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Comparisons of Actual Fish Observations with Simulated Suitable Fish Habitat in Minnesota Lakes

by

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Abstract

The purpose of this study is to relate simulated water quality with fish presence observations. The typical seasonal patterns of water temperatures and dissolved oxygen concentrations in twenty-seven classes of Minnesota lakes have been simulated by calibrated models and related to observations of three fish guilds i.e. coldwater, coolwater, and warmwater fishes. Data from 3002 lakes were available in the Minnesota Department of Natural Resources lake database. Water temperature and dissolved oxygen criteria derived from a very large USEPA fish-temperature data base and dissolved oxygen observations were used to define and link simulated water temperatures and dissolved oxygen conditions to suitability of habitats for various species of fish. One-dimensional, dynamic models driven by 25 years of observed weather data were used to model daily water temperature and dissolved oxygen as a function of depth. The lakes are categorized according to surface area, maximum depth, and Secchi depth as a measure of trophic state. Good agreement between fish observations and numerical simulations of fish habitat defined by water temperatures and dissolved oxygen concentrations was found.

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[1]The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, religion, color, sex, national origin, handicap, age, or veteran status.

Table of Contents

List of Tables

List of Figures

Acknowledgements

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1. INTRODUCTION

It has been observed for some time that concentrations of "greenhouse gases" (carbon dioxide, methane etc.) have been increasing in the earth's atmosphere (Ramanathan et al., 1985; Bolin and Doos, 1986; Mitchell, 1989). It is also known that these gases can affect global climate, possibly resulting in mean warming of the earth's surface, terrestrial and aquatic. Freshwater lake temperatures and dissolved oxygen concentrations will respond to the atmospheric changes (Magnuson and Hill, 1990; Schindler et al., 1990; Stefan et al., 1993). These changes in lake water temperature and dissolved oxygen dynamics are expected to have effects on lake ecosystems, and the fishes therein (Meisner et al., 1987; Coutant, 1990; Magnuson et al., 1990; Chang et al., 1992). The University of Minnesota and the Environmental Research Laboratory-Duluth initiated a cooperative investigation to determine the potential impacts of global warming on lake and stream environmental conditions and their concomitant fishery resources. Minnesota was selected as the pilot area because of the known quality and accessibility of historical weather data, and its rich fishery resources databases.

Temperature and dissolved oxygen concentrations (D.O.) are considered the two most significant water quality parameters influenced by climate change, and both control survival and growth of fishes. The deterioration of habitats for certain species of fishes and the improvement for others are assessed in a previous study (Stefan et al., 1992a; 1992b) in terms of only these two parameters. Water temperatures and D.O. concentrations in the lakes were simulated by deterministic models with past and future climate conditions as input. The results indicated which of 27 classes of lakes will have thermal and dissolved oxygen conditions suitable for different fishes after a doubling of atmospheric CO_2. The results quantify the change in available habitat, defined by suitable water temperature and D.O. conditions, for the three temperature guilds (coldwater, coolwater, and warmwater fish) of fishes. Not included are secondary effects of climate change such as interactions between food production rates relative to demand, invasion of more thermally tolerant predators and competitors, etc.

A comparison of actually observed fish guilds with model simulations of suitable habitat under past climate conditions was advisable, if not necessary, for several reasons: a) suitability of habitats for various fish species is herein based on only two water quality parameters (temperature and D.O.), b) longterm (25 year) averages of water temperatures and D.O. concentrations were modeled, and c) water temperature criteria were means for thermal guilds, rather than for individual species which contributes to overlaps and uncertainty at the fringes of each guild (Fig 1.[2]). The purpose of this paper is to outline the methods and results of such a comparison. Observed fish species in 3002 Minnesota lakes (MLFDB) were related to modeled habitat conditions. A series of tests were performed to evaluate the dependability of the model habitat predictions. These tests involved comparisons between the guilds of fish predicted to be able to inhabit specific classes of lakes and actually observed fishes in those classes of lakes.

Conditions of temperature and D.O. suitable for fishes from each of the three guilds i.e. cold-, cool-, and warmwater fishes were established. They were compared to simulated values for each of 27 lake classes to determine expected presence or absence of a fish guild in a particular lake class. Actually the simulation does not propose that the guild is or even should be present, only that conditions of temperature and D.O. would or would not enable representatives of a guild to be present. This concept was recently applied in a field study by Headrick and Carline (1993) among others. Survival criteria in terms of temperature and D.O., and were applied to simulated daily water temperature and D.O. versus depth profiles under past weather conditions. The 27 classes of Minnesota lakes were defined on the basis of surface area, maximum depth, and Secchi depth (trophic state) as defined in Table 1. If the temperature and/or D.O. criteria for survival of a fish guild were not met at any depth in a lake over a period of seven or more days it was considered that the habitat was untenable for that fish guild.

The model comparisons were made for fish guilds rather than individual species for two reasons: a) to use the extensive habitat simulation results which had been obtained for mean fish guild temperature criteria and b) to use the entire fish observation data base available (i.e., some species temperature tolerances are unknown). The drawback of this choice was that within a guild, temperature tolerances vary significantly. For each guild, the model used a mean of the maximum tolerable water temperatures (Table 2) as determined from all species within a guild and represented in the field temperature data base, to distinguish between suitable and unsuitable habitat for the entire guild. The average guild temperature was chosen initially because it is more likely to indicate an effect of climate change than values near the higher end of the range of temperatures for each guild (Table 2). The present comparison of model-derived and survey data was initiated to more firmly establish the relationship between use of this model and actual field observations.

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[2]The means and standard deviations of the three normal distributions in Fig. 1 were estimated from the Ultimate Upper Incipient Lethal Temperature (UUILT) values given in p. A-10 of the summary report by Stefan et al., 1992a.

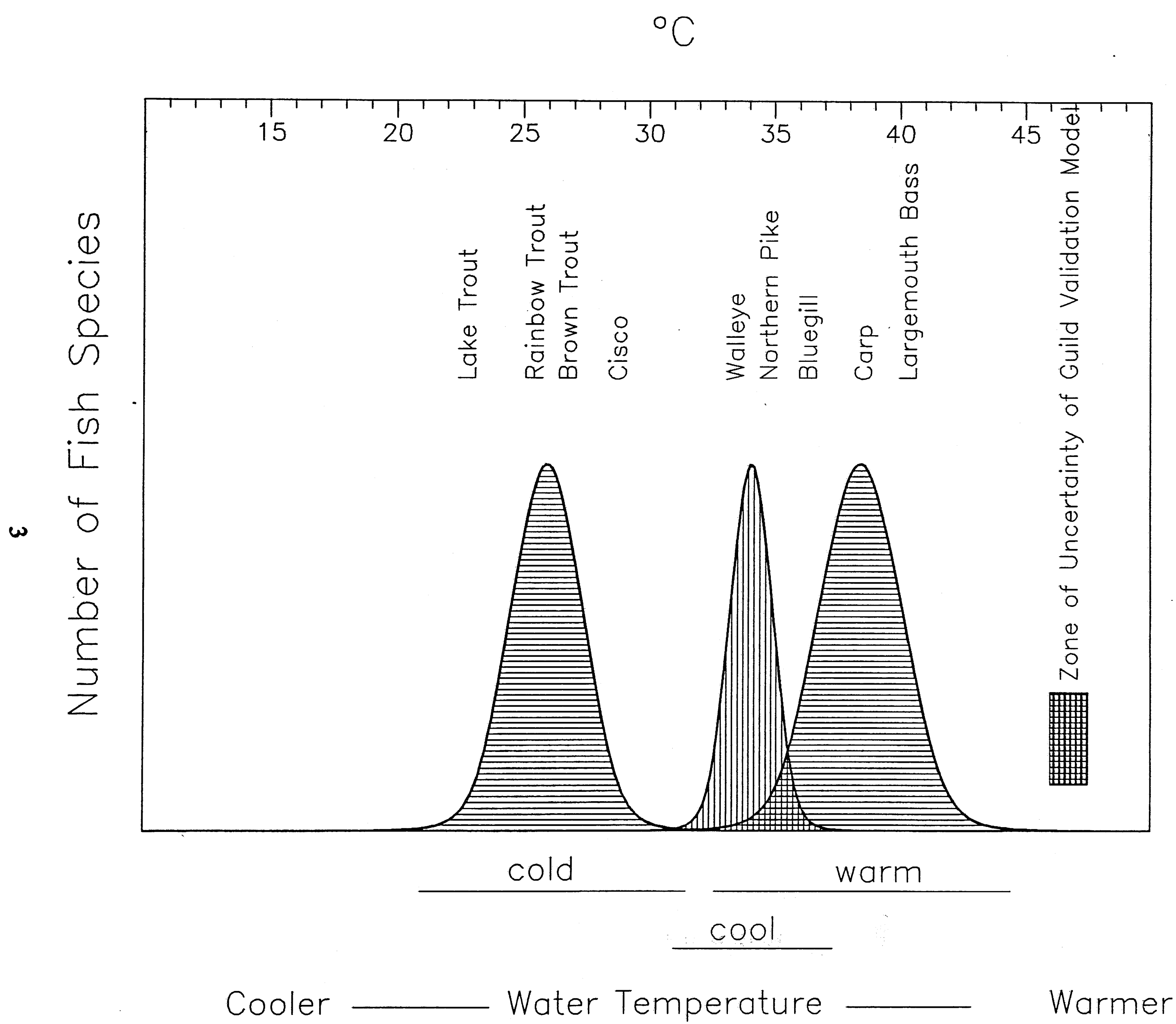


Fig. 1. **Schematic of representation of three thermal fish guilds (Modified from Ryder & Kerr, 1987).**

Table 1. Physical parameters used to define 27 Minnesota lake classes

Lake key parameter	Descriptive term	Representative value used	Range	Cumulative frequency
Maximum depth (m)	Shallow	4.0	< 5.0	Lower 30%
	Medium	13.0	5.0-20.0	Central 60%
	Deep	24.0	> 20.0	Upper 10%
Surface area (km^2)	Small	0.2	< 0.4	Lower 30%
	Medium	1.7	0.4-5.0	Central 60%
	Large	10.0	> 5.0	Upper 10%
Secchi depth (m)	Eutrophic	1.2	< 1.8	Lower 20-50%
	Mesotrophic	2.5	1.8-4.5	Central 20-50%
	Oligotrophic	4.5	> 4.5	Upper 0-10%

Table 2. Thermal criteria (°C) for fish (guild means and ranges for species within a guild)

Guild	Lower good growth limits	Upper good growth limits	Upper lethal limits	Optimum
Coldwater	9.0 (6.4-11.8)	18.5 (15.5-21.2)	23.4 (22.1-26.6)	15.3 (11.5-18.7)
Coolwater	16.3 (13.2-18.2)	28.2 (27.7-28.8)	30.4 (28.0-32.3)	25.1 (24.0-25.7)
Warmwater	19.7 (17.7-22.5)	32.3 (31.4-34.7)	undetermined	29.2 (27.0-32.0)

2. SIMULATIONS OF ENVIRONMENTAL CONDITIONS IN MINNESOTA LAKES

2.1 Water temperature and dissolved oxygen profile simulations

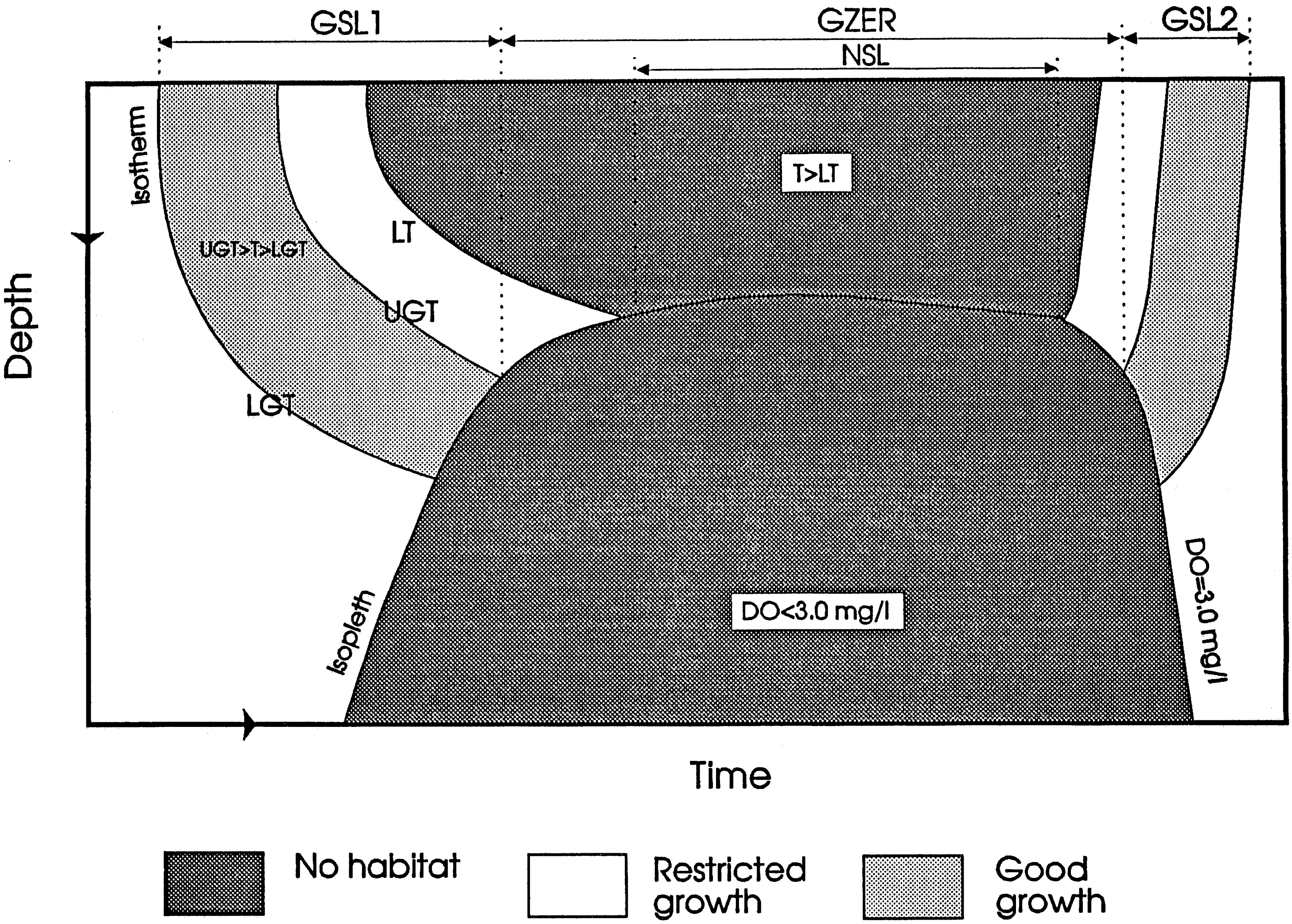
Simulations of water temperatures were made for the 27 classes of lakes in southern and northern Minnesota with a one-dimensional time-variable (unsteady) simulation model operated on daily timesteps (Hondzo and Stefan, 1993). Twenty-five years (1955-1979) of recorded weather conditions were used as input data in these simulations. Output from the lake water temperature model was used in a dissolved oxygen model (Stefan and Fang, 1993a) to predict oxygen concentrations in the same 27 lake classes for the same period of time (Stefan and Fang, 1993b). As a result of this extensive simulation work a 25-year average temperature and dissolved oxygen structure was estimated in the 27 lake classes for northern and southern Minnesota. Simulated vertical profiles of daily water temperature and dissolved oxygen concentrations in a given lake class over the past 25 years were obtained for the open water season, the length of which was found by the model itself. Lakes are ice free in southern Minnesota from approximately April to November, and in northern Minnesota from approximately May to October.

2.2 Fish thermal and dissolved oxygen requirements

Temperature criteria for the three fish guilds were developed from the USEPA fish-temperature database management system (FTDMS)(Hokanson et al., 1990). Fish survival and growth temperature criteria were applied to simulated daily water temperature. Figure 2 shows schematically how this was done. Three simulated isotherms were singled out for each fish guild. They designate the survival (lethal) temperature, the upper good growth temperature limit and the lower good growth temperature limit, respectively (Table 2). Dissolved oxygen survival limits were selected at 2.5 mg l^{-1} for warmwater fishes, and 3.0 mg l^{-1} for cool and warmwater fishes (Chapman, 1986). The isopleth which designates this critical D.O. survival value is also shown in Fig. 2. Between these lines, three habitats can be identified:

(a) uninhabitable space when temperature is above or D.O. is below the survival limit,

(b) good growth habitat if temperature is between the upper and lower growth limits and D.O. is above the survival limit, and



LGT = Lower good growth temperature limit
UGT = Upper good growth temperature limit
LT = Lethal temperature
NSL = Non-survival perid
GSL = Growth season length (GSL=GSL1+GSL2)
GZER= No growth period
DO = Dissolved oxygen

Fig. 2. Schematic of the distribution over time and depth of those isotherms and dissolved oxygen isopleths which are considered critical to the survival and growth of a fish species or guild in a lake.

(c) restricted growth habitat if temperature is above the upper good growth limit but below the survival limit, or if temperature is below the lower good growth limit, and D.O. is above critical.

2.3 Suitable fish habitat

The application of the fish survival criteria to the simulated water temperature and dissolved oxygen profiles in the 27 classes of lakes produced information.. on suitable and unsuitable lake habitat volume and lake habitat bottom area (Stefan et al., 1992; 1992b). Some of that information will be presented herein for comparison with observed fish presence or absence.

3. FISH OBSERVATIONS IN MINNESOTA LAKES

The Minnesota Department of Natural Resources has developed a Minnesota Lake Fisheries Data Base (MLFDB, 1990) which contains data from fish surveys and lake characteristics for 3002 Minnesota lakes (Schupp, 1992). This database was combined by the USEPA/ERLD (O'Brien, personal communication) with geographic information and then used to analyze fish species distribution in the 27 classes of lakes in northern and southern Minnesota, based on the parameters summarized in Table 1 as described by Stefan et al., 1992a. Appendix gives a summary of the available fish observation data.

4. COMPARISON OF FISH OBSERVATIONS WITH HABITAT SIMULATIONS

4.1 Concept

The model simulates water quality conditions which by use of temperature and D.O. criteria are translated into suitable fish habitat volume of a particular guild. If at least one representative fish of a particular guild in a particular class of lake is observed where the model predicts suitability of that lake class for fishes of that guild, agreement between model and observation can be claimed (agreement, **A**). Similarly if fishes are observed where the model simulates uninhabitable conditions, disagreement between model and observations is concluded (disagreement, **D**). If fishes of a certain guild were not observed in the lake (no data, **ND**), no conclusions can be drawn by comparison with model simulations i.e. if simulations predict suitable habitat (water quality), the fish may not have had access to the lake and therefore could not be expected in that habitat. Similarly if the simulation predicts unsuitable habitat, lack of observations does not guarantee the absence of that particular fish species or guild, only that they were not observed or reported. The above concept is summarized in Table 3.

4.2 Results

The reliability of the fish habitat model was evaluated by comparing the number of lakes with suitable habitat based on the model simulations to the actual fish observations. The comparison was made somewhat difficult by the fact that the suitable habitat estimation in different lake classes was based on the fish guild approach i.e. the mean of the highest tolerable temperatures for a group of similarly sensitive (i.e. cold-, cool- or warmwater) fish, while the observations were reported for individual fish species. A first set of comparisons for 2231 northern and 771 southern Minnesota lakes is given in Table 4 and Table 5, respectively. These tables identify the 27 lake classes according to the classification scheme given in Table 1. The number of lakes in each class is given in the fourth column. The shaded cell under the heading "OBSERVED" indicates that at least one of the species in a particular fish guild was observed in at least one lake of a given lake class. A shaded cell under the heading "SIMULATED" indicates habitable (survival) conditions for species of a particular fish guild in a given lake class. An empty cell indicates that the simulation predicts uninhabitable conditions in a given lake category. An empty cell with the **ND** label indicates that no fish species of a particular guild was observed in that lake class. Simultaneous presence of shading in both the simulation and observation columns indicate agreement (label **A**) of simulations and observations. Presence of shading in the observation column and absence of shading in simulation column indicates disagreement (label **D**).

Table 3. Options of model/observation comparisons

Model predicts suitable habitat	Fish presence observed	Conclusion
Yes	Yes	Agreement (A)
Yes	No	None (no data, ND)
No	Yes	Disagreement (D)
No	No	None (no data, ND)

Table 4. Comparison of fish guild observations and simulated suitable habitat in 2231 northern Minnesota lakes

LAKE CHARACTERISTICS				FISH GUILD					
				OBSERVED			SIMULATED		
MAX. DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NUMBER OF LAKES	COLD	COOL	WARM	COLD	COOL	WARM
SHALLOW (4)	SMALL (0.2)	EUTROPHIC	185	ND	A	A			
		MESOTROPHIC	189	A	A	A			
		OLIGOTROPHIC	3	A	A	A			
SHALLOW (4)	MEDIUM (1.7)	EUTROPHIC	150	A	A	A			
		MESOTROPHIC	99	A	A	A			
		OLIGOTROPHIC	2	ND	A	A			
SHALLOW (4)	LARGE (10)	EUTROPHIC	7	A	A	A			
		MESOTROPHIC	3	A	A	A			
		OLIGOTROPHIC	0	0	0	0	0	0	0
MEDIUM (13)	SMALL (0.2)	EUTROPHIC	85	ND	A	A			
		MESOTROPHIC	350	A	A	A			
		OLIGOTROPHIC	76	A	A	A			
MEDIUM (13)	MEDIUM (1.7)	EUTROPHIC	102	A	A	A			
		MESOTROPHIC	531	A	A	A			
		OLIGOTROPHIC	78	A	A	A			
MEDIUM (13)	LARGE (10)	EUTROPHIC	14	A	A	A			
		MESOTROPHIC	46	A	A	A			
		OLIGOTROPHIC	2	A	A	A			
DEEP (24)	SMALL (0.2)	EUTROPHIC	6	ND	A	A			
		MESOTROPHIC	26	A	A	A			
		OLIGOTROPHIC	26	A	A	A			
DEEP (24)	MEDIUM (1.7)	EUTROPHIC	3	A	A	A			
		MESOTROPHIC	103	A	A	A			
		OLIGOTROPHIC	69	A	A	A			
DEEP (24)	LARGE (10)	EUTROPHIC	5	A	A	A			
		MESOTROPHIC	54	A	A	A			
		OLIGOTROPHIC	17	A	A	A			
SUM			2231						

shaded cell indicates that fish of that guild are present or suitable habitat is simulated
ND no data; A model agreement; 0 no lake exists in this class

Table 5. Comparison of fish guild observations and simulated suitable habitat in 771 southern Minnesota lakes

LAKE CHARACTERISTICS				FISH GUILD					
				OBSERVED			SIMULATED		
MAX. DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NUMBER OF LAKES	COLD	COOL	WARM	COLD	COOL	WARM
SHALLOW (4)	SMALL (0.2)	EUTROPHIC	45	ND	A	A			
		MESOTROPHIC	12	ND	A	A			
		OLIGOTROPHIC	1	ND	ND	A			
SHALLOW (4)	MEDIUM (1.7)	EUTROPHIC	168	ND	A	A			
		MESOTROPHIC	25	ND	A	A			
		OLIGOTROPHIC	2	ND	ND	ND			
SHALLOW (4)	LARGE (10)	EUTROPHIC	19	D	A	A			
		MESOTROPHIC	2	ND	A	A			
		OLIGOTROPHIC	0	0	0	0	0	0	0
MEDIUM (13)	SMALL (0.2)	EUTROPHIC	82	ND	A	A			
		MESOTROPHIC	71	D	A	A			
		OLIGOTROPHIC	6	ND	A	A			
MEDIUM (13)	MEDIUM (1.7)	EUTROPHIC	142	D	A	A			
		MESOTROPHIC	102	D	A	A			
		OLIGOTROPHIC	7	ND	A	A			
MEDIUM (13)	LARGE (10)	EUTROPHIC	17	D	A	A			
		MESOTROPHIC	5	D	A	A			
		OLIGOTROPHIC	0	0	0	0	0	0	0
DEEP (24)	SMALL (0.2)	EUTROPHIC	1	ND	A	ND			
		MESOTROPHIC	7	D	A	A			
		OLIGOTROPHIC	0	0	0	0	0	0	0
DEEP (24)	MEDIUM (1.7)	EUTROPHIC	10	D	A	A			
		MESOTROPHIC	33	D	A	A			
		OLIGOTROPHIC	3	ND	A	A			
DEEP (24)	LARGE (10)	EUTROPHIC	5	A	A	A			
		MESOTROPHIC	6	A	A	A			
		OLIGOTROPHIC	0	0	0	0	0	0	0
SUM			771						

shaded cell indicates that fish of that guild are present or suitable habitat is simulated; **clear cell** indicates that fish of that guild was not present or suitable habitat is unsuitable; **ND** no data; **A** model agreement; **D** model disagreement; **0** no lake exists in this class

For cool and warmwater fishes there is full agreement between simulations and observations in all lake classes in northern Minnesota (Table 4). Unshaded boxes with the ND label (in 4 of the 27 lake classes) indicate lack of data for coldwater fish. There is full agreement for cool and warmwater fishes in all lake classes in southern Minnesota lakes (Table 5). For coldwater fishes, disagreement (**D**) occurred in 9 lake classes, where observations of coldwater species were made in lakes where simulations indicated unsuitable habitat for the coldwater guild.

A further species-level examination of this only disagreement between predicted versus observed lake inhabitants indicated that the coldwater species observed were primarily lake whitefish and lake herring (cisco). Lake trout were found in only one of 43 southern Minnesota lakes in nine classes containing coldwater fish. The model correctly predicted suitable coldwater fish habitat in two classes (eleven lakes) of southern Minnesota, and the species recorded from surveys were whitefish and herring in eight of these lakes.

5. DISCUSSION

As stated previously, fishes of a guild should not be observed in all lakes where suitable water temperature and dissolved oxygen are indicated by the model simulations. Reasons why fish may not be observed in a lake with simulated suitable habitat are related to

biology:

(a) lack of accessibility of a lake by streams suitable for fish migration,

(b) lack of tributaries suitable for spawning/reproduction,

(c) refugia may enable survival opportunities where lethality would be predicted on the basis of predictions for general waterbody conditions,

management:

(d) stocking of lakes with game fish or eliminating undesirable species biases fish presence results,

data collection:

(e) fish collections may not have covered the same time period as the simulations (1955-1979),

and modeling concepts:

(f) model imperfections; simulated water temperatures and D.O. concentrations have uncertainty measurable as standard errors of 1.0°C and 1.0 to 2.0 mg/l, respectively,

(g) the FTDMS water temperature criterion for fish presence or absence is subjectively chosen to be the upper 95% cumulative frequency value for field data derived maximum temperatures; fish can resist stressful high temperatures for a time and still not be lost from the system, i.e. acute lethal temperatures are 2-3°C higher than tolerances based on geographic distribution relationships and are time of exposure dependent,

(h) this (FTDMS) temperature criterion is compared to the estimated maximum of water temperatures averaged over 25 years; it is conceivable that fish presence and distribution is more in response to episodes of extreme temperature excursions, rather than longterm averages,

(i) simulations of environmental habitability are based on guild mean values and the thermal tolerance limits for an individual species may lie at the upper or lower extreme for a guild resulting in guild mean predicted absence within the range of their tolerance,

(j) survival of warmwater species may be limited by winter conditions which were not simulated.

The observation of guild members in lakes where model results indicated they should not be present was termed "disagreement". However, if the model does a good job of predicting suitable habitat, one would expect to find the most tolerant species within a guild in a lake where simulations based on guild average temperatures predicts unsuitable conditions. Both lake herring and lake whitefish are among the more tolerant of cold water species, having upper incipient lethal temperatures (UILT) of 26.6 (Edsall and Rottiers, 1976) and 25.7°C (Edsall and Colby, 1970), respectively. The main difference between the UILT and FTDMS maximum tolerable temperatures for 14 cold and coolwater species is -1.4°C, so an estimated FTDMS value for herring and whitefish based on this relationships would be 24.3 and 25.2°C, respectively. Therefore, the model applied previously (Stefan et al., 1993) using an FTDMS-based guild mean value of 23.4°C should not have predicted the absence of these species. It did fail in the case of the one lake class (and one actual lake) in which lake trout were observed (UILT 23.5°C (Gibson and Fry, 1954) - 1.4°C = 22.1°C estimated FTDMS value). In other words, the apparent predictive capability would have been very good if restricted in the case of coldwater fish, to those species whose FTDMS values were less than the guild mean. Any one of a number of the reasons mentioned in the previous paragraph (e.g. refugia, model imperfections, management actions) could explain the lake trout failure presence in a simulated unsuitable habitat.

It is interesting that all the model vs. observation "disagreements" occurred among coldwater fish in southern Minnesota lakes. The result indicates, for lakes in the south, that when coldwater fish habitats are predicted to be there, the coldwater fish also were there. If lack of observed fish in the north where habitable conditions were predicted is interpreted as possible model failure (Table 4), the failure percentage is still low (only 4 out of 26 lake classes). The high percent of "disagreement" in the south as compared to the north is quite likely due to warmer, more eutrophic water in the south, causing more lakes to have conditions approaching the upper tolerance limits for the guild. Northern lakes, on the other hand, maintained conditions suitable for guild members with lower temperature requirements. The two southern lake classes in which the simulated coldwater fish habitat was actually inhabited by coldwater fish were larger and deeper and had thermal and D.O.

conditions more closely resembling northern Minnesota lakes.

Several conclusions seem warranted from the above discussion. The predictive power of the model seems very good, even though "disagreement" was indicated by the analysis procedure used (i.e. the disagreement could be explained through result interpretation consistent with model operation). The results indicate that guild values at or near the upper range limits are probably more appropriate for estimating suitable temperature and D.O. habitat conditions for a wide range of guild members. It is quite likely that previous analysis of global warming effects using guild mean temperatures values (Stefan et al., 1992a) overestimated global climate effects attributable to temperature and D.O. changes. It is therefore appropriate that further projections of global climate effects be quantified using upper extremes of the FTDMS base guild temperature range, or values for individual fish species, and that the result be again compared with fish survey observations to evaluate modeling capabilities.

6. REFERENCES

Bolin B. & B.R. Doos (1986). The greenhouse effect, climate change and ecosystems, John Wiley and Sons, New York, 541 pp.

Chapman, G. (1986). Ambient aquatic life criteria for dissolved oxygen, USEPA, 440/586-003, 46 pp.

Chang, L.H., S.F. Railsback & R.T. Brown (1992). Use of reservoir water quality model to simulate global climate change effects on fish habitat, **Climatic Change**, Vol 20, 271-296.

Coutant, C.C. (1990). Temperature-oxygen habitat for freshwater and coastal striped bass in a changing climate, **Transactions of the American Fisheries Society**, Vol. 119(2), 240-253.

Edsall, T.A. and P.A. Colby (1970). Temperature tolerance of young-of-the-year cisco, *Coregonus artedii*, **Transactions of American Fisheries Society**, Vol. 99(3), 526-531.

Edsall, T.A. and D.V. Rottiers (1976). Temperature tolerance of young-of-the-year lake whitefish, **Journal Fisheries Research Board of Canada,** *Coronus clupeaformis.*

Gibson, E.S. and F.E.J. Fry (1954). The performance of lake trout, *Salvelinus foutinalis*, at various level of temperature and oxygen pressure, **Canadian Journal Zoology**, Vol. 32(3), 252-260.

Headrick, M.R. & R.F. Carline (1993). Restricted summer habitat and growth of Northern Pike in two southern Ohio impoundments, **Transactions of the American Fisheries Society**, Vol. 122, 228-236.

Hokanson, K.E.F., B. Goodno & J.G. Eaton (1990). Evaluation of field and laboratory derived fish thermal requirements for global climate warming impact assessment, USEPA ORD, "A" Milestone Report, 56 pp.

Hondzo, M. & H.G. Stefan (1993). Water temperature characteristics of lakes subjected to climate change, **Climatic Change**, 24, 187-211.

Magnuson, J.J., J.D. Meisner, & D.K. Hill (1990). Potential changes in thermal habitat of Great Lakes fish after global climate warming, **Transactions of the American Fisheries Society**, Vol. 119(2), 254-264.

Magnuson, J.J. & D.K. Hill (1990). Potential effects of global climate warming on the growth and prey consumption of Great Lakes fish, **Transactions of the American Fisheries Society**, Vol. 119(2), 265-275.

Meisner, J.D., J.L. Goddier, H.A. Regier, B.J. Shuter, & W.J. Christie (1987). An assessment of the effects of climate warming on Great Lakes Basin fishes, **Journal of Great Lakes Research**, Vol. 13(3), 340-352.

Mitchell, J.F.B. (1989). The Greenhouse effect and climate change, Reviews of **Geophysics,** Vol 27(1), 115-139.

MLFDB (1990). Minnesota Department of Natural Resources, Fisheries Division Lake Data Base (D. Schupp, personal communication), expanded by US Environmental Protection Agency, Environmental Research Laboratory-Duluth (B. Goodno, personal communication).

Ramanathan V., R.J. Cicerone, H.B. Singh, & J.P. Kehl (1985). Trace gastrends and their potential role in climate change, **Journal of Geophysical Research**, Vol. 90, 5547-5566.

Ryder, R.A. & S.R. Kerr (1978). The adult Walleye in the percid community-a niche definition based on feeding behavior and food specificity, **Am. Fish Soc. Spec.**, Pub. 11, 39-51.

Schindler, D.W., K.G. Beaty, E.J. Fee, D.R. Cruikshank, E.R. DeBruyn, D.L. Findley, G.A. Londsey, J.A. Sherer, M. Stainton, & M.A. Turner (1990). Effects of climatic warming on lakes of the Central Boreal Forests, **Science**, Vol. 250(16), 967-970.

Schupp, D. (1992). An ecological classification of Minnesota lakes with associated fish communities, Investigational report 417, Minnesota Department of Natural Resources, St. Paul, MN, 27 pp.

Stefan, H.G., M. Hondzo, B. Sinokrot, X. Fang, J.G. Eaton, B.E. Goodno, K.E.F. Hokanson, J.H. McCormick, D.G. O'Brien & J.A. Wisniewski (1992a). A methodology to estimate global climate change impacts on lake and stream environmental conditions and fishery resources with application to Minnesota, University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Project Report No. 323, 2nd revised edition, 222 pp.

Stefan, H.G., M. Hondzo, J.G. Eaton, and J.H. McCormick (1992b). Predicted effects of global climate change on fishes of Minnesota lakes, University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Project Report No. 334, 45 pp.

Stefan H.G. & X. Fang (1993a). Dissolved oxygen model for north central US lakes, **Ecological Modeling**, in press.

Stefan, H.G. & X. Fang (1993b). Model simulations of dissolved oxygen characteristics of Minnesota lakes: Past and future, **Environmental Management**, in press.

Stefan, H.G., M. Hondzo, and X. Fang (1993). Lake water quality modeling for projected future climate scenarios, **Journal of Environmental Quality**, 22(3), 417-431.

Appendix. Fish species observation summary.

	NORTH		SOUTH		TOTAL	
Class: 01 SSE (Depth/Area/Secchi)						
WHITE SUCKER	122/185	65.9%	22/ 45	48.9%	144/230	62.6%
YELLOW PERCH	112/185	60.5%	16/ 45	35.6%	128/230	55.7%
NORTHERN PIKE	99/185	53.5%	14/ 45	31.1%	113/230	49.1%
BLUEGILL	29/185	15.7%	30/ 45	66.7%	59/230	25.7%
BLACK CRAPPIE	30/185	16.2%	29/ 45	64.4%	59/230	25.7%
WALLEYE	35/185	18.9%	10/ 45	22.2%	45/230	19.6%
BROWN BULLHEAD	22/185	11.9%	13/ 45	28.9%	35/230	15.2%
GOLDEN SHINER	12/185	6.49%	17/ 45	37.8%	29/230	12.6%
LARGEMOUTH BASS	9/185	4.86%	16/ 45	35.6%	25/230	10.9%
GREEN SUNFISH	9/185	4.86%	14/ 45	31.1%	23/230	10.0%
CARP	2/185	1.08%	17/ 45	37.8%	19/230	8.26%
WHITE CRAPPIE	0/185	0.00%	12/ 45	26.7%	12/230	5.22%
SMALLMOUTH BASS	8/185	4.32%	1/ 45	2.22%	9/230	3.91%
FRESHWATER DRUM	0/185	0.00%	2/ 45	4.44%	2/230	0.87%
WHITE BASS	0/185	0.00%	1/ 45	2.22%	1/230	0.43%
Class: 02 SSM (Depth/Area/Secchi)						
YELLOW PERCH	136/189	72.0%	10/ 12	83.3%	146/201	72.6%
NORTHERN PIKE	127/189	67.2%	8/ 12	66.7%	135/201	67.2%
WHITE SUCKER	128/189	67.7%	7/ 12	58.3%	135/201	67.2%
BLUEGILL	48/189	25.4%	10/ 12	83.3%	58/201	28.9%
WALLEYE	51/189	27.0%	5/ 12	41.7%	56/201	27.9%
BLACK CRAPPIE	40/189	21.2%	9/ 12	75.0%	49/201	24.4%
LARGEMOUTH BASS	37/189	19.6%	7/ 12	58.3%	44/201	21.9%
BROWN BULLHEAD	36/189	19.0%	5/ 12	41.7%	41/201	20.4%
GOLDEN SHINER	14/189	7.41%	2/ 12	16.7%	16/201	7.96%
GREEN SUNFISH	6/189	3.17%	3/ 12	25.0%	9/201	4.48%
SMALLMOUTH BASS	9/189	4.76%	0/ 12	0.00%	9/201	4.48%
WHITE CRAPPIE	1/189	0.53%	3/ 12	25.0%	4/201	1.99%
LAKE WHITEFISH	4/189	2.12%	0/ 12	0.00%	4/201	1.99%
LAKE HERRING (CISCO)	4/189	2.12%	0/ 12	0.00%	4/201	1.99%
CARP	1/189	0.53%	3/ 12	25.0%	4/201	1.99%
Class: 03 SSO (Depth/Area/Secchi)						
BLUEGILL	1/ 3	33.3%	1/ 1	100%	2/ 4	50.0%
NORTHERN PIKE	2/ 3	66.7%	0/ 1	0.00%	2/ 4	50.0%
WHITE SUCKER	2/ 3	66.7%	0/ 1	0.00%	2/ 4	50.0%
YELLOW PERCH	2/ 3	66.7%	0/ 1	0.00%	2/ 4	50.0%
WALLEYE	1/ 3	33.3%	0/ 1	0.00%	1/ 4	25.0%
SMALLMOUTH BASS	1/ 3	33.3%	0/ 1	0.00%	1/ 4	25.0%
LAKE HERRING (CISCO)	1/ 3	33.3%	0/ 1	0.00%	1/ 4	25.0%
LAKE TROUT	1/ 3	33.3%	0/ 1	0.00%	1/ 4	25.0%

SSE = Shallow (depth), Small (area), Eutrophic.

	NORTH		SOUTH		TOTAL	
Class: 04 SME (Depth/Area/Secchi)						
YELLOW PERCH	137/150	91.3%	111/168	66.1%	248/318	78.0%
WHITE SUCKER	127/150	84.7%	102/168	60.7%	229/318	72.0%
NORTHERN PIKE	124/150	82.7%	103/168	61.3%	227/318	71.4%
WALLEYE	93/150	62.0%	88/168	52.4%	181/318	56.9%
BLACK CRAPPIE	61/150	40.7%	108/168	64.3%	169/318	53.1%
BLUEGILL	62/150	41.3%	103/168	61.3%	165/318	51.9%
CARP	5/150	3.33%	94/168	56.0%	99/318	31.1%
BROWN BULLHEAD	47/150	31.3%	42/168	25.0%	89/318	28.0%
LARGEMOUTH BASS	33/150	22.0%	37/168	22.0%	70/318	22.0%
GREEN SUNFISH	9/150	6.00%	49/168	29.2%	58/318	18.2%
WHITE CRAPPIE	0/150	0.00%	55/168	32.7%	55/318	17.3%
GOLDEN SHINER	16/150	10.7%	34/168	20.2%	50/318	15.7%
FRESHWATER DRUM	0/150	0.00%	18/168	10.7%	18/318	5.66%
LAKE HERRING (CISCO)	8/150	5.33%	0/168	0.00%	8/318	2.52%
WHITE BASS	0/150	0.00%	8/168	4.76%	8/318	2.52%
SMALLMOUTH BASS	6/150	4.00%	1/168	0.60%	7/318	2.20%
LAKE WHITEFISH	2/150	1.33%	0/168	0.00%	2/318	0.63%
Class: 05 SMM (Depth/Area/Secchi)						
YELLOW PERCH	93/ 99	93.9%	16/ 25	64.0%	109/124	87.9%
NORTHERN PIKE	89/ 99	89.9%	17/ 25	68.0%	106/124	85.5%
WHITE SUCKER	85/ 99	85.9%	12/ 25	48.0%	97/124	78.2%
WALLEYE	64/ 99	64.6%	12/ 25	48.0%	76/124	61.3%
BLUEGILL	51/ 99	51.5%	18/ 25	72.0%	69/124	55.6%
BLACK CRAPPIE	43/ 99	43.4%	14/ 25	56.0%	57/124	46.0%
LARGEMOUTH BASS	38/ 99	38.4%	8/ 25	32.0%	46/124	37.1%
BROWN BULLHEAD	36/ 99	36.4%	6/ 25	24.0%	42/124	33.9%
GREEN SUNFISH	2/ 99	2.02%	10/ 25	40.0%	12/124	9.68%
GOLDEN SHINER	5/ 99	5.05%	7/ 25	28.0%	12/124	9.68%
CARP	3/ 99	3.03%	9/ 25	36.0%	12/124	9.68%
SMALLMOUTH BASS	10/ 99	10.1%	1/ 25	4.00%	11/124	8.87%
LAKE HERRING (CISCO)	7/ 99	7.07%	0/ 25	0.00%	7/124	5.65%
WHITE CRAPPIE	0/ 99	0.00%	4/ 25	16.0%	4/124	3.23%
LAKE WHITEFISH	2/ 99	2.02%	0/ 25	0.00%	2/124	1.61%
FRESHWATER DRUM	0/ 99	0.00%	1/ 25	4.00%	1/124	0.81%
WHITE BASS	0/ 99	0.00%	1/ 25	4.00%	1/124	0.81%
Class: 06 SMO (Depth/Area/Secchi)						
BLACK CRAPPIE	2/ 2	100%	0/ 2	0.00%	2/ 4	50.0%
BLUEGILL	2/ 2	100%	0/ 2	0.00%	2/ 4	50.0%
NORTHERN PIKE	2/ 2	100%	0/ 2	0.00%	2/ 4	50.0%
YELLOW PERCH	2/ 2	100%	0/ 2	0.00%	2/ 4	50.0%
BROWN BULLHEAD	1/ 2	50.0%	0/ 2	0.00%	1/ 4	25.0%
LARGEMOUTH BASS	1/ 2	50.0%	0/ 2	0.00%	1/ 4	25.0%
GOLDEN SHINER	1/ 2	50.0%	0/ 2	0.00%	1/ 4	25.0%
WALLEYE	1/ 2	50.0%	0/ 2	0.00%	1/ 4	25.0%
WHITE SUCKER	1/ 2	50.0%	0/ 2	0.00%	1/ 4	25.0%

	NORTH		SOUTH		TOTAL	
Class: 07 SLE (Depth/Area/Secchi)						
YELLOW PERCH	7/ 7	100%	17/ 19	89.5%	24/ 26	92.3%
NORTHERN PIKE	7/ 7	100%	16/ 19	84.2%	23/ 26	88.5%
WALLEYE	7/ 7	100%	16/ 19	84.2%	23/ 26	88.5%
WHITE SUCKER	7/ 7	100%	16/ 19	84.2%	23/ 26	88.5%
BLACK CRAPPIE	4/ 7	57.1%	18/ 19	94.7%	22/ 26	84.6%
BLUEGILL	4/ 7	57.1%	14/ 19	73.7%	18/ 26	69.2%
CARP	1/ 7	14.3%	17/ 19	89.5%	18/ 26	69.2%
BROWN BULLHEAD	3/ 7	42.9%	9/ 19	47.4%	12/ 26	46.2%
WHITE CRAPPIE	0/ 7	0.00%	11/ 19	57.9%	11/ 26	42.3%
LARGEMOUTH BASS	2/ 7	28.6%	5/ 19	26.3%	7/ 26	26.9%
WHITE BASS	0/ 7	0.00%	6/ 19	31.6%	6/ 26	23.1%
FRESHWATER DRUM	0/ 7	0.00%	5/ 19	26.3%	5/ 26	19.2%
GREEN SUNFISH	0/ 7	0.00%	4/ 19	21.1%	4/ 26	15.4%
GOLDEN SHINER	0/ 7	0.00%	3/ 19	15.8%	3/ 26	11.5%
LAKE WHITEFISH	1/ 7	14.3%	1/ 19	5.26%	2/ 26	7.69%
SMALLMOUTH BASS	0/ 7	0.00%	1/ 19	5.26%	1/ 26	3.85%
Class: 08 SLM (Depth/Area/Secchi)						
BLACK CRAPPIE	3/ 3	100%	2/ 2	100%	5/ 5	100%
NORTHERN PIKE	3/ 3	100%	2/ 2	100%	5/ 5	100%
WHITE SUCKER	3/ 3	100%	2/ 2	100%	5/ 5	100%
YELLOW PERCH	3/ 3	100%	2/ 2	100%	5/ 5	100%
WALLEYE	3/ 3	100%	1/ 2	50.0%	4/ 5	80.0%
BLUEGILL	2/ 3	66.7%	1/ 2	50.0%	3/ 5	60.0%
BROWN BULLHEAD	2/ 3	66.7%	1/ 2	50.0%	3/ 5	60.0%
GOLDEN SHINER	2/ 3	66.7%	1/ 2	50.0%	3/ 5	60.0%
LARGEMOUTH BASS	2/ 3	66.7%	0/ 2	0.00%	2/ 5	40.0%
CARP	0/ 3	0.00%	2/ 2	100%	2/ 5	40.0%
GREEN SUNFISH	0/ 3	0.00%	2/ 2	100%	2/ 5	40.0%
LAKE WHITEFISH	1/ 3	33.3%	0/ 2	0.00%	1/ 5	20.0%
SMALLMOUTH BASS	1/ 3	33.3%	0/ 2	0.00%	1/ 5	20.0%
LAKE HERRING (CISCO)	1/ 3	33.3%	0/ 2	0.00%	1/ 5	20.0%
WHITE CRAPPIE	0/ 3	0.00%	1/ 2	50.0%	1/ 5	20.0%
Class: 10 MSE (Depth/Area/Secchi)						
NORTHERN PIKE	61/ 85	71.8%	60/ 82	73.2%	121/167	72.5%
YELLOW PERCH	61/ 85	71.8%	57/ 82	69.5%	118/167	70.7%
BLACK CRAPPIE	43/ 85	50.6%	73/ 82	89.0%	116/167	69.5%
BLUEGILL	37/ 85	43.5%	73/ 82	89.0%	110/167	65.9%
WHITE SUCKER	46/ 85	54.1%	50/ 82	61.0%	96/167	57.5%
BROWN BULLHEAD	35/ 85	41.2%	43/ 82	52.4%	78/167	46.7%
LARGEMOUTH BASS	24/ 85	28.2%	45/ 82	54.9%	69/167	41.3%
CARP	1/ 85	1.18%	50/ 82	61.0%	51/167	30.5%
GOLDEN SHINER	10/ 85	11.8%	37/ 82	45.1%	47/167	28.1%
WALLEYE	23/ 85	27.1%	22/ 82	26.8%	45/167	26.9%
GREEN SUNFISH	2/ 85	2.35%	30/ 82	36.6%	32/167	19.2%
WHITE CRAPPIE	0/ 85	0.00%	27/ 82	32.9%	27/167	16.2%
FRESHWATER DRUM	0/ 85	0.00%	3/ 82	3.66%	3/167	1.80%
SMALLMOUTH BASS	1/ 85	1.18%	1/ 82	1.22%	2/167	1.20%
WHITE BASS	0/ 85	0.00%	1/ 82	1.22%	1/167	0.60%

	NORTH		SOUTH		TOTAL	
Class: 11 MSM (Depth/Area/Secchi)						
NORTHERN PIKE	246/350	70.3%	66/ 71	93.0%	312/421	74.1%
YELLOW PERCH	257/350	73.4%	50/ 71	70.4%	307/421	72.9%
WHITE SUCKER	199/350	56.9%	38/ 71	53.5%	237/421	56.3%
BLUEGILL	173/350	49.4%	63/ 71	88.7%	236/421	56.1%
BLACK CRAPPIE	162/350	46.3%	61/ 71	85.9%	223/421	53.0%
LARGEMOUTH BASS	150/350	42.9%	51/ 71	71.8%	201/421	47.7%
BROWN BULLHEAD	120/350	34.3%	47/ 71	66.2%	167/421	39.7%
WALLEYE	96/350	27.4%	22/ 71	31.0%	118/421	28.0%
GREEN SUNFISH	23/350	6.57%	39/ 71	54.9%	62/421	14.7%
GOLDEN SHINER	30/350	8.57%	23/ 71	32.4%	53/421	12.6%
CARP	3/350	0.86%	23/ 71	32.4%	26/421	6.18%
LAKE HERRING (CISCO)	22/350	6.29%	3/ 71	4.23%	25/421	5.94%
SMALLMOUTH BASS	12/350	3.43%	3/ 71	4.23%	15/421	3.56%
WHITE CRAPPIE	0/350	0.00%	13/ 71	18.3%	13/421	3.09%
LAKE TROUT	7/350	2.00%	1/ 71	1.41%	8/421	1.90%
LAKE WHITEFISH	6/350	1.71%	0/ 71	0.00%	6/421	1.43%
FRESHWATER DRUM	0/350	0.00%	1/ 71	1.41%	1/421	0.24%
Class: 12 MSO (Depth/Area/Secchi)						
YELLOW PERCH	50/ 76	65.8%	5/ 6	83.3%	55/ 82	67.1%
NORTHERN PIKE	41/ 76	53.9%	6/ 6	100%	47/ 82	57.3%
WHITE SUCKER	40/ 76	52.6%	3/ 6	50.0%	43/ 82	52.4%
LARGEMOUTH BASS	36/ 76	47.4%	6/ 6	100%	42/ 82	51.2%
BLUEGILL	35/ 76	46.1%	6/ 6	100%	41/ 82	50.0%
BLACK CRAPPIE	27/ 76	35.5%	6/ 6	100%	33/ 82	40.2%
BROWN BULLHEAD	17/ 76	22.4%	5/ 6	83.3%	22/ 82	26.8%
WALLEYE	17/ 76	22.4%	4/ 6	66.7%	21/ 82	25.6%
GREEN SUNFISH	10/ 76	13.2%	5/ 6	83.3%	15/ 82	18.3%
LAKE TROUT	8/ 76	10.5%	0/ 6	0.00%	8/ 82	9.76%
GOLDEN SHINER	6/ 76	7.89%	1/ 6	16.7%	7/ 82	8.54%
SMALLMOUTH BASS	7/ 76	9.21%	0/ 6	0.00%	7/ 82	8.54%
LAKE HERRING (CISCO)	4/ 76	5.26%	0/ 6	0.00%	4/ 82	4.88%
Class: 13 MME (Depth/Area/Secchi)						
NORTHERN PIKE	98/102	96.1%	135/142	95.1%	233/244	95.5%
YELLOW PERCH	96/102	94.1%	135/142	95.1%	231/244	94.7%
BLACK CRAPPIE	79/102	77.5%	136/142	95.8%	215/244	88.1%
WHITE SUCKER	92/102	90.2%	120/142	84.5%	212/244	86.9%
BLUEGILL	76/102	74.5%	136/142	95.8%	212/244	86.9%
WALLEYE	79/102	77.5%	111/142	78.2%	190/244	77.9%
BROWN BULLHEAD	65/102	63.7%	97/142	68.3%	162/244	66.4%
LARGEMOUTH BASS	51/102	50.0%	111/142	78.2%	162/244	66.4%
CARP	9/102	8.82%	106/142	74.6%	115/244	47.1%
GOLDEN SHINER	13/102	12.7%	80/142	56.3%	93/244	38.1%
GREEN SUNFISH	10/102	9.80%	64/142	45.1%	74/244	30.3%
WHITE CRAPPIE	0/102	0.00%	68/142	47.9%	68/244	27.9%
LAKE HERRING (CISCO)	22/102	21.6%	1/142	0.70%	23/244	9.43%
FRESHWATER DRUM	1/102	0.98%	19/142	13.4%	20/244	8.20%
WHITE BASS	0/102	0.00%	11/142	7.75%	11/244	4.51%
SMALLMOUTH BASS	6/102	5.88%	3/142	2.11%	9/244	3.69%
LAKE WHITEFISH	5/102	4.90%	1/142	0.70%	6/244	2.46%

	NORTH		SOUTH		TOTAL	
Class: 14 MMM (Depth/Area/Secchi)						
NORTHERN PIKE	509/531	95.9%	99/102	97.1%	608/633	96.1%
YELLOW PERCH	487/531	91.7%	98/102	96.1%	585/633	92.4%
WHITE SUCKER	461/531	86.8%	87/102	85.3%	548/633	86.6%
BLUEGILL	395/531	74.4%	101/102	99.0%	496/633	78.4%
WALLEYE	411/531	77.4%	79/102	77.5%	490/633	77.4%
BLACK CRAPPIE	382/531	71.9%	100/102	98.0%	482/633	76.1%
LARGEMOUTH BASS	357/531	67.2%	87/102	85.3%	444/633	70.1%
BROWN BULLHEAD	307/531	57.8%	78/102	76.5%	385/633	60.8%
LAKE HERRING (CISCO)	179/531	33.7%	14/102	13.7%	193/633	30.5%
GREEN SUNFISH	81/531	15.3%	62/102	60.8%	143/633	22.6%
GOLDEN SHINER	56/531	10.5%	33/102	32.4%	89/633	14.1%
CARP	22/531	4.14%	60/102	58.8%	82/633	13.0%
SMALLMOUTH BASS	69/531	13.0%	6/102	5.88%	75/633	11.8%
LAKE WHITEFISH	21/531	3.95%	0/102	0.00%	21/633	3.32%
WHITE CRAPPIE	0/531	0.00%	20/102	19.6%	20/633	3.16%
FRESHWATER DRUM	1/531	0.19%	6/102	5.88%	7/633	1.11%
LAKE TROUT	2/531	0.38%	0/102	0.00%	2/633	0.32%
WHITE BASS	0/531	0.00%	2/102	1.96%	2/633	0.32%
Class: 15 MMO (Depth/Area/Secchi)						
NORTHERN PIKE	71/ 78	91.0%	6/ 7	85.7%	77/ 85	90.6%
YELLOW PERCH	73/ 78	93.6%	4/ 7	57.1%	77/ 85	90.6%
WHITE SUCKER	67/ 78	85.9%	3/ 7	42.9%	70/ 85	82.4%
LARGEMOUTH BASS	62/ 78	79.5%	6/ 7	85.7%	68/ 85	80.0%
WALLEYE	61/ 78	78.2%	5/ 7	71.4%	66/ 85	77.6%
BLUEGILL	58/ 78	74.4%	6/ 7	85.7%	64/ 85	75.3%
BLACK CRAPPIE	51/ 78	65.4%	6/ 7	85.7%	57/ 85	67.1%
BROWN BULLHEAD	37/ 78	47.4%	5/ 7	71.4%	42/ 85	49.4%
LAKE HERRING (CISCO)	21/ 78	26.9%	0/ 7	0.00%	21/ 85	24.7%
SMALLMOUTH BASS	20/ 78	25.6%	0/ 7	0.00%	20/ 85	23.5%
GREEN SUNFISH	14/ 78	17.9%	4/ 7	57.1%	18/ 85	21.2%
CARP	3/ 78	3.85%	2/ 7	28.6%	5/ 85	5.88%
GOLDEN SHINER	2/ 78	2.56%	2/ 7	28.6%	4/ 85	4.71%
LAKE WHITEFISH	4/ 78	5.13%	0/ 7	0.00%	4/ 85	4.71%
LAKE TROUT	3/ 78	3.85%	0/ 7	0.00%	3/ 85	3.53%
WHITE CRAPPIE	0/ 78	0.00%	1/ 7	14.3%	1/ 85	1.18%

	NORTH		SOUTH		TOTAL	
Class: 16 MLE (Depth/Area/Secchi)						
BLACK CRAPPIE	14/ 14	100%	17/ 17	100%	31/ 31	100%
NORTHERN PIKE	14/ 14	100%	17/ 17	100%	31/ 31	100%
WALLEYE	14/ 14	100%	17/ 17	100%	31/ 31	100%
WHITE SUCKER	14/ 14	100%	17/ 17	100%	31/ 31	100%
YELLOW PERCH	14/ 14	100%	17/ 17	100%	31/ 31	100%
BLUEGILL	10/ 14	71.4%	16/ 17	94.1%	26/ 31	83.9%
LARGEMOUTH BASS	7/ 14	50.0%	14/ 17	82.4%	21/ 31	67.7%
BROWN BULLHEAD	9/ 14	64.3%	11/ 17	64.7%	20/ 31	64.5%
CARP	2/ 14	14.3%	15/ 17	88.2%	17/ 31	54.8%
GOLDEN SHINER	2/ 14	14.3%	11/ 17	64.7%	13/ 31	41.9%
WHITE CRAPPIE	0/ 14	0.00%	13/ 17	76.5%	13/ 31	41.9%
FRESHWATER DRUM	1/ 14	7.14%	10/ 17	58.8%	11/ 31	35.5%
LAKE HERRING (CISCO)	9/ 14	64.3%	1/ 17	5.88%	10/ 31	32.3%
GREEN SUNFISH	1/ 14	7.14%	6/ 17	35.3%	7/ 31	22.6%
SMALLMOUTH BASS	3/ 14	21.4%	2/ 17	11.8%	5/ 31	16.1%
WHITE BASS	0/ 14	0.00%	4/ 17	23.5%	4/ 31	12.9%
LAKE WHITEFISH	4/ 14	28.6%	0/ 17	0.00%	4/ 31	12.9%
Class: 17 MLM (Depth/Area/Secchi)						
NORTHERN PIKE	46/ 46	100%	5/ 5	100%	51/ 51	100%
YELLOW PERCH	46/ 46	100%	5/ 5	100%	51/ 51	100%
WALLEYE	45/ 46	97.8%	5/ 5	100%	50/ 51	98.0%
WHITE SUCKER	45/ 46	97.8%	5/ 5	100%	50/ 51	98.0%
BLACK CRAPPIE	38/ 46	82.6%	5/ 5	100%	43/ 51	84.3%
LAKE HERRING (CISCO)	38/ 46	82.6%	2/ 5	40.0%	40/ 51	78.4%
BLUEGILL	32/ 46	69.6%	5/ 5	100%	37/ 51	72.5%
BROWN BULLHEAD	31/ 46	67.4%	4/ 5	80.0%	35/ 51	68.6%
LARGEMOUTH BASS	28/ 46	60.9%	4/ 5	80.0%	32/ 51	62.7%
SMALLMOUTH BASS	15/ 46	32.6%	0/ 5	0.00%	15/ 51	29.4%
GREEN SUNFISH	9/ 46	19.6%	2/ 5	40.0%	11/ 51	21.6%
CARP	4/ 46	8.70%	5/ 5	100%	9/ 51	17.6%
LAKE WHITEFISH	7/ 46	15.2%	0/ 5	0.00%	7/ 51	13.7%
FRESHWATER DRUM	4/ 46	8.70%	0/ 5	0.00%	4/ 51	7.84%
GOLDEN SHINER	1/ 46	2.17%	1/ 5	20.0%	2/ 51	3.92%
WHITE CRAPPIE	0/ 46	0.00%	1/ 5	20.0%	1/ 51	1.96%
Class: 18 MLO (Depth/Area/Secchi)						
LAKE WHITEFISH	2/ 2	100%	0/ 0	****%	2/ 2	100%
NORTHERN PIKE	2/ 2	100%	0/ 0	****%	2/ 2	100%
WALLEYE	2/ 2	100%	0/ 0	****%	2/ 2	100%
WHITE SUCKER	2/ 2	100%	0/ 0	****%	2/ 2	100%
YELLOW PERCH	2/ 2	100%	0/ 0	****%	2/ 2	100%
BLACK CRAPPIE	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
BLUEGILL	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
BROWN BULLHEAD	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
CARP	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
FRESHWATER DRUM	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
GREEN SUNFISH	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
LARGEMOUTH BASS	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
SMALLMOUTH BASS	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%
LAKE HERRING (CISCO)	1/ 2	50.0%	0/ 0	****%	1/ 2	50.0%

	NORTH			SOUTH			TOTAL		
Class: 19 DSE (Depth/Area/Secchi)									
NORTHERN PIKE	6/	6	100%	1/	1	100%	7/	7	100%
BLACK CRAPPIE	5/	6	83.3%	0/	1	0.00%	5/	7	71.4%
BLUEGILL	4/	6	66.7%	0/	1	0.00%	4/	7	57.1%
YELLOW PERCH	4/	6	66.7%	0/	1	0.00%	4/	7	57.1%
BROWN BULLHEAD	3/	6	50.0%	0/	1	0.00%	3/	7	42.9%
LARGEMOUTH BASS	3/	6	50.0%	0/	1	0.00%	3/	7	42.9%
WHITE SUCKER	2/	6	33.3%	0/	1	0.00%	2/	7	28.6%
WALLEYE	1/	6	16.7%	0/	1	0.00%	1/	7	14.3%
Class: 20 DSM (Depth/Area/Secchi)									
NORTHERN PIKE	20/	26	76.9%	7/	7	100%	27/	33	81.8%
BLUEGILL	17/	26	65.4%	7/	7	100%	24/	33	72.7%
YELLOW PERCH	17/	26	65.4%	6/	7	85.7%	23/	33	69.7%
LARGEMOUTH BASS	14/	26	53.8%	7/	7	100%	21/	33	63.6%
BLACK CRAPPIE	12/	26	46.2%	6/	7	85.7%	18/	33	54.5%
WHITE SUCKER	14/	26	53.8%	2/	7	28.6%	16/	33	48.5%
BROWN BULLHEAD	10/	26	38.5%	5/	7	71.4%	15/	33	45.5%
WALLEYE	5/	26	19.2%	1/	7	14.3%	6/	33	18.2%
GREEN SUNFISH	1/	26	3.85%	5/	7	71.4%	6/	33	18.2%
CARP	0/	26	0.00%	5/	7	71.4%	5/	33	15.2%
GOLDEN SHINER	4/	26	15.4%	1/	7	14.3%	5/	33	15.2%
LAKE HERRING (CISCO)	4/	26	15.4%	1/	7	14.3%	5/	33	15.2%
SMALLMOUTH BASS	1/	26	3.85%	1/	7	14.3%	2/	33	6.06%
LAKE TROUT	1/	26	3.85%	0/	7	0.00%	1/	33	3.03%
Class: 21 DSO (Depth/Area/Secchi)									
WHITE SUCKER	18/	26	69.2%	0/	0	****%	18/	26	69.2%
NORTHERN PIKE	15/	26	57.7%	0/	0	****%	15/	26	57.7%
YELLOW PERCH	14/	26	53.8%	0/	0	****%	14/	26	53.8%
BLUEGILL	13/	26	50.0%	0/	0	****%	13/	26	50.0%
LARGEMOUTH BASS	13/	26	50.0%	0/	0	****%	13/	26	50.0%
BLACK CRAPPIE	9/	26	34.6%	0/	0	****%	9/	26	34.6%
LAKE TROUT	7/	26	26.9%	0/	0	****%	7/	26	26.9%
BROWN BULLHEAD	5/	26	19.2%	0/	0	****%	5/	26	19.2%
LAKE HERRING (CISCO)	4/	26	15.4%	0/	0	****%	4/	26	15.4%
WALLEYE	4/	26	15.4%	0/	0	****%	4/	26	15.4%
GREEN SUNFISH	2/	26	7.69%	0/	0	****%	2/	26	7.69%
GOLDEN SHINER	1/	26	3.85%	0/	0	****%	1/	26	3.85%
Class: 22 DME (Depth/Area/Secchi)									
BLACK CRAPPIE	3/	3	100%	10/	10	100%	13/	13	100%
BLUEGILL	3/	3	100%	10/	10	100%	13/	13	100%
NORTHERN PIKE	3/	3	100%	10/	10	100%	13/	13	100%
WALLEYE	3/	3	100%	10/	10	100%	13/	13	100%
WHITE SUCKER	3/	3	100%	10/	10	100%	13/	13	100%
YELLOW PERCH	3/	3	100%	10/	10	100%	13/	13	100%
LARGEMOUTH BASS	1/	3	33.3%	9/	10	90.0%	10/	13	76.9%
BROWN BULLHEAD	1/	3	33.3%	8/	10	80.0%	9/	13	69.2%
CARP	0/	3	0.00%	9/	10	90.0%	9/	13	69.2%
GREEN SUNFISH	0/	3	0.00%	5/	10	50.0%	5/	13	38.5%
LAKE HERRING (CISCO)	2/	3	66.7%	2/	10	20.0%	4/	13	30.8%
GOLDEN SHINER	0/	3	0.00%	4/	10	40.0%	4/	13	30.8%
WHITE CRAPPIE	0/	3	0.00%	3/	10	30.0%	3/	13	23.1%
SMALLMOUTH BASS	1/	3	33.3%	1/	10	10.0%	2/	13	15.4%

	NORTH		SOUTH		TOTAL	
Class: 23 DMM (Depth/Area/Secchi)						
NORTHERN PIKE	96/103	93.2%	32/ 33	97.0%	128/136	94.1%
WHITE SUCKER	91/103	88.3%	31/ 33	93.9%	122/136	89.7%
YELLOW PERCH	81/103	78.6%	31/ 33	93.9%	112/136	82.4%
BLUEGILL	72/103	69.9%	33/ 33	100%	105/136	77.2%
BLACK CRAPPIE	72/103	69.9%	32/ 33	97.0%	104/136	76.5%
WALLEYE	74/103	71.8%	28/ 33	84.8%	102/136	75.0%
LARGEMOUTH BASS	70/103	68.0%	30/ 33	90.9%	100/136	73.5%
BROWN BULLHEAD	56/103	54.4%	29/ 33	87.9%	85/136	62.5%
LAKE HERRING (CISCO)	56/103	54.4%	16/ 33	48.5%	72/136	52.9%
GREEN SUNFISH	19/103	18.4%	22/ 33	66.7%	41/136	30.1%
CARP	8/103	7.77%	20/ 33	60.6%	28/136	20.6%
SMALLMOUTH BASS	16/103	15.5%	1/ 33	3.03%	17/136	12.5%
LAKE TROUT	15/103	14.6%	0/ 33	0.00%	15/136	11.0%
LAKE WHITEFISH	11/103	10.7%	1/ 33	3.03%	12/136	8.82%
GOLDEN SHINER	4/103	3.88%	8/ 33	24.2%	12/136	8.82%
FRESHWATER DRUM	2/103	1.94%	2/ 33	6.06%	4/136	2.94%
WHITE CRAPPIE	1/103	0.97%	1/ 33	3.03%	2/136	1.47%
Class: 24 DMO (Depth/Area/Secchi)						
WHITE SUCKER	63/ 69	91.3%	3/ 3	100%	66/ 72	91.7%
YELLOW PERCH	52/ 69	75.4%	3/ 3	100%	55/ 72	76.4%
NORTHERN PIKE	50/ 69	72.5%	3/ 3	100%	53/ 72	73.6%
BLUEGILL	35/ 69	50.7%	3/ 3	100%	38/ 72	52.8%
LARGEMOUTH BASS	32/ 69	46.4%	3/ 3	100%	35/ 72	48.6%
WALLEYE	33/ 69	47.8%	1/ 3	33.3%	34/ 72	47.2%
BLACK CRAPPIE	30/ 69	43.5%	3/ 3	100%	33/ 72	45.8%
LAKE HERRING (CISCO)	33/ 69	47.8%	0/ 3	0.00%	33/ 72	45.8%
LAKE TROUT	30/ 69	43.5%	0/ 3	0.00%	30/ 72	41.7%
SMALLMOUTH BASS	26/ 69	37.7%	1/ 3	33.3%	27/ 72	37.5%
BROWN BULLHEAD	17/ 69	24.6%	3/ 3	100%	20/ 72	27.8%
GREEN SUNFISH	12/ 69	17.4%	3/ 3	100%	15/ 72	20.8%
GOLDEN SHINER	5/ 69	7.25%	1/ 3	33.3%	6/ 72	8.33%
LAKE WHITEFISH	6/ 69	8.70%	0/ 3	0.00%	6/ 72	8.33%
CARP	1/ 69	1.45%	2/ 3	66.7%	3/ 72	4.17%
Class: 25 DLE (Depth/Area/Secchi)						
BLACK CRAPPIE	5/ 5	100%	5/ 5	100%	10/ 10	100%
NORTHERN PIKE	5/ 5	100%	5/ 5	100%	10/ 10	100%
WALLEYE	5/ 5	100%	5/ 5	100%	10/ 10	100%
WHITE SUCKER	5/ 5	100%	5/ 5	100%	10/ 10	100%
YELLOW PERCH	5/ 5	100%	5/ 5	100%	10/ 10	100%
LAKE HERRING (CISCO)	4/ 5	80.0%	4/ 5	80.0%	8/ 10	80.0%
BROWN BULLHEAD	3/ 5	60.0%	5/ 5	100%	8/ 10	80.0%
BLUEGILL	3/ 5	60.0%	5/ 5	100%	8/ 10	80.0%
LARGEMOUTH BASS	2/ 5	40.0%	5/ 5	100%	7/ 10	70.0%
CARP	1/ 5	20.0%	4/ 5	80.0%	5/ 10	50.0%
GREEN SUNFISH	1/ 5	20.0%	3/ 5	60.0%	4/ 10	40.0%
SMALLMOUTH BASS	1/ 5	20.0%	3/ 5	60.0%	4/ 10	40.0%
LAKE WHITEFISH	2/ 5	40.0%	1/ 5	20.0%	3/ 10	30.0%
WHITE CRAPPIE	0/ 5	0.00%	2/ 5	40.0%	2/ 10	20.0%
FRESHWATER DRUM	1/ 5	20.0%	0/ 5	0.00%	1/ 10	10.0%
GOLDEN SHINER	0/ 5	0.00%	1/ 5	20.0%	1/ 10	10.0%

	NORTH			SOUTH			TOTAL		
Class: 26 DLM (Depth/Area/Secchi)									
NORTHERN PIKE	54/	54	100%	6/	6	100%	60/	60	100%
WHITE SUCKER	54/	54	100%	6/	6	100%	60/	60	100%
YELLOW PERCH	54/	54	100%	6/	6	100%	60/	60	100%
WALLEYE	53/	54	98.1%	6/	6	100%	59/	60	98.3%
LAKE HERRING (CISCO)	54/	54	100%	4/	6	66.7%	58/	60	96.7%
BROWN BULLHEAD	45/	54	83.3%	6/	6	100%	51/	60	85.0%
BLACK CRAPPIE	43/	54	79.6%	6/	6	100%	49/	60	81.7%
BLUEGILL	40/	54	74.1%	6/	6	100%	46/	60	76.7%
LARGEMOUTH BASS	40/	54	74.1%	6/	6	100%	46/	60	76.7%
SMALLMOUTH BASS	17/	54	31.5%	5/	6	83.3%	22/	60	36.7%
GREEN SUNFISH	15/	54	27.8%	6/	6	100%	21/	60	35.0%
LAKE WHITEFISH	13/	54	24.1%	0/	6	0.00%	13/	60	21.7%
CARP	8/	54	14.8%	5/	6	83.3%	13/	60	21.7%
GOLDEN SHINER	3/	54	5.56%	0/	6	0.00%	3/	60	5.00%
FRESHWATER DRUM	2/	54	3.70%	0/	6	0.00%	2/	60	3.33%
LAKE TROUT	1/	54	1.85%	0/	6	0.00%	1/	60	1.67%
Class: 27 DLO (Depth/Area/Secchi)									
WHITE SUCKER	17/	17	100%	0/	0	****%	17/	17	100%
WALLEYE	16/	17	94.1%	0/	0	****%	16/	17	94.1%
YELLOW PERCH	14/	17	82.4%	0/	0	****%	14/	17	82.4%
NORTHERN PIKE	13/	17	76.5%	0/	0	****%	13/	17	76.5%
SMALLMOUTH BASS	13/	17	76.5%	0/	0	****%	13/	17	76.5%
LAKE HERRING (CISCO)	11/	17	64.7%	0/	0	****%	11/	17	64.7%
LAKE TROUT	10/	17	58.8%	0/	0	****%	10/	17	58.8%
LARGEMOUTH BASS	7/	17	41.2%	0/	0	****%	7/	17	41.2%
LAKE WHITEFISH	7/	17	41.2%	0/	0	****%	7/	17	41.2%
BLACK CRAPPIE	6/	17	35.3%	0/	0	****%	6/	17	35.3%
BLUEGILL	6/	17	35.3%	0/	0	****%	6/	17	35.3%
BROWN BULLHEAD	5/	17	29.4%	0/	0	****%	5/	17	29.4%
GREEN SUNFISH	4/	17	23.5%	0/	0	****%	4/	17	23.5%
CARP	1/	17	5.88%	0/	0	****%	1/	17	5.88%
GOLDEN SHINER	1/	17	5.88%	0/	0	****%	1/	17	5.88%