

# Minnesota National Lakes Assessment Project:

Fish-based Index of Biotic Integrity (IBI) for Minnesota Lakes

*This report is part of a series based on Minnesota's participation in  
U.S. EPA's 2007 National Lake Assessment*



**Nick Proulx  
And  
Melissa Drake  
Minnesota Department of Natural Resources**

**November 2009**



# **Minnesota National Lakes Assessment Project:**

## **Fish-based Index of Biotic Integrity (IBI) for Minnesota Lakes**

### **ACKNOWLEDGEMENTS**

NLAP study coordination: Steve Heiskary, Minnesota Pollution Control Agency (MPCA) & Michael Duval, Minnesota Department of Natural Resources (MDNR)

MPCA (Environmental Analysis and Outcomes) sampling team leaders: Jesse Anderson, Steve Heiskary, Matt Lindon, and Kelly O'Hara (emphasis on water quality and sediment sample collection)

MPCA student interns – David Tollefson and Monica Brooks

MDNR sampling team: Paul Eiler, Mark Henry, Andy Levar, Dale Lockwood and Jason Neuman (emphasis on near-shore assessment, plant identification and benthic collection) – Lake IBI sampling: Bobbi Chapman, Paul Eiler (plus another staff member from NE), Chris Foster, Chris Gelner, Melissa Lasch, Ryan Lisson, Jason Neuman, Ryan Ransom, Nissa Rudh, and Kimberly Strand.

U.S. Forest Service (sampling assistance in Superior National Forest): Jason Butcher, Brent Flatten, and Ken Gebhardt (coordination)

Report author: Nick Proulx, MDNR

Report Review: Pam Anderson and Steve Heiskary (Environmental Analysis and Outcomes) MPCA and Michael Duval (Fisheries) and David Wright (Ecological Resources), MDNR

**Table of Contents**

Introduction.....1  
Background .....4  
Method.....4  
Results and Discussion .....5  
Summary and Conclusions .....18  
References .....19

**List of Tables**

Table 1. Recommended sampling stations by size of lake.....5  
Table 2. NLAP lake IBI sampling lake summary.....6  
Table 3. Fish species collected across all sampling gears.....8

**List of Figures**

Figure 1. Location of Minnesota’s NLAP lakes as surveyed in 2007-2008.....2  
Figure 2. Location of Minnesota’s NLAP IBI lakes as surveyed in 2007-2008.....3  
Figure 3. IBI scores for the NLAP lakes surveyed in 2007-2008.....7  
Figure 4. Distribution NLAP lake characteristics.....10  
Figure 5. Distribution of NLAP IBI scores and all other IBI scores .....11  
Figure 6. Boxplot of IBI scores by trophic state for NLAP and other IBI lakes.....11  
Figure 7. Relationship between IBI and trophic state for NLAP and other IBI lakes.....12  
Figure 8. Relationship between IBI and floristic quality for NLAP and other IBI lakes.....12  
Figure 9. Relationship between IBI and watershed landuse for NLAP and other IBI lakes.....13  
Figure 10. Relationship between NLAP IBI and physical lake characteristics.....15  
Figure 11. Relationship between NLAP IBI and chemical measures.....16  
Figure 12. Relationship between NLAP IBI and aquatic plant measures.....17

**List of Appendixes**

Appendix A. Example IBI scoring sheet.....20

## **Introduction**

### **National Lakes Assessment Project (NLAP) Overview**

The U.S. Environmental Protection Agency (EPA) has a responsibility to assess the health of the Nation's water resources. One of the methods for assessment is statistically-based surveys. The Survey of the Nation's Lakes, conducted in 2007, is one of a series of water surveys being conducted by states, tribes, the U.S. EPA, and other partners. In addition to lakes, partners will also study coastal waters, wadable streams, rivers, and wetlands in a revolving sequence. The purpose of these surveys is to generate statistically-valid and environmentally relevant reports on the condition of the Nation's water resources of streams, lakes, wetlands and estuaries at nation-wide and regional scales.

The goal of the Lakes Survey is to address two key questions about the quality of the Nation's lakes, ponds, and reservoirs:

- What percent of the Nation's lakes are in good, fair, and poor condition for key indicators of trophic state, ecological health, and recreation?
- What is the relative importance of key stressors such as nutrients and pathogens?

The sampling design for this survey is a probability-based network which will provide statistically-valid estimates of the condition of all lakes with known confidence. It is designed using modern survey techniques. Sample sites are selected at random to represent the condition of all lakes across each the nation and each region. A total of 909 lakes in the conterminous U.S. are included in the Lakes Survey. The sample set is comprised of natural and man-made freshwater lakes, ponds, and reservoirs greater than 10 acres and at least one meter in depth located in the conterminous United States.

The typical sampling effort at each site includes a variety of samples (measurements) collected at a mid-lake index site (often over the deepest point in the lake) including: a two meter integrated sample for water chemistry, chlorophyll-a, microcystin and algal identification; oxygen and temperature profiles; zooplankton tow; and sediment core sample for diatom reconstruction of total phosphorus (based on top and bottom slices from the core) and surface sediment sample for mercury. In addition, 10 random near-shore sites are qualitatively assessed for various littoral and riparian habitat-related measures and a sample for a bacterial indicator was collected. Further details on the survey including methods, parameters measured, and statistical design may be found on the USEPA NLAP web page at: <http://www.epa.gov/owow/lakes/lakesurvey/> .

### **Minnesota's NLAP Overview**

Minnesota's 2007 NLAP effort was led by the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR). Various other collaborators were engaged in this study as well including the U.S. Forest Service (USFS), Minnesota Department of Agriculture (MDA), and U.S. Geological Survey (USGS). MPCA and MDNR combined on initial planning of the survey and conducted a vast majority of the sampling, which took place in July and August for the vast majority of the lakes. USFS staff were instrumental in sampling of remote lakes in the Boundary Waters Canoe Area Wilderness (BWCAW).

Minnesota received 41 lakes as a part of the original draw of lakes for the national survey – the most of any of the lower 48 states. Minnesota chose to add nine lakes to the survey to yield the 50 lakes needed for statistically-based statewide estimates of condition (Figure 1). In addition to the 50 lakes several reference lakes were later selected and sampled by USEPA as a part of the overall NLAP effort. Data from the reference lakes provide an additional basis for assessing lake condition as a part of NLAP.

In addition to adding lakes Minnesota chose to add several value-added measurements as well to the survey of lakes. Examples of these add-ons are: pesticide samples (in conjunction with the MDA); water mercury (in conjunction with USGS); sediment samples for analysis of metals, trace organics and other parameters; identification of macrophytes and maximum rooting depth of macrophytes at the random near-shore sites; fish-based lake IBI sampling; and samples for microcystin at the index and a random near-shore site. Each of these add-ons and several of the standard assessments will be the subject of a series of reports that draw from the NLAP work.

**Figure 1. Location of Minnesota’s NLAP lakes as surveyed in 2007-2008.**



Oct 2007

**Report focus: Fish-based Index of Biotic**

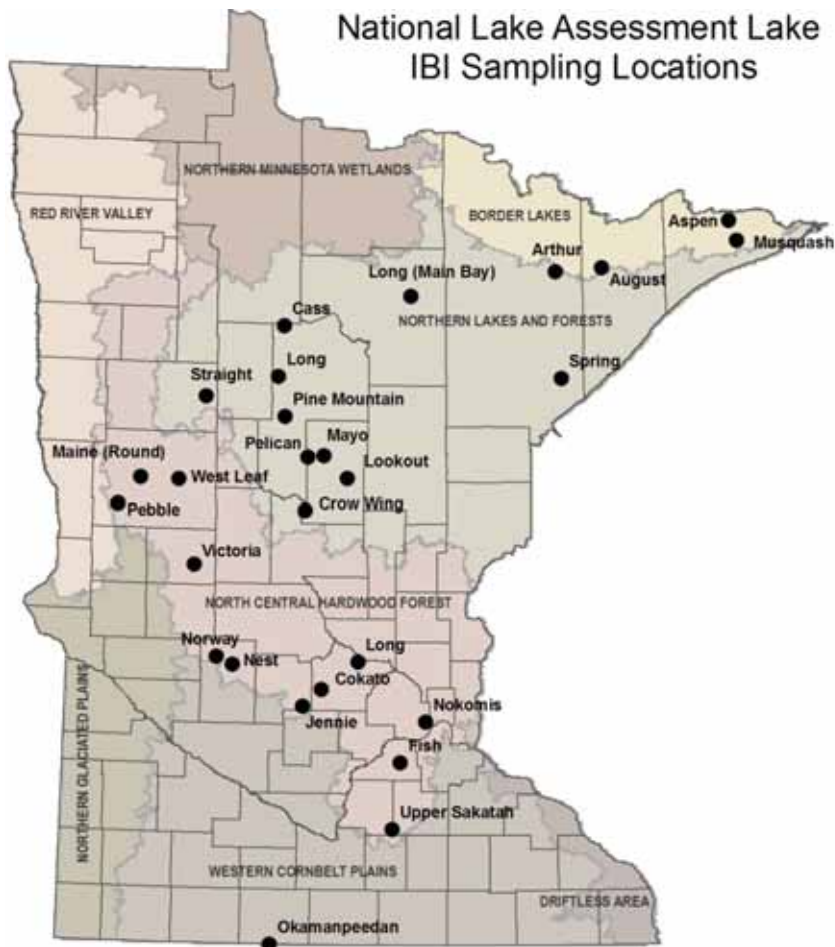
**Integrity (IBI) for Minnesota Lakes**

The fish-based lake IBI sampling is an add-on to the NLAP standard protocol. Not all NLAP lakes were sampled because the lake IBI requires that lakes are managed for game fish and this was not the case for all NLAP lakes. Out of the 50 NLAP lakes, 27 were managed for game fish and thus met the minimum data needs to complete an IBI survey (Figure 2). Given that only 27 lakes were sampled, statistically-based statewide estimates of condition may not be possible for fish communities, however there are roughly 5400 lakes managed for game fish in which estimates of condition are possible.

The objectives for this Minnesota add-on survey are:

1. Lake IBI sampling has been restricted to specific lake types based on chemical, physical and to some extent biological information. These lakes were not chosen randomly, rather targeted as good candidates for tool development. The NLAP study will expand the use of the fish-based lake IBI sampling within the state and provide an opportunity to validate additional lake types.
2. Provide comparison between lake IBI scores and physical, chemical and biological parameters collected for this study. Parameters that strongly correlate with IBI scores can be used to validate the IBI tool as well as the use of biological indicators to evaluate lake health.

**Figure 2. Location of Minnesota’s NLAP IBI lakes.**



**Background**

The Index of Biotic Integrity (IBI) is a frequently used standardized method to measure the status of an aquatic community and thereby make inferences about the relative health of that waterbody (Karr 1981). An IBI utilizes multiple measures of a biological community, called metrics, and compares those measures to those of high-quality or reference sites. Metrics reflect aspects of the structure, function, or some other measurable characteristic of the biotic community that responds in a predictable manner to stressors (Fausch et al. 1990). Metrics are based on species presence and/or abundance and are standardized to a fixed range of potential values. A low score can indicate impairment.

## **Methods**

The fish-based lake IBI under development by the Minnesota DNR incorporates fish data collected by gill nets, trap nets, shoreline seining and shoreline backpack electrofishing. Four different sampling techniques are used because no single gear is sufficient to sample all habitat types or all species present in a lake. All sampling was completed between June 15 and September 15. The gill nets and trap nets were placed according to established protocols set up by MnDNR Fisheries as part of their traditional game fish surveys (MNDNR 1993). Trap net and gill net set locations were chosen to sample the available habitat and the number of net sets per lake was based on lake size. The trap nets have a 12.2-m lead that is 1.1 m deep with two 1.8m X 0.9m frames and six 0.76m hoops with a 13cm diameter throat and mesh size of 19mm. Gill nets are 76m X 1.8m with six 15.2m panels of 19-, 32-, 38-, and 51-mm bar mesh. Both net types were set overnight and the fish were worked up the next day, including counts, lengths and weights for each individual game species. Data were expressed as average catch (numbers and pounds) per net by species and net type. For this study, MnDNR Fisheries completed all game fish surveys.

The nearshore sampling consists of seining and backpack electrofishing at a predefined number of stations that are 30m in length and equally spaced around the perimeter of the lake. The number of stations sampled varied by lake size (Table 1). The type of seine depended on the habitat in the station area. A 50ft, ¼ inch mesh seine was used when there was limited underwater obstructions (habitat) and a 15ft, 1/8 inch mesh seine was deployed in challenging near-shore conditions, such as heavy vegetation, coarse woody debris, boulders, etc. Backpack electrofishing was completed on stations where it could be deployed safely. At some stations only one method could be used, but this should have minimal impact on the overall IBI score. At each station, fish were identified and counted by gear type. Fish voucher specimens were taken for each species and later catalogued in the Indiana Biological Survey.

The fish-base IBI is calculated using sampling data from trap nets, gill nets, and the nearshore sampling (Appendix A). Species were classified into tolerance, feeding, habitat specialist, and family according to Drake and Pereira (2002) and Drake and Valley (2005). Trapnet data were used to calculate metrics describing the relative biomass of tolerant, insectivore, and omnivore fishes, while gill nets were used to calculate metrics describing the relative biomass of intolerant and top carnivore fishes. Nearshore data were used to calculate metrics describing the relative abundance of intolerant, vegetation dwelling, and small benthic dwelling fishes. Richness metrics, defined as the number of species within tolerance, feeding, habitat, and family groups, were calculated by combining species presence across all sampling gears. Metrics were

standardized to values between 0 and 10 using criteria from Drake and Pereira (2002). The IBI contains a total of 16 metrics with a maximum possible score of 160.

**Table 1. Recommended number of sampling stations by size of lake.**

Stations	Range in Hectares	Range in Acres
10	48 – 200	100 – 500
12	300 – 500	500 – 1200
16	500 – 800	1200 – 2000
18	800 – 1000	2000 – 2500
20	>1000	>2500

## Results and Discussion

Twenty-one lakes were surveyed in 2007 and 6 lakes were surveyed in 2008. IBI scores ranged from 34 to 138 with a median of 72 (Table 2). Lakes with higher IBI scores were geographically located in the northern portion of the state, while lakes with lower scores were found in the central and southern part of the state (Figure 3). This pattern is likely related to landuse differences with primarily forested habitat to the north and landscapes with higher percentages of agriculture and urban development to the south and west.

The average number of fish species captured was 19, with a range of 7-28 species per lake. Table 3 summarizes the fish catch across all sampling gears, with 55 total species and 41,706 individuals captured. Bluegill (*Lepomis macrochirus*) and yellow perch (*Perca flavescens*) were sampled with the highest frequency, while five species had less than 5 individuals captured total. Two Minnesota listed species of concern, the pugnose shiner (*Notropis anogenus*) and least darter (*Etheostoma microperca*), were sampled in three lakes and two lakes, respectively.

**Table 2. NLAP lake IBI sampling summary. Highlighted lakes have characteristics consistent with the validated IBI dataset.**

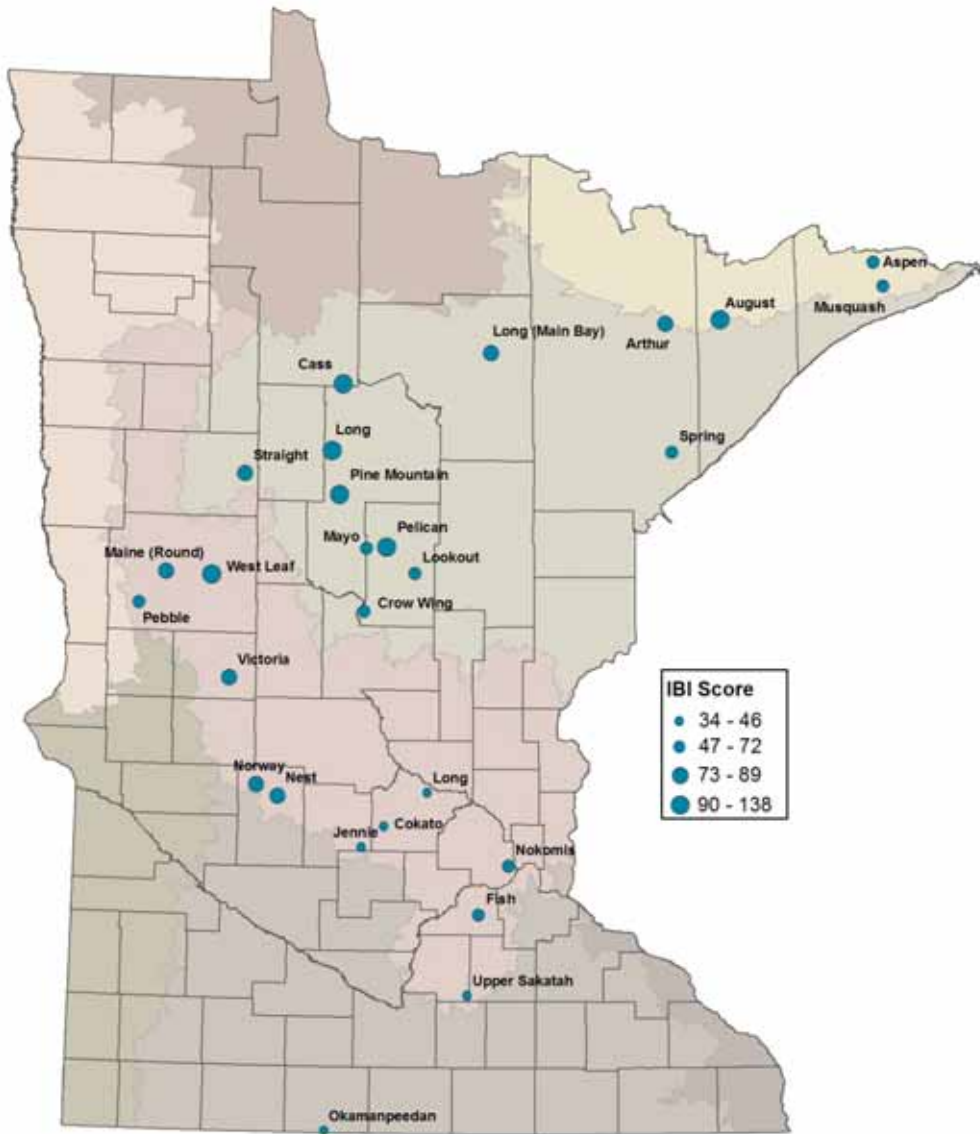
Lake Name	EPA #	DOW #	County	IBI Score	# of spp	Lake Size (acres)	Lake Class*
<b>Straight</b>	<b>NLA06608-0366</b>	<b>03001000</b>	<b>Becker</b>	<b>88</b>	<b>21</b>	<b>470</b>	<b>25</b>
Cass	NLA06608-0403	04003000	Beltrami	138**	26	15,958	22
<b>Pine Mountain</b>	<b>NLA06608-0494</b>	<b>11041100</b>	<b>Cass</b>	<b>111</b>	<b>27</b>	<b>1,558</b>	<b>22</b>
Pelican	NLA06608-0238	18030800	Crow Wing	110	26	8,367	22
<b>Crow Wing</b>	<b>NLA06608-0990</b>	<b>18015500</b>	<b>Crow Wing</b>	<b>55</b>	<b>18</b>	<b>355</b>	<b>31</b>
Victoria	NLA06608-0622	21005400	Douglas	89	27	417	25
<b>Nokomis</b>	<b>NLA06608-0679</b>	<b>27001900</b>	<b>Hennepin</b>	<b>68</b>	<b>20</b>	<b>201</b>	<b>24</b>
Nest	NLA06608-0215	34015400	Kandiyohi	84	22	1,008	24
Norway	NLA06608-1383	34025100	Kandiyohi	79	27	2,327	24
Upper Sakatah	NLA06608-1303	40000200	Le Sueur	35	23	892	41
Okamanpeedan	NLA06608-0759	46005100	Martin	34***	19	2,268	41
<b>Pebble</b>	<b>NLA06608-0174</b>	<b>56082900</b>	<b>Otter Tail</b>	<b>72</b>	<b>19</b>	<b>170</b>	<b>31</b>
West Leaf	NLA06608-0878	56011400	Otter Tail	104	28	693	27
Maine (Round)	NLA06608-1198	56047600	Otter Tail	89	19	86	28
<b>Fish</b>	<b>NLA06608-0935</b>	<b>70006900</b>	<b>Scott</b>	<b>64</b>	<b>17</b>	<b>173</b>	<b>24</b>
Arthur	NLA06608-1342	69015400	St. Louis	84	14	76	11
Long	NLA06608-0743	86006900	Wright	34	19	87	30
<b>Long (Main Bay)</b>	<b>NLA06608-0958</b>	<b>31026601</b>	<b>Itasca</b>	<b>95</b>	<b>20</b>	<b>361</b>	<b>25</b>
August	NLA06608-1038	38069100	Lake	110	13	229	12
Jennie	NLA06608-1175	47001500	Meeker	34	17	1,064	41
<b>Cokato</b>	<b>NLA06608-0551</b>	<b>86026300</b>	<b>Wright</b>	<b>46</b>	<b>19</b>	<b>545</b>	<b>24</b>
Aspen	NLA06608-0890	16020400	Cook	59	7	141	6
Musquash	NLA06608-1274	16010400	Cook	65**	7	133	8
Lookout	NLA06608-0771	18012300	Crow Wing	64	11	226	37
<b>Mayo</b>	<b>NLA06608-1262</b>	<b>18040800</b>	<b>Crow Wing</b>	<b>61</b>	<b>18</b>	<b>175</b>	<b>39</b>
Spring	NLA06608-1347	69012900	St. Louis	63	19	99	19
<b>Long</b>	<b>NLA06608-0942</b>	<b>11048000</b>	<b>Cass</b>	<b>115</b>	<b>18</b>	<b>284</b>	<b>23</b>

\* Schupps lake classification (1992)

\*\* IBI score scaled to 13 metrics because trap net data was not available.

\*\*\* IBI score scaled to 14 metrics because gill net data was not available.

Figure 3. IBI scores for the NLAP lakes surveyed in 2007-2008.



**Table 3. Total number of fish by species by all sample gears combined and percent frequency overall all lakes combined.**

<b>Species</b>	<b>Total</b>	<b>%</b>	<b>Species</b>	<b>Total</b>	<b>%</b>
banded killifish	407	0.98	largemouth bass	1426	3.42
bigmouth buffalo	6	0.01	least darter	13	0.03
bigmouth shiner	111	0.27	logperch	52	0.12
black bullhead	1517	3.64	longnose dace	165	0.40
black crappie	2881	6.91	mimic shiner	807	1.93
blackchin shiner	110	0.26	mottled sculpin	10	0.02
blacknose shiner	431	1.03	muskellunge	1	0.002
blackside darter	12	0.03	northern pike	981	2.35
Bluegill	8188	19.63	orangespotted sunfish	36	0.09
bluntnose minnow	2323	5.57	pearl dace	8	0.02
Bowfin	12	0.03	pugnose shiner	24	0.06
brook silverside	1602	3.84	pumpkinseed sunfish	1003	2.40
brook stickleback	3	0.01	rock bass	373	0.89
brown bullhead	1686	4.04	shorthead redhorse	1	0.002
burbot	14	0.03	smallmouth bass	123	0.29
central mudminnow	69	0.17	splake	58	0.14
channel catfish	85	0.20	spotfin shiner	55	0.13
common carp	3281	7.87	spottail shiner	481	1.15
common shiner	353	0.85	tadpole madtom	23	0.06
creek chub	4	0.01	tiger muskellunge	3	0.01
fathead minnow	325	0.78	tullibee (cisco)	342	0.82
freshwater drum	10	0.02	walleye	1152	2.76
golden shiner	657	1.58	white bass	123	0.29
green sunfish	361	0.87	white crappie	58	0.14
hybrid sunfish	346	0.83	white sucker	783	1.88
Iowa darter	359	0.86	yellow bullhead	1250	3.00
johnny darter	466	1.12	yellow perch	6731	16.14

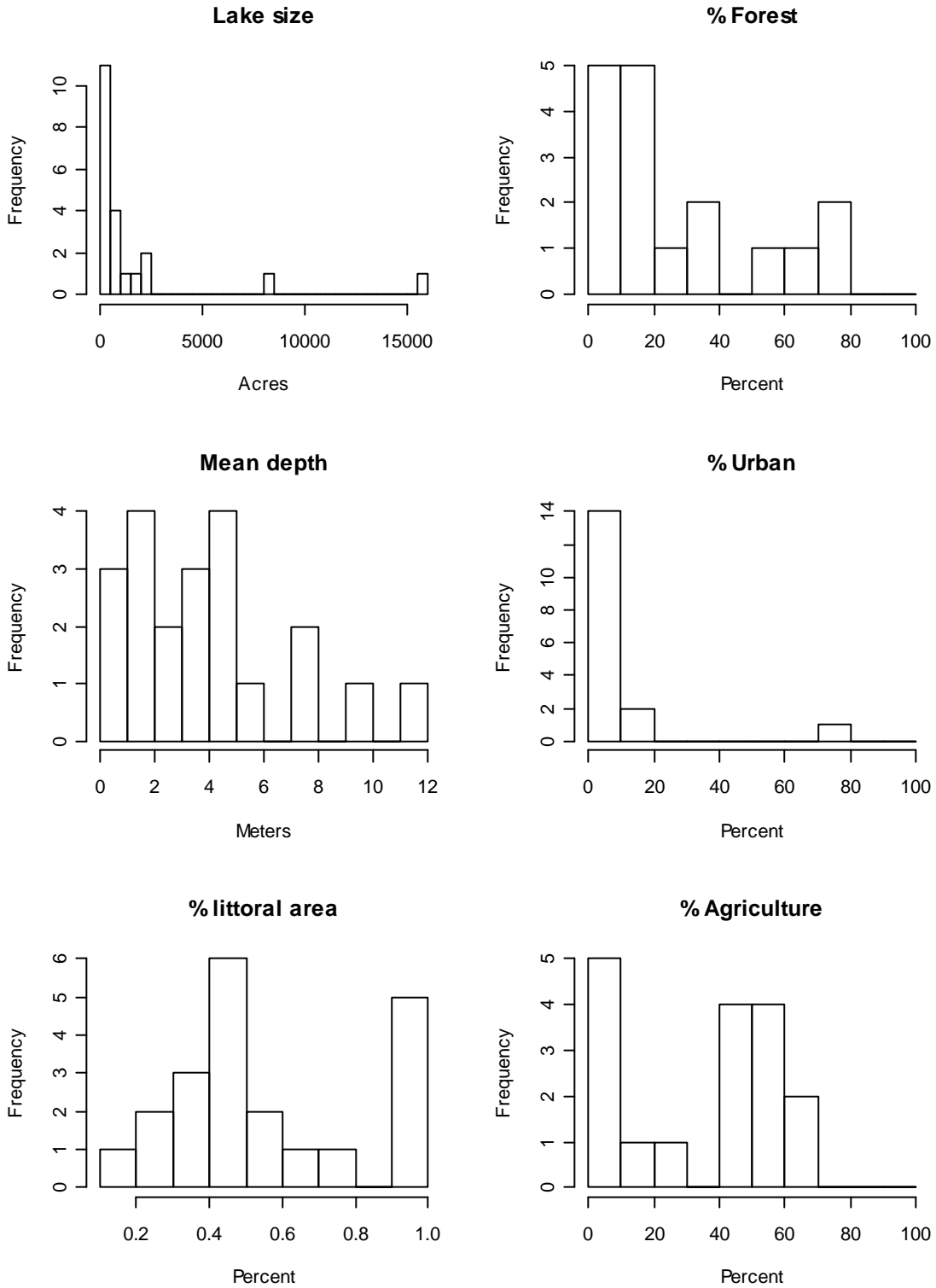
## Expansion of the lake IBI tool

The NLAP stratified random sampling design resulted in a suite of lakes that varied in size, average depth, trophic status, Schupp lake type, and geographic location. The wide range of lake characteristics in the NLAP data set (Figure 4) provided an opportunity to further evaluate the performance of the Minnesota DNR fish-based lake IBI. Currently, the IBI has only been validated for a select subset of Minnesota lakes (Drake and Pereira 2002; Drake and Valley 2005). Specific characteristics include lakes between 100 – 500 acres in size, located in central Minnesota, and with similar geophysical and chemical composition (10 lake classes; Schupp 1992). Ten NLAP lakes have characteristics consistent with the validated IBI dataset (Table 2; highlighted), while the remaining do not. Of the remaining 17 lakes, 2 lakes are from validated lake classes but are larger than 500 acres and 15 lakes are from 11 classes currently not validated for the lake IBI. Of these 15 lakes, 7 lakes are larger than 500 acres.

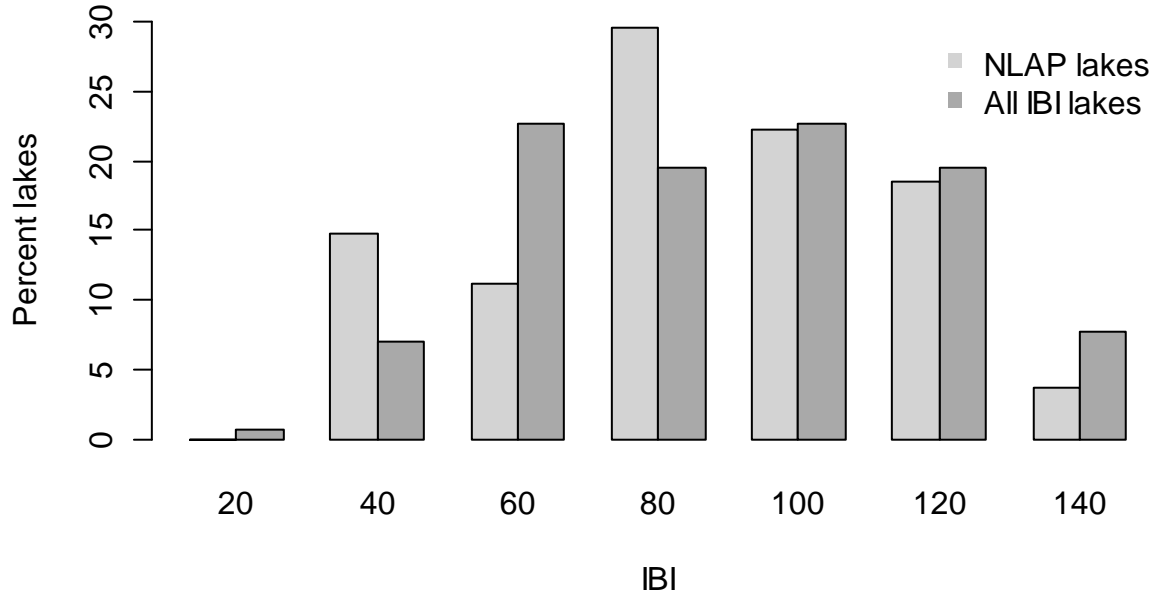
For comparison purposes only, the relative distributions of IBI scores were compared between NLAP lakes and all other lakes with IBI scores (N=269; Figure 5). The NLAP lakes had a mean IBI of 76 which did not differ significantly from the mean IBI of 79 for other IBI lakes (t-test,  $t = -0.53$ ,  $df = 31.24$ ,  $p = 0.60$ ). The mean size ( $t = 1.09$ ,  $df = 26.48$ ,  $p = 0.28$ ), maximum depth ( $t = -1.036$ ,  $df = 31.83$ ,  $p = 0.31$ ), percent littoral area ( $t = 0.60$ ,  $df = 30.79$ ,  $p = 0.55$ ), and shoreline development index ( $t = 0.31$ ,  $df = 34.15$ ,  $p\text{-value} = 0.76$ ) did not differ significantly between the NLAP and other IBI lakes. The mean trophic state based on Secchi depth was significantly greater for the NLAP lakes than the other IBI lakes (t.test,  $t = 2.68$ ,  $df = 31.02$ ,  $p = 0.012$ ). Mean percent forest (t.test,  $t = -0.41$ ,  $df = 19.21$ ,  $p = 0.68$ ), agriculture (t.test,  $t = -0.30$ ,  $df = 19.99$ ,  $p\text{-value} = 0.77$ ), and urban (t.test,  $t = 1.53$ ,  $df = 19.56$ ,  $p = 0.14$ ) watershed land use was similar between NLAP and other IBI lakes. Categorizing lakes into distinct trophic classes and comparing means, no significant differences were detected between NLAP and other IBI lakes (GLM:  $df = 4, 277, F = 64.58, P < 0.0001$ ; Figure 6).

Drake and Valley (2005) used trophic state, aquatic habitat (floristic quality index), and percent landuse (forest, agriculture, and urban) in the watershed to compare the performance among the original IBI lakes (Drake and Pereira 2002), an independent set of lakes of the same lake types, and a set of lakes with a broader range of characteristics (Drake and Valley 2005). This comparison served as a way of validating the IBI for those lake types. To replicate this analysis, the IBI response to measures of human disturbances for the NLAP lakes was compared to the IBI response for the other lakes. For these analyses the non-NLAP lakes were divided into two groups, the lakes used in Drake and Pereira (2002) and Drake and Valley (2005) and all other IBI lakes (non-validation lakes). Floristic quality indices were not available for the non-validation lakes. The response of the IBI to landuse and floristic quality were similar among the 3 groups of lakes, but the IBI response to trophic state (based on Secchi depth) differed for the NLAP lakes (GLM-slope test:  $df = 2, 281, F = 5.48, P = 0.005$ ; figures 7-9).

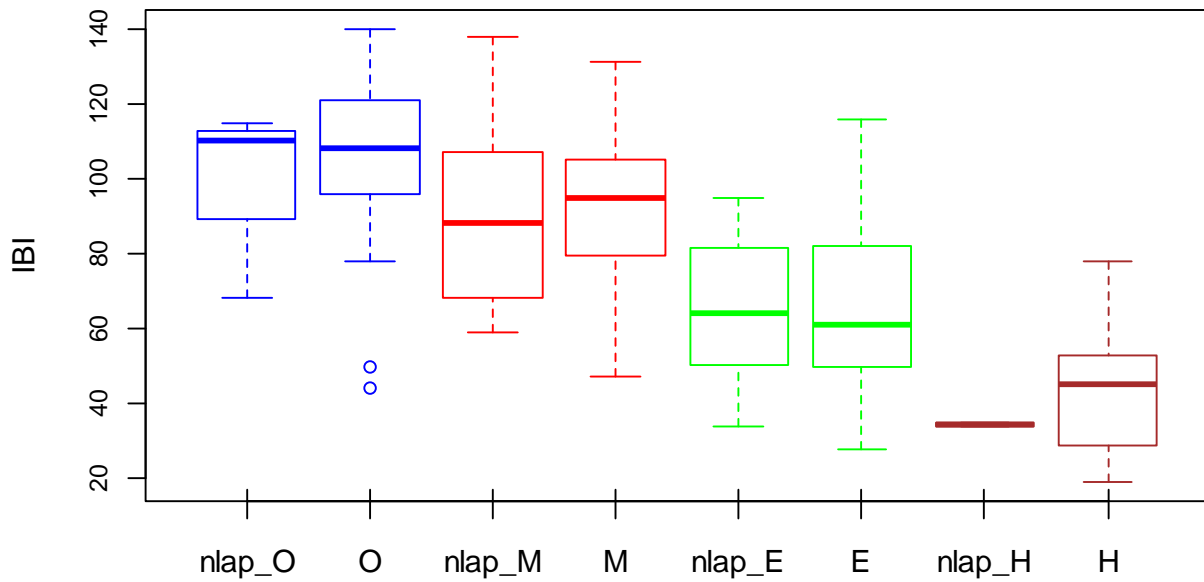
**Figure 4. Distribution of NLAP lake characteristics.**



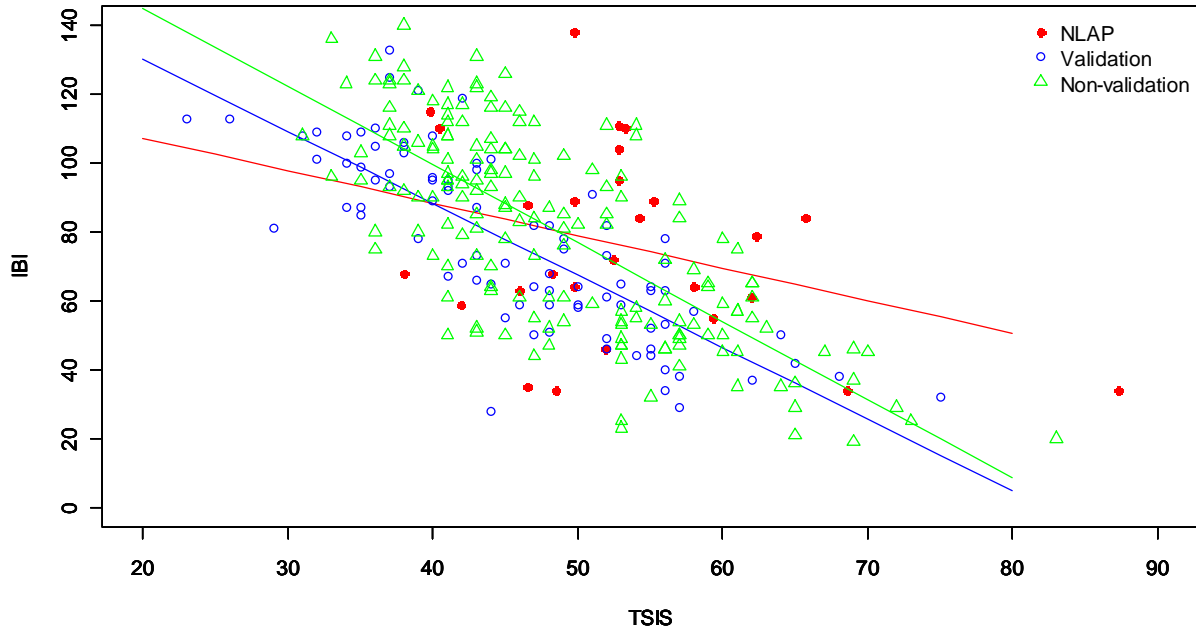
**Figure 5. Relative distribution of IBI scores for NLAP lakes and all other IBI lakes.**



**Figure 6. Boxplot of IBI scores by trophic state (determined by long-term monitoring) between NLAP and all other sampled lakes (O=oligotrophic, M=mesotrophic, E=eutrophic, and H=hypereutrophic).**



**Figure 7. Observed and predicted relationship between trophic state (TSIS: based on Secchi depth) and IBI for the NLAP, validation, and non-validation lakes.**



**Figure 8. Observed and predicted relationship between floristic quality index and IBI for the NLAP and validation lakes.**

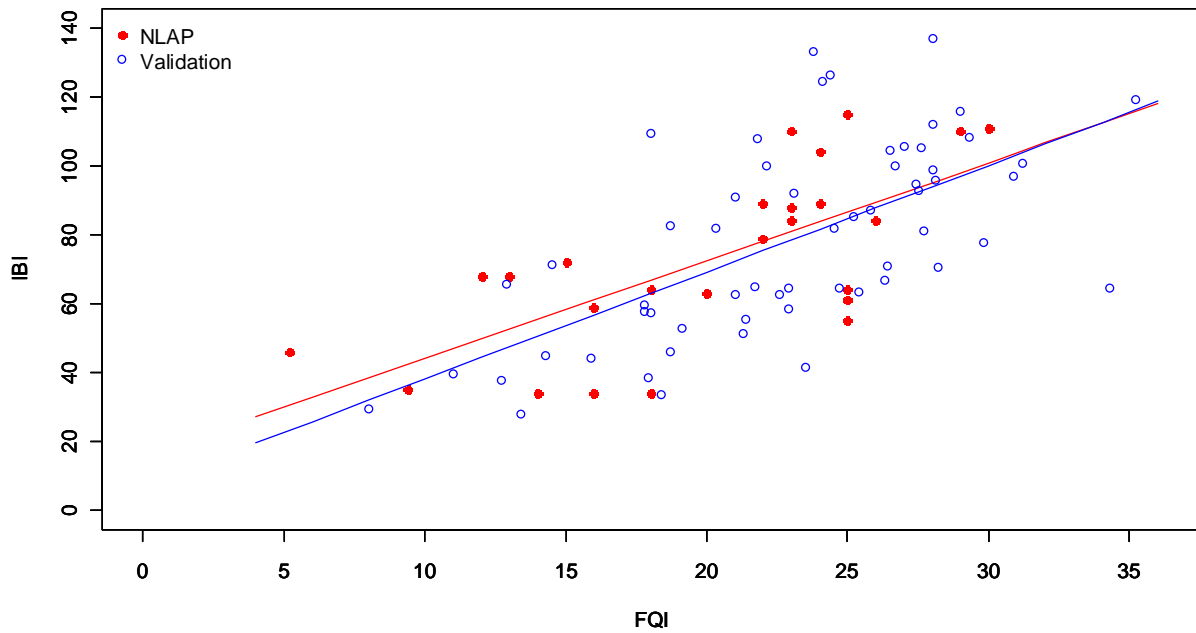
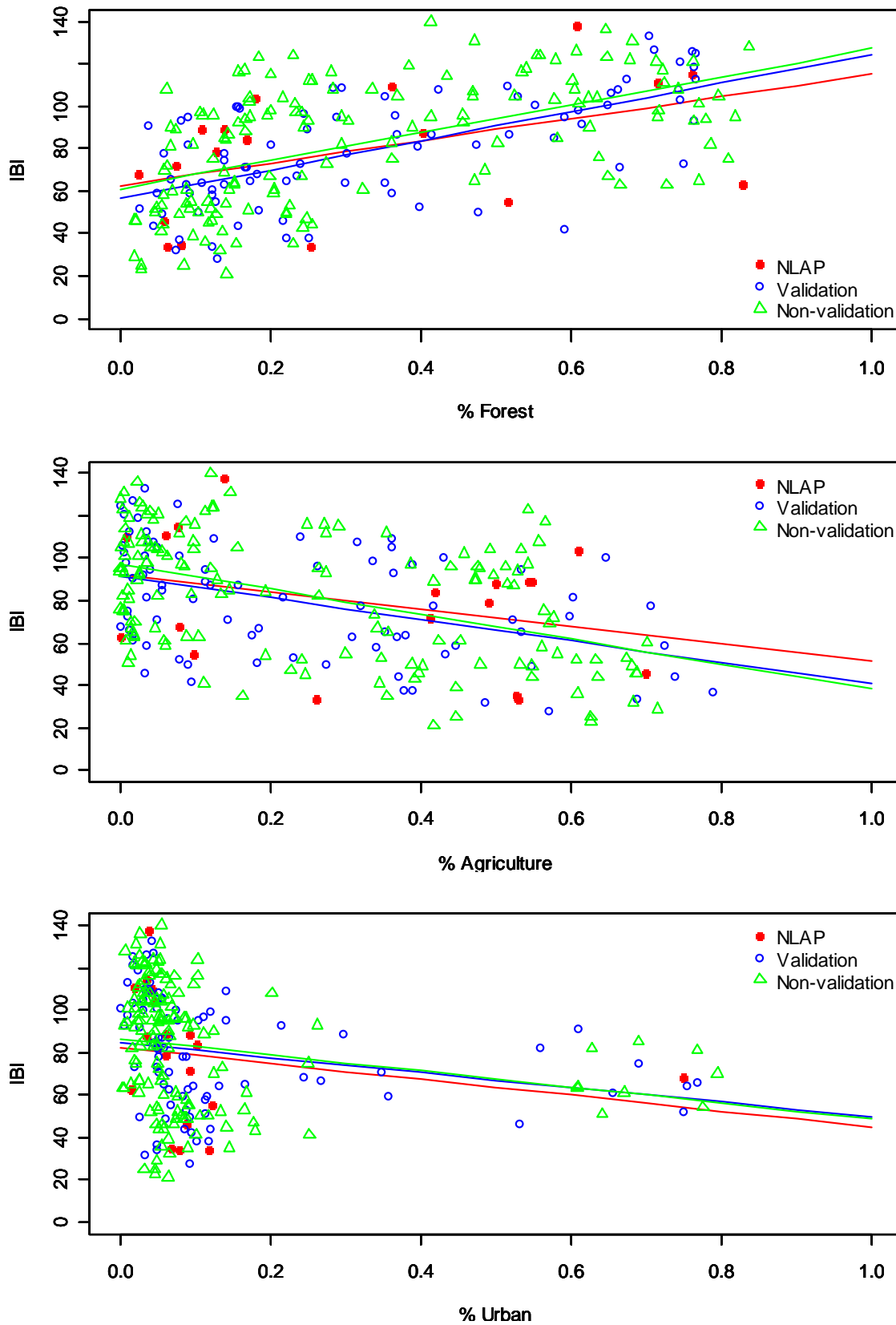


Figure 9. Observed and predicted relationship between land use and IBI for the NLAP, validation, and non-validation lakes.



## Chemical and Physical Parameters

In a state with over 10,000 lakes, sampling the biotic community in all waterbodies is a daunting task. The Minnesota add-on IBI sampling provided an opportunity to identify correlations between water quality measurements and the biotic community, as defined by the IBI score. IBI scores were evaluated against both physical and water quality attributes of the study lakes to identify potential relationships between the IBI and chemical measures and to identify potential interactions between the IBI response and physical lake characteristics.

The IBI scores for NLAP lakes trended in expected directions for various watershed disturbances like forest, agriculture and urbanization (Figures 7-9), as human disturbance in the watershed increased IBI scores tended to decrease.

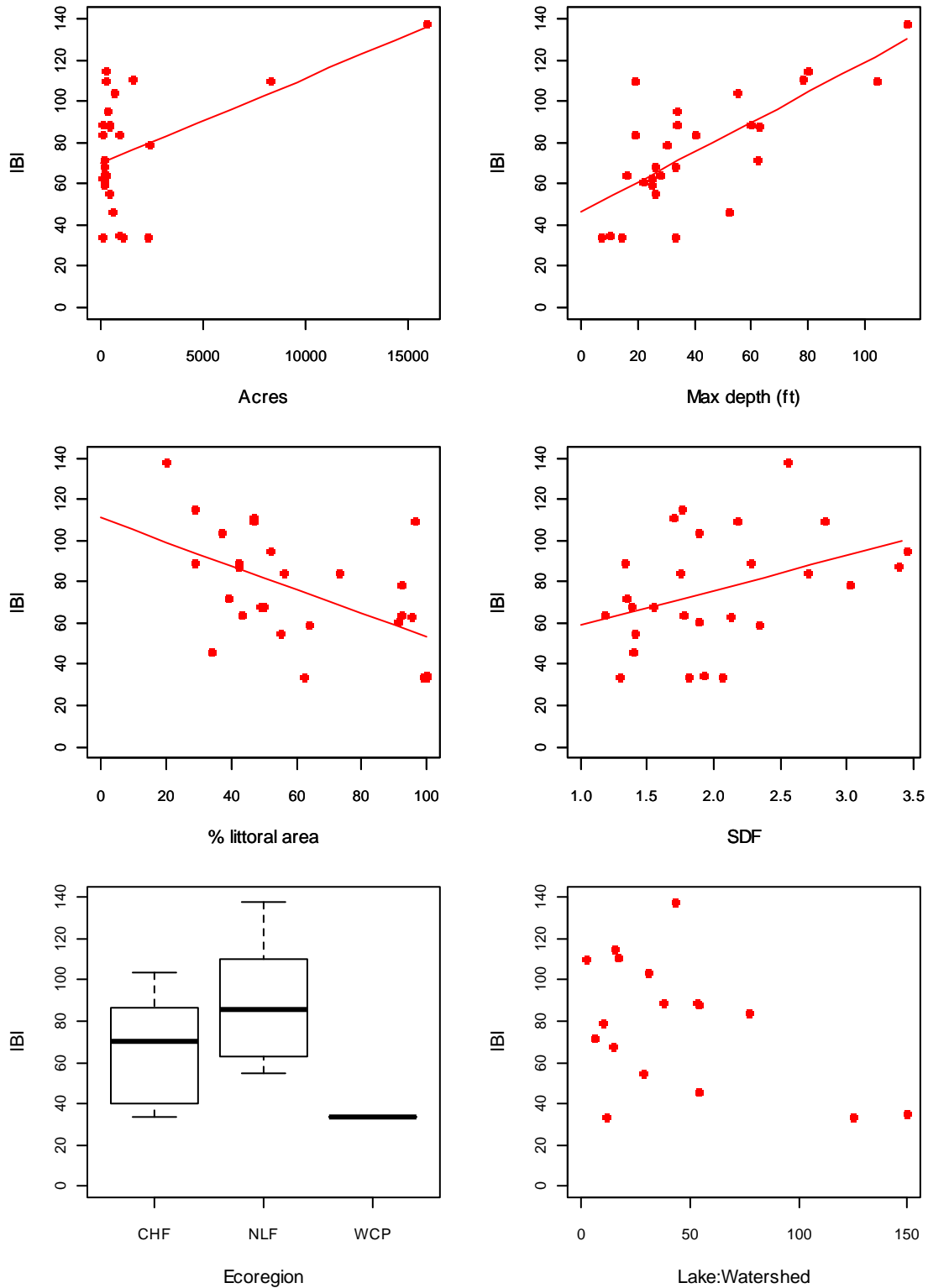
NLAP IBI scores were positively related to lake size ( $df = 1,25$ ,  $F=7.88$ ,  $P=0.01$ ), maximum depth ( $df = 1,25$ ,  $F=28.7$ ,  $P<0.0001$ ), and shoreline development factor (measure of the shape of a lake[higher values indicate more complex shorelines];  $df = 1,25$ ,  $F=4.44$ ,  $P=0.05$ ) and negatively related to percent littoral area ( $df = 1,25$ ,  $F=9.94$ ,  $P=0.004$ ; figure 10). IBIs for lakes in the validation data set were also positively correlated to maximum depth and negatively correlated with percent littoral area, but not to lake size or shoreline development factor, likely because lakes were chosen to have similar characteristics and didn't cover as wide of a range. Removing the 4 lakes that are greater than 2000 acres eliminates the significant relationship between IBI and lake size and shoreline development factor. Mean IBI differed by ecoregion (figure 10). In general IBIs for lakes in the Northern Lakes and Forest ecoregion (mean, 87) were greater than IBIs for lakes in the Central Hardwood Forest ecoregion (mean, 67; t-test:  $df=23.9$ ,  $t=-2.09$ ,  $P=0.05$ ). Only one lake was located in the Western Corn Belt Plains ecoregion (IBI, 34). IBI was not related to lake size to watershed size ratio (figure 10). The positive correlation between IBI scores and max depth is not surprising given the natural resiliency and subsequent ability to absorb some anthropogenic stressors that deeper lakes generally possess.

Scatterplots of water chemistry measures and IBIs are shown in figure 11. Only total nitrogen displayed significant negative relationship with IBI (LM:  $df=1,25$ ,  $F=10.0$ ,  $P=0.004$ ).

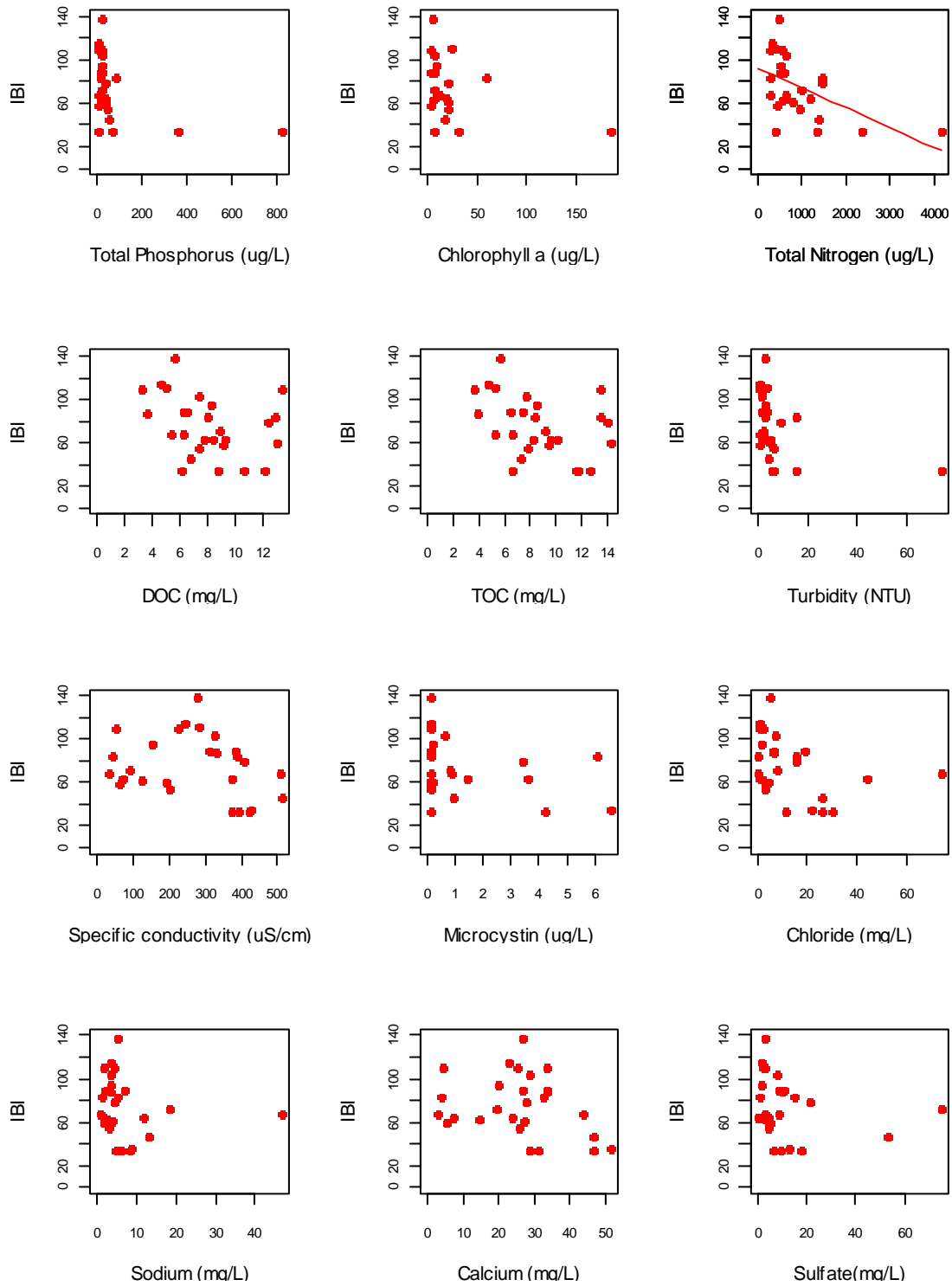
## Biological Parameters

Another Minnesota add-on included aquatic macrophyte surveys for all NLAP lakes. As noted earlier in the report, the response of IBIs for NLAP lakes to floristic quality was similar to the response for other IBI lakes (LM:  $df=1,23$ ,  $F=21.21$ ,  $P=0.0001$ ; figure 8 and 12). NLAP IBIs were also positively related to maximum rooted depth of aquatic plants (LM,  $df=1,21$ ,  $F=14.08$ ,  $P=0.001$ ) and number of aquatic plant species (LM:  $df=1,23$ ,  $F=18.25$ ,  $P=0.0003$ ). Aquatic plants offer several advantages for bioassessment including immobility, ease of identification, ease of sampling, and relationships with lake fisheries (Beck and Hatch 2009).

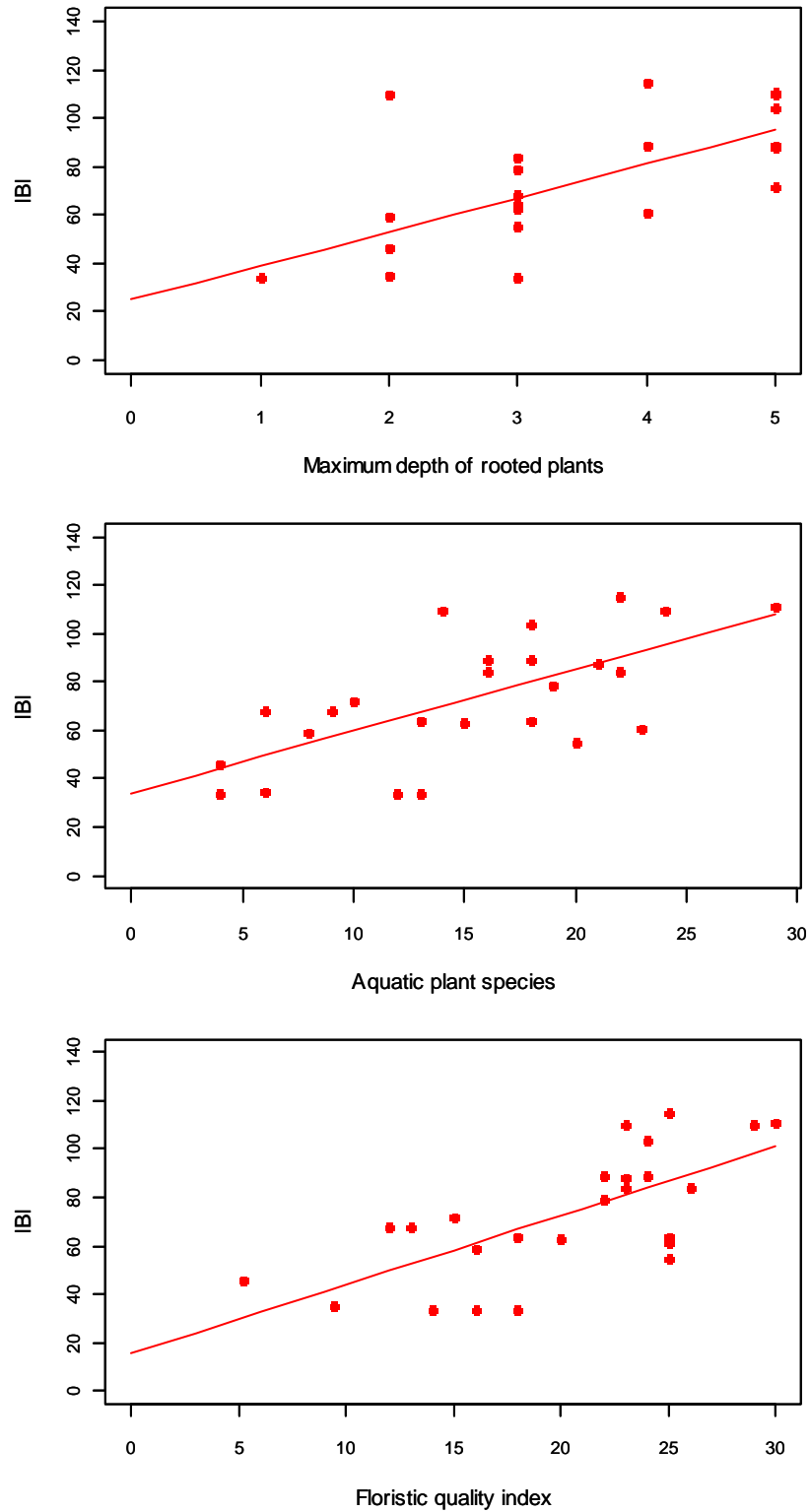
**Figure 10. Relationship between IBI and lake size (acres), maximum depth (ft), percent littoral area, and shoreline development factor (SDF). A line indicates a significant relationship.**



**Figure 11. Scatterplots of chemical parameters and IBI scores for NLAP lakes. A line indicates significant relationship.**



**Figure 12. Relationship between IBI and maximum depth of rooted aquatic plants, number of aquatic plant species, and floristic quality index. A line indicates a significant relationship.**



## Summary and Conclusions

The NLAP study provided an opportunity to evaluate the Minnesota fish-based lake IBI on a broader range of lakes. Results indicated that for the most part, IBIs for the NLAP lakes performed similarly to IBIs for validated lakes types. However, there are some areas that need further work. For example, IBI scoring criteria for lakes over 2000 acres or lakes with very complex shorelines likely needs adjustments. A larger data set would be needed to explore these relationships.

The IBI tool has not been developed to the point where scores can be categorized by some measure of health, i.e. excellent, good, fair, poor, or even at the pass/fail level. However, the distribution of the NLAP IBI scores was similar to the larger IBI data set and displayed similar geographic tendencies. Given the random lake selection design and assuming that enough game fish managed lakes were included in the IBI sampling, this might allow for extrapolation to all Minnesota game-fish lakes. At this point the NLAP lake IBI scores suggest that the majority of the NLAP lakes have fish communities that are similar to the majority of the other lakes with IBI scores, with some lakes with low scores and some lakes with high scores.

The IBI was sensitive to some physical attributes of the study lakes such as maximum depth and percent littoral area, both of which influence the resiliency of a lake and were correlated with trophic state. IBIs were also related to lake size with larger lakes having greater scores. This was not surprising given the inherent relationship between lake size and species richness (Minns et al. 1989; Pierce et al. 1994). The current metric scoring criteria appear adequate for lakes up to 2000 acres in size. The positive relationship between IBIs and shoreline development factor is likely related to more complex shorelines providing more habitat types thus allowing greater species richness and/or providing species refuges from disturbances. Additional research is needed to determine which metrics need adjustment for larger and/or more complex lakes. In addition, at least two of the shallow lakes in the NLAP data set are known to experience winterkill, a condition not addressed in the original IBI development. Furthermore, three NLAP lakes are softwater lakes, a characteristic not covered in the original IBI development but known to influence species richness (Rahel 1986). Aquatic vegetation, another biological community surveyed for this study, tended to be most closely correlated with the fish-based IBI. This underlines the relevance of vegetation as not only habitat, but also another lake health indicator for which an IBI could be developed. Water chemistry correlations provided limited information regarding fish community response to water quality impairments, however the data set was small (N<30) and relationships may have been confounded by the broad range of physical lake characteristics.

Findings from this study and other lake IBI work are positive indications that the fish-based IBI continues to serve as a measure of fish community response to human disturbance across a gradient of lakes. Additional work is needed to expand the application of the fish-based lake IBI to more lake types and to validate this tool as a viable method for assessing lake impairment as part of Minnesota's 303(d) "Impaired Waters" assessments.

We would like to thank the Environmental Protection Agency and the Minnesota Pollution Control Agency for providing funding and coordination for this project.

## References

- Beck, M.W., Hatch, L.K., 2009. A review of research on the development of lake indices of biotic integrity. *Environ. Rev.* 17, 21-44.
- Drake M. T. and D.L. Pereira, 2002. Development of a Fish-Based Index of Biotic Integrity for Small Inland Lakes in Central Minnesota. *North American Journal of Fisheries Management* 22:1105-1123.
- Drake, M., and R. Valley. 2005. Validation and Application of a Fish-based Index of Biotic Integrity for Small Central Minnesota lakes. *North American Journal of Fisheries Management* 25:1095-1111.
- Fausch, K. D., J. Lyons, J. R. Karr, and P. L. Angermeier. 1990. Fish communities as indicators of environmental degradation. *American Fisheries Society Symposium* 8:123-144.
- Karr, J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6(6):21-27.
- Minns, C. K. 1989. Factors affecting fish species richness in Ontario lakes. *Transactions of the American Fisheries Society* 118:533-545.
- MNDNR (Minnesota Department of Natural Resources). 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Section of Fisheries, Special Publication 147, St. Paul.
- Pierce, C. L., J. B. Rassmussen, and W. C. Legget. 1994. Littoral fish communities in southern Quebec lakes: relationships with limnological and prey resource variables. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1128-1138.
- Rahel, F. J. 1984. Factors structuring fish assemblages along a bog lake successional gradient. *Ecology* 65(4):1276-1289.
- Schupp D.H. 1992. An Ecological Classification of Minnesota Lakes with Associated Fish Communities. Minnesota Department of Natural Resources Investigational Report 417: 27pp.

## Appendix A. Example IBI scoring sheet.

Fill in yellow cells with total number or total weight

NS = combined seining and backpack electrofishing (numbers)

TN = weight in trap nets

GN = weight in gill nets

Species	Tolerance	Feeding	Habitat	Present	# in/wt in/wt in			Species richness	Raw	Calculation	Score
					NS	TN	GN				
Bowfin		Tc	Veg	0			native	0.000	0.00	0.00	
Burbot		Tc		0			intolerant	0.000	0.00	0.00	
Lognose gar		Tc		0			tolerant	0.000	0.00	0.00	
Shortnose gar		Tc		0			insectivore	0.000	0.00	0.00	
Cisco	I	Fi		0			omnivore	0.000	0.00	0.00	
Lake whitefish	I	In		0			cyprinid	0.000	0.00	0.00	
Lake sturgeon		In		0			small benthic dwelling	0.000	0.00	0.00	
Rainbow trout		Tc		0			vegetation dwelling	0.000	0.00	0.00	
Central mudminnow		In	Veg	0							
Northern pike		Tc	Veg	0			<b>Nearshore composition</b>				
Muskellunge	I	Tc	Veg	0			intolerant	0	0	0	
Tiger muskellunge		Tc		0			small benthic dwelling	0!	0	0	
Common carp	T	Om		0			vegetation dwelling	0	0	0	
Brassy minnow		He		0							
Hornyhead chub	I	In		0			<b>Trap net composition</b>				
Golden shiner		In		0			insectivore	0	0	0	
Emerald shiner		In		0			omnivore	0	0	0	
Bigmouth shiner		In		0			tolerant	0	0	0	
Blackchin shiner	I	In	Veg	0							
Blacknose shiner	I	In	Veg	0			<b>Gill net composition</b>				
Pugnose shiner	I	In	Veg	0			top carnivore	0	0	0	
Spottail shiner		In		0			intolerant	0	0	0	
Spotfin shiner		In		0							
Mimic shiner	I	In	Veg	0			<b>Overall Score</b>			0	
Sand shiner		In		0							
Common shiner		In		0							
Northern redbelly dace		He	Veg	0							
Finescale dace		In		0							
Bluntnose minnow		Om		0							
Fathead minnow	T	Om		0							
Creek chub	T	In		0							
Longnose dace	I	In	Smb	0							
Blacknose dace		Om	Smb	0							
White sucker	T	Om		0							
Bigmouth buffalo		In		0							
Smallmouth buffalo		In		0							
Shorthead redhorse		In		0							
Golden redhorse		In		0							
Greater redhorse	I	In		0							
Silver redhorse		In		0							
Quillback		In		0							
River carpsucker		Om		0							
Black bullhead	T	Om		0							
Yellow bullhead		Om		0							
Brown bullhead		Om		0							
Tadpole madtom		In	Smb/Veg	0							
Stonecat	I	In	Smb	0							
Flathead catfish		Tc		0							
Channel catfish		Tc		0							
Banded killifish	I	In		0							
Brook silverside		In		0							
Brook stickleback		In		0							
Rock bass	I	Tc		0							
Green sunfish		In		0							
Pumpkinseed		In		0							

Maximum score = 160

Bluegill		In		0				
Longear sunfish	I	In		0				
Hybrid sunfish		In		0				
Orangespotted sunfish		In		0				
Smallmouth bass	I	Tc		0				
Largemouth bass		Tc		0				
White crappie		Tc		0				
Black crappie		Tc		0				
Rainbow darter	I	In	Smb	0				
Least darter	I	In	Smb/veg	0				
Iowa darter	I	In	Smb/veg	0				
Blacksided darter		In	Smb	0				
Johnny darter		In	Smb	0				
Yellow perch		In		0				
Log perch		In	Smb	0				
Walleye		Tc		0				
Sauger		Tc		0				
Trout perch		In		0				
Mottled sculpin	I	In	Smb	0				
White bass		Tc		0				
Freshwater drum		Om		0				
TOTALS				0	0	0.00	0.00	