased turbidity or warming and decreased dissolved oxygen concentration (TOL) (USEPA 1993; Hickman and McDonough 1996).

Three fish species were not counted in calculating data for the TFS metric because they were stocked into lakes for management purposes and were not reproducing in the lakes. They included triploid grass carp, hybrid sunshine bass (female white bass *Morone chrysops* × male striped bass *M. saxatilis*), and striped bass. However, these species were included in the trophic feeding guild metrics because they functioned as herbivores or piscivores. They were also classified as intolerant, intermediately tolerant, or tolerant species so IBI scores for tolerance to increased warming or turbidity and decreased dissolved oxygen concentration could be assigned.

The North Carolina's Department of Environment, Health, and Natural Resources (NCDEHNR 1997) classified the fish trophic feeding guilds based on fish food habit data and tolerance ratings for fish species characteristic of southern latitudes. Following the reasoning of Leonard and Orth (1986), the arbitrarily defined category of "omnivore" was replaced with the "generalist" category defined as "species that ate a wide range of foods or that adapted readily to shifts in availability of food taxa." In this study, fish classified as omnivores by the NCDEHNR (1997) were referred to as generalists. The NCDEHNR (1997) fish classification scheme was used to classify 33 of the 46 fish species collected in our study of 60 Florida lakes. The remaining 13 fish species not listed in the NCDEHNR (1997) fish classification scheme were classified according to Lee et al. (1980), and the same criteria used by the NCDEHNR (1997) was used to define fish trophic feeding guilds and tolerance ratings.

The 1991 Pilot Project noted that: "fish species richness and number of native fish species were directly related to lake area, as predicted from the theory of island biogeography (MacArthur and Wilson 1967; Barbour and Brown 1974), in which lakes function as islands in the terrestrial landscape" (USEPA 1993:66).

Because the number of fish species increases with lake surface area and because all eight metrics tested were based on species presence–absence information, "maximum species lines" were calculated for each of the eight individual fish assemblage metrics (Fausch et al. 1984). The data used to calculate these maximum species lines come from Bachmann et al. (1996). The purpose of calculating species richness versus lake surface area relationships was to predict the expected total fish species richness and richness of specific taxa for application of the IBI. It is assumed that the maximum species lines define the standards for "excellent" fish communities for purposes of scoring the IBI (Fausch et al. 1984).

For example, TFS values for each lake were plotted against the $\log_{10}$ of each lake's surface area. The upper bound of the 95% confidence intervals plotted on the relation between the $\log_{10}$ of lake surface area, and the number of fish species was considered the maximum species line (Figure 1).

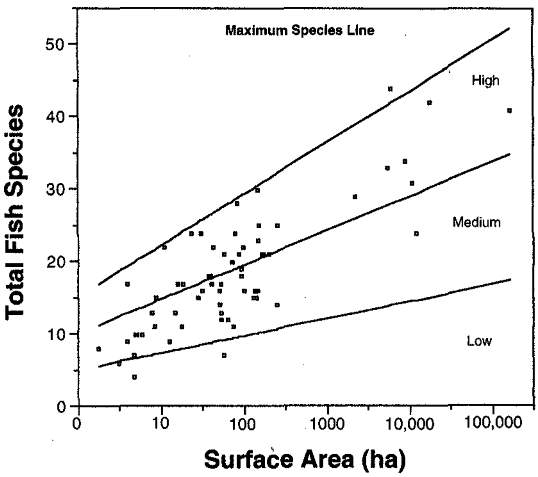

FIGURE 1.—Example of the maximum species line for the number of fish species plotted against lake surface area. The area below the maximum species line was trisected so that threshold values for assigning IBI scores (high, medium, low) for the TFS metric could be calculated (Fausch et al. 1984).

The area below the maximum species line was trisected; threshold values were calculated to determine whether the observed TFS value for each lake was high, medium, or low; and IBI scores were assigned as 5, 3, or 1, respectively (Fausch et al. 1984). All metrics (TFS, NFS, LEP, PIS, INV, INT) with values that were expected to decrease in response to lake degradation (USEPA 1993; Hickman and McDonough 1996) were examined, and IBI scores were assigned in this manner. Those metrics (GEN, TOL) with values that were expected to increase in response to lake degradation (Hickman and McDonough 1996) were examined, and high, medium, or low values were assigned IBI scores of 1, 3, or 5, respectively.

After IBI scores were assigned for each of the eight metric values, the eight individual metric IBI scores were then added together to calculate a total IBI score for each of the 60 Florida lakes (Fausch et al. 1984). Total IBI scores could potentially range from a minimum of 8 to a maximum of 40. Total IBI scores were then tested for their ability to estimate the degree of anthropogenic impact and watershed disturbance to the 60 Florida lakes.

The 1991 Pilot Project selected lakes with different types and amounts of human activity in their watersheds, including farming, forestry, residential development, and fish stocking programs. The 60 lakes sampled in Canfield and Hoyer's (1992) study had a similar range of watershed disturbances, and most had boat ramps, recognized by the 1991 Pilot Project as an indicator of at least a minimal level of disturbance (USEPA 1993). Investigators on the 1991 Pilot Project consulted with state water quality experts and fishery biologists and conducted limited field reconnaissance to select candidate lakes and determine their associated disturbance gradients. In this study, three separate methods were used to determine the degree of human disturbance.

The first approach for estimating the degree of human disturbance used personal observations that classified each lake as having a low, moderate, or high degree of anthropogenic impact and watershed disturbance (D. E. Canfield, Jr. and M. V. Hoyer, University of Florida, personal observations). Lakes with histories of receiving treated wastewater or agricultural runoff and extensive human development in the watershed were classified as lakes with high anthropogenic impacts. Lakes in remote areas of Florida with minimal human development in the watershed were classified as lakes with low anthropogenic impacts; the remaining lakes were classified as moderately impacted.

The second method for estimating the degree of human disturbance used chloride ion concentrations measured in the lakes. Lake chloride ion concentration is recognized as a quantitative indicator of human population density in a watershed and, therefore, anthropogenic impact (USEPA 1993). Chloride concentrations are generally much higher in water from wastewater treatment plants or septic fields than from local groundwater because sodium chloride is a common article of human diets and passes unchanged through the digestive system (APHA 1985). Many rural homes in Florida also use water softeners that discharge more than 250 kg of dissolved sodium chloride per year (estimated for a family of three) through septic tanks or directly on the watershed.

The 1991 Pilot Project states that chloride ion concentration is an acceptable indicator of land use intensity in humid, temperate regions and that increases in chloride ion concentration can be caused by watershed disturbances, including sewage effluent inputs, cattle ranching, septic tank seepage, storm water runoff, and pulpwood bleaching (USEPA 1993). It is important to note that most of the 60 Florida study lakes were inland water bodies that did not have direct connections to any saltwater springs or streams that could potentially contribute chloride. Those lakes that did have connections with salt water (Apopka, Harris, Lochloosa, and Carlton) are headwater lakes that are at least 80.5 km from salt water and are not tidally influenced.

A third method used to estimate the degree of human disturbance to these 60 Florida lakes was road density in the lake watershed. The number of roads in a 34-km^2 and 412-km^2 area around the center of each lake was counted for lakes less than 2,000 ha and lakes greater than 2,000 ha, respectively. This yielded an estimate of road density (number of roads/km^2) in the immediate area surrounding the lakes. The roads were counted from maps generated by a mapping program (Map-Expert-TM, version 2.0; DeLorme 1993).

The 1991 Pilot Project defines trophic status as "the abundance or production of algae and macrophytes" (USEPA 1993). Therefore, adjusted total chlorophyll concentrations, calculated by Canfield and Hoyer (1992) for each of the 60 Florida lakes, were used in this study to estimate trophic status. This method uses the actual total chlorophyll concentration measured in a lake water sample plus the potential increase to the total chlorophyll concentration that could result if all the nutrients contained in a lake's macrophyte biomass were released into the water and subsequently converted into algal biomass (see Canfield and Hoyer 1992).

Fore et al. (1994) found that the statistical properties of the IBI supported the use of standard analysis techniques, such as one-way analysis of variance (ANOVA) for hypothesis testing. Therefore, to determine if the total IBI scores could predict varying degrees of anthropogenic impact, one-way ANOVA was used to test for a statistical relation between the total IBI scores and the three estimated degrees of anthropogenic impact. When a significant treatment effect (degree of anthropogenic impact) was detected, a Tukey–Kramer honestly significant difference (HSD) analysis was used to test between the three levels of anthropogenic impacts. Least-squares regression analyses were also used to compare total IBI scores with chloride concentration and road density.

The data used to assign IBI scores for the eight individual fish assemblage metrics were also correlated with chloride concentration, road density, lake surface area, lake trophic state as estimated by adjusted total chlorophyll concentration (Canfield and Hoyer 1992), and aquatic macrophyte abundance as estimated by the percentage of a lake's volume infested (PVI). This was done to examine the relationships of two indicators of anthropogenic impact and three major environmental factors with the data used to assign the IBI scores for the eight fish assemblage metrics.

Before regression analyses or correlation analyses, chloride concentration, road density, lake surface area, and adjusted total chlorophyll concentration were $\log_{10}$ transformed to overcome heterogeneity of variances. All computations were performed with the JMP statistical package (SAS Institute 1989). Unless otherwise stated, statements of statistical significance imply $P < 0.05$.

Results and Discussion

A majority of the 60 Florida study lakes sampled by Canfield and Hoyer (1992) were in inland areas of north-central and central Florida, but three lakes were in the western Florida panhandle. The lakes ranged in surface area from 2 ha (Little Fish Pond) to more than 12,400 ha (Lake Apopka), although 75% were between 10 and 300 ha (Table 1). The lakes were shallow, with mean depths ranging from 0.6 to 5.9 m and had aquatic macrophyte abundance (PVI) ranging from less than 1% to 100% (Table 1).

Lake trophic status ranged from oligotrophic to hypereutrophic, determined by using adjusted total chlorophyll concentration as the trophic status indicator and the classification system proposed by Forsberg and Ryding (1980) for chlorophyll-*a* concentration (Table 1). Mean total phosphorus concentrations ranged from 1 to 1,043 μg/L, and average total nitrogen concentrations ranged from 82 to 6,340 μg/L. Mean Secchi depths ranged from 0.3 to 5.8 m, and mean total chlorophyll-*a* concentrations ranged from 1 to 241 μg/L.

In all, 46 fish species were collected from the 60 Florida lakes by means of the various sampling methods employed by Canfield and Hoyer (1992; Table 2). Thirty-eight of the species had geographic distributions that overlapped the locations of all 60 lakes (Table 2; Lee et al. 1980). The eight exceptions were the inland silverside, Atlantic needlefish, redbreast sunfish, flier, blue tilapia, triploid grass carp, striped bass, and hybrid sunshine bass.

Of the 46 fish species tested in this study, 43 were native species, 6 were recognized as *Lepomis* species, 11 were classified as piscivores, and 27 were classified as invertivores (Table 2). Only one species, the golden shiner, was classified as omnivorous using the NCDEHNR (1997) fish classification scheme, and for this study, it was placed in the generalist trophic feeding guild. Two fish species were classified as intolerant and 12 species were classified as tolerant (Table 2).

The inland silverside and the taillight shiner were

TABLE 1.—Surface area; mean depth; means for lake trophic state indicators, including total phosphorus (P), total nitrogen (N), total chlorophyll (chl), and Secchi depth; percent lake volume infested with aquatic macrophytes (PVI); and mean adjusted total chlorophyll (ATC) for the 60 Florida lakes sampled by Canfield and Hoyer (1992) and used in this study. Lake trophic status was classified from adjusted total chlorophyll according to Forsberg and Ryding (1980).

Trophic category and lake name	Surface area (ha)	Mean depth (m)	Total P (μg/L)	Total N (μg/L)	Total chl (μg/L)	Secchi depth (m)	PVI (%)	ATC (μg/L)
Oligotrophic								
Barco	13	4.4	2	80	1	5.4	1.3	1
Cue	59	3.5	5	90	2	5.8	0.5	3
Grasshopper	59	2.7	6	260	1	3.7	17.2	2
Lawbreaker	5	4.3	1	110	1	5.5	0.5	1
Mountain 2	55	3.3	17	330	2	2.4	4.6	2
Picnic	18	3.3	8	140	1	2.6	5.4	2
Tomahawk	15	4.4	6	190	1	4.2	12.1	3
Turkey Pen	6	5.0	2	130	1	3.2	2.6	1
Mesotrophic								
Bull Pond	11	2.3	11	520	3	1.4	11.4	4
Keys Pond	5	2.9	2	210	1	5.3	7.9	4
Loften	5	2.6	5	630	2	2.5	21.9	4
Mill Dam	85	5.7	11	460	4	2.7	9.1	6
Moore	28	2.9	5	350	3	5.3	13.9	5
Suggs	73	2.0	66	1,250	4	0.5	0.5	4
Eutrophic								
Baldwin	80	4.5	21	530	18	1.6	1.3	18
Bell	32	2.7	17	640	20	1.5	0.5	20
Brim Pond	3	4.0	9	620	8	2.2	1.2	9
Catherine	41	3.2	2	300	2	3.2	9.3	12
Clear	64	5.9	21	760	21	1.3	5.0	21
Crooked	8	2.3	7	310	5	3.1	2.8	13
Douglas	16	1.2	11	1,120	2	1.5	67.3	12
Fish	89	1.9	25	940	18	1.0	1.4	19
Gate Lake	8	1.8	28	410	20	1.1	17.5	20
Harris	5,580	4.0	28	1,550	37	0.6	2.4	38
Hartridge	176	3.4	11	490	4	2.3	11.5	28
Killarny	96	4.7	21	600	22	1.0	0.5	22
Koon	44	1.5	5	690	3	1.4	92.6	17
Lindsey	55	2.2	19	640	6	1.9	79.6	36
Little Fish	2	1.2	21	1,160	13	1.4	30.7	32
Live Oak	152	3.0	13	390	9	2.6	55.1	18
Marianna	204	3.8	26	1,050	21	1.3	35.7	22
Mountain	51	1.6	37	810	10	1.7	20.7	22
Orienta	52	3.4	25	450	9	2.2	0.5	9
Pasadena	151	3.1	15	700	3	2.2	61.6	13
Patrick	159	1.8	10	1,810	5	2	42.1	16
Pearl	24	2	28	820	22	0.9	1.7	22
Susannah	31	3.9	23	670	25	1.5	1.1	26
Thomas	55	3.9	22	760	10	1.8	0.5	10
Watertown	19	3.8	27	780	24	1	0.8	24
West Moody	39	3.5	14	580	2	2.8	89.3	19
Hypereutrophic								
Alligator	137	1.1	371	2,370	84	0.5	10	84
Apopka	12,412	1.6	140	3,790	127	0.3	2.1	127
Bivens Arm	76	1.2	384	3,260	241	0.4	1.4	268
Bonny	143	2	59	1,860	40	0.6	6.5	51
Carlton	155	3.6	92	3,230	173	0.4	0.5	173
Carr	254	1.9	19	870	11	1.8	100	201
Clay	5	2.3	7	360	4	4	76.3	97
Conine	96	3.5	1,043	2,060	110	0.5	0.5	110
Deep	4	3	2	160	1	5.1	20.5	100
Holden	102	4.5	44	1,230	64	0.5	0.5	64
Hollingsworth	144	1.5	113	2,520	135	0.3	0.5	136
Hunter	40	1.7	98	1,720	82	0.5	0.5	83
Lochloosa	2,309	1.8	32	1,050	22	1	57.2	45
Miona	169	2.3	12	870	8	1.5	86	62
Okahumpka	271	0.9	21	1,030	11	1.4	98.1	350
Round Pond	4	1.3	3	440	3	2.6	79.4	47
Rowell	147	1.3	66	910	47	0.8	10.3	47
Swim Pond	9	0.6	25	1,030	11	0.6	77.8	118
Wales	132	3.4	27	900	42	0.8	0.3	42
Wauberg	100	3.6	166	1,480	102	0.6	0.5	112

TABLE 2.—Family, common name, scientific name, number of lakes in which the species was captured, trophic feeding guild, (PIS = piscivore, INV = invertivore, HER = herbivore, PLA = planktivore, GEN = generalist), and tolerance rating (INT = intolerant, TOL = tolerant, ITM = intermediate) for the 46 fish species collected in 60 Florida lakes sampled by Canfield and Hoyer (1992) and used in this study.

Family	Common name	Scientific name	Number of lakes	Trophic guild	Tolerance rating
Amiidae	Bowfin	*Amia calva*	29	PIS	ITM
Anguillidae	American eel	*Anguilla rostrata*	3	INV	ITM
Aphredoderidae	Pirate perch	*Aphredoderus sayanus*	4	INV	ITM
Atherinidae	Brook silverside	*Labidesthes sicculus*	46	INV	ITM
Atherinidae	Inland silverside	*Menidia beryllina*	6	INV	INT
Belonidae	Atlantic needlefish	*Strongylura marina*	3	PIS	ITM
Catostomidae	Lake chubsucker	*Erimyzon sucetta*	44	INV	ITM
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*	44	PIS	ITM
Centrarchidae	Blackbanded sunfish	*Enneacanthus chaetodon*	1	INV	ITM
Centrarchidae	Bluegill	*Lepomis macrochirus*	59	INV	ITM
Centrarchidae	Bluespotted sunfish	*Enneacanthus gloriosus*	25	INV	ITM
Centrarchidae	Dollar sunfish	*Lepomis marginatus*	20	INV	ITM
Centrarchidae	Everglades pygmy sunfish	*Elassoma evergladei*	11	INV	ITM
Centrarchidae	Flier	*Centrarchus macropterus*	4	INV	ITM
Centrarchidae	Largemouth bass	*Micropterus salmoides*	59	PIS	ITM
Centrarchidae	Redbreast sunfish	*Lepomis auritus*	5	INV	ITM
Centrarchidae	Redear sunfish	*Lepomis microlophus*	46	INV	ITM
Centrarchidae	Spotted sunfish	*Lepomis punctatus*	19	INV	ITM
Centrarchidae	Warmouth	*Lepomis gulosus*	59	INV	ITM
Cichlidae	Blue tilapia	*Oreochromis aureus*	15	HER	TOL
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	24	PLA	ITM
Clupeidae	Threadfin shad	*Dorosoma petenense*	22	PLA	ITM
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*	47	GEN	ITM
Cyprinidae	Grass carp	*Ctenopharyngodon idella*	11	HER	TOL
Cyprinidae	Taillight shiner	*Notropis maculatus*	12	INV	INT
Cyprinodontidae	Bluefin killifish	*Lucania goodei*	25	HER	TOL
Cyprinodontidae	Flagfish	*Jordanella floridae*	5	HER	TOL
Cyprinodontidae	Golden topminnow	*Fundulus chrysotus*	30	INV	TOL
Cyprinodontidae	Lined topminnow	*Fundulus lineolatus*	19	INV	ITM
Cyprinodontidae	Pygmy killifish	*Leptolucania ommata*	5	INV	TOL
Cyprinodontidae	Seminole killifish	*Fundulus seminolis*	29	INV	ITM
Esocidae	Chain pickerel	*Esox niger*	12	PIS	ITM
Esocidae	Redfin pickerel	*Esox americanus americanus*	11	PIS	ITM
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*	34	INV	TOL
Ictaluridae	Channel catfish	*Ictalurus punctatus*	1	INV	ITM
Ictaluridae	Tadpole madtom	*Noturus gyrinus*	13	INV	ITM
Ictaluridae	White catfish	*Ameiurus catus*	13	PIS	TOL
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	34	INV	TOL
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	36	PIS	TOL
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	10	PIS	ITM
Percichthyidae	Striped bass	*Morone saxatilis*	3	PIS	ITM
Percichthyidae	Sunshine bass	*Morone chrysops* ♀ × *M. saxatilis* ♂	9	PIS	ITM
Percidae	Swamp darter	*Etheostoma fusiforme*	38	INV	ITM
Poeciliidae	Eastern mosquitofish	*Gambusia holbrooki*	47	INV	TOL
Poeciliidae	Least killifish	*Heterandria formosa*	18	INV	ITM
Poeciliidae	Sailfin molly	*Poecilia latipinna*	13	HER	TOL

species classified as generally intolerant to increased temperature and turbidity or decreased dissolved oxygen concentration using the NCDEHNR (1997) fish classification scheme (Table 2). The following four fish species were classified as tolerant to increased temperature and turbidity or decreased dissolved oxygen concentration using the NCDEHNR (1997) fish classification scheme: brown bullhead, white catfish, yellow bullhead, and eastern mosquitofish. Eight fish species not listed in the NCDEHNR (1997) fish classification scheme were classified as tolerant according to Lee et al. (1980): the blue tilapia, grass carp, bluefin killifish, flagfish, golden topminnow, pygmy killifish, Florida gar, and sailfin molly (Table 2).

The data used to assign IBI scores for the eight fish assemblage metrics, the IBI scores assigned for each fish assemblage metric, and the calculated total IBI scores for each of the 60 Florida lakes are reported in Table 3. Total IBI scores ranged from 14 to 38. Lakes with the highest total IBI scores should be lakes with the lowest degrees of watershed disturbance and anthropogenic impact (Karr 1981).

Of the 60 Florida lakes, 19 were classified as lakes with low anthropogenic impact, 17 as lakes with moderate anthropogenic impact, and 24 as lakes with high anthropogenic impact (Table 4). Chloride concentrations averaged 7.5, 10.0, and 24.3 mg/L for lakes characterized by low, moderate and high anthropogenic impact, respectively (Figure 2). Road density averaged 1.5, 3.6, and 5.2 roads/km^2 for lakes with low, moderate, and high anthropogenic impact (Figure 2). Thus, both chloride concentration and road density estimates tended to agree with the subjective classification of anthropogenic impacts to these lakes.

Some lakes characterized by low anthropogenic impact (Catherine, Clay, Grasshopper, Round Pond, and Tomahawk) were in the Ocala National Forest and had minimal watershed disturbance. These lakes averaged a low chloride concentration of 9.1 mg/L and a low road density of 1.5 roads/km^2, which supported their classification as lakes with low anthropogenic impact (Table 4). Some lakes characterized by high anthropogenic impact (Apopka, Carlton, Conine, Douglas, and Rowell) had received sewage effluents or agricultural discharges for years before sampling. These lakes averaged a high chloride concentration of 35.6 mg/L and a high road density of 4.1 roads/km^2, again validating the subjective classification of these lakes as having high anthropogenic impact (Table 4).

Examining the total IBI scores, a one-way ANOVA detected a statistically significant effect of the subjective classification groups (low, moderate, and high anthropogenic impact) on the total IBI score (Figure 3). Using a Tukey–Kramer HSD test, pairwise comparisons among total IBI means revealed a significant difference between lakes with high anthropogenic impact and lakes with both moderate and low anthropogenic impact. The mean total IBI scores for lakes with low and moderate anthropogenic impact were 25.6 and 24.6, respectively; the mean total IBI score for lakes with high anthropogenic impact was 29.6 (Figure 3). These tests show that lakes characterized by high anthropogenic impact had higher total IBI scores, which is contrary to what would be expected for total IBI scores for lakes with high anthropogenic impact (i.e., lower total IBI scores).

Regression analysis showed that chloride concentrations were also positively related to total IBI scores ($r^2 = 0.22$; $P < 0.05$), which is again the opposite of what the total IBI scores were supposed to indicate. Regression analysis showed no significant relation between road density and total IBI scores ($r^2 = 0.006$; $P = 0.52$). However, to show that human development and watershed disturbance results in lower total IBI scores, there should be a negative relationship between both chloride concentration and road density and total IBI scores. Thus, total IBI scores did not accurately indicate the degree of human impact estimated by chloride concentration or road density.

The five pristine lakes from the Ocala National Forest (Catherine, Clay, Grasshopper, Round Pond, and Tomahawk) averaged a total IBI score of 24, with a range of 18–32 (Table 3). The five lakes with known point-sources of treated wastewater or agricultural effluent (Apopka, Carlton, Conine, Douglas, and Rowell) averaged a higher total IBI score of 31.2, with a range of 24–36 (Table 3). Thus, the total IBI scores were again unable to predict the known degree of human impact to these two groups of lakes.

Total IBI scores were not able to accurately predict the level of watershed disturbance as estimated with three different indicators (qualitative limnological expertise, chloride concentration, and road density). Therefore, correlation coefficients were calculated for the relation between the data used to assign IBI scores for each of the eight individual fish assemblage metrics and chloride concentration, road density, lake surface area, adjusted total chlorophyll concentration, and PVI (Table 5).

Values used to assign IBI scores for each of the eight metrics were all significantly and positively correlated with lake chloride concentration (Table 5). It is important to note that values for the TFS, NFS, LEP, PIS, INV, and INT metrics should be negatively correlated with increasing lake chloride concentration, an indicator of watershed development and anthropogenic land use intensity. Values used to assign IBI scores for six of the eight metrics were not significantly correlated with road density (Table 5). Two metrics (LEP, GEN) were significantly and positively correlated with road density. These data suggest that the majority of the eight individual fish assemblage metrics were unable to accurately estimate the degree of anthropogenic impact to the 60 Florida lakes.

Values used to assign IBI scores for each of the eight metrics were all positively correlated with lake surface area (Table 5). Similar results for the

TABLE 3.—Measured values for each of the eight fish assemblage metrics, assigned scores (in parentheses) for the index of biotic integrity (IBI), and total IBI scores calculated for each for the 60 Florida lakes.

Lake	Total fish	Native fish	*Lepomis*	Piscivores	Generalists	Inverti-vores	Intolerant	Tolerant	Total IBI score
Alligator	16 (3)	16 (3)	4 (3)	4 (3)	1 (5)	11 (3)	0 (1)	3 (5)	26
Apopka	21 (3)	20 (3)	3 (3)	8 (3)	1 (5)	10 (3)	2 (5)	8 (5)	30
Baldwin	23 (5)	23 (5)	5 (5)	6 (5)	1 (5)	13 (5)	1 (5)	8 (1)	36
Barco	9 (3)	9 (3)	2 (1)	2 (1)	1 (3)	6 (3)	0 (1)	1 (5)	20
Bell	16 (3)	16 (3)	4 (3)	4 (3)	1 (3)	9 (3)	0 (1)	3 (5)	24
Bivens Arm	11 (3)	10 (3)	3 (3)	3 (3)	1 (5)	5 (1)	0 (1)	4 (5)	24
Bonny	16 (3)	15 (3)	3 (3)	5 (3)	1 (5)	7 (3)	1 (5)	3 (5)	30
Brim Pond	6 (1)	6 (1)	2 (1)	2 (1)	1 (3)	3 (1)	0 (1)	1 (5)	14
Bull Pond	22 (5)	22 (5)	4 (5)	5 (5)	1 (3)	16 (5)	1 (5)	4 (3)	36
Carlton	24 (5)	23 (5)	5 (5)	7 (5)	1 (5)	12 (3)	2 (5)	6 (3)	36
Carr	14 (3)	14 (3)	3 (3)	4 (3)	1 (5)	9 (3)	0 (1)	3 (5)	26
Catherine	17 (3)	17 (3)	4 (3)	1 (1)	1 (3)	15 (5)	0 (1)	2 (5)	24
Clay	7 (1)	7 (1)	2 (1)	1 (1)	0 (5)	6 (3)	0 (1)	2 (5)	18
Clear	11 (3)	11 (3)	3 (3)	3 (3)	1 (5)	7 (3)	0 (1)	3 (5)	26
Conine	18 (3)	17 (3)	4 (3)	6 (5)	1 (5)	9 (3)	2 (5)	5 (5)	32
Crooked	11 (3)	11 (3)	2 (1)	1 (1)	1 (3)	9 (3)	0 (1)	2 (5)	20
Cue	7 (1)	7 (1)	2 (1)	1 (1)	0 (5)	6 (1)	0 (1)	1 (5)	16
Deep	17 (5)	17 (5)	2 (1)	4 (5)	0 (5)	12 (5)	0 (1)	4 (3)	30
Douglas	17 (5)	17 (5)	4 (5)	3 (3)	1 (3)	12 (5)	1 (5)	5 (3)	34
Fish	21 (5)	20 (5)	5 (5)	4 (3)	1 (5)	12 (3)	1 (5)	3 (5)	36
Gate Lake	13 (3)	13 (3)	3 (3)	3 (3)	1 (3)	7 (3)	0 (1)	3 (5)	24
Grasshopper	21 (5)	21 (5)	4 (3)	6 (5)	0 (5)	15 (5)	0 (1)	5 (3)	32
Harris	31 (5)	30 (5)	6 (5)	10 (5)	1 (5)	17 (5)	1 (3)	8 (5)	38
Hartridge	21 (3)	20 (3)	5 (5)	4 (3)	1 (5)	13 (3)	0 (1)	5 (5)	28
Holden	16 (3)	15 (3)	3 (3)	4 (3)	1 (5)	8 (3)	0 (1)	6 (3)	24
Hollingsworth	14 (3)	13 (3)	3 (3)	3 (1)	1 (5)	8 (3)	1 (5)	5 (5)	28
Hunter	16 (3)	15 (3)	4 (3)	4 (3)	1 (3)	9 (3)	1 (5)	7 (3)	26
Keys Pond	10 (3)	10 (3)	2 (1)	1 (1)	0 (5)	8 (3)	0 (1)	4 (3)	20
Killarny	17 (3)	16 (3)	5 (5)	4 (3)	1 (5)	8 (3)	0 (1)	6 (3)	26
Koon	22 (5)	21 (5)	3 (3)	5 (5)	1 (3)	15 (5)	0 (1)	7 (3)	30
Lawbreaker	4 (1)	4 (1)	1 (1)	0 (1)	0 (5)	3 (1)	0 (1)	1 (5)	16
Lindsey	12 (3)	12 (3)	3 (3)	3 (3)	1 (5)	7 (3)	0 (1)	5 (3)	24
Little Fish	8 (3)	8 (3)	3 (3)	2 (3)	1 (3)	5 (3)	0 (1)	2 (5)	24
Live Oak	23 (5)	23 (5)	5 (5)	7 (5)	1 (5)	13 (3)	0 (1)	5 (5)	34
Lochloosa	28 (5)	28 (5)	4 (3)	7 (3)	1 (5)	17 (5)	1 (3)	8 (3)	32
Loften	10 (3)	10 (3)	2 (1)	3 (3)	0 (5)	7 (3)	0 (1)	0 (5)	24
Marianna	21 (3)	20 (3)	5 (5)	4 (3)	1 (5)	12 (3)	0 (1)	6 (3)	26
Mill Dam	28 (5)	28 (5)	5 (5)	6 (5)	1 (5)	19 (5)	1 (5)	6 (3)	38
Miona	21 (5)	21 (5)	4 (3)	3 (1)	1 (5)	15 (5)	0 (1)	6 (3)	28
Moore	15 (3)	15 (3)	3 (3)	3 (3)	0 (5)	12 (5)	0 (1)	2 (5)	28
Mountain	14 (3)	14 (3)	3 (3)	3 (3)	1 (3)	9 (3)	0 (1)	4 (5)	24
Mountain 2	17 (3)	17 (3)	3 (3)	2 (1)	1 (5)	12 (3)	0 (1)	6 (3)	22
Okahumpka	25 (5)	25 (5)	5 (5)	6 (5)	1 (5)	14 (5)	0 (1)	8 (3)	34
Orienta	15 (3)	15 (3)	3 (3)	4 (3)	0 (5)	8 (3)	0 (1)	4 (5)	26
Pasadena	16 (3)	16 (3)	3 (3)	3 (1)	1 (5)	10 (3)	0 (1)	6 (3)	22
Patrick	25 (5)	25 (5)	5 (5)	7 (5)	1 (5)	14 (5)	0 (1)	7 (3)	34
Pearl	23 (5)	23 (5)	6 (5)	5 (5)	1 (3)	14 (5)	0 (1)	5 (3)	32
Picnic	11 (3)	11 (3)	2 (1)	1 (1)	0 (5)	10 (3)	0 (1)	2 (5)	22
Round Pond	9 (3)	9 (3)	2 (1)	1 (1)	0 (5)	7 (3)	0 (1)	2 (5)	22
Rowell	28 (5)	28 (5)	4 (3)	8 (5)	1 (5)	17 (5)	1 (5)	7 (3)	36
Suggs	20 (5)	20 (5)	3 (3)	6 (5)	1 (5)	13 (5)	0 (1)	4 (5)	34
Susannah	23 (5)	23 (5)	4 (3)	5 (5)	1 (3)	14 (5)	0 (1)	9 (1)	28
Swim Pond	15 (3)	15 (3)	4 (5)	1 (1)	1 (3)	13 (5)	0 (1)	4 (3)	24
Thomas	13 (3)	12 (3)	3 (3)	2 (1)	1 (5)	9 (3)	0 (1)	4 (5)	24
Tomahawk	13 (3)	13 (3)	3 (3)	1 (1)	0 (5)	12 (5)	0 (1)	4 (5)	26
Turkey Pen	10 (3)	10 (3)	2 (1)	1 (1)	0 (5)	9 (3)	0 (1)	3 (5)	22
Wales	14 (3)	13 (3)	2 (1)	4 (3)	1 (5)	6 (1)	0 (1)	4 (5)	22
Watertown	16 (3)	16 (3)	4 (5)	3 (3)	1 (3)	9 (3)	0 (1)	5 (3)	24
Wauberg	21 (5)	21 (5)	5 (5)	5 (3)	1 (5)	14 (5)	1 (5)	5 (5)	38
West Moody	18 (5)	18 (5)	3 (3)	4 (3)	1 (3)	12 (3)	0 (1)	6 (3)	26

TABLE 4.—Chloride concentrations, road density, and estimates of anthropogenic (H = high, M = moderate, L = low) impact based on the qualitative observations of watershed development and lake use provided by Canfield and Hoyer (unpublished) for the 60 Florida lakes.

Lake	Chloride (mg/L)	Road density (roads/km^2)	Anthropogenic impact
Alligator	12.5	4.90	M
Apopka	39.8	2.10	H
Baldwin	12.7	9.96	M
Barco	5.4	1.69	L
Bell	17.7	5.53	H
Bivens Arm	13.6	5.74	M
Bonny	26.4	11.41	H
Brim Pond	6.8	1.93	L
Bull Pond	12.3	1.99	L
Carlton	42.4	3.75	H
Carr	3.6	1.40	L
Catherine	9.0	2.11	L
Clay	9.9	1.90	L
Clear	23.4	3.39	H
Conine	43.5	7.02	H
Crooked	7.3	0.98	M
Cue	6.8	1.78	M
Deep	6.3	2.53	L
Douglas	43.7	4.64	H
Fish	27.6	3.39	H
Gate Lake	9.9	6.33	M
Grasshopper	12.2	0.65	L
Harris	19.7	2.12	H
Hartridge	22.7	6.21	H
Holden	20.0	11.18	H
Hollingsworth	17.8	9.78	H
Hunter	13.4	6.75	M
Keys Pond	6.0	1.99	M
Killarny	14.0	6.06	M
Koon	6.2	0.68	L
Lawbreaker	7.8	0.65	L
Lindsey	4.6	1.87	M
Little Fish	5.6	1.75	L
Live Oak	24.7	2.76	H
Lochloosa	12.3	0.72	M
Loften	2.6	1.49	L
Marianna	30.6	4.76	H
Mill Dam	9.4	3.72	M
Miona	17.7	1.19	H
Moore	2.9	0.68	L
Mountain	19.3	1.72	H
Mountain 2	10.8	6.39	M
Okahumpka	24.1	2.29	H
Orienta	15.7	11.68	H
Pasadena	26.2	2.05	H
Patrick	28.8	1.01	H
Pearl	18.6	9.39	H
Picnic	10.6	1.40	L
Round Pond	8.3	1.16	L
Rowell	33.3	1.25	H
Suggs	12.8	1.58	L
Susannah	11.8	9.48	M
Swim Pond	9.7	2.05	M
Thomas	17.4	7.05	H
Tomahawk	6.3	1.84	L
Turkey Pen	2.1	1.63	L
Wales	12.3	3.92	M
Watertown	8.4	3.39	M
Wauberg	11.3	1.19	L
West Moody	20.5	1.31	H

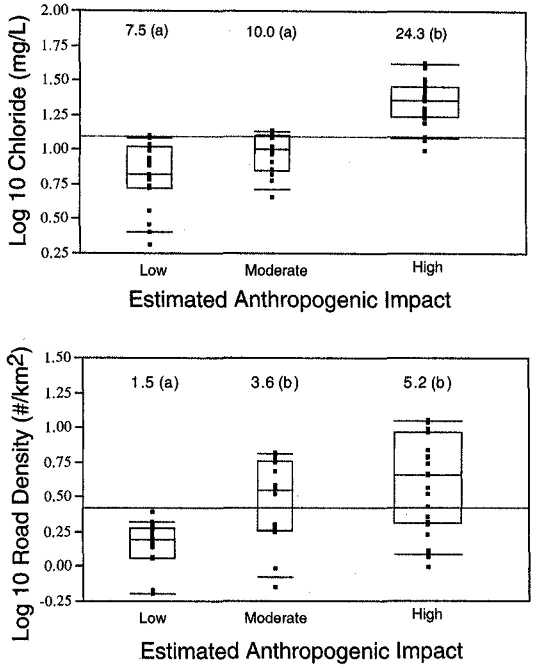

FIGURE 2.—Relationships between the qualitative grouping of anthropogenic impact for 60 Florida lakes and both the chloride concentrations and road densities measured for those lakes. Average chloride concentrations and road densities for each anthropogenic impact group are recorded above the box plots, and averages with different letters are significantly different ($P < 0.05$), as determined by one-way analysis of variance, followed by a Tukey–Kramer HSD test. The long horizontal line represents the grand mean of all values. The quantile box plots show the median as a line across the middle of the box, the 25th and 75th quantiles are the ends of the box, and the 10th and 90th quantiles are the short horizontal lines below and above the box.

TFS and NFS metrics have also been reported by Bachmann et al. (1996). They found that 70% of the variance in total species numbers was explained by lake surface area for 65 Florida lakes. Keller and Crisman (1990) also found increased fish species richness with increased surface area in Florida lakes. Several other studies have also documented the relationship between species richness and surface area (Barbour and Brown 1974; Magnuson 1976; Browne 1981; Tonn and Magnuson 1982; Eadie et al. 1986). This known relation between lake surface area and species number is the reason for creating the "maximum species" line used in calculating threshold values for assigning IBI scores to observed metric values (Figure 1; Fausch et al. 1984).

Values used to assign IBI scores for all but one

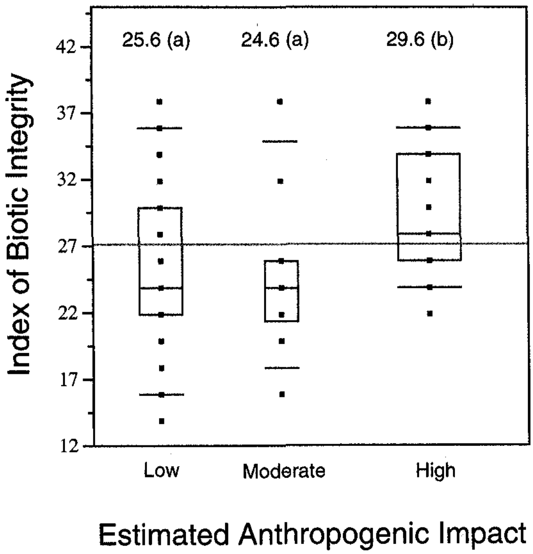

FIGURE 3.—Relationship between the qualitative grouping of anthropogenic impact and the total index of biotic integrity scores calculated for 60 Florida lakes. Average index of biotic integrity scores for each anthropogenic impact group are recorded above the box plots. Averages with different letters are significantly different ($P < 0.05$), as determined by a one-way analysis of variance, followed by a Tukey–Kramer honestly significant difference test. The long horizontal line represents the grand mean of all values. The quantile box plots show the median as a line across the middle of the box, the 25th and 75th quantiles are the ends of the box, and the 10th and 90th quantiles are the short horizontal lines below and above the box.

of the eight metrics (INV) were all positively correlated with adjusted total chlorophyll (Table 5). This is not surprising because other researchers have found positive relationships between the increased trophic status of a water body and the species numbers, biomass, and richness of aquatic organisms found in a water body (Nilsson and Nilsson 1978; Murphy et al. 1984; Brown and Dinsmore 1986; Keller and Crisman 1990; Bachmann et al. 1996). Productive aquatic ecosystems with higher trophic status have been found by some researchers to support a greater number and biomass of organisms and more specialized species (Hutchinson 1959; MacArthur 1970; Wright 1983).

However, other researchers have found that negative relationships exist between aquatic ecosystems of higher trophic status and the types of fish found in these systems (Lee et al. 1991). In water bodies of higher trophic status, the proportion of piscivorous fish species declines relative to the number of fish species (Kautz 1982; Persson et al. 1988). Bays and Crisman (1983) also found that lake trophic status in Florida lakes was related to fish species composition, with the percentage composition of sport fish (principally centrarchids) declining and the percentage composition of rough fish (especially gizzard shad) increasing in lakes of higher trophic status.

Bachmann et al. (1996) found that species richness was weakly, yet positively, correlated with chlorophyll *a* ($r = 0.17$) and that only five fish species (lake chubsucker, golden topminnow, lined topminnow, redfin pickerel, and Everglades pygmy sunfish) showed decreases in frequency of occurrence with increasing lake trophic status. These results indicate that these five species were more commonly collected in lakes with lower nutrient and algal concentrations, but all other species stayed the same or increased in frequency of occurrence in lakes classified with a higher trophic status. Bachmann et al. (1996) concluded there was no indication that the number of fish species de-

TABLE 5.—Correlation coefficients (*P*-values) between chloride concentration, road density, lake surface area, lake trophic status (estimated from adjusted total chlorophyll), and percent lake volume infested with aquatic plants (PVI) and the values of the eight fish assemblage index of biotic integrity (IBI) metrics calculated for the 60 Florida study lakes sampled by Canfield and Hoyer (1992). Correlation coefficients marked with an asterisk are significant at $P \leq 0.05$.

IBI metric	Chloride (mg/L)	Road density (roads/km^2)	Lake surface area (ha)	Adjusted total chlorophyll (μg/L)	PVI
Total fish	0.52 (≤0.05)*	0.08 (0.52)	0.66 (≤0.05)*	0.28 (≤0.05)*	0.13 (0.32)
Native fish	0.49 (≤0.05)*	0.05 (0.69)	0.64 (≤0.05)*	0.25 (≤0.05)*	0.16 (0.22)
Lepomis	0.53 (≤0.05)*	0.29 (≤0.05)*	0.52 (≤0.05)*	0.34 (≤0.05)*	0.03 (0.83)
Piscivores	0.53 (≤0.05)*	0.10 (0.44)	0.72 (≤0.05)*	0.37 (≤0.05)*	−0.02 (0.87)
Generalists	0.50 (≤0.05)*	0.34 (≤0.05)*	0.45 (≤0.05)*	0.45 (≤0.05)*	−0.07 (0.62)
Invertivores	0.27 (≤0.05)*	−0.15 (0.26)	0.43 (≤0.05)*	0.05 (0.69)	0.31 (≤0.05)*
Intolerant	0.49 (≤0.05)*	0.18 (0.17)	0.47 (≤0.05)*	0.33 (≤0.05)*	−0.24 (0.06)
Tolerant	0.52 (≤0.05)*	0.22 (0.10)	0.64 (≤0.05)*	0.38 (≤0.05)*	0.08 (0.57)

clined with increasing trophic state in their set of 65 Florida lakes.

Studies at more northern latitudes have concluded that eutrophication can lead to loss of dissolved oxygen in the hypolimnion of deep, stratified lakes and to changes in preferred foods, which may result in changes in fish assemblages, especially for salmonids, coregonids, and species such as the deepwater sculpin *Myoxocephalus quadricornis* (Larkin and Northcote 1969; Christie 1972; Colby et al. 1972). These coldwater fish groups and species are not found in Florida lakes, which are generally shallow, lack cold hypolimnia, and do not ice over in the winter as do many northern lakes. As a result, fish assemblages in Florida lakes may not respond to eutrophic conditions in the same way as coldwater fish assemblages (with salmonids and coregonids) found in northern lakes (Bachmann et al. 1996).

The values used to assign IBI scores for seven of the eight metrics were not significantly correlated with lake aquatic macrophyte abundance (Table 5). Only one metric (INV) was positively correlated with PVI. These results were surprising because some researchers have claimed that changes in aquatic plant communities caused by stocking grass carp at high densities have had negative effects on fish species richness (Ware and Gasaway 1978). In this study of 60 Florida lakes, PVI provided little predictive information concerning the response of seven of the eight fish assemblage metrics (Table 5). Researchers have stated that an optimal amount of aquatic plants is required to maintain the biotic integrity of aquatic ecosystems and claim that very low or very high concentrations of aquatic plants negatively affect IBI metric values and the IBI scores assigned for a lake (USEPA 1993). Because the evidence provided by this study does not support these claims, researchers may encounter inconclusive results when using these eight fish assemblage metrics to detect changes in fish assemblages caused by the management or nonmanagement of aquatic plants in lakes.

The results of this study suggest that lake surface area and lake trophic status are important factors influencing most of the eight fish assemblage metrics used in this study. Because lakes in Florida range in size from less than 2 ha to more than 180,000 ha, the influence of lake surface area on fish assemblages must be carefully considered before attempting to use fish assemblages as measures of human impact. Florida lakes also range naturally from oligotrophic to hypereutrophic because of the diversity of physiogeographic regions found within the state (Canfield and Hoyer 1988; Griffith et al. 1997). The physiographic region has an important influence on the lake's trophic status. For example, lakes on the phosphorus-rich Lakeland–Bone Valley Upland lake region in central Florida will be naturally more productive and will support more fish and wildlife than lakes on the nutrient-limited Northern and Southern Lake Wales Ridge lake regions. Therefore, lake regions should also be considered when using an IBI approach for Florida lakes because lake trophic status has been shown positively related to seven of the eight fish assemblage metrics tested in this study (Table 5).

Increases in trophic status can also be related to anthropogenic impact, and the resulting increases in productivity have the potential to positively influence the eight fish assemblage metrics tested in this study. Therefore, fish assemblage metrics may be inappropriate indicators of watershed disturbance and anthropogenic impact if these disturbances result in increases in trophic status.

Based on the data presented in this paper, the degree of anthropogenic impacts to this set of 60 Florida lakes was not accurately estimated with the IBI approach. Because lake surface area and lake trophic status have a dominant and positive effect on the majority of the eight fish assemblage metrics tested for this study, the utility of the IBI approach for estimating watershed disturbances and anthropogenic impacts in lake data sets having wide ranges of surface areas and trophic state classifications may be limited.

Conclusion

Numerous environmental factors significantly influence the distribution and abundance of fish species and, therefore, the fish assemblages found in lakes. Two of the three environmental factors tested in this study, lake surface area and lake trophic status, had significant and positive influences on the IBI scores assigned to lakes. Because aquatic ecosystems draw many of their attributes from the watersheds that they drain, the dominant environmental and ecological factors influencing IBI scores must be clearly understood before the IBI approach is used to estimate watershed disturbance and biological integrity.

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