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A Proposed Aquatic Plant Community Biotic Index for Wisconsin Lakes

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ABSTRACT / The Aquatic Macrophyte Community Index (AMCI) is a multipurpose tool developed to assess the biological quality of aquatic plant communities in lakes. It can be used to specifically analyze aquatic plant communities or as part of a multimetric system to assess overall lake quality for regulatory, planning, management, educational, or research purposes. The components of the index are maximum depth of plant growth; percentage of the littoral zone vegetated; Simpson's diversity index; the relative frequencies of submersed, sensitive, and exotic species; and taxa number. Each parameter was scaled based on data distributions from a statewide database, and scaled values were totaled for the AMCI value. AMCI values were grouped and tested by ecoregion and lake type (natural lakes and impoundments) to define quality on a regional basis. This analysis suggested that aquatic plant communities are divided into four groups: (1) Northern Lakes and Forests lakes and impoundments, (2) North-Central Hardwood Forests lakes and impoundments, (3) Southeastern Wisconsin Till Plains lakes, and (4) Southeastern Wisconsin Till Plains impoundments, Driftless Area Lakes, and Mississippi River Backwater lakes. AMCI values decline from group 1 to group 4 and reflect general water quality and human use trends in Wisconsin. The upper quartile of AMCI values in any region are the highest quality or benchmark plant communities. The interquartile range consists of normally impacted communities for the region and the lower quartile contains severely impacted or degraded plant communities. When AMCI values were applied to case studies, the values reflected known impacts to the lakes. However, quality criteria cannot be used uncritically, especially in lakes that initially have low nutrient levels.

Biological assessment techniques that measure environmental quality using fish, macroinvertebrates, periphyton, and diatoms are fairly well developed for streams and rivers (Barbour and others 1996). Much less has been done to develop bioassessment tools for lakes and impoundments. To the best of our knowledge, few if any bioassessment tools make use of aquatic macrophytes in streams or lakes.

Aquatic macrophytes are an important part of the aquatic ecosystem, and there are numerous advantages for using them in an overall biological assessment program. Macrophytes are primarily nonmobile, preventing them from fleeing rapid environmental changes. The perennial species integrate environmental changes over periods longer than annual events, and they may integrate the cumulative effects of successive disturbances. Aquatic macrophytes respond to nutrients, light, toxins, competition and other impacts from exotics, and management stresses (Adams and Sand-Jensen 1991). Specifically, species responses to water drawdown, aquatic herbicides, and turbidity are well documented (Nichols and Vennie 1991). However, responses to contaminants such as acids, metals, organics, and salinity are less well known. The reader is cautioned that responses are not always linear. In oligotrophic systems, nutrient additions, for example, may enhance the aquatic plant community, while in eutrophic systems, further nutrient additions may degrade the aquatic plant community (Davis and Brinson 1980). Sampling aquatic macrophyte communities and aquatic macrophyte taxonomy is reasonably straightforward; therefore, an assessment can be made with a reasonable amount of effort, and the ecology of a variety of species is well-enough known that some reasonable interpretation of habitat impacts can be assessed from macrophyte community responses.

Biocriteria were initially developed for assessing water quality for regulatory purposes, but a successful macrophyte index could also be used for defining the

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biotic potential of an aquatic resource (Weber and others 1995), planning and priority setting for aquatic macrophyte management programs, assessing the results of management practices, promoting awareness and educating various user groups, and providing a tool to study ecological processes, especially the long-term trends in aquatic macrophyte communities or littoral zone changes. An index can be used independently to answer questions about the aquatic macrophyte community or as part of a multimetric system to assess overall lake or stream quality (Gerritsen and others 1995, Wisconsin Department of Natural Resources 1996).

During the summer of 1994 we assessed the aquatic macrophyte communities in nine northern Wisconsin flowages (impoundments) and developed an index that reflected the quality of these aquatic macrophyte communities (Weber and others 1995). The Aquatic Macrophyte Community Index (AMCI) was used to define the quality of aquatic macrophyte communities in other northern Wisconsin flowages as part of the criteria for designating a flowage an Outstanding Resource Water (Wisconsin Department of Natural Resources 1996). Although this preliminary effort for classifying flowages showed great promise, it was developed for a very limited geographic area.

Time did not allow us to rigorously test the index for consistency and performance as suggested by Gerritsen and others (1995), no analysis was done to calibrate the index for seasonal and sampling variability, and the index was not tested on lakes with a variety of management histories to determine its analytical sensitivity. A statewide index that was calibrated for ecoregional and water type differences would be much more useful. To do this, a regional framework of comparison values needed to be developed.

The objectives of this study were to expand the AMCI concept to lakes and impoundments on a statewide basis, to test additional criteria and scaling methods to determine if they enhanced AMCI performance, to calibrate the resulting index for ecoregional and lake type (natural lakes versus impoundments) differences, to estimate the changes in AMCI caused by seasonal and sampling variability, and to test the AMCI on some lakes with known disturbance histories to determine if AMCI analysis provides reasonable results.

Methods

Data Sources

We developed a database by compiling lake plant surveys from the Wisconsin Department of Natural Resources Benchmark Lake Study, Inland Lake Renewal Studies, and Ambient Lake surveys; the University of Wisconsin–Center for Limnology Littoral Zone Project surveys; The US Geological Survey, Environmental Management Technical Center, surveys of Mississippi River impoundments; and the surveys done on northern Wisconsin flowage for Outstanding Resource Waters designation (Weber and others 1995). The database contains 363 lake surveys, although some surveys are of the same lake for different years. All lake surveys were used to scale the selected parameters. We realize that this may weight the results from some lakes over others, but at this point we do not consider it a major concern. We are only trying to establish a range and general distribution of selected parameters, and each lake-sampling period represents different data points. As we explain later, this list was edited to a single lake-sampling time for calibrating AMCI values.

All lake surveys were done using techniques similar to those described by Jesson and Lound (1962) and Deppe and Lathrop (1992). This is a stratified random technique with transects evenly spaced around a waterbody. Along each transect, sampling points are randomly located in predetermined depth classes. A sampling point is a 2-m-diameter circle divided into quarters. The presence of a species is noted in each quarter of the circle.

Parameters Selected

The parameters selected for the AMCI were the maximum depth of plant growth, the percentage of the littoral area vegetated, Simpson's diversity index, the relative frequency of submersed species, the relative frequency of sensitive species, taxa number, and the relative frequency of exotic species.

The maximum depth of plant growth was the deepest sampling point with vegetation. The percentage of the littoral area vegetated was: (sampling points with vegetation/total sampling points equal to or less than the maximum depth of plant growth) × 100. This statistic gives the probability of finding vegetation at any point in the littoral zone. Species frequencies equaled: (sampling points with a species/total sampling points equal to or less than the maximum depth of plant growth) × 100. Frequencies were converted to relative frequencies by dividing the frequency of the species by the sum of frequencies for all species. The values for selected groups of species were summed to calculate the relative frequencies of submersed species, sensitive species, and exotic species. A modified version: [1 − sum(species relative frequencies^2)] × 100, was used to calculate Simpson's (1949) diversity index. Taxa number was a count of all species sampled. A generic level taxa was counted if it represented an unidentified species different from other species of that genera found in the sample. Frequencies were used as the quantitative measure of plant abundance because they are less influenced by seasonal variation than is density or biomass (Natelson 1954).

Correlation analysis (Minitab 1994) was used to determine if any parameters were so highly correlated as to be redundant. Most parameters were significantly correlated with each other but well below the 0.9 level that Gerritsen and others (1995) suggest as the criterion for deleting a parameter for redundancy.

Scaling Parameters and Calculating the AMCI

Each parameter was scaled on a 1–10 basis, with 10 representing the highest quality condition. Maximum depth of plant growth is positively correlated with water clarity (Nichols 1992). Deeper plant growth indicates clear water and low nutrient levels. For scaling, the distribution of maximum depth values were divided into deciles and each decile was assigned a value between 1 and 10. If the maximum depth of plant growth equaled the maximum depth of the lake, the maximum depth parameter was assigned a value of 10 even if the depth was shallower than would normally rate a 10.

High-quality conditions for the amount of littoral zone vegetated are difficult to define. From a plant's "perspective" 100% of the littoral zone vegetated is the best. The habitat is suitable everywhere for plant growth, but this is probably not the natural condition for most lakes. As habitat for other organisms, a value around 50% vegetated may be most desirable (many references in Nichols 1997). Little plant growth indicates potentially serious littoral habitat limitations. A littoral zone 50% or more vegetated was assigned a value of 10. The remaining range from 0% to 50% was equally divided to assign values 1–9.

For diversity and number of taxa, the higher the value is, the better the quality. These values were handled like the maximum depth of plant growth—the range was divided into deciles to assign values from 1 to 10 with the most diverse or highest taxa number decile receiving a 10.

Sensitivity to disturbance is a broad concept because species vary in sensitivity based on the type of disturbance. We assigned sensitive status to species based on the work of Davis and Brinson (1980) (Table 1), who grouped submersed macrophytes on their tendency to decrease in biomass or disappear with increasing alteration of the ecosystem. They stated that ecosystem alterations are caused by a number of factors but the net result is usually increased turbidity. The higher the relative frequency of sensitive species is, the better. However, more than 20% of the data points had no sensitive species. If a lake had no sensitive species, we assigned it a value of 1. If it had any sensitive species, it was assigned a value of at least 3. The values from 3 to 10 were assigned by dividing the range of greater than 0% sensitive species to the maximum into eight equal groups.

Table 1. Sensitive species[a]

Scientific name	Common name
Ceratophyllum echinatum	spiny hornwort
Eriocaulon aquaticum	pipewort
Isoetes lacustris	lake quillwort
Lobelia dortmanna	water lobelia
Myriophyllum farwellii	Farwell's water-milfoil
Myriophyllum tenellum	dwarf water-milfoil
Potamogeton alpinus	alpine pondweed
Potamogeton amplifolius	large-leaf pondweed
Potamogeton foliosus	leafy pondweed
Potamogeton friesii	Fries pondweed
Potamogeton gramineus	variable-leaf pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton robbinsii	fern pondweed
Potamogeton strictifolius	stiff pondweed
Potamogeton vaseyi	Vasey's pondweed
Potamogeton zosteriformis	flat-stem pondweed
Ranunculus longirostris	white water crowfoot
Utricularia gibba	humped bladderwort
Utricularia intermedia	flat-leaf bladderwort
Utricularia vulgaris	great bladderwort

[a]Sensitive designation is after Davis and Brinson, 1980. Naming follows Gleason and Cronquist, 1991.

Assigning values to the amount of submersed vegetation is also difficult. Gerritsen and others (1995) recommend using only submersed vegetation in an index. We believe there is useful information provided by comparing submersed to nonsubmersed (emergent and floating-leaved) vegetation. In highly turbid conditions emergent or floating-leaf species may be the only survivors (Davis and Brinson 1980, Moss and others 1997). Furthermore, some emergent species can survive heavy wave action (natural or human caused by boat traffic, Murphy and Eaton 1983). High frequencies of nonsubmersed species can indicate water quality problems. Low values of nonsubmersed species may act as a surrogate variable for high riparian development. Often when lake shore property is developed, emergent and floating-leaf vegetation is removed to make a "clean" beach area. Certainly there are areas that are not naturally suited for nonsubmersed species. Emergents may be underreported in some cases because of difficulties defining the lake shore so that lake plants are separated from plants in a lake-shore wetland. We assigned a value of 10 to lakes with a relative frequency of submersed species between 75% and 85%. There is some support in the literature for these being typical natural values (Hutchinson 1975, Wetzel 1975). The dis-

Table 2. Scaled values for characteristics measured in the Aquatic Macrophyte Community Index (AMCI)

Maximum depth of plant growth (m)	Scaled value	Maximum depth of plant growth (m)	Scaled value
<1.4	1	7 and 8	3
1.4 to 2.0	2	9	4
2.0 to 2.7	3	10 and 11	5
2.7 to 3.0	4	12 and 13	6
3.0 to 3.2	5	14 and 15	7
3.2 to 3.7	6	16 to 19	8
3.7 to 4.0	7	19 to 25	9
4.0 to 4.5	8	≥25	10
4.5 to 5.0	9	Exotic species (relative %)	
≥5.0	10	0	10
Littoral area vegetated (%)		0.1 to 5	6
<18	1	5 to 10	5
18 to 24	2	10 to 20	4
24 to 29	3	20 to 30	3
29 to 32	4	30 to 45	2
32 to 34	5	≥45	1
34 to 37	6	Simpson's diversity	
37 to 40	7	index	
40 to 45	8	<60	1
45 to 50	9	60 to 70	2
≥50	10	70 to 76	3
Submersed species (relative %)		76 to 80.5	4
<34	1	80.5 to 83.5	5
34 to 43	2	83.5 to 85.5	6
43 to 49	3	85.5 to 87.5	7
49 to 58	4	87.5 to 90	8
58 to 60	5	90 to 92	9
60 to 65	6	≥92	10
65 to 68	7	Sensitive species	
68 to 72	8	(relative %)	
72 to 75	9	<0.1	1
75 to 85	10	0.1 to 2	3
85 to 90	9	2 to 4	4
90 to 92.5	8	4 to 9	5
92.5 to 95	7	9 to 13	6
95 to 97.5	6	13 to 17	7
≥97.5	5	17 to 22	8
Taxa number		22 to 30	9
<5	1	≥30	10
5 and 6	2		

tribution of values from 75% to the minimum were divided into nine parts and scaled from 9 to 1. Values greater than 85% were divided equally and scaled from 9 to 5.

High frequencies of exotic species indicate degraded conditions, so scaling is inverse. High frequencies receive low scale values. However, more than 40% of the data points had no exotic species. If a lake had no exotic species, it received a 10. If it had any exotic species, it received not more than a 6. The range of frequencies greater than 0% were divided into six parts to assign values 6–1. Species considered exotic in this study were *Lythrum salicaria* (purple loosestrife), *Myriophyllum spicatum* (Eurasian water-milfoil), *Najas marina* (spiny naiad), *Phalaris arundinacea* (Reed canary grass), and *Potamogeton crispus* (curly-leaf pondweed) (Swink and Wilhelm 1994).

The scaling values are provided in Table 2. An AMCI value is calculated by adding the scaled values for the seven parameters. Any lake could receive a score of 7 for the poorest quality macrophyte community to 70 for the highest quality plant community. Realistically, no lake reaches either end point.

Calibrating AMCI Values for Ecoregional and Water-Type Differences

After calculating AMCI values, the lake list was edited and only the single highest AMCI value for a lake

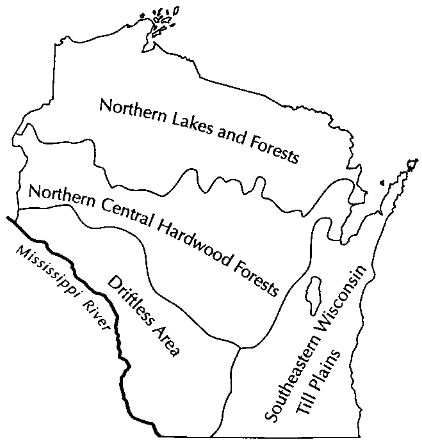

Figure 1. Ecoregions of Wisconsin (after Omernick and Gallant 1988).

sampled multiple times was retained. This shows the highest AMCI potential that the lake displayed. Lakes with less than 40 sampling points were deleted. Although this value is arbitrary, it is a level of at least ten transects and four depth zones sampled per lake. Below this level the frequency of any species varies by more than 2.5% with its inclusion or exclusion in a sampling point.

The remaining 147 lakes were initially assigned to eight ecoregion–water-type categories. Ecoregion boundaries followed Omernik and Gallant (1988, Figure 1) and water types were either natural lakes or impoundments. Water-type classification was obtained from the Wisconsin Department of Natural Resources General Waters File. The initial groupings were: (1) Northern Lakes and Forests lakes, (2) Northern Lakes and Forests impoundments, (3) North-Central Hardwood Forests lakes, (4) North-Central Hardwood Forests impoundments, (5) Southeastern Wisconsin Till Plains lakes, (6) Southeastern Wisconsin Till Plains impoundments, (7) Driftless Area lakes (almost all are impoundments), and (8) Mississippi River Backwater lakes. Moods median test and inspection of box plots (Minitab 1994) were used to combine groups that did not have significantly different median values into final groups. Discriminate analysis (Minitab 1994, Yandell 1997) was used to determine how well the chosen parameters classified lakes into the final lake groups.

Calibrating Reference Conditions

Gerritsen and others (1995) described two ways to establish reference conditions. The first, and preferred method, selects sites on a priori definition of reference site conditions. This method involves selecting a number of minimally impacted lakes in a region and calibrating parameters based on conditions in these lakes. We used the second method. We developed reference criteria based on conditions found in a representative sample of lakes within a class. This method better suited our data. Many of the lakes in the database were impoundments where, by definition, no minimally impacted conditions exist. Lakes in about two thirds of the state are subject to strong human impact from urbanization or agriculture. Even lakes in the least impacted area of the state were historically subjected to strong human impact from logging, fires, and agriculture. We therefore established reference conditions within each of the final ecoregion–lake type groups based not on unimpacted conditions, but on the best AMCI values found within the groups. For our study, reference conditions do not represent the biotic potential for lakes in the absence of human activity or pollution, but they are based on the best plant communities we could find in a distribution of plant communities from a ecoregion–lake type group. We call lakes with AMCI values in the upper quartile of an ecoregion–lake type group reference or benchmark lakes. They are lakes with the highest quality plant communities that are found in the region. The values in the interquartile range (25%–75%) are normally impacted or impaired lakes. AMCI values represent plant communities for lakes that have typical types of disturbance for the region. The lower quartile represents severely impacted or impaired lakes. These AMCI values are below levels that are expected even in lakes with average amounts of human disturbance. This differs from the criteria of Gerritsen and others (1995), which suggest that a lake is not considered impaired unless it falls below the lower quartile of the reference distribution. We use box plots to illustrate the range and distribution of AMCI values by ecoregion–lake type group.

Quantifying AMCI Variability Caused by Seasonal and Sampling Differences

The database contained 46 lakes that were sampled twice during the same growing season. They formed the basis for estimating the seasonal and sampling variability in AMCI values. The early lake sampling was in late June or early July and the late sampling was in August or early September. A paired *t* test of means (Minitab 1994) was used to determine if AMCI values of the early sampling were significantly different from those of the late sampling; a one-tailed 95% confidence interval for absolute change in AMCI values between early and late sampling dates was determined.

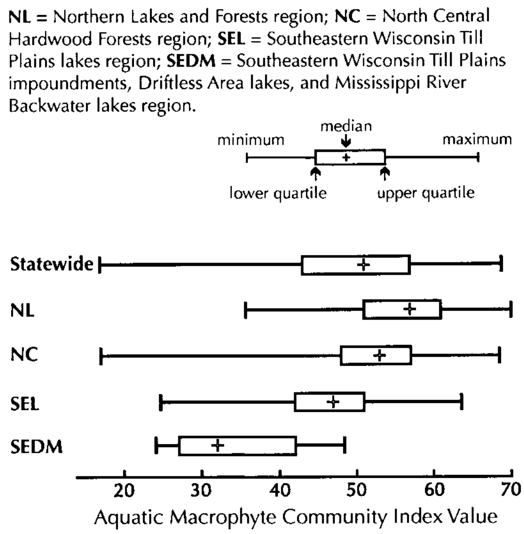

Figure 2. Box plots showing the distribution of Aquatic Macrophyte Community Index (AMCI) values on a statewide and regional basis.

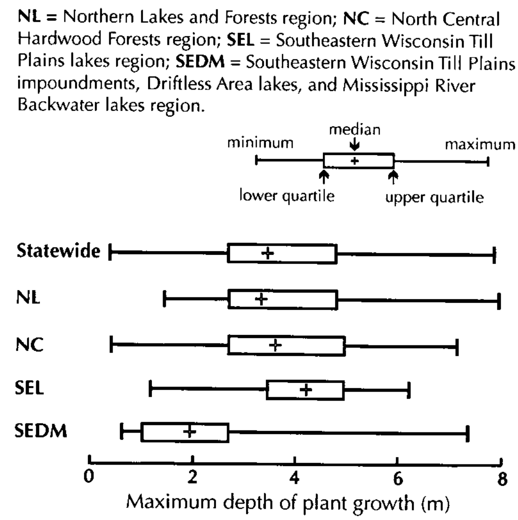

Figure 3. Box plots showing the distribution of the maximum depth of plant growth on a statewide and regional basis.

Results

Final Ecoregion—Water-Type Groups

Median AMCI values for the eight original ecoregion–water-type groups were significantly different ($P < 0.01$). However, inspection of the box plots suggested that each group was not significantly different from every other group. The medians of groups that appeared most similar were tested in a pairwise fashion, and if the group medians were not significantly different they were combined. This resulted in four final ecoregion–water type groups: (1) Northern Lakes and Forests lakes and impoundments (NL), (2) North-Central Hardwood Forests lakes and impoundments (NC), (3) Southeastern Wisconsin Till Plains lakes (SEL), and (4) Southeastern Wisconsin Till Plains impoundments, Driftless Area lakes, and Mississippi River Backwater lakes (SEDM).

Natural lakes from the NL and NC regions were combined and compared to the combined values of impoundments for the two regions. Contrary to suggestions (Gerritsen and others 1995), no significant differences in median AMCI values were found between natural lakes and impoundments; therefore, there is no biological reason, at least from an AMCI perspective, to keep the classes separate within these two ecoregions.

Regional Differences and Calibration of AMCI Values

The NL region had the highest median AMCI value, followed by the NC region, the SEL region, and finally the SEDM region (Figure 2). There are no lakes in the SEDM region that ranked above the lower quartile of lakes in the NL region and three fourths of the lakes in the SEL region would be in the lower quartile of NL lakes.

The greatest median for maximum depth of plant growth was in the SEL ecoregion. The NL and NC had similar median depths and were slightly shallower than the SEL median depth. All three groups were easily separated from the SEDM group, whose median maximum depth of plant growth was the shallowest (Figure 3). The median maximum depth for the SEDM group would receive a scaled value of 2 vs 7 for the NL and NC groups and 8 for the SEL group.

The NC and SEL regions had the highest median percentage of the littoral zone vegetated. This is followed by the NL region and then the SEDM region (Figure 4). Any of these median values would rate a scaled AMCI value of 10.

The NL region had the highest diversity followed by the NC region, the SEL region, and finally the SEDM region (Figure 5). The interquartile ranges also increased dramatically from the NL to the SEDM regions. Some SEDM lakes had a diversity of 0. The vegetation in these lakes was monotypes.

The SEL region had the highest median relative frequency of submersed species (Figure 6). However, based on scaling values, higher was not better (see Table 2 for scaling values). Only the NL region had a median relative frequency that rated a scaled value of 10. The other groups had higher relative frequencies.

The median values of relative frequency of sensitive species dropped in stepwise fashion from the NL re-

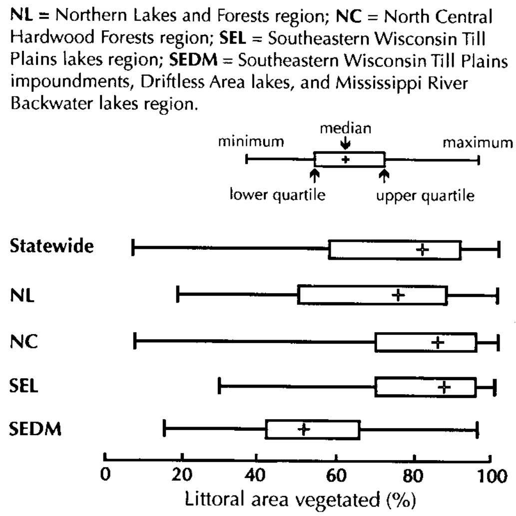

Figure 4. Box plots showing the distribution of the percentage of the littoral area vegetated on a statewide and regional basis.

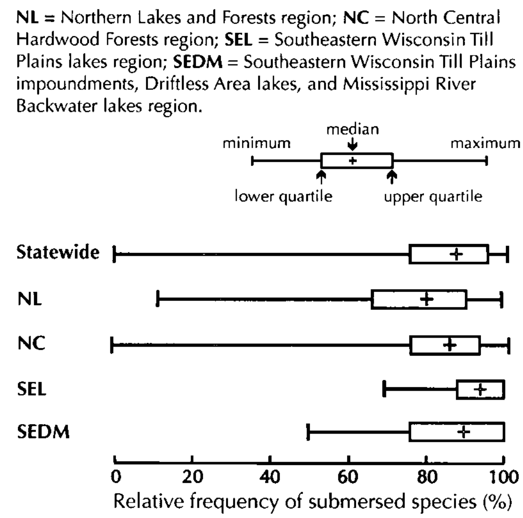

Figure 6. Box plots showing the distribution of the relative frequency of submersed species on a statewide and regional basis.

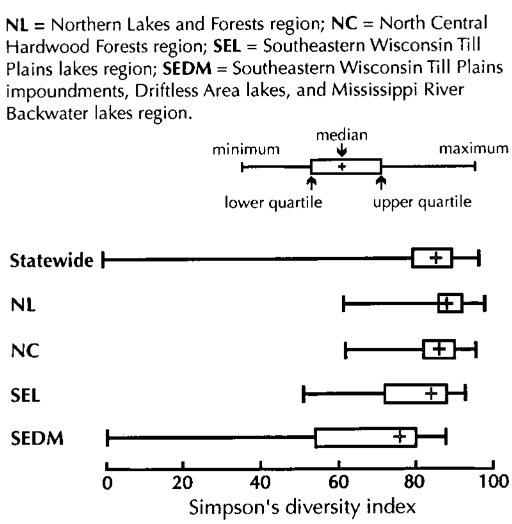

Figure 5. Box plots showing the distribution of Simpson's diversity index on a statewide and regional basis.

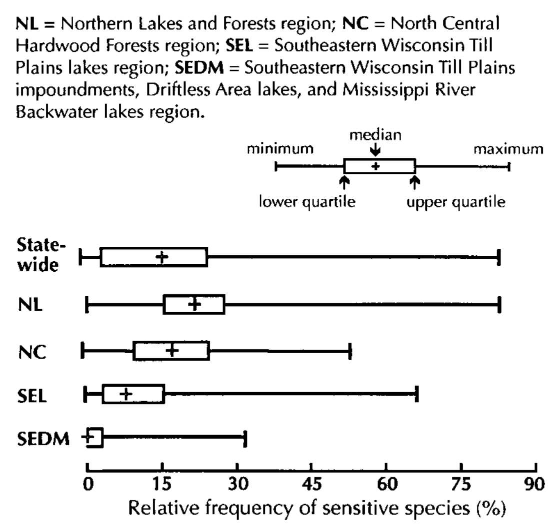

Figure 7. Box plots showing the distribution of the relative frequency of sensitive species on a statewide and regional basis.

gion, to the NC region, to the SEL region, to the SEDM region (Figure 7). Sensitive species are uncommon in SEDM lakes. This region had a median value of 0% for sensitive species. None of the median relative frequency values rated a scaled AMCI value of 9 or 10.

The number of taxa per lake ranged from 1 to 42, and the median number of taxa dropped from the NL region, to the NC region, to the SEL region, to the SEDM region (Figure 8). None of the median values would rate a 9 or 10 as a scaled AMCI value.

Few exotic species were found in the NL or NC regions. Southern areas had exotic species and their values varied dramatically. The exotic species values ranged from 0% to 70.6% in the SEL region and from 0% to 43.7% in the SEDM region (Figure 9). The statewide median value for relative frequency of exotic species was 0%, indicating that exotic plant species are not found in a majority of lakes on a statewide basis.

Using the parameters selected, discriminate analysis

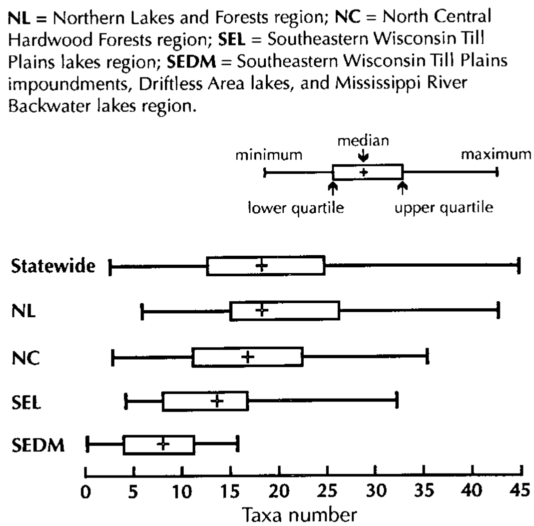

Figure 8. Box plots showing the distribution of taxa numbers on a statewide and regional basis.

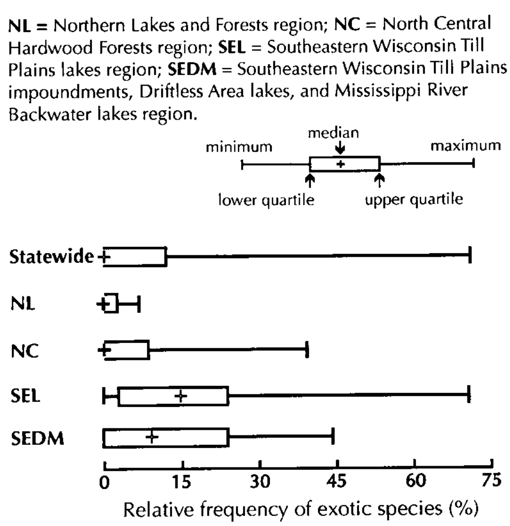

Figure 9. Box plots showing the distribution of the relative frequency of exotic species on a statewide and regional basis.

correctly classified a lake into the proper regional group 63% of the time on a statewide basis. This proportion of correct classifications varied from 50% to 74% with, as expected, the groups that were most different having the higher percentages of correct classifications (Table 3).

Seasonal and Sampling Variability

Mean AMCI values were not significantly different between early and late samples ($P < 0.05$). Of the 46 lakes tested, the AMCI value decreased in 24 lakes and increased or stayed the same in 22, so no seasonality was shown in AMCI values. The one-tailed, 95% confidence interval for the absolute change between early and late sampling dates was 4.7. In other words, if AMCI values varied by more than 4.7, the variation is not likely caused by seasonal or sampling variability.

Table 3. Proportion of correct classification using discriminate analysis to place a lake plant community into one of four regions using seven selected parameters[a]

	True group			
Put into group	NL	NC	SEL	SEDM
NL	37	11	3	0
NC	13	20	5	2
SEL	0	8	19	5
SEDM	0	1	5	21
% correct	74	50	59	67
Overall % correct	63			

[a]NL = Northern Lakes and Forests region; NC = North Central Hardwood Forests region; SEL = Southeastern Wisconsin Till Plains lakes region; SEDM = Southeastern Wisconsin Till Plains impoundments, Driftless Area lakes, and Mississippi River Backwater lakes.

Example Applications

Lake Mendota—Long-Term Decline in Quality

Lake Mendota is a 3985-ha lake located in Madison, Wisconsin, part of the SEL region. Since European settlement it has an approximately 150-year history of human impact, including water level fluctuation, dredging, aquatic plant management, exotic species introductions, and point and nonpoint sediment and nutrient input (Nichols and Lathrop 1994). It also has a long history of quantitative aquatic plant surveys, the earliest being completed in 1912 (Denniston 1921). The 1912 survey was compared to a 1992 survey to provide an 80-year profile of aquatic plant community change.

Over this time the AMCI dropped from 61 to 48 (Table 4). The plant community went from one that was in the upper quartile or benchmark lake on a statewide and regional basis to one that was slightly above the median for the SEL region. Decreases in diversity, relative frequency of sensitive species, and taxa number and an increase in the relative frequency of exotic species were the major causes for AMCI decline.

Table 4. Comparison of Lake Mendota plant community parameters between 1912 and 1992

Year[a]	Max. depth plant growth (m)	Littoral area veg. (%)	Simpson's diversity	Submersed species (rel. %)	Sensitive species (rel. %)	Taxa (Nr)	Exotic species (rel. %)	AMCI
1912[a]	5.5	50	90	98.9	20.8	20	0	61
1992	4.5	72	83.5	92.3	5.4	15	20.2	48

[a]Data from Denniston (1921).

Table 5. Comparison of Lake Wingra plant community parameters before and after a *Myriophyllum spicatum* decline

Year	Max. depth plant growth (m)	Littoral area veg. (%)	Simpson's diversity	Submersed species (rel. %)	Sensitive species (rel. %)	Taxa (Nr)	Exotic species (rel. %)	AMCI
1969[a]	3.1	81.7	54	99	0.7	18	68.9	33
1995	3.5	78.4	84.9	95.1	16.3	16	37.4	45

[a]Data from Nichols and Mori (1971).

Lake Wingra—Improved Conditions with a Eurasian Water-Milfoil (*Myriophyllum spicatum*) Decline

Lake Wingra is a 137-ha lake also in the Madison, Wisconsin, area. When it was first quantitatively sampled in 1969, it was at the height of a *M. spicatum* invasion (Nichols and Mori 1971). The *M. spicatum* population declined in the mid-1970s (Carpenter 1980). A 1995 sampling reflects conditions in Lake Wingra approximately 20 years after this decline.

During this time period the aquatic plant community improved from one that was severely impacted with an AMCI value in the lower quartile for the SEL region to one that showed average impacts with an AMCI value just slightly below the median (Table 5). The greatest improvement occurred in the diversity and relative frequency of sensitive species. The relative frequency of exotic species declined but using scaled values, it made only 1 point of difference in the AMCI value.

Franklin Lake—Improved AMCI, Increased Nutrient Inputs?

Franklin Lake is a 361-ha lake in the NL region of Wisconsin. It is a very soft water seepage lake with slightly acid water. In 1972 Franklin Lake had 31 dwellings on it and it was surrounded by wild, wooded upland. By 1997 there were 34 residences on the lake with many of the properties having large lawns that were maintained to the lake edge. Fertilizer run-off, increased stormwater, and an increased number of septic systems have likely increased nutrient inputs to Franklin Lake. Increased complaints of algal blooms and decreased Secchi readings also indicate an increased nutrient status (Laura Herman, Wisconsin Department of Natural Resources, personal communication).

The aquatic plant community was sampled four times during the 10-year period between 1987 and 1997 as part of the Wisconsin Department of Natural Resources ambient lake monitoring program. During this time the AMCI value in Franklin Lake increased from a value below the median for the NL region to one that was in the upper quartile for the region (Table 6). In this case change in the AMCI value is what is important rather than the direction of change. AMCI values indicate a higher quality plant community, other indicators suggest a decline in water quality. In nutrient-poor Franklin Lake, nutrient additions probably enhanced the aquatic plant community. The most telling parameter is the decline of sensitive species over the 10-year period. The increased depth of plant growth may have been caused by annual precipitation differences. Drought conditions in 1987 caused low lake levels.

Lily Lake—A Dredging Impact

Lily Lake is a 37-ha lake in Kenosha County, part of the SEL region of Wisconsin. Prior to dredging, the maximum lake depth was 1.8 m and vegetation extended across the entire lake bottom. Because of profuse plant growth, the lake was dredged to a sand bottom or to a maximum depth of 6.6 m, whichever came first. Dredging occurred between July 1978 and June 1980 and was part of a lake-renewal plan. It removed a majority of the plant biomass as well as plant propagules and nutrient-rich sediment (Nichols 1984). The AMCI for the combined sampling of two years

Table 6. Comparison of Franklin Lake plant community parameters between 1987 and 1997

Year	Max. depth plant growth (m)	Littoral area veg. (%)	Simpson's diversity	Submersed species (rel. %)	Sensitive species (rel. %)	Taxa (Nr)	Exotic species (rel. %)	AMCI
1987	2.7	83.8	86.6	63.5	49.5	12	0	53
1991	2.7	94.5	90.1	57.9	25.1	19	0	55
1994	4.1	96.2	89.9	65.1	39.6	18	0	61
1997	4.6	94.8	91.8	61.4	31.1	19	0	63

Table 7. Comparison of Lily Lake plant community parameters before and after dredging

	Max. depth plant growth (m)	Littoral area veg. (%)	Simpson's diversity	Submersed species (rel. %)	Sensitive species (rel. %)	Taxa (Nr)	Exotic species (rel. %)	AMCI
Before dredging	1.8	100	85	100	24.8	13	7	51
After dredging	4	82	77	100	1	11	11.7	39

before dredging (1976 and 1977) are compared to the two years after dredging (1981 and 1982). A drop in AMCI is expected because of the substantial impact to the plant community.

The AMCI value dropped from 51 to 39, from a value that was on the border of the upper quartile for the SEL region to a value that was in the lower quartile for the SEL region (Table 7). Dredging reduced diversity, relative frequency of sensitive species, and taxa number and increased the relative frequency of exotic species. The most dramatic change occurred in the relative frequency of sensitive species that declined from 24.8% to 1%. *Potamogeton illinoensis, P. zosteriformis, P. robbinsii*, and *P. amplifolius* were all dramatically reduced by dredging. The maximum depth of plant growth was greater after dredging, but it was scaled higher (a 10) before dredging because vegetation extended across the entire lake bottom. By 1990 the maximum depth of plant growth increased by about 1 m, and *P. robbinsii* and *P. illinoensis*, both sensitive species, constituted about 70% of the relative biomass (Garrison and Ihm 1991). The increase in these metrics would increase the AMCI value, but an AMCI value could not be calculated because of differences in sampling techniques.

Discussion

AMCI analysis and calibration suggest that the aquatic plant communities in Wisconsin are divided into four groups based on quality. Median AMCI values decline from the Northern Lakes and Forest region, to the North-Central Hardwood Forests region, to Southeastern Wisconsin Till Plains lakes, to Southeastern Wisconsin Till Plains impoundments, Driftless Area lakes, and Mississippi River Backwater lakes. This decline in AMCI reflects general water-quality trends in the state (Lillie and Mason 1983) and general human use patterns that increase from north to south. Water-quality, land-use, and human-use patterns are also more variable in southern areas of the state. This variability is reflected in the differences in interquartile ranges of some of the parameters that are generally greater for southerly waters. However, even in southern areas it is possible to find high-quality plant communities and in northern areas it is possible to find poor-quality plant communities. Therefore, it is useful to place the quality of a lake or flowage in a regional and statewide perspective. Based on these trends it appears that AMCI values confirm what might be predicted from other water-quality and human-use factors. It is therefore a useful tool for quantifying macrophyte community quality. This tool can be used as part of a multimetric approach for assessing lake or impoundment quality or singly to analyze macrophyte community dynamics.

In a limited number of applications, the AMCI reliably reflected changes that might be predicted from the type or intensity of disturbance. This is a small sample, but there are few cases where disturbance and plant community change are well documented. Certainly refinements to the AMCI are probable as more data become available. Assigning scaling values is somewhat subjective, so they are open to debate. Different scaling factors, different sensitive and exotic species, etc., have to be used if the AMCI concept is used in regions other than Wisconsin. However, the basic parameters appear to be a useful way of characterizing aquatic plant community quality.

The Franklin Lake example shows that the index cannot be used uncritically. Here the AMCI value increased, which suggests a positive change in water quality. However, other evidence indicates that the water quality change was not for the better. Nutrient additions to this infertile lake improved conditions for aquatic plant growth.

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