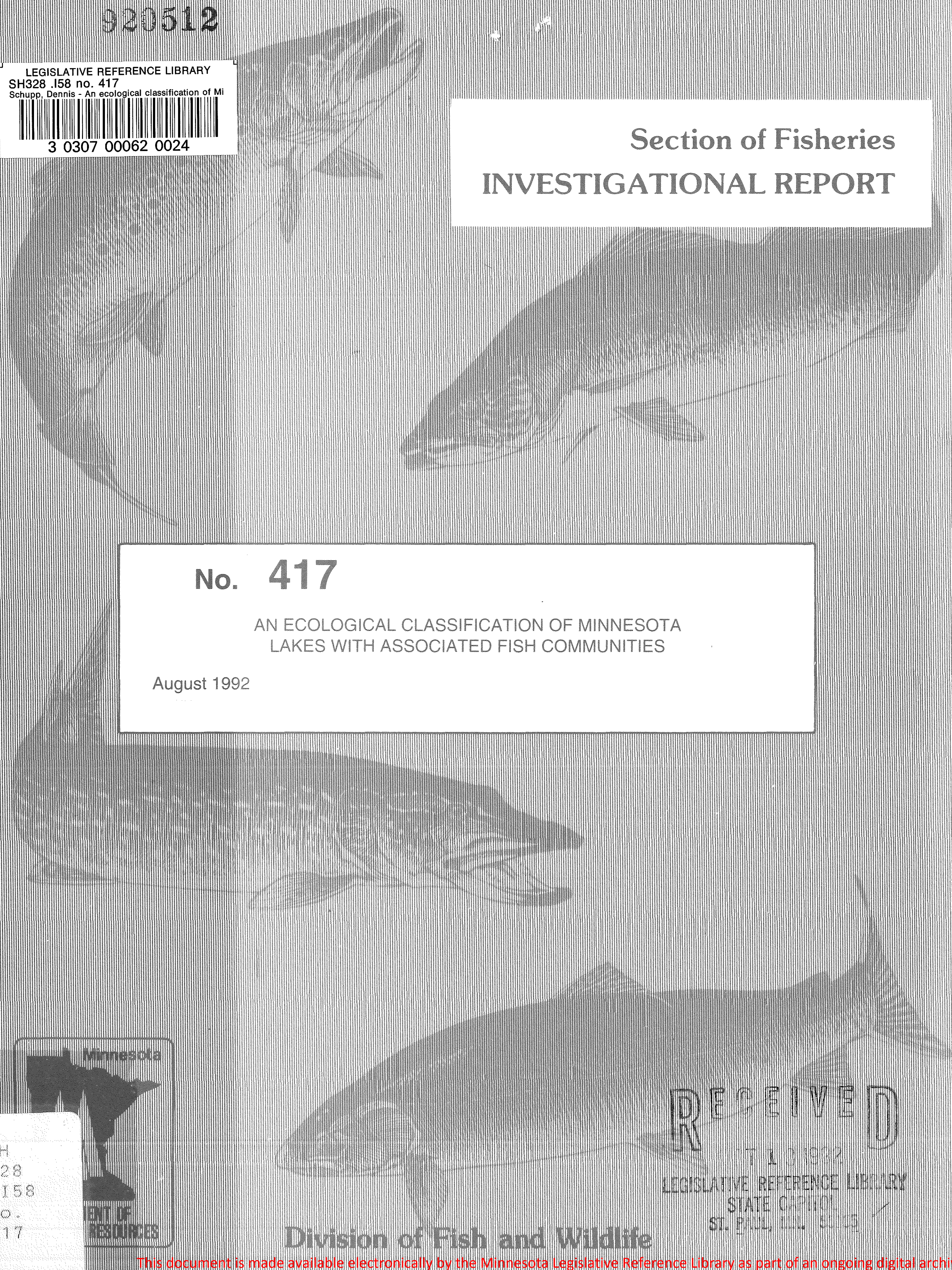

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AN ECOLOGICAL CLASSIFICATION OF MINNESOTA LAKES WITH ASSOCIATED FISH COMMUNITIES

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AN ECOLOGICAL CLASSIFICATION OF MINNESOTA LAKES WITH ASSOCIATED FISH COMMUNITIES[1]

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Abstract--Limnological variables from 3,029 Minnesota lakes were used to ecologically classify the lakes into 44 types. Principal components analysis classified the variables into three types: variables associated with lake size; variables associated with lake depth; and variables associated with the chemical fertility of the lakes, and length of the growing season. Reductions in sums of squares due to classification ranged from 56 to 89% for six physical and chemical variables. Gill and trap net catch indices within lake classes were used to characterize fish communities for each lake class. Intra-class variation of gill and trap net CPUE and mean weights of 23 species of fish were also reduced. Variation in these measures, however, remains high. Examples of the use of inter-quartile ranges of CPUE and average size for rapid assessment of lake survey results are presented. The classification and recommended evaluation of netting surveys is intended to stimulate analysis of surveys from an aquatic community viewpoint. This approach can aid fishery managers to quickly separate likely problems from natural biological variation. Their time and resources should thus be used more effectively.

Introduction

Nearly all lakes in Minnesota were formed by glacial action (Schwartz and Thiel 1954), but they vary widely in limnological characteristics. The species and community assemblages of fish are usually those best adapted to the unique conditions in a lake. Rational management of the lakes for fish production should consider the community structure best suited for a lake.

Moyle (1946) found that the chemical parameters, total alkalinity and total phos phorous, were useful predictors of pond productivity and were related to total fish caught in lake survey gill nets. Moyle concluded that lake productivity must be evaluated in the light of water quality and lake basin form. He also cited Thompson (1941) that length of the growing season and water temperature are also important when lakes in different latitudes and altitudes are compared. Minnesota covers a range of 5° 30' latitude.

Rounsefell (1946) concluded that fish production was related to the size of the water body, and that the smaller the lake the greater was the production of fish per unit

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area. Rawson (1952) showed that mean depth was related to fish production. Ryder (1965) combined chemical and physical factors (TDS and mean depth) to develop the widely used Morphoedaphic Index (MEI).

More recently, multivariate analysis techniques have been used to classify lakes and community types. Johnson et al. (1977) used principal component and discriminant analysis to classify 2,496 Ontario lakes that sorted into 15 groups based on the presence or absence of four game fish species: walleye *Stizostedion vitreum*, northern pike *Esox lucius*, lake trout *Salvelinus namaycush*, and smallmouth bass *Micropterus dolomieu*. Canonical discriminant analysis was used to assess the degree to which the species associations could be identified using limnological variables. This work has been extended, adding brook trout *Salvelinus fontinalis* and lake whitefish *Coregonus clupeaformis*. Ontario has classified all inventoried lakes into one of 63 community assemblage types (Ontario Ministry of Natural Resources 1978). Tonn et al. (1983) used ordination, classification, and discriminant analysis to study the fish assemblages in 18 small Wisconsin lakes. They used the results of the discriminant analysis to successfully predict the fish assemblage in 11 additional lakes using five variables: area, maximum depth, pH, watershed size, and conductivity. Dolman (1990) used cluster analysis to classify 132 Texas reservoirs into five groups based on species associations. Canonical correlation was used to analyze relations between the species associations and environmental variables.

Lake surveys in Minnesota began in 1935 (Moyle 1946). Early surveys included contour maps that showed the extent and nature of aquatic vegetation and bottom-soil types, and measurements of water temperatures, DO, pH, total alkalinity, and TDS. Fish were sampled by gill nets and seines. Trap nets were added as a fish sampling gear in 1951, and since then survey methods have been standard. Most surveys are of short duration lasting one week or less.

Though the earliest effort at classification of Minnesota fish lakes was made by Eddy (1938), it was the work of Moyle (1946; 1950) that led to the development of a classification system for Minnesota lakes that has been used for more than 30 years. The principal parameters used in the classification were the size and depth of the lake, and total alkalinity. Scidmore (1970) listed seven ecological lake types. While the system has been useful, it has also been misused. Fishery managers frequently assigned an ecological classification to a lake based on the species for which they were managing. This often depended on the fish that were being stocked, and sometimes resulted in the lake being reclassified with each change of management objectives.

Abundances of fish were judged by comparing lake survey net catches to statewide median net catches without reference to the lake type (Moyle 1950; Moyle and Lound 1960; Scidmore 1970). The number and sizes of fish caught in survey nets are usually interpreted only as measures of abundance, but net catches also reflect the response of fish to their particular environment.

The purpose of this study was: (1) to develop a refined ecological classification of Minnesota's fish lakes using limnological variables measured during lake surveys; (2) to evaluate factors that influence lake survey net catches of fish; and (3) to establish benchmarks other than statewide medians for evaluating lake survey net catches of fish. The results of this analysis should allow fishery managers to make more realistic judgments of the status of fish communities from lake surveys by considering conditions in the particular lake at the time of the survey.

Materials and Methods

Data used for this study were from 5,625 lake surveys. Most of the surveys were done from 1974 through 1986 since survey data was not computerized until 1983. Only the most recent survey on each lake was entered at that time. There were, however, 901 surveys in the data base that were done before 1974. The earliest of these was conducted in 1951.

Variables identifying each survey and associated limnological variables were extracted from the lake survey data base for this study (Table 1). Measurement variables were examined for obvious errors and corrected. For example, if shoreline development (SDF) for a lake was calculated to be less than one, the reported measurement of lake area or shoreline length was wrong. Detected errors were corrected by contacting the appropriate Fishery Management Area for accurate information. Detected errors found were usually typographical and were often misplaced decimals.

Additional variables describing physical characteristics of the lakes were derived from the data base. These include: shoreline development (SDF); area: shoreline length ratio; and lake volume (maximum depth /3 X lake area). Frequency distributions of each measurement variable were examined and data transformations were made where indicated. Distributions of physical variables were normalized using natural logarithms. Chemical variables or those related to water chemistry (secchi disc transparency) were normalized using square root transformations.

Survey gill and trap net catches of 28 fish species were included (Table 2). Gill and trap net specifications have been constant since 1951 except that nylon webbing replaced cotton or linen during the 1960s. Netting effort increased with lake size (Moyle 1950; Moyle and Lound 1960). Total numbers and pounds of each species caught, and number of lifts for each gear type were used to calculate mean CPUE (catch per unit effort) for each survey. Mean weights for each species and gear type were calculated. Obvious errors in reported net catches were detected and corrected. Calculation of a mean weight of 60 pounds for bluegill is an example of an obvious error. Distributions of mean catches and mean weights were normalized using natural logarithms.

Statistical Analysis

Only eight of the transformed or derived physical and chemical variables were available for most lakes (74%) in the data base. These were: area, maximum depth, percent littoral, total alkalinity (TA), secchi disc transparency, SDF, lake volume, and area:shoreline ratio. Lakes with several surveys were used only once in the analysis. Secchi transparencies and TA from multiple surveys of specific lakes were averaged.

Table 1. Physical and chemical variables in the lake survey data base used for this study.

Fishery Management Area	Lake area (acres)
Watershed	Maximum depth (ft)
Lake Identification Number	Median depth (ft)
Date of survey	Percent littoral
Extent of emergent vegetation	Shoreline length (mi)
Max. depth, submerged vegetation	Longest length (mi)
Thermocline beginning (ft)	Bottom soil types
Thermocline depth (ft)	Secchi transparency (ft)
Outlet flow (cfs)	Total alkalinity (ppm)
Water level fluctuations (ft)	pH
Annual	Total phosphorous (ppm)
Long-term	Total nitrogen (ppm)
	TDS (ppm)

Table 2. Common and scientific names of fish species included in this study, and codes used to identify them. See Figure 8.

Common name	Code	Scientific name
Bowfin	BF	*Amia calva*
Cisco	TU	*Coregonus artedi*
Lake whitefish	WF	*Coregonus clupeaformis*
Lake trout	LT	*Salvelinus naymaycush*
Northern pike	NP	*Esox lucius*
Muskellunge	MU	*Esox maxquinongy*
Carp	CA	*Cyprinus carpio*
Golden shiner	GSH	*Notemigonus crysoleucas*
White sucker	WS	*Catostomus commersoni*
Bigmouth buffalo	BMB	*Ictiobus cyprinellus*
Shorthead redhorse	RH	*Moxostoma macrolepidotum*
Black bullhead	BLB	*Ameiurus melas*
Yellow bullhead	YB	*Ameiurus natalis*
Brown bullhead	BRB	*Ameiurus nebulosus*
Burbot	BUR	*Lota lota*
White bass	WB	*Morone chrysops*
Rock bass	RB	*Ambloplites rupestris*
Green sunfish	GSF	*Lepomis cyanellus*
Pumpkinseed	PS	*Lepomis gibbosus*
Bluegill	BG	*Lepomis macrochirus*
Smallmouth bass	SMB	*Micropterus dolomieu*
Largemouth bass	LMB	*Micropterus salmoides*
White crappie	WC	*Pomoxis annularis*
Black crappie	BC	*Pomoxis nigromaculatus*
Yellow perch	YP	*Perca flavescens*
Sauger	SAU	*Stizostedion canadense*
Walleye	WA	*Stizostedion vitreum*
Freshwater drum	FWD	*Aplodinotus grunniens*

Length of the growing season was estimated for each lake as the number of days between the beginning of late spring and the beginning of late fall, and used in later analyses. Baker and Strub (1963) defined the beginning of late spring as the time when less than 20% of the minimum temperatures are 32°F or lower. They defined the beginning of late fall as the time when more than 10% of the minimum temperatures are 32°F or lower.

Principal component analysis (Pielou 1984; Weisberg 1985) was performed using the nine variables listed above for 3,029 lakes. The analysis indicated that three components would explain 78.7% of the variance among lakes. Variables related to lake size (area, volume, area:shoreline ratio) accounted for 39.2%; variables related to depth (maximum depth, percent littoral, secchi transparency) for 24.3%; and total alkalinity, SDF, and growing season for the remaining 15.2%.

Each pair of the transformed variables was examined for colinearity. Relationships between total alkalinity and lake area, maximum depth, and secchi transparency were non-linear. Separating lakes in the three northeastern counties of Cook, Lake, and St. Louis from lakes in the rest of Minnesota eliminated significant non-linearity between total alkalinity and the other three variables. Lake basins in the northeastern counties were formed mainly through scouring of Precambrian rock by glacial ice sheets (Schwartz and Thiel 1954). Lakes throughout the rest of Minnesota were formed mainly by the deposition of glacial debris. Moyle (1956) pointed out the differences in water chemistry resulting from the different glacial histories.

A second division of the lakes was made based on an examination of the distribution of percent littoral (Figure 1). The distribution is nearly normal from 0 to 80% littoral. The number of lakes increases from 80 to 100% littoral. The division of lakes into groups < 80% littoral and ≥ 80% littoral is an approximate separation of lakes that rarely or never winter-kill from those that frequently winter-kill.

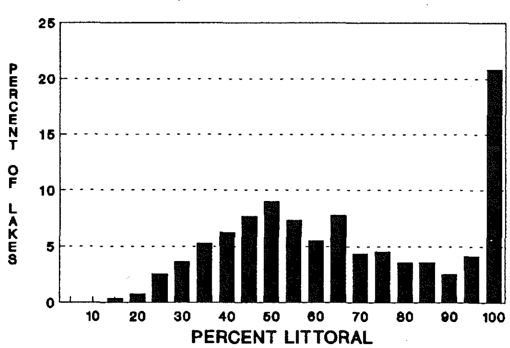


Figure 1. Frequency distribution (%) of percent littoral area for 3,029 classified lakes.

Thus all further analyses were done on four groups of lakes: high and low littoral zone lakes in northeastern Minnesota; and high and low littoral zone lakes in the rest of Minnesota. A k-means cluster analysis (Davis 1986) was performed on each of the four groups of lakes using the nine variables. The final choice of k was based on a comparison of the results of analyses using several values of k for each group.

The success of the four cluster analyses was evaluated using discriminant analysis. The nine variables used for clustering were reduced to seven through step-up regression. Variables eliminated were highly correlated such as area, maximum depth, and lake volume or area, SDF, and area:shoreline ratio. Only one or two variables from each of the above groups was retained for further analysis based on F-ratios. Thus seven variables were used in the discriminant analysis for each of the four lake groups.

Linear discriminant functions were used to assign each lake to a predicted class. The assigned classes were cross-tabulated with the results from cluster analysis. Final classification of each of the four groups of lakes was accepted when the percent reduction in classification error exceeded 90% of that expected if the lakes had been randomly classified.

Lakes in Koochiching, Itasca, and Carlton counties which border on St. Louis County were analyzed with both geographic groups. Results of this dual analysis determined into which of the two geographic groups these lakes were ultimately placed.

Gains resulting from the classification were evaluated by comparing the sums of squares (SS) due to classification to the Total SS from a General Linear Model ANOVA. This was done for six limnological variables, and for CPUE and mean weights of several species of fish in gill and trap nets. The results were also compared to a similar analysis using the original ecological classification (Scidmore 1970) for Minnesota lakes.

The Morphoedaphic Index (MEI) (Ryder 1965) and Carlson's Trophic Status Index (TSI) (Carlson 1977) were calculated for each lake. Total dissolved solids were estimated using the equation:

$$TDS = 28.83 + 1.2098 \text{ TA ppm.}$$

The slope of this equation is nearly the same as that estimated by Ryder (1964) but the intercept is about 5 units larger. Carlson's TSI was estimated from secchi disc transparency. The lake classes were numbered in order of increasing MEI.

Lake Classification

The classification resulted in 44 lake classes among four groups:

< 80% littoral	≥ 80% littoral
Northeastern Minnesota	
11	8
Other Minnesota	
15	10

Lake Classes 1 through 19 lie mainly in the three northeastern counties and most are soft-water lakes (Table 3). Class 11, which contains abandoned iron-ore mine pits, and Class 19 are the only hard-water classes in northeastern Minnesota. The remaining Classes (20-44) are mainly hard-water lakes. The exceptions are Classes 20, 21, and 37 which average less than 50 ppm total alkalinity.

Lake Class numbers increase approximately from northeast to southwest within the state with increasing productivity (MEI) (Figure 2). Moyle (1956) pointed out the general increase in water fertility on a northeast-southwest axis, and concomitant increases in standing crops of fishes.

In a statistical sense, the goal of the classification was to reduce variation among lakes within classes. The classification succeeded in that endeavor (Table 4). The SS due to classification for six limnological variables ranged from 56.0 to 88.9% of the total SS. The greatest reductions were for physical variables. The smallest reduction was for secchi disc transparency which varies seasonally.

The lake classification also resulted in gains in relation to the original ecological classes (Scidmore 1970) (Table 4). The reduction in SS due to classification ranged from 45 to 146% higher than the earlier classification for six variables. The greatest reductions were for lake area and secchi disc transparency.

Similar reductions in SS due to classification were observed for 145 lakes not included in the original analysis but classified later (Table 5). The reduction in SS due to classification for lake size in this group was 56.7% compared to 80.0% for the original analysis. The range of lake sizes was not as great in this group since the largest lakes had already been classified.

Evaluation of Net Catches

Net catches are highly variable while mean sizes are less variable due to net selectivity. The reduced variation of limnological characteristics among lake classes was associated with significantly reduced variation of numbers and sizes of 23 fish species caught in lake survey gill or trap nets (Tables 6 and 7).

Effects of Classification

Based on F-ratios, the most significant reductions due to classification were for black bullhead *Ameiurus melas* in both net types (Table 6). The lake class SS for black bullhead accounted for 30 and 24% of the total for gill and trap nets, respectively. Black bullhead abundance increases markedly with increased eutrophication (Figure 3). The results for black crappie *Pomoxis migromaculatus* were similar. Classification accounted for 23.0 and 19.5% of the variation in gill and trap nets. Black crappie abundance also increases with increased eutrophication (Figure 4). White sucker *Catostomus commersoni* reached their highest abundance in Lake Classes 1-19, the rocky lakes of the Precambrian shield (Figure 5). The classification accounted for 25.6% of the total SS for gill net CPUE of suckers. The median percentage reduction in CPUE SS due to classification was 20.0% for gill and 10.3% for trap nets. SS of total biomass of all species per net lift were reduced 23.2% for gill and 28.4% for trap nets. Total biomass per net increased in general from oligotrophic through hypereu-

Table 3. Mean values of selected physical and chemical parameters for 44 Lake Classes. TSI is an abbreviation for Carlson's Trophic State Index.

Lake Class	Area, (A)	Maximum depth (Ft)	Littoral %)	Total alkalinity	Secchi (Ft)	SDF	MEI	TSI
1	1,671	139.7	0.207	22.01	19.09	3.27	1.29	34.6
2	38,885	123.2	0.294	23.54	7.64	7.78	1.63	47.8
3	356	73.4	0.377	18.11	13.94	3.32	2.26	39.2
4	58	49.9	0.375	16.20	16.01	1.58	3.24	37.2
5	294	68.3	0.246	27.61	13.31	1.86	3.09	39.8
6	168	37.2	0.626	15.04	8.13	3.22	4.25	46.9
7	1,379	41.6	0.513	28.30	8.34	3.20	5.30	46.6
8	134	40.8	0.528	27.57	9.96	1.81	5.14	44.0
9	32	28.4	0.659	17.08	9.87	1.61	5.64	44.1
10	211	31.5	0.517	34.11	6.81	1.75	7.26	49.5
11	46	55.3	0.334	107.90	13.20	1.53	11.22	39.9
12	143	25.5	0.861	21.00	10.23	2.11	6.90	43.6
13	80	23.3	0.848	21.43	7.46	1.67	7.66	48.2
14	28	13.8	0.990	18.34	7.91	1.67	12.21	47.3
15	104	12.6	0.991	17.20	5.38	2.82	13.40	52.9
16	688	15.0	0.981	23.33	5.44	2.03	12.76	52.7
17	93	8.3	0.999	17.40	4.73	1.50	20.87	54.7
18	22	6.4	0.999	17.20	4.06	1.55	27.96	56.9
19	139	14.6	0.983	75.64	6.71	1.50	27.33	49.7
20	130	53.6	0.405	34.33	9.80	1.67	4.45	44.2
21	44	34.0	0.621	25.70	6.94	1.40	5.33	49.2
22	3,011	104.3	0.338	136.30	10.90	2.74	5.94	42.7
23	285	77.6	0.283	121.83	14.18	1.59	7.37	38.9
24	364	60.5	0.404	142.89	6.39	1.51	10.52	50.4
25	474	57.2	0.466	142.52	11.81	2.46	11.26	41.5
26	108,722	70.7	0.436	129.57	5.73	1.91	11.22	52.0
27	2,230	60.9	0.445	161.97	8.47	1.49	12.42	46.3
28	60	48.3	0.413	141.64	13.21	1.40	13.63	39.9
29	215	33.5	0.639	90.00	9.96	1.48	13.26	44.0
30	43	41.7	0.530	141.48	5.40	1.35	15.65	52.8
31	344	39.7	0.426	162.52	9.07	1.36	17.87	45.4
32	647	34.9	0.633	145.88	4.33	2.31	19.23	56.0
33	86	33.7	0.629	176.92	7.64	2.01	23.46	47.8
34	222	27.5	0.634	146.27	4.29	1.30	23.40	56.1
35	403	33.1	0.848	100.00	7.70	2.54	15.33	47.7
36	52	25.5	0.869	93.03	6.91	1.52	17.56	49.3
37	62	14.8	0.986	43.90	5.77	1.50	17.55	51.9
38	276	27.5	0.863	154.48	5.34	1.41	26.54	53.0
39	213	17.0	0.980	91.92	6.49	1.42	27.55	50.2
40	830	14.0	0.990	153.54	4.81	1.57	51.50	54.5
41	3,377	16.7	0.963	179.27	3.05	2.48	57.74	61.0
42	238	12.8	0.991	145.46	3.60	2.67	59.45	58.7
43	306	10.0	1.000	164.92	2.26	1.40	76.44	65.4
44	81	6.5	1.000	130.11	3.04	1.38	124.40	61.1

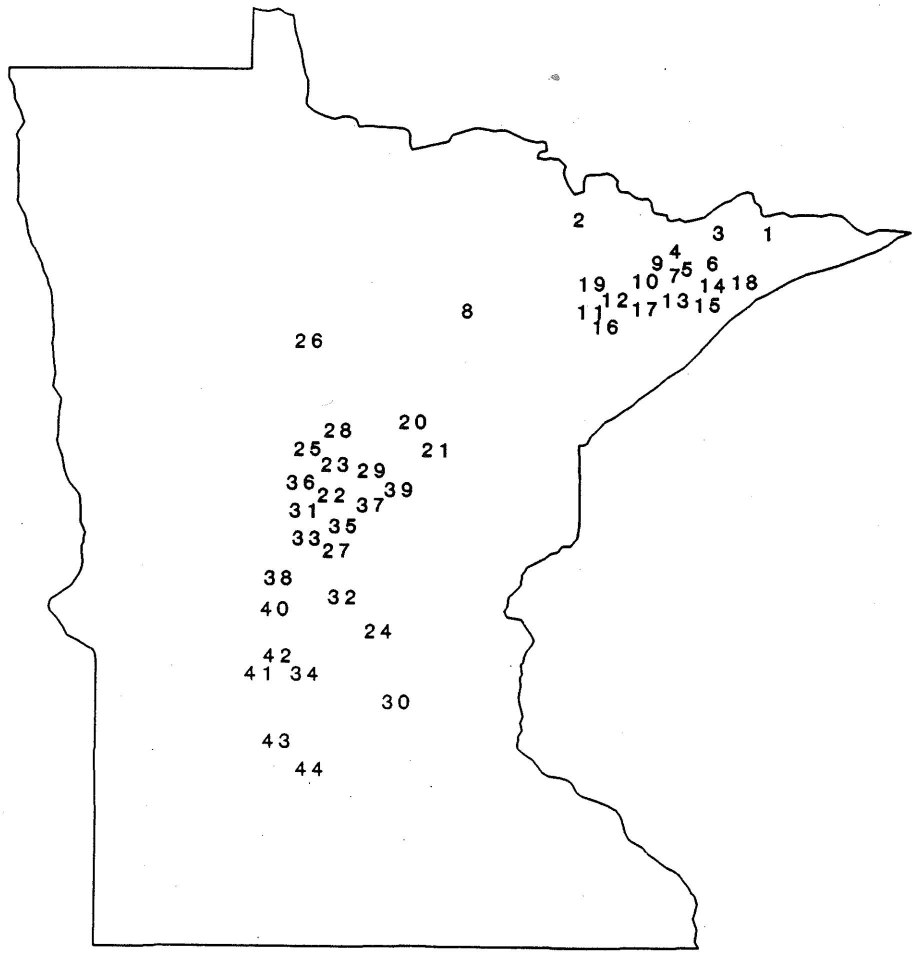


Figure 2. Approximate geographic centers of 44 lake classes.

trophic lake classes (Figure 6), reflecting increasing productivity.

The most significant reduction in variation of mean weights was for black bullhead in gill nets (Table 7). Classification accounted for 21.2% of the total SS for mean weight of black bullhead in gill nets. Reduction in SS for mean weight of trap netted black bullhead (13.1%) was among the higher reductions for that gear. The abundant populations of black bullhead in hypereutrophic lakes usually consist of small fish. Classification accounted for 22.8% of the total SS for mean weight of cisco *Coregonus artedi* in gill nets. Abundant populations of relatively small cisco occur in the Precambrian shield lakes of northeastern Minnesota. The median percentage reduction in mean weight SS due to classification was 11.2% for gill nets and 9.2% for trap nets.

Lakes Classified Later

Similar gains from classification for gill and trap net CPUE, and mean weights were observed in data from 263 lake surveys of 145 lakes classified after the original analysis (Tables 8 and 9). Significant reductions ($P < 0.05$) in total SS were achieved for CPUE of northern pike, white sucker and walleye, and for mean weight of white sucker and black and brown bullhead *Ameiurus nebulosus* in gill nets (Table 8). In trap nets, significant reductions were achieved for CPUE of carp *Cyprinus carpio*, black and yellow bullhead *Ameiurus natalis*, rock bass *Ambloplites rupestris*, and black crappie (Table 9). Significant reductions in trap net mean weights SS were achieved for bowfin *Amia calva*, rock bass, and pumpkinseed *Lepomis gibbosus*. Reductions in total biomass per lift in this sample were similar

Table 4. Summary of ANOVA results for six variables in relation to the classification of 3,029 Minnesota lakes and to the original ecological (Ecoclass) classification.

	Total df	Total SS	Lake Class SS	F	P	Ecoclass SS	SS Ratio Lake Class: Ecoclass
Area	3,028	5,862.5	4,570.7	245.62	< 0.001	1,855.4	2.46
Maximum depth	3,028	1,861.8	1,503.0	291.24	< 0.001	982.3	1.53
Littoral %	3,028	218.3	194.0	554.48	< 0.001	126.8	1.53
Total alkalinity	3,028	51,475.8	37,887.6	193.82	< 0.001	25,210.0	1.50
Secchi disc	3,028	2,139.1	1,198.9	88.64	< 0.001	610.9	1.96
SDF	3,028	365.3	211.9	95.99	< 0.001	66.4	1.45

Table 5. Summary of ANOVA results for six variables in relation to the lake classification for 145 Minnesota lakes classified after the original analysis.

	Total df	Total SS	Lake Class SS	F	P
Area	144	216.27	122.55	4.23	< 0.001
Maximum depth	144	116.00	90.67	11.69	< 0.001
Littoral %	144	11.10	9.54	19.62	< 0.001
Total alkalinity	144	2,439.04	1,598.20	5.98	< 0.001
Secchi disc	144	134.71	83.02	5.24	< 0.001
SDF	144	18.72	12.64	6.53	< 0.001

Table 6. Summary of ANOVA results of gill and trap net CPUE for 23 species of fish in relation to the classification of 3,029 Minnesota lakes and to the original ecological (Ecoclass) classification.

Species	Total df	Total SS	Lake Class SS	F	P	Ecoclass SS	SS Ratio Lake Class: Ecolass
			Gill nets				
LT	151	240.25	53.88	3.68	< 0.001	20.09	2.68
CS	1,121	2,577.30	310.71	4.13	< 0.001	148.74	2.09
WF	169	536.72	247.99	5.45	< 0.001	164.25	1.51
NP	4,949	5,118.61	760.65	19.91	< 0.001	406.91	1.87
MU	113	190.15	124.28	7.38	< 0.001	82.69	1.50
CA	663	1,715.73	275.98	5.33	< 0.001	180.76	1.53
WS	4,155	7,019.88	1,793.78	32.82	< 0.001	1,540.59	1.16
RH	288	493.93	154.87	3.30	< 0.001	95.60	1.62
BLB	2,642	11,447.39	3,431.60	30.14	< 0.001	2,030.22	1.69
YB	2,100	4,827.89	338.97	4.46	< 0.001	96.66	3.51
BRB	1,717	3,868.80	620.47	8.67	< 0.001	354.28	1.75
BUR	227	281.06	136.73	7.65	< 0.001	88.99	1.54
SMB	501	730.32	180.47	4.37	< 0.001	71.99	2.51
LMB	1,890	2,008.70	168.73	4.14	< 0.001	45.62	3.70
WC	378	979.41	91.85	1.76	0.021	25.58	3.59
BC	3,150	7,495.23	1,724.57	22.66	< 0.001	890.00	1.94
YP	4,637	12,677.54	1,293.06	12.13	< 0.001	841.64	1.54
WA	3,498	5,256.70	917.53	16.99	< 0.001	561.81	1.63
Lbs/ lift	2,737	5,294.72	1,229.24	40.04	< 0.001	396.78	3.10
			Trap nets				
BF	1,427	1,087.24	54.15	2.62	< 0.001	12.48	4.34
CA	1,005	1,891.56	295.61	7.57	< 0.001	184.45	1.60
BLB	2,484	11,984.32	2,877.22	19.81	< 0.001	1,694.61	1.70
YB	2,540	4,543.22	377.25	6.48	< 0.001	165.90	2.27
BRB	2,092	4,909.14	634.95	7.82	< 0.001	308.73	2.06
RB	1,558	2,008.92	239.67	4.77	< 0.001	64.51	3.72
GSF	880	1,888.32	142.66	2.03	< 0.001	20.70	6.89
PS	3,486	6,092.25	459.64	6.69	< 0.001	171.30	2.68
BG	3,858	10,637.54	1,100.08	10.74	< 0.001	676.20	1.63
SMB	236	353.74	103.77	2.65	< 0.001	57.82	1.79
LMB	2,432	2,742.14	179.45	4.08	< 0.001	36.80	4.88
WC	390	1,212.96	112.64	1.89	0.012	9.88	11.40
BC	3,427	8,317.46	1,621.07	19.51	< 0.001	673.88	2.41
Lbs/ lift	4,831	6,024.96	1,711.20	44.17	< 0.001	974.29	1.76

Table 7. Summary of ANOVA results of mean weights of 23 species of fish caught in gill or trap nets in relation to the classification of 3,029 Minnesota lakes and to the original ecological (Ecoclass) classification.

Species	Total df	Total SS	Lake Class SS	F	P	Ecological SS	SS Ratio Lake Class: Ecoclass
				Gill nets			
LT	146	108.51	7.93	0.97	0.479	0.56	14.16
CS	1,109	765.58	174.38	8.79	< 0.001	108.94	1.60
WF	160	90.71	20.82	1.77	0.023	4.09	5.09
NP	4,854	1,282.93	82.65	7.70	< 0.001	31.67	2.61
MU	112	52.32	20.58	2.65	< 0.001	7.18	2.87
CA	652	791.04	76.39	2.92	< 0.001	39.35	1.94
WS	4,050	1,246.73	93.58	7.56	< 0.001	35.83	2.61
RH	287	94.22	14.18	1.28	0.148	2.96	4.79
BLB	2,620	1,329.44	281.82	18.78	< 0.001	173.07	1.63
YB	2,092	610.26	76.78	8.46	< 0.001	38.95	1.97
BRB	1,710	706.20	108.03	8.17	< 0.001	67.96	1.59
BUR	221	152.31	47.49	3.55	< 0.001	22.20	2.14
SMB	495	254.92	28.57	1.66	0.012	9.32	3.07
LMB	1,878	1,087.53	42.10	1.80	0.001	5.34	7.88
WC	376	155.17	13.12	1.56	0.056	2.41	5.44
BC	3,132	1,463.30	146.51	8.39	< 0.001	57.22	2.56
YP	4,542	1,240.21	101.62	9.34	< 0.001	41.01	3.42
WA	3,453	1,540.58	140.44	7.95	< 0.001	94.83	2.83
				Trap nets			
BF	1,420	279.42	18.29	3.25	< 0.001	9.44	1.94
CA	988	717.64	57.09	3.47	< 0.001	28.22	2.02
BLB	2,469	1,267.19	165.92	9.39	< 0.001	96.31	1.72
YB	2,532	505.96	49.01	7.65	< 0.001	29.06	1.69
BRB	2,074	717.88	100.01	8.49	< 0.001	56.32	1.78
RB	1,542	498.90	50.14	3.99	< 0.001	27.64	1.81
GSF	867	431.59	31.64	2.00	< 0.001	1.50	21.09
PS	3,465	1,268.22	117.18	8.35	< 0.001	24.63	4.76
BG	3,840	1,565.38	75.72	4.71	< 0.001	24.42	3.10
SMB	233	147.15	32.05	1.75	0.011	6.72	4.77
LMB	2,425	2,484.23	107.16	2.62	< 0.001	36.99	2.90
WC	386	138.67	12.66	1.84	0.016	1.46	8.67
BC	3,409	1,335.98	131.24	8.73	< 0.001	36.49	3.60

Table 8. Summary of ANOVA results of gill net CPUE and mean weights of 9 species of fish in relation to the lake classification for 145 Minnesota lakes classified after the original analysis.

Species	Total df	Total SS	Lake Class SS	F	P
			CPUE		
CS	20	66.16	42.24	1.18	0.420
NP	151	149.14	56.29	2.55	< 0.001
WS	129	210.76	115.21	3.65	< 0.001
BLB	79	299.61	92.85	1.64	0.082
YB	38	107.16	42.08	1.40	0.227
BRB	41	120.34	49.54	1.21	0.323
BC	95	182.53	50.32	1.43	0.137
YP	147	279.03	82.88	1.46	0.074
WA	93	189.13	89.93	2.47	0.002
			Mean Weight		
CS	20	11.67	8.78	2.02	0.162
NP	151	32.63	7.85	1.33	0.143
WS	129	54.53	20.12	1.77	0.017
BLB	79	34.60	12.09	1.96	0.029
YB	38	11.52	2.91	0.73	0.708
BRB	41	12.75	7.18	2.23	0.035
BC	95	57.68	13.73	1.16	0.316
YP	146	44.70	11.35	1.16	0.274
WA	93	60.42	18.99	1.25	0.234

Table 9. Summary of ANOVA results of trap net CPUE and mean weights of 12 species of fish in relation to the lake classification for 145 Minnesota lakes classified after the original analysis.

Species	Total df	Total SS	Lake Class SS	F	P
			CPUE		
BF	32	19.06	5.18	0.71	0.714
CA	36	86.43	43.14	2.99	0.013
BLB	84	474.02	208.18	2.51	0.003
YB	54	98.61	54.28	2.45	0.011
BRB	59	121.39	47.44	1.73	0.078
RB	32	63.48	45.65	4.27	0.002
GSF	28	40.54	19.69	1.46	0.234
PS	111	197.75	46.92	1.13	0.333
BG	127	331.20	78.31	1.56	0.073
LMB	73	77.78	15.65	0.77	0.724
WC	17	61.67	35.31	2.46	0.093
BC	111	238.06	72.60	1.78	0.032
			Mean Weight		
BF	32	4.58	3.14	4.16	0.003
CA	36	37.22	13.24	1.66	0.149
BLB	84	49.37	15.40	1.45	0.132
YB	54	8.00	3.45	1.52	0.141
BRB	58	24.01	6.45	0.96	0.510
RB	32	16.75	10.61	2.88	0.018
GSF	28	14.42	4.19	0.63	0.778
PS	110	52.69	18.48	1.93	0.014
BG	127	56.11	7.55	0.78	0.733
LMB	73	77.96	15.92	0.78	0.709
WC	17	9.46	4.05	1.37	0.306
BC	110	42.77	11.59	1.49	0.100

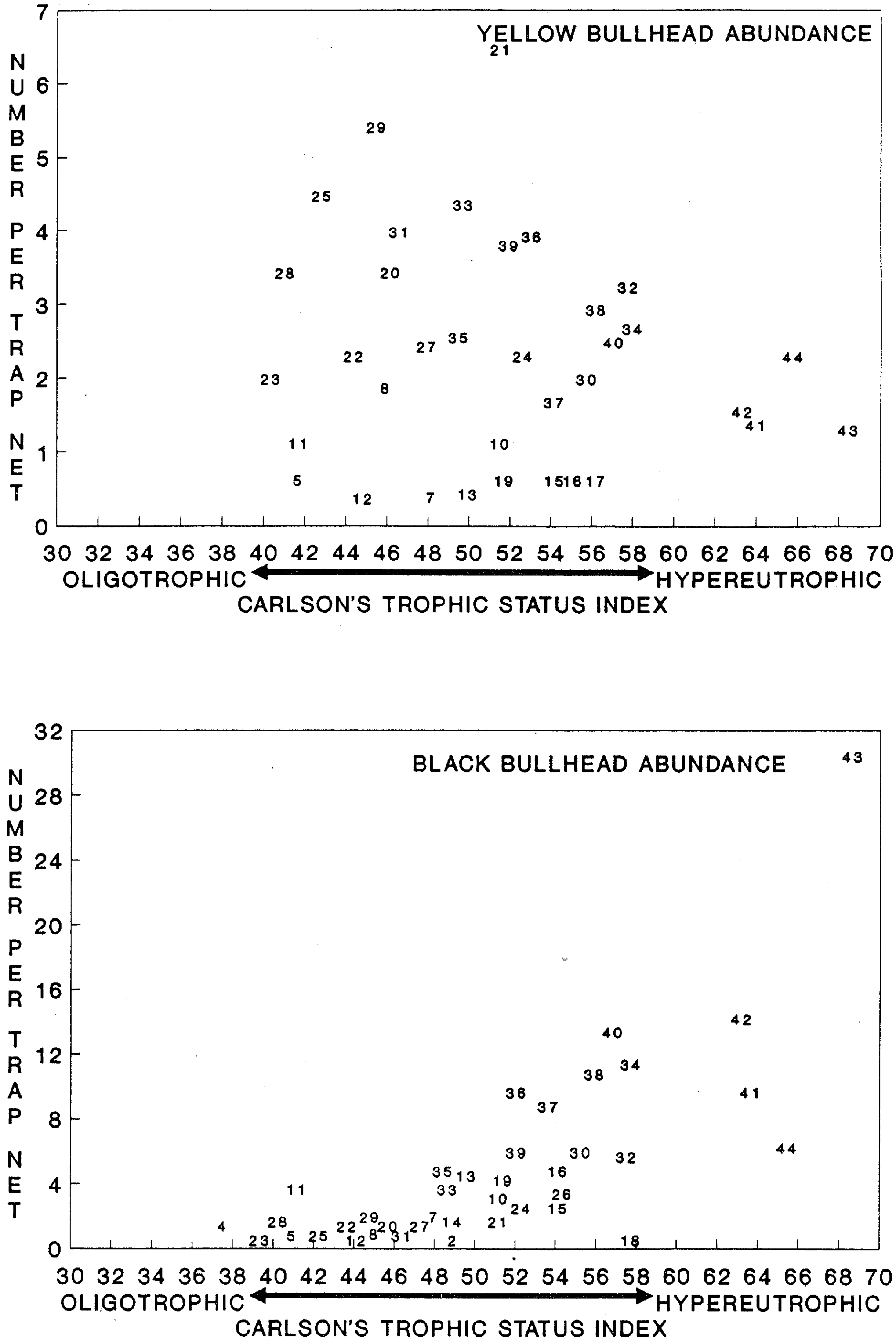


Figure 3. Median CPUE of yellow and black bullhead in lake survey trap nets for each lake class, and in relation to trophic status of the lake classes.

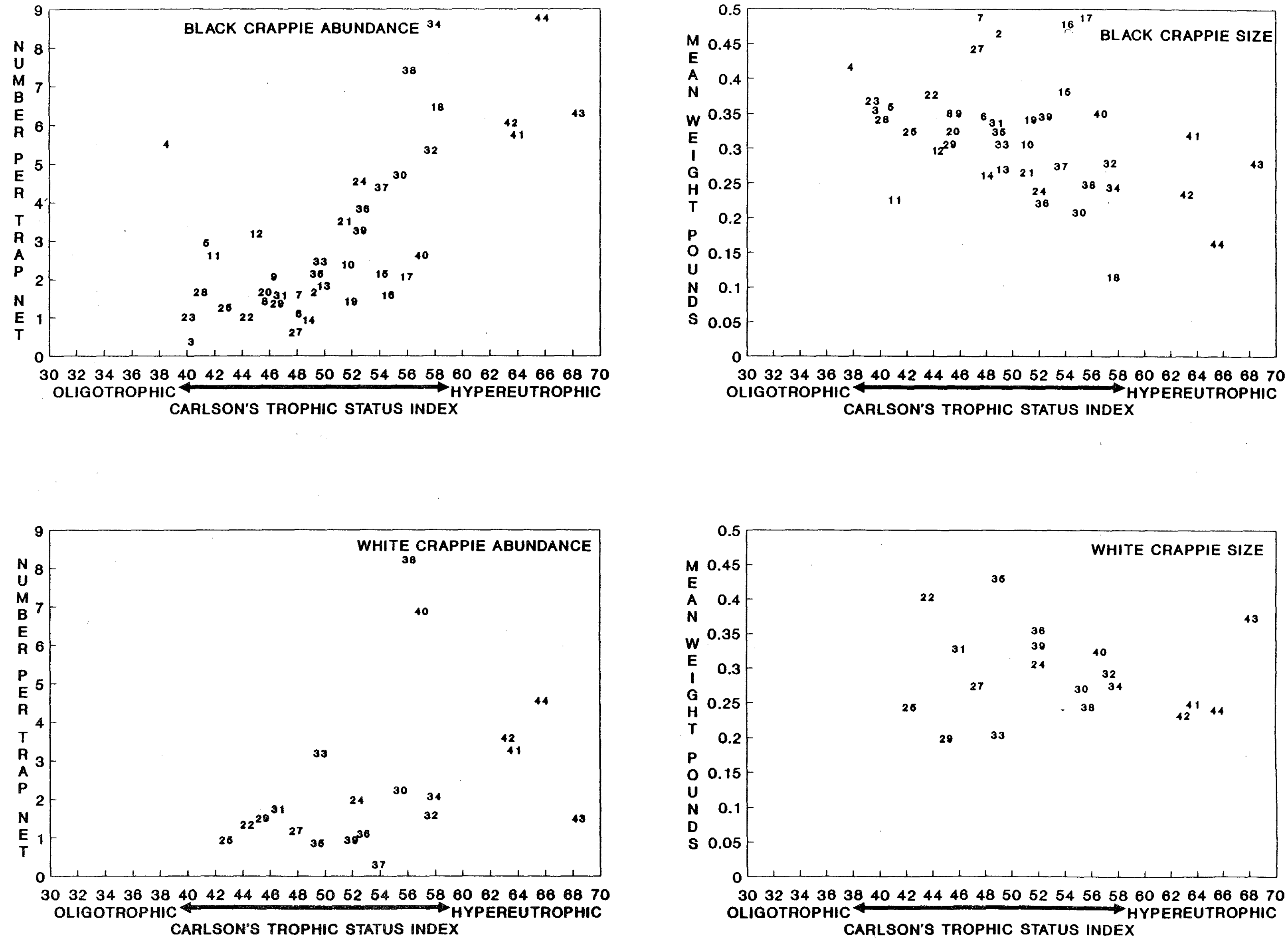
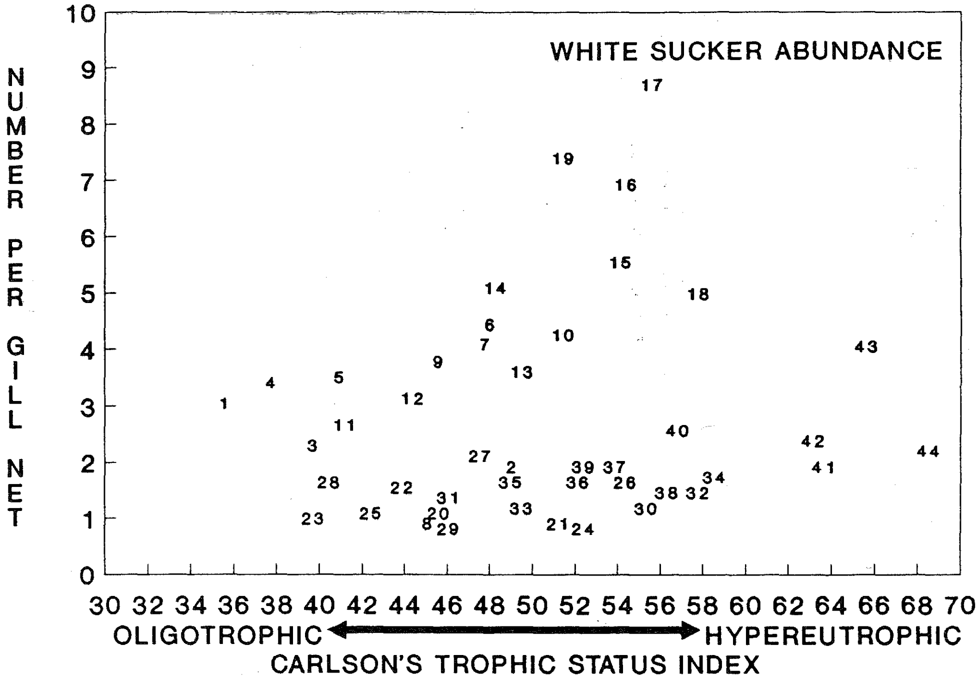


Figure 4. Median CPUE and mean weights of white and black crappie in lake survey trap nets for each lake class, and in relation to trophic status of the lake classes.



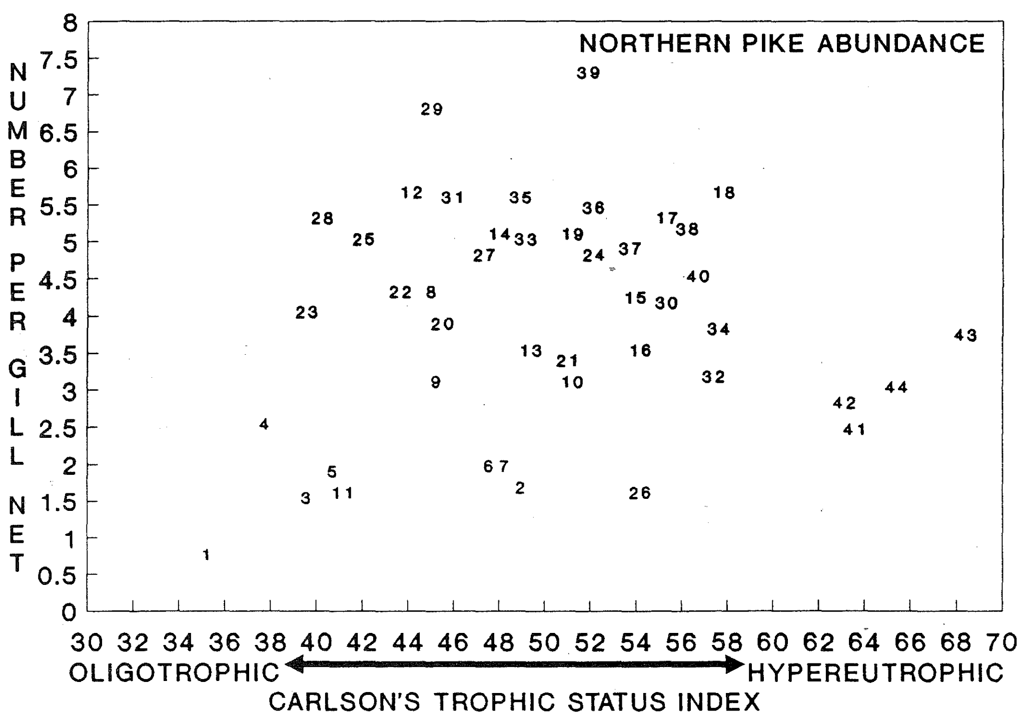
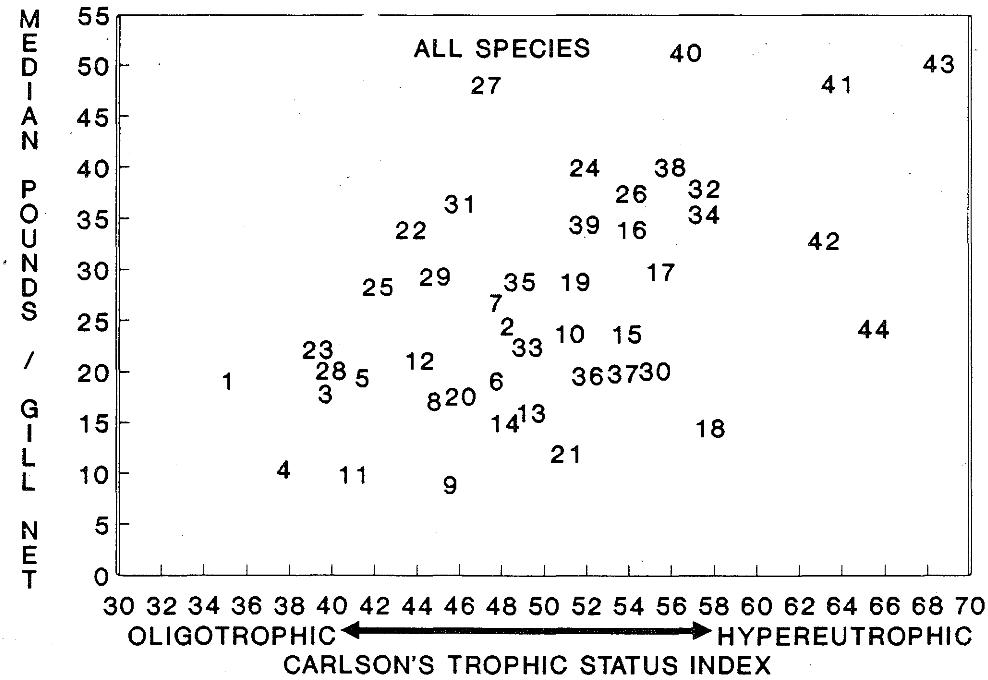


Figure 5. Median CPUE of white sucker and northern pike in lake survey gill nets for each lake class, and in relation to trophic status of the lake classes.



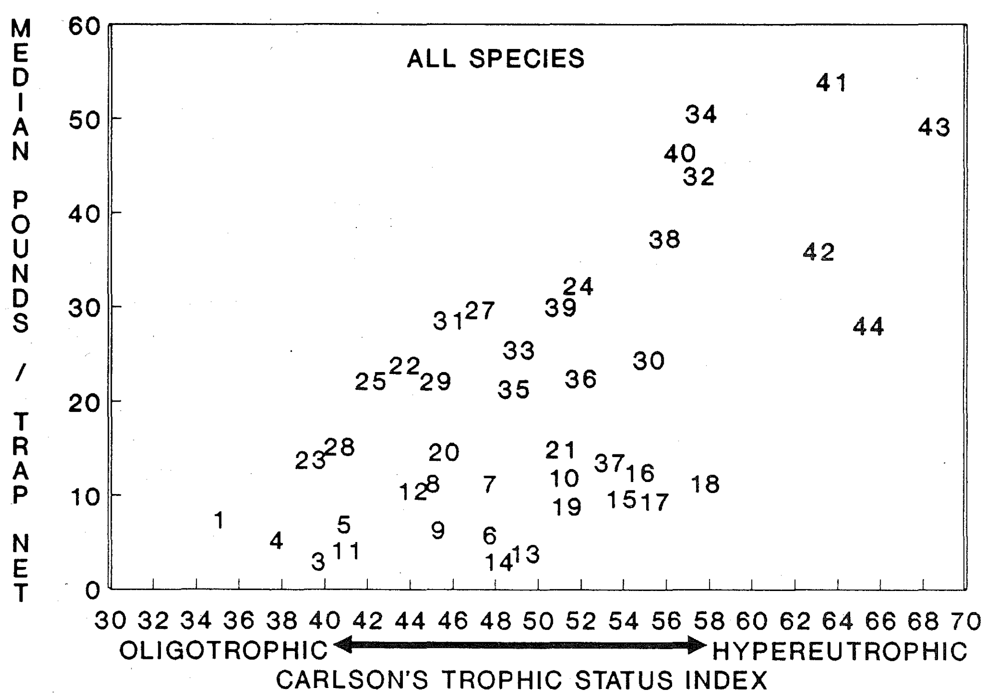


Figure 6. Median weight per gill and trap net in lake surveys for all species combined, and in relation to trophic status of the lake classes.

to those of the original classification, 25.1% for gill nets and 35.7% for trap nets.

Comparison to Earlier Classification

The lake classification also resulted in reductions in variation of net CPUE and mean weights when compared to the older ecological classification (Scidmore 1970) (Tables 6 and 7). The median reduction in total SS, expressed as a percentage, over the ecological classification was 72 and 141% for gill and trap net CPUE, respectively (Table 6). The median reduction in SS for mean weights was 185% in gill nets and 190% in trap nets (Table 7). SS for total biomass per net lift was reduced by 210 and 76% for gill and trap nets, respectively.

The largest gains in gill net CPUE were for lake trout, yellow bullhead, smallmouth and largemouth bass *Micropterus salmoides*, and white crappie *Pomoxis annularis*. The largest gains in trap net CPUE were for bowfin, rock bass, largemouth bass, and white and black crappie. Catches of yellow bullhead and both crappie species were strongly related to water clarity. Yellow bullhead catches were highest in relatively clear water (Figure 3) while crappie catches were highest in turbid water (Figure 4). The other centrarchid species listed above are also likely favored by clear water. Lake Class 1 (Table 3) comprises most of the lakes with lake trout present and is also the lake class with the clearest water. Water clarity was not among the variables used in the earlier ecological classification (Scidmore 1970).

Despite the gains for largemouth bass in both gears, evaluating bass abundance with netting surveys is still questionable. Reductions in SS due to classification for largemouth bass CPUE was 8.4% in gill nets and 6.5% in trap nets. These were among the lowest observed reductions.

The smallest gain in CPUE (16%) was for white sucker in gill nets. Many northeastern Minnesota lakes, where suckers are most abundant, were contained in two classes of the earlier system. Sucker abundance was apparently reflected nearly as well by that system as by the newer classification.

The largest gains in gill net mean weight were for lake trout, lake whitefish, shorthead redhorse *Moxostoma macrolepidotum*, largemouth bass, and white crappie. The largest gains in trap net mean weights were for green sunfish *Lepomis cyanellus*, pumpkinseed, smallmouth bass, and white and black crappie. No ready explanation, such as water clarity, suggests itself for these gains.

The difficulty in evaluating the status of largemouth bass populations by netting surveys was also evident in this analysis (Table 7). There was an increase in mean weight SS due to classification of 688% for gill nets, and 190% for trap nets over the earlier classification. The lake class SS, however, accounted for only 3.9 and 4.3% of the gill and trap net total SS, respectively. These were the lowest for any species in either gear.

Evaluation of Individual Surveys

Since lake classification usually accounted for less than 30% of the total SS for CPUE and less than 20% for mean weight, most of the variation in CPUE and mean weight remains unexplained. Medians and inter-quartile ranges for CPUE and mean weights of northern pike and walleye for selected lake classes are presented (Figure 7). The range of catches and sizes is high for some lake classes but quite low for others.

Inter-quartile ranges can be used as benchmarks for quick evaluations of survey net catches. Three examples of the use of inter-quartile ranges to evaluate survey catches are presented (Table 10). The first example, Knife Lake, is a case where drastic changes in community structure occurred between surveys. The second example, Big Sand Lake, is a case where the fish community has varied little over nine years. Big Spunk Lake is an example of a lake classified (Lake Class 31) after the analysis reported here. Survey net catches were com-

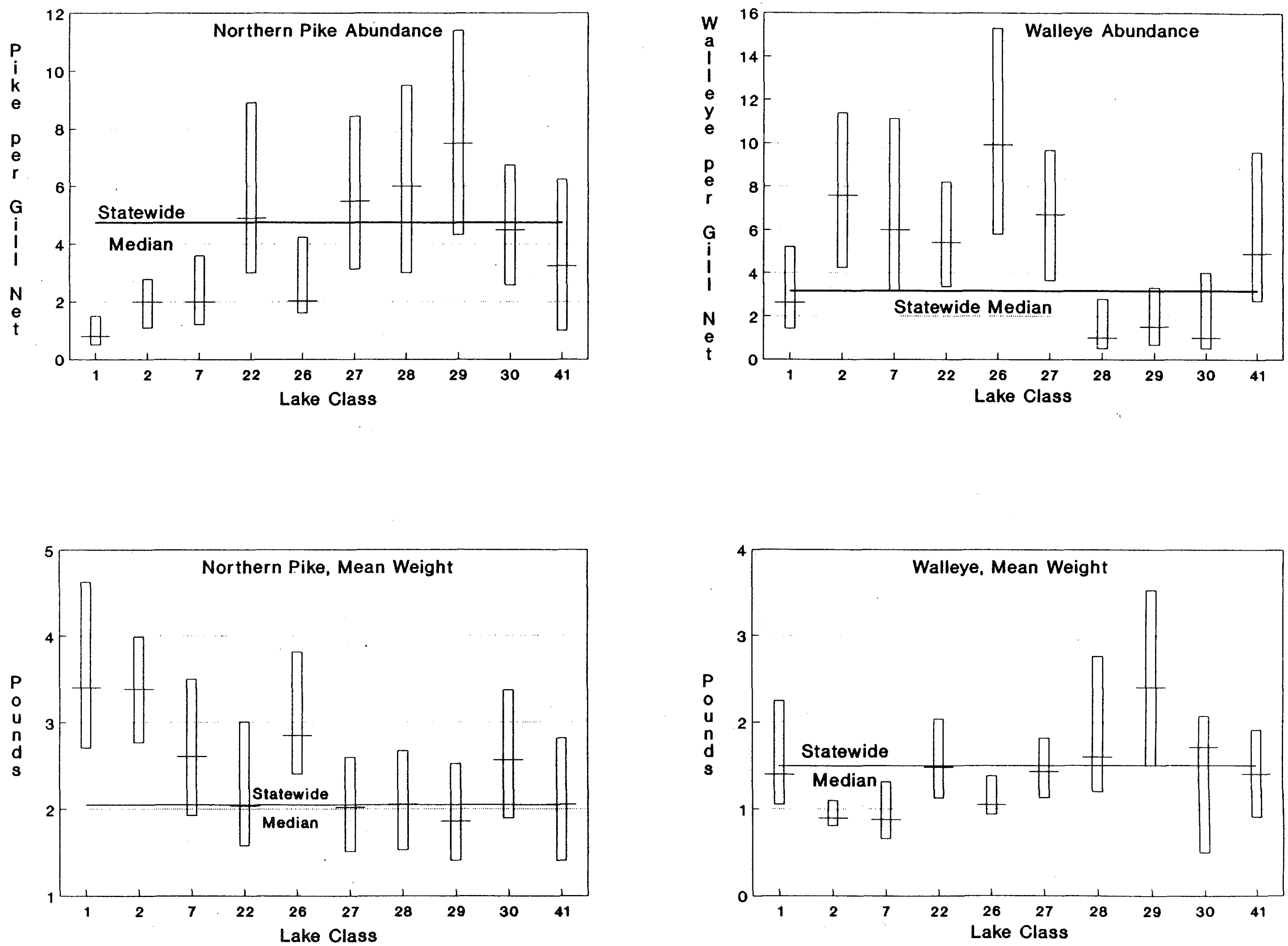


Figure 7. Intra-class medians, inter-quartile ranges, and the statewide median of northern pike and walleye CPUE, and mean weights for selected lake classes.

Table 10. Mean CPUE and mean weight (pounds) of selected species from recent lake surveys of Knife Lake, Kanabec County, Big Sand Lake, Hubbard County, and Big Spunk Lake, Stearns County, and inter-quartile ranges of these variables for all surveys for the appropriate Lake Class. Values lying outside inter-quartiles are in bold type.

		CPUE				Mean Weight			
Species	Gear	Mean			Inter-quartile Range	Weight			Inter-quartile Range
		Knife (Lake Class 40)							
		1979	1985			1979	1985		
Northern pike	Gill	**11.25**	**1.27**		2.11- 9.00	1.77	**3.96**		1.47-2.68
Carp	Gill	**32.87**	**28.91**		0.45-12.67	**0.21**	**0.99**		1.29-4.92
White sucker	Gill	2.62	**1.00**		1.50- 5.67	1.45	**0.65**		1.41-2.26
White crappie	Gill	1.12	**18.36**		0.38-17.67	0.26	0.21		0.13-0.30
Black crappie	Gill	2.62	**29.45**		1.00-17.33	0.38	**0.19**		0.20-0.38
Yellow perch	Gill	15.00	**0.09**		7.13-40.83	0.17	**0.40**		0.15-0.30
Walleye	Gill	**21.50**	**0.45**		2.67-10.00	**0.95**	**2.81**		1.03-2.11
All species (Pounds)	Gill	59.24	45.56		38.47-74.92				
		Big Sand (Lake Class 23)							
		1978	1983	1986		1978	1983	1986	
Cisco	Gill	1.36	-	**0.29**	0.58- 6.43	0.80	-	0.50	0.43-1.03
Northern pike	Gill	**1.00**	**2.11**	**1.71**	3.00- 8.00	**3.25**	**4.70**	**6.47**	1.58-3.01
White sucker	Gill	2.82	1.89	1.71	0.91- 3.14	**2.34**	**1.41**	**2.41**	1.50-2.25
Rock bass	Trap	**13.92**	**4.47**	3.67	0.80- 4.07	0.29	**0.24**	0.30	0.28-0.53
Bluegill	Trap	**1.83**	**1.07**	**3.13**	3.27-42.83	0.19	**0.23**	0.20	0.11-0.22
Yellow perch	Gill	17.55	12.22	17.14	5.75-27.20	0.15	0.18	0.17	0.12-0.21
Walleye	Gill	7.00	4.11	**12.14**	3.38- 8.21	1.57	**1.07**	1.36	1.13-2.04
All species (Pounds)	Gill	**27.43**	**22.26**	43.05	28.11-50.43				
All species (Pounds)	Trap	**8.21**	**2.47**	**3.24**	9.64-21.62				
		Big Spunk (Lake Class 31)[a]							
		1987				1987			
Northern pike	Gill	7.17			3.45-10.50	1.85			1.42-2.74
White sucker	Gill	2.17			0.50- 2.83	1.73			1.70-2.46
Yellow bullhead	Trap	4.43			1.50-11.58	**0.32**			0.49-0.86
Green sunfish	Trap	**2.71**			0.25- 2.00	**0.07**			0.10-0.20
Pumpkinseed	Trap	**1.43**			2.50-10.40	0.15			0.13-0.23
Bluegill	Trap	**57.29**			11.71-55.00	0.16			0.13-0.23
Black crappie	Trap	**19.43**			0.56- 3.17	**0.24**			0.25-0.50
Yellow perch	Gill	13.00			4.50-37.17	0.10			0.10-0.18
Walleye	Gill	2.00			1.25- 5.33	2.13			1.19-2.90
All species (Pounds)	Gill	28.55			26.87-51.85				
All species (Pounds)	Trap	22.50			11.33-29.92				

[a]Big Spunk Lake was classified and surveyed after the original lake classification.

pared to inter-quartile ranges established before the lake was classified.

Catches of northern pike, carp, and walleye in the 1979 survey of Knife Lake were above the third quartile for lakes of Class 40. The mean weight of pike was normal (within the inter-quartile range), while carp and walleye were small (below the first quartile). Numbers and sizes of white sucker, white and black crappie, and yellow perch *Perca flavescens* were within normal ranges. By 1985, catches of pike, walleye, and perch had declined to less than the first quartile. Mean sizes were above the third quartile. Carp were still abundant and small. Catches of crappie had increased to levels above the third quartile and average size declined between surveys. Catches and sizes of suckers declined between surveys. Total weight of all species was within normal ranges for both surveys.

Big Sand Lake supports a typical percid community. The results of three surveys over nine years were fairly similar (Table 10). Net catches indicated low abundance of northern pike and bluegill, while abundance of suckers and perch were within normal ranges. Walleye catches were also within normal ranges for two of the three surveys, while rock bass catches were high for two surveys. Pike sizes were large while perch sizes were normal. Total weight of all species tended to be low for both gill and trap nets.

Catches and sizes of northern pike, white sucker, yellow perch, and walleye from Big Spunk Lake were within normal ranges for lakes of Class 31. Catches of green sunfish, bluegill, and black crappie were above the third quartile while the catch of pumpkinseed was below the first quartile. Mean weights of yellow bullhead, green sunfish, and black crappie were below the first quartile.

Fish Communities

Community structure among the lake classes varied (Figure 8). Assemblages dominated by white sucker and walleye, or white sucker and northern pike were most common in northeastern Minnesota. Piscivores were uncommon or low in abundance in some smaller northeastern lake classes.

Assemblages dominated by northern pike and walleye, or northern pike and bluegill were most common in the southwesterly lake classes (Figure 8). Generally, lake classes which consisted of large lakes (larger than 1,000 A) had a high component of percids while small lakes had a high component of centrarchids. As lake classes approached hypereutrophy, black bullhead were more common as a significant part of the community structure.

Abundances of some closely related species varied with trophic state of the lake. For example, yellow bullhead were most common in mesotrophic classes (Figure 3), and were associated with relatively clear water. Black bullhead were associated with more turbid waters. Black and white crappie abundances increased, and average sizes declined in the more eutrophic classes (Figure 4). Higher proportions of white crappie in relation to black crappie were also evident in the more eutrophic classes.

Figure 8 indicates several groups of lake classes with the same species assemblages. While the same species made up the highest percentage of biomass in sampling nets within these groups, total biomass and the abundances and sizes of several species varied considerably between lake classes (Table 11).

Lakes in Class 6 are deeper and have less littoral than Classes 15 and 16 and thus are less productive (Table 3). This is reflected in lower biomass per gill net lift and lower catches of northern pike and yellow perch (Table 11). The perch also averaged smaller than in the latter two lake classes. Lakes in Class 15 are smaller than those in Class 16. Catches of yellow perch and walleye were lower in Class 15 and the perch average size was smaller. Walleye reach their greatest abundance in large, shallow lakes (Scott and Crossman 1973).

Lakes in Class 8 are deeper, have less littoral, and have clearer water than those in

FISH COMMUNITIES ASSOCIATED WITH EACH LAKE CLASS

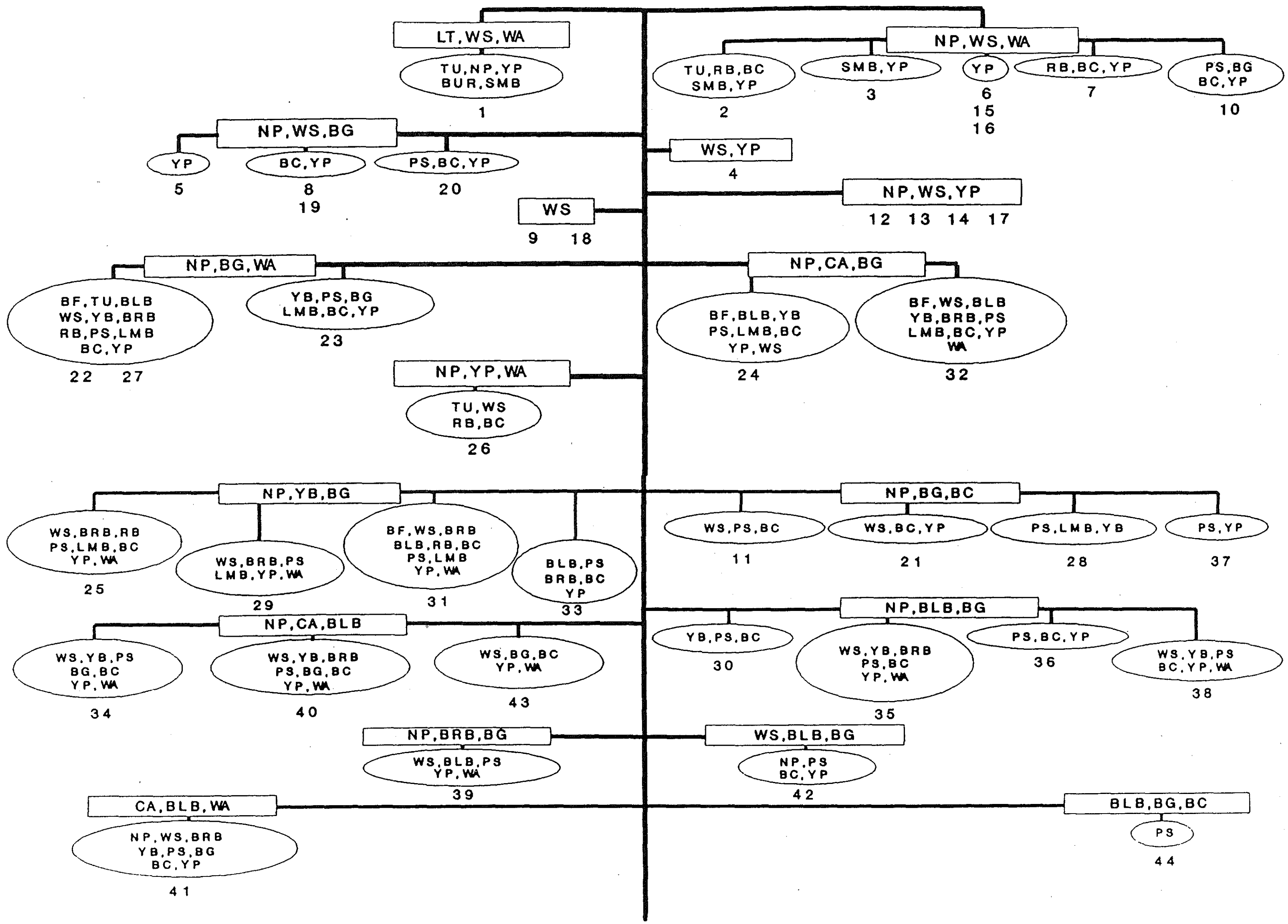


Figure 8. Fish assemblages associated with each lake class. One to three primary species, those making up the highest percentage of biomass in gill or trap nets, are indicated in rectangles. Secondary species (indicated in ellipses) were captured in at least 50% of the surveys.

Table 11. Differences in CPUE or mean weight (Lbs) of selected species in gill (G) or trap (T) nets for lake classes indicated to have similar community assemblages in Figure 8. All indicated differences are significant at $P \leq 0.05$ (t-test).

Lake Class	Gear	Total lbs/ lift All Species	Northern pike No.	Northern pike Lbs	White sucker No.	White sucker Lbs	Rock bass No.	Rock bass Lbs	Bluegill No.	Bluegill Lbs	Black crappie No.	Black crappie Lbs	Yellow perch No.	Yellow perch Lbs	Walleye No.	Walleye Lbs
6	G	20.2[ab]	1.9[ab]	2.2[b]	4.4[b]								1.8[ab]	0.14[ab]	3.5[b]	
15	G	26.0[c]	4.2										5.5[c]	0.19[c]	2.6[c]	
16	G	36.2	3.5	1.7	6.9								8.5	0.23	5.9	
8	G	16.5[d]			0.9[d]									0.13[d]		
19	G	30.1			7.4									0.17		
8	T								11.9[d]	0.17[d]						
19	T								2.9	0.27						
12	G	25.2[ef]	5.7[e]	2.1[fg]	3.1[q]									0.12[fg]		
13	G	13.5[i]	3.6[hi]	2.1[hi]	3.6[i]									0.14[i]		
14	G	14.2[j]	5.1	1.6	5.0[j]									0.16[j]		
17	G	23.2	5.3	1.6	8.6									0.20		
22	G	33.1[k]			1.5[k]								12.0[k]			
27	G	46.4			2.1								18.8			
22	T	13.0[k]					1.8[k]	0.30[k]			1.0[k]	0.36[k]				
27	T	18.6					1.2	0.36			0.6	0.44				

[a]Lake Class 6 differs from Lake Class 15

[b]Lake Class 6 differs from Lake Class 16

[c]Lake Class 15 differs from Lake Class 16

[d]Lake Class 8 differs from Lake Class 19

[e]Lake Class 12 differs from Lake Class 13

[f]Lake Class 12 differs from Lake Class 14

[g]Lake Class 12 differs from Lake Class 17

[h]Lake Class 13 differs from Lake Class 14

[i]Lake Class 13 differs from Lake Class 17

[j]Lake Class 14 differs from Lake Class 17

[k]Lake Class 22 differs from Lake Class 27

Class 19 (Table 3). The lower productivity of lakes in Class 8 is reflected in lower biomass per gill net lift than in Class 19 (Table 11). Bluegill abundance was higher in Class 8 while abundance of white sucker was higher in Class 19. Lakes in Class 19 are subject to periodic winterkill. Bluegill are probably less tolerant of low oxygen conditions than suckers and are also favored by greater water clarity.

Lake Classes 12, 13, 14, and 17 are similar in that they are small lakes that are mostly littoral (Table 3). Lakes in Class 12 tend to be relatively clear while those in Class 17 tend to be turbid. Biomass in gill nets was higher in Classes 12 and 17 than in the other two classes (Table 11). Catches of white sucker were higher in Class 17 lakes than in any other class (Figure 5). Yellow perch were relatively large in these lakes. Northern pike abundance averaged lower in Lake Class 13 than in the other three classes (Figure 5).

Lake Classes 22 and 27 are relatively large, hard-water lakes (Table 3). Lakes in Class 22 tend to be deeper, have clearer water, and the lake basins are more irregular in shape than those in Class 27. The higher productivity of lakes in Class 27 is reflected in higher biomass per lift for both gill and trap nets (Table 11). Abundances of white sucker and yellow perch were higher in Class 27 lakes. Abundances of rock bass and black crappie were higher, and average sizes smaller in Class 22 lakes.

Lake Classes 9 and 18 are indicated to be dominated by white sucker (Figure 8). These two classes consist of small lakes but differ in that lakes in Class 9 are deeper and have clearer water than those in Class 18. Suckers appeared in 52.3% of the surveys of Class 9 lakes and in 49.3% of the surveys of Class 18. No other species appeared in as many as one-half the surveys. Abundance of pike and suckers (Figure 5) were high for Class 18 lakes when they were present.

Discussion

The lake classification was successful in grouping lakes with similar morphoedaphic characteristics. Different community assemblages were associated with different lake classes. The advantage to fishery management is that successful management in one or a few lakes of a given ecological type should, in theory, have a higher probability of success in other lakes of that type. This concept has been described as "assessment by analogy" by Hoenig et al. (1987), and was implicit in the classifications reported by Johnson et al. (1977) and Tonn et al. (1983). Ontario explicitly formalized this concept in 1978 (Ontario MNR 1978). There is, however, no evidence that this management approach will succeed. Classification does provide a formal structure for testing the hypothesis.

The classification by Johnson et al. (1977) and Tonn et al. (1983) for Ontario lakes and for this study had similar goals, but started from opposite ends of the spectrum. Johnson et al. (1977) and Tonn et al. (1983) began by analyzing community structures, and then analyzing limnological variables associated with those structures. In this study, lakes were classified using limnological variables, while community structure associated with the classification were analyzed later.

Lake classification using limnological variables was chosen as a starting point because several species, particularly walleye and northern pike, have been widely stocked throughout Minnesota. Other human influences, especially agricultural practices, lakeshore development, and fishing have also altered community assemblages in many lakes. It was felt that the optimum fish communities for the different lake classes could be better delineated by classifying lakes by physical and chemical habitat rather than by community assemblage. The species most strongly associated with each lake class (Figure 8) are also those most likely to thrive under good fishery management practices.

Despite the opposite approaches taken by Johnson et al. (1977) and this study, there were some parallel results. Ontario added brook trout and lake whitefish to the combination of species used by Johnson et al. (1977) (Ontario MNR 1978). This resulted in classifying Ontario's lakes into 63 community types (classes). Brook trout were a component of 32 of Ontario's community types, but are uncommon in Minnesota lakes. Minnesota does, however, have lake classes that appear to be ecological equivalents to lakes in Ontario that support brook trout. Lake trout were a component of 16 of the Ontario community types, but were a major component in only one of the Minnesota lake classes. Six of the remaining 15 Ontario community types had parallel community structures to those in the 19 northeastern Minnesota lake classes. These were mainly in northwestern Ontario where Minnesota shares a border of more than 350 miles.

Statistically significant reductions in variation of CPUE and mean weights of individual species in gill and trap nets were achieved through classification, but more than 80% of the variation was still unaccounted for in most cases. This should not be surprising since fish are not uniformly distributed in a lake. Estimates of abundance and size would also be influenced by varying year class strengths. Dolman (1990) reported improved precision of statewide C/f estimates from electrofishing surveys of 33-43% for bluegill, and 11-23% for largemouth bass as a result of reservoir classification. Seasonal effects on net CPUE and mean weights of captured fish are also evident in the Minnesota data base. Further analyses incorporating seasonal effects may improve the precision of CPUE and mean weight estimates.

Since the variation of catch indices within lake classes remains relatively high, the significance of changes can still be difficult to interpret. Moyle (1950), and Moyle and Lound (1960) recommended comparing mean catches for a survey to a statewide median and testing for statistical differences at the 80% probability level.

In practice, Minnesota fishery managers have usually compared mean catches to the appropriate statewide medians without regard to statistical significance. Management plans were often based on these comparisons. Statewide medians have some value, but are a poor standard for a given survey since they don't consider the influence of habitat on the observed catches. The failure to consider the statistical significance of any differences has probably led to many erroneous conclusions.

It is recommended here that survey net catches be compared to intra-class quartiles rather than to medians. Catches below the first quartile or above the third quartile for a particular lake class should be viewed as unusual, and meriting more detailed examination. Catches within the inter-quartile range can be viewed as normal for that lake type. Fishery managers should thus be able to identify possible problems rapidly from a lake survey, and focus their efforts on resolving them. This is particularly important where fishery managers are responsible for many lakes, but are able to assess their lakes only infrequently with brief, standardized lake surveys.

Use of quartiles to identify unusual net catches is a statistically conservative approach. It has the advantage of aiding rapid identification of gross departures from more typical catches, but is not a substitute for statistical testing.

The results of the Knife Lake surveys are an example of the potential value of using quartiles, not only to identify unusual catches, but to provide a framework for evaluating the catches and considering solutions. High catches of pike and walleye, such as those in 1979, are usually judged as favorable since these species are highly desired by anglers. Judging the catches by comparison to quartiles would have flagged these as unusual and a potential problem.

By 1985, the CPUEs of all seven species listed for Knife Lake (Table 10), and six of the seven mean weights were outside the inter-quartile ranges. One possible speculative cause of the changes observed between 1979 and 1985 is that the high populations of small to moderate piscivores may have decimated the normal yellow perch population present in 1979. Perch is a preferred prey for both pike and walleye. Black and white crappie benefitted from the decline in perch, and may have affected recruitment of pike and walleye, leading to the low populations of large piscivores present in 1985. The true causes of the changes are unknown. This example does, however, illustrate how the use of quartiles can promote consideration of changes in the fish community and their causes. Knife Lake and its watershed was treated with rotenone in 1989 because of the changes in community structure.

In contrast, catches from Big Sand Lake indicated a relatively stable fish community. The unusual catches observed can probably be attributed to variations in year-class strengths, or may simply be the result of sampling errors.

Management Implications

The greatest value of organizing survey data as in Table 10 is that it forces viewing the results in the context of fish community structure. Analyzing the results from a holistic viewpoint rather than from the single species approach so common until now should lead to management recommendations that have a higher probability of success. The following set of simple questions is suggested as an outline for evaluating survey results and developing management plans:

1. Is the unusual catch (CPUE or size) a problem?
2. Do I want to do something about it?
3. Can I do something about it?
4. What are the possible consequences of a management action on the target species and on the associated fish community?
5. How will the results of the management action be evaluated?

The last two questions may be the most important, and are also the most likely to be overlooked or ignored. Evaluation of management actions, including the consequences on the aquatic community, should be axiomatic. Lack of evaluation leads to the continuing inertia of expensive management failures so common to management agencies (Lewis et al. 1987; Loftus 1987), or even worse, to the disruption or loss of valuable aquatic communities. Fishery managers must be aware that processes which alter community metabolism are difficult if not impossible to reverse once in operation (Colby et al. 1987).

The approach to evaluating survey results and management actions using quartiles as a first step is relatively simple and fast. Even those fishery managers who are burdened with the responsibility of too many waters should be able to quickly sort out their most pressing problems. Setting management priorities based on an evaluation of likely problems that can be solved should lead to a more rational use of the limited time and resources common to most fishery managers.

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