STUDY PERFORMANCE REPORT

State: Michigan

Project No.: F-80-R-3

Study No.: 701

Title: Decision-support tools for managing fisheries of inland lakes

Period Covered: October 1, 2001 to September 30, 2002

Study Objective: To prepare reviews of the characteristics of Michigan's inland lakes and of fisheries management of selected species in inland lakes, and to develop decision-support tools to help manage fisheries on inland lakes. One critical set of tools to be developed is methods for allocating fish among multiple fisheries that occur in the same lake, given a safe harvest level. Another objective of this study is to develop tools that help fisheries managers compare the status and potential of specific lakes and fisheries.

Summary: This year I began a review of the characteristics of Michigan's inland lakes. Tables were prepared describing the characteristics of lakes 1000 acres and larger. Figures were prepared that show the variation among lakes in certain lake characteristics. A start was made on reviewing the fisheries management of selected centrarchid species in inland lakes. No progress was made in developing methods for allocating fish among multiple fisheries that occur in the same lake.

Findings: Jobs 1, 2, 3, and 5 were scheduled for 2001-02, and progress is reported below.

Job 1. Title: Review the characteristics of Michigan's inland lakes.–I reviewed the characteristics of Michigan's inland lakes and summarized quantitative information on lake size, depth, and various water quality variables. Previous descriptions of Michigan inland lakes have been done by Hooper (1955) and Schneider (1975a, b). The following narrative attempts to briefly describe the broad patterns of variation among Michigan lakes and to explain the relation between various lake characteristics and a lake's ecology and fisheries. Lake characteristics discussed include geographic location in the state, surface area, depth, temperature, trophic state, summer phosphorus concentration, summer dissolved oxygen concentration at the bottom, transparency, alkalinity, and pH.

Geographic Location

Inland lakes are found throughout Michigan. A map showing locations of lakes at least 10 acres in surface area produces a recognizable picture of the state, including both peninsulas and the larger islands in the Great Lakes. One consequence of this widespread distribution is that some of the variation in characteristics of lakes reflects the underlying geographic variation in surface geology, climate, topography and land use. Some of these influences are discussed below.

Lake Surface Area and Depth

Lake surface area and depth influence almost all aspects of a lake's limnology, ecology, and fisheries. Together, area and depth determine lake volume and influence water temperature, whether a lake will stratify, mixing depth, fish assemblage, and aspects of the aquatic food web (Ragotzkie 1978; Magnuson et al. 1998; Tessier and Woodruff 2002). Lake volume, relative to the rate at which water flows into a lake, determines the replacement time of water in the lake – the hydrologic turnover time, which influences the concentration of nutrients and other chemicals in the lake. Larger lakes are more likely to have stream connections to lower lakes, to have more fish species, and to have larger populations of certain species.

Lakes have been classified on the basis of lake area. Kalff (2002) distinguished great lakes (≥10,000 km^2), large lakes (10,000-100 km^2), medium lakes (100-1 km^2), small lakes (1-0.1 km^2), large ponds (0.1-0.01 km^2), and other ponds (<0.01 km^2). (Note that 1 km^2 = 100 ha = about 250 acres.) Michigan's boundary encompasses portions of some of the largest lakes in North America, designated Laurentian Great Lakes. The remaining inland lakes of Michigan are pretty good lakes.

Michigan has a very large number of small lakes, and few large lakes, and many lakes in between (Table 1, Figure 1). The total number of "lakes" in Michigan depends on the lower size limit defined for the count. Considering lakes 10 acres and larger, the current count is 6,360 lakes in Michigan. (The tourist information that refers to Michigan's 11,000 lakes must be using a lower size limit of about 4 acres.) The size distribution of Michigan lakes follows a power-law distribution (Figure 1). One consequence is that large lakes represent a large fraction of the total surface area (Figure 2). For example, according to GIS information used in this study, 64,797 water bodies have a total surface area of 864,334 acres; the 96 lakes with area at least 1,000 acres make up 43% of the total. The 6,341 lakes ≥ 10.0 acres represent 91.1% of the total; 26,055 lakes ≥ 1.0 acres represent 98.2% of the total.

Table 2 shows information on 96 lakes at least 1000 acres in surface area. These lakes are ranked by surface area, obtained from GIS polygon information. Maximum depth was obtained from Humphrys and Green (1962). Humphrys and Green (1962) classified lakes as to origin (Table 3); 79% were classified as natural lake or pond, 6% as artificial lake, 4% as natural lake with a dam, 4% as gravel pit or quarry pond, and 2% as fish and wildlife flooding. Trophic status (TS) was assigned by Michigan Department of Environmental Quality, Land and Water Management Division as oligotrophic, mesotrophic, eutrophic, or hypereutrophic (see below). Table 2 also indicates the Great Lakes Basin and Fisheries Management Unit (Table 4) for each lake. Under Study 674, a unique code (New_Key) was assigned to each lake based on the numbering system for counties and lakes developed by Humphrys and Green (1962).

The observed size distribution of Michigan lakes has several implications for fisheries management. One is that by managing a relatively small number of large lakes Fisheries Division can manage a relatively large percentage of the total lake area of the state. It can take a lot of effort, however, to quantitatively sample fish in these large lakes. Another implication is that there are so many small lakes that it is not feasible for Fisheries Division to manage them individually. One approach would be to develop management recommendations for categories or classes of small lakes to guide others (e.g., lake associations) in carrying out management actions. There is also a relationship between lake size and lake ownership; small lakes are more likely to be private than large lakes.

Lakes have been classified as shallow or deep, depending on whether or not they thermally stratify. The density of water decreases as temperature increases above 4°C (Wetzel 1975). As a lake warms in the spring the lake can become thermally stratified. Wind mixes the upper water, producing a well-mixed layer of less dense, warmer water of nearly uniform temperature (the epilimnion) that floats above a layer of more dense, cooler water (the hypolimnion). The transition zone between these layers is the metalimnion or thermocline, where the water temperature decreases rapidly with depth. In a lake that is shallow the wind can mix the water all the way to the bottom. Such a lake is not thermally stratified.

In recent years, it has become apparent that shallow lakes can have alternative stable states. A shallow lake can be in either a clear-water state dominated by macrophytes or a turbid state dominated by phytoplankton (Balls et al. 1989; Scheffer 1989; Scheffer et al. 1993; Janse 1997; Jeppesen et al. 1997).

Temperature

Temperature is one of the most important habitat variables for fish. Temperature strongly influences species composition of water bodies and fish growth rates.

Lakes have been classified as warmwater or coldwater lakes. Typically, lakes are thermally stratified in summer, and some have sufficient oxygen levels in the hypolimnion to support fish such as trout (Schneider 1975a, b).

Trophic State, Phosphorus, and Dissolved Oxygen Concentration

Phosphorus is usually the limiting nutrient in freshwater lakes (Wetzel 1975). Because body composition of aquatic plants is relatively constant, plant growth can continue until one of the required nutrients is no longer available in the necessary proportions. Phosphorus concentration in late summer is a good indicator of the nutrient status of a lake (Carlson 1977).

Lakes have been classified according to nutrient status. Lakes that receive low amounts of nutrients are termed oligotrophic. Lakes that receive medium, high, or very high amounts of nutrients are termed mesotrophic, eutrophic, and hypereutrophic, respectively. In oligotrophic lakes the water is clear, because the concentration of phytoplankton is very low, and the oxygen concentration all the way to the bottom is high enough to support fish. In eutrophic lakes, the water is often more greenish in color, because of high phytoplankton concentrations, and by late summer, respiration and decomposition of organic matter has lowered the dissolved oxygen concentration to zero at the bottom of the lake. Vollenweider used a critical total phosphorus concentration of 10 μg/L (or 10 parts per billion, ppb) to separate oligotrophic from mesotrophic lakes, 30 μg/L to separate mesotrophic from eutrophic lakes, and 100 μg/L to separate eutrophic from hypereutrophic lakes (Wetzel 1975; Kalff 2002).

Biological productivity is greater in lakes that receive more nutrients. Hanson and Leggett (1982) demonstrated that lakes with higher total phosphorus concentrations had higher standing crops of fish (kg/ha). Nutrient status and productivity influence the type of fish community likely to be present. Lakes with high nutrients often develop low concentrations of dissolved oxygen in the hypolimnion (Figure 3). Trout, a species preferred by some anglers, are usually found in oligotrophic lakes and only rarely in eutrophic lakes because of their requirement for high concentrations of oxygen in cold water.

Transparency

Transparency affects the foraging ability of visual predators. Walleye appear to grow best at an intermediate level of water transparency; they tend to grow more slowly at very high and very low levels of transparency. Visual feeders such as bluegill do better in lakes with high transparency; high turbidity decreases the range at which they can detect zooplankton prey. Some rough fish, such as common carp, can grow in very turbid water.

Macrophytes only grow where light level is high enough that net production is positive. The maximum depth at which macrophytes grow is therefore affected by water transparency. If the water is sufficiently turbid, submerged aquatic macrophytes do not survive (although emergent macrophytes may persist). So water transparency influences the composition of the aquatic plant community, which can be an important feeding habitat and refuge from predation for juvenile fishes.

Alkalinity and pH

Alkalinity measures the acid neutralizing capacity of lake water. Alkalinity refers to the quantity and kinds of compounds that shift pH to the alkaline side of neutrality (Wetzel 1975). In most freshwater lakes and streams the hydroxyl, bicarbonate, and carbonate ions represent the major buffering system. Only lakes with low alkalinity have pH substantially below 7.0.

Fish species vary in their tolerance of low pH. Minnows are very intolerant, whereas yellow perch are more tolerant.

There is a strong spatial variation in lake alkalinity across the State. Lakes in the western Upper Peninsula tend to have the lowest alkalinity, and lakes in the southern Lower Peninsula tend to have the highest alkalinity (Figure 4). In Michigan, there are few lakes with pH low enough to affect the fish assemblage, and these are almost all found in the Upper Peninsula. In northern Wisconsin, low pH was more likely to be associated with small lake area.

Job 2. Title: Review Michigan's fisheries management of selected species.–I started a review of Michigan's fisheries management of bluegill and largemouth bass. My review started with a description of centrarchid reproduction, emphasizing bluegill, and factors influencing successful reproduction.

In Michigan, fish species in the family Centrarchidae reproduce in late spring and summer. Temperature is a strong cue for initiation of reproductive behavior. Smallmouth and largemouth bass are the first to reproduce. Bluegills usually begin to nest during mid to late May in southern Michigan.

Fishes in the family Centrarchidae give parental care (Balon 1975, 1981). Typically, the male makes a shallow bowl-like depression in the substrate using vigorous beats of his tail. Females select a male with which to mate, enter the nest, and release eggs, which are immediately fertilized by the male. The female then leaves the nest; she may mate with additional males. The eggs are adhesive and stick to the bottom of the nest. The male then continuously guards the nest for approximately 10 days (depending on temperature), until the swim-up fry are able to leave the nest.

While guarding the nest, males are particularly vulnerable to angling. Because the usual bottom debris is fanned away during nest construction, often exposing stones and gravel within a circular shape, nests are often detectable by anglers. Males do not leave the nest for more than a few seconds, even to feed. They may lose about 10-15% of their body weight during this nesting period, so they become quite hungry.

Claussen (1991) studied reproduction by bluegill in Lake Opinicon, a large lake in Ontario, and found that males were more likely to abandon their nests during periods of low temperature. The average number of bluegill swim-up fry per nests decreased as average temperature decreased. In the upper Midwest, including Michigan, reproduction of many centrarchid species, including bluegill, appears to have been disrupted by the climate changes caused by the volcanic eruption of Mount Pinatubo in the Philippines (Schneider and Lockwood 2002). This volcano erupted on 15 June 1991, producing the second largest volume of magma (about 5 km^3) (Newhall et al. 2002) and the largest stratospheric volcanic aerosol cloud of the 20th century (Robock 2002).

The effects of this cloud caused surface air temperatures over the Northern Hemisphere to be up to 2°C cooler than normal in the summer of 1992. It also caused the winter to be warmer than normal in 1991-1992 and 1992-1993 (Robock 2002). The cool summer temperatures in 1992 apparently caused many centrarchid males to abandon their nests or to forgo nest construction.

Job 3. Title: Develop models for allocating fish among multiple fisheries.–Because of other assignments, due in part to several retirements, no progress was made in developing methods for allocating fish among multiple fisheries that occur in the same lake.

Job 5. Title: Write progress report.–This progress report has been prepared.

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Table 1.–Number (N) and total area (acres) of inland lakes in different size categories in the State and within the four Great Lakes basins of Michigan. Lake surface area was obtained from GIS polygon information. The largest inland lake is Houghton Lake, with a surface area of 20,075 acres.

Size Category	State		Erie		Huron		Michigan		Superior	
	N	Total area	N	Total area	N	Total area	N	Total area	N	Total area
$10{,}000 \le A$	10	144,745	0	0	3	44,212	5	76,597	2	23,936
$3{,}000 \le A < 10{,}000$	19	111,512	0	0	5	30,478	13	77,026	1	4,008
$1{,}000 \le A < 3{,}000$	67	111,861	4	4,858	14	21,913	37	65,682	12	19,409
$300 \le A < 1{,}000$	275	140,655	27	14,329	58	31,830	149	72,235	41	22,261
$100 \le A < 300$	725	121,059	85	14,394	137	23,555	424	69,616	79	13,494
$30 \le A < 100$	1,855	100,357	216	11,608	381	20,451	1,049	56,515	209	11,782
$10 \le A < 30$	3,391	57,988	406	7,118	712	11,989	1,805	31,091	468	7,790
$3 \le A < 10$	7,293	39,637	851	4,655	1,469	7,836	3,664	20,140	1,309	7,005
$1 \le A < 3$	12,421	21,364	1,445	2,488	2,515	4,330	6,149	10,604	2,312	3,942
$A < 1$	38,740	15,888	4,564	1,919	8,439	3,311	19,642	8,075	6,095	2,583
Subtotal for $A \ge 10$	6,342	788,176	738	52,307	1,310	184,428	3,482	448,762	812	102,679
Total	64,796	865,066	7,598	61,370	13,733	199,905	32,937	487,582	10,528	116,209

Table 2.–Lakes at least 1000 acres in surface area in Michigan. Lakes are ranked by surface area, obtained from GIS information. Maximum depth (Z_{max}, feet), origin code (O, see Table 3) and Town Range Section (TRS) were primarily obtained from Humphrys and Green (1962). Trophic status (TS) was assigned by MDEQ LWMD. Information on presence of a boat access site (Boat) was obtained from MDNR Parks and Recreation Division. GB and FMU indicate the Great Lakes Basin and Fisheries Management Unit (see Table 4). The New_Key code is a unique value for each lake, and is based on the numbering system for counties and lakes developed by Humphrys and Green (1962).

Rank	Lake Name	County	Acres	Z_{max}	TS	O	Boat	TRS	GB	FMU	New_Key
1	Houghton Lake	Roscommon	20,075	20	E	2	Yes	T22NR3WS2	M	LMC	72-78
2	Torch Lake	Antrim	18,722	297	O	2	Yes	T28NR8WS4	M	LMC	5-51
3	Burt Lake	Cheboygan	17,395	73	O	2	Yes	T35NR3WS1	H	LHN	16-193
4	Charlevoix, Lake	Charlevoix	17,268	120	O	1	Yes	T32NR7WS3	M	LMC	15-21
5	Mullett Lake	Cheboygan	16,704	147	O	2	Yes	T35NR2WS3	H	LHN	16-192
6	Gogebic, Lake	Ontonagon	13,127	37	M	5	Yes	T46NR42WS3	S	LSW	27-966
7	Portage Lake	Houghton	10,808	54	M	1	Yes	T53NR33WS3	S	LSW	31-993
8	Manistique Lake	Mackinac	10,346	25	M	1		T44NR11WS6	M	LMN	48-53
9	Higgins Lake	Roscommon	10,186	141	O	2	Yes	T23NR4WS10	M	LMC	72-117
10	Black Lake	Cheboygan	10,114	50	M	5	Yes	T35NR1ES1	H	LHN	16-144
11	Crystal Lake	Benzie	9,869	162	O	2		T26NR15WS6	M	LMC	10-42
12	Hubbard Lake	Alcona	8,768	97	O	5	Yes	T27NR7ES1	H	LHN	1-165
13	Indian Lake	Schoolcraft	8,647	18	E	1		T41NR16WS3	M	LMN	75-69
14	Leelanau, Lake	Leelanau	8,607	62	O	2	Yes	T28NR12WS1	M	LMC	45-3
15	Elk Lake	Grand Traverse	8,195	192	O	2	Yes	T28NR9WS2	M	LMC	5-2
16	Fletcher Pond	Alpena	6,819		E	5	Yes	T30NR5ES2	H	LHN	4-4
17	Glen Lake	Leelanau	6,286	130	O	2	Yes	T28NR13WS6	M	LMC	45-9
18	Grand Lake	Presque Isle	5,823		O	2	Yes	T33NR8ES4	H	LHN	71-87
19	Long Lake	Alpena	5,342	33	M	2	Yes	T32NR8ES15	H	LHN	4-42
20	Michigamme Reservoir	Iron	4,892		M	5		T44NR31WS14	M	LMN	36-204
21	Hamlin Lake	Mason	4,622	86	E	2	Yes	T19NR17WS5	M	LMC	53-155
22	Walloon Lake	Charlevoix	4,567	100	O	2		T33NR5WS6	M	LMC	15-25
23	Vieux Desert, Lac[1]	Gogebic	4,370	38	M	5	Yes	T43NR38WS24	M	LMN	27-3
24	Brevoort Lake	Mackinac	4,315	30	E	2	Yes	T41NR5WS2	M	LMN	49-45
25	Michigamme, Lake	Marquette	4,292	72	O	5		T47NR30WS9	M	LMN	7-199
26	Muskegon Lake	Muskegon	4,232	70	E	1	Yes	T10NR16WS18	M	LMC	61-66
27	South Manistique Lake	Mackinac	4,133	29	E	2	Yes	T44NR11WS18	M	LMN	49-280
28	Siskiwit Lake	Keweenaw	4,008	142		1		T65NR35WS16	S	LSW	42-165
29	Douglas Lake	Cheboygan	3,727			1	Yes	T37NR3WS17	H	LHN	16-252
30	Long Lake	Grand Traverse	2,911	88	O	1		T27NR12WS9	M	LMC	28-214
31	Hardy Dam Pond	Newaygo	2,773		M	5		T13NR10WS6	M	LMC	54-80
32	Skegemog, Lake	Kalkaska	2,767	30	M	1		T28NR9WS13	M	LMC	5-1
33	Dead Riv. Storage Basin	Marquette	2,737		O	5	Yes	T48NR26WS6	S	LSW	52-1263
34	Gun Lake	Barry	2,735	68	M	2		T2NR10WS4	M	LMS	3-95
35	Mitchell, Lake	Wexford	2,649		E	2	Yes	T21NR9WS6	M	LMC	83-4
36	White Lake	Muskegon	2,536	80	E	1	Yes	T11NR17WS5	M	LMC	61-125
37	Platte Lake	Benzie	2,532	90	M	1	Yes	T26NR15WS1	M	LMC	10-39
38	Saint Helen, Lake	Roscommon	2,416		M	2	Yes	T23NR1WS15	H	LHN	72-95
39	Torch Lake	Houghton	2,401		M	1	Yes	T55NR32WS5	S	LSW	31-1178
40	Crooked Lake	Emmet	2,352	68	M	2	Yes	T35NR4WS15	H	LHN	24-27
41	Peavy Pond	Iron	2,348			5		T42NR31WS4	M	LMN	36-32
42	Bond Falls Flowage	Ontonagon	2,127	80	M	5		T46NR38WS5	S	LSW	66-31
43	Portage Lake	Manistee	2,116	60	M	1	Yes	T23NR16WS22	M	LMC	51-142
44	Gull Lake	Kalamazoo	2,046		M	1		T1NR9WS31	M	LMS	8-180
45	Independence, Lake	Marquette	2,041	33	E	2		T51NR26WS19	S	LSW	52-1703
46	Missaukee, Lake	Missaukee	2,035	28	M	1		T22NR7WS6	M	LMC	57-45

Table 2.–Continued.

Rank	Lake Name	County	Acres	Z_{max}	TS	O	Boat	TRS	GB	FMU	New_Key
47	Milakokia Lake	Mackinac	2,031	26	M	2	Yes	T42NR12WS2	M	LMN	49-127
48	Otsego Lake	Otsego	2,013	23	M	1	Yes	T29NR3WS4	H	LHN	69-61
49	Green Lake	Grand Traverse	1,995	102	O	1	Yes	T25NR12WS4	M	LMC	28-56
50	Duck Lake	Grand Traverse	1,945	98	O	1	Yes	T26NR12WS14	M	LMC	28-124
51	Margrethe, Lake	Crawford	1,922	65	M	2	Yes	T26NR4WS8	M	LMC	20-44
52	Paradise, Lake	Emmet	1,912	17	E	2		T38NR3WS18	M	LMC	16-302
53	Hodenpyl Dam Pond	Wexford	1,902		M	3		T23NR13WS24	M	LMC	51-126
54	Bear Lake	Manistee	1,874	24	E	1	Yes	T23NR15WS4	M	LMC	51-132
55	Macatawa, Lake	Ottawa	1,801	40	H	1	Yes	T5NR15WS25	M	LMS	70-36
56	Bellaire, Lake	Antrim	1,789	99	O	2	Yes	T29NR8WS1	M	LMC	5-50
57	North Manistique Lake	Luce	1,709	50	O	2	Yes	T45NR11WS17	M	LMN	48-49
58	Allegan, Lake	Allegan	1,695		H	5	Yes	T2NR13WS18	M	LMS	3-162
59	Foote Dam Pond	Iosco	1,695		O	5		T24NR7ES13	H	LHN	35-205
60	Martiny Lake	Mecosta	1,663		E	7	Yes	T15NR8WS5	H	LHS	54-90
61	Cooke Dam Pond	Iosco	1,635			5		T24NR6ES23	H	LHN	35-201
62	Tawas Lake	Iosco	1,616	5	E	1	Yes	T22NR8ES4	H	LHS	35-54
63	Coldwater Lake	Branch	1,581	87	M	1	Yes	T7SR6WS22	M	LMS	12-90
64	Intermediate Lake	Antrim	1,571	82	M	2	Yes	T30NR8WS1	M	LMC	5-75
65	Cleveland Cliffs Basin	Alger	1,489		E	5	Yes	T45NR20WS6	S	LSE	2-230
66	Gratiot, Lake	Keweenaw	1,452	78	O	1	Yes	T57NR30WS3	S	LSW	42-36
67	McDonald Lake	Schoolcraft	1,441		M	1		T41NR13WS5	M	LMN	75-30
68	Betsy Lake	Luce	1,426	30		1		T49NR8WS13	S	LSE	48-443
69	Silver Lake Basin	Marquette	1,425	70		6		T49NR28WS6	S	LSW	52-1505
70	Van Etten Lake	Iosco	1,409	32	H	2	Yes	T24NR9ES6	H	LHN	35-219
71	Sanford Lake	Midland	1,402	20	E	5	Yes	T15NR1WS1	H	LHS	56-14
72	Devils Lake	Lenawee	1,312	63	M	2	Yes	T5SR1ES26	E	LE	46-45
73	West Twin Lake	Montmorency	1,306	35	M	1	Yes	T29NR1ES19	H	LHN	60-19
74	Cass Lake	Oakland	1,279	123	M	2		T2NR9ES2	E	LE	63-1337
75	Belleville Lake	Wayne	1,253	16	H	5	Yes	T3SR7ES24	E	LE	82-157
76	La Belle, Lac	Keweenaw	1,205	39	M	1	Yes	T57NR29WS3	S	LSW	42-33
77	Holloway Reservoir	Genesee	1,173		H	6		T8NR8ES1	H	LHS	25-125
78	Cadillac, Lake	Wexford	1,172	28	E	2	Yes	T21NR9WS4	M	LMC	83-3
79	Wixom Lake	Gladwin	1,142	40	E	5	Yes	T17NR1WS36	H	LHS	26-3
80	Croton Dam Pond	Newaygo	1,129	34	E	5		T12NR11WS4	M	LMC	62-61
81	Millecoquins Lake	Mackinac	1,123		M	1	Yes	T43NR10WS1	M	LMN	49-262
82	Austin Lake	Kalamazoo	1,102	14	M	1	Yes	T3SR11WS23	M	LMS	39-263
83	Spring Lake	Ottawa	1,097	47	E	1		T8NR16WS1	M	LMS	61-10
84	Tippy Dam Pond	Manistee	1,086			5	Yes	T21NR13WS4	M	LMC	51-5
85	Chicagon Lake	Iron	1,083		M	2	Yes	T42NR34WS1	M	LMN	36-137
86	Pickerel Lake	Emmet	1,082	21	M	1		T35NR4WS21	H	LHN	24-31
87	Greenwood Reservoir	Marquette	1,073	38	M	3		T47NR28WS18	M	LMN	52-1807
88	Desor, Lake	Keweenaw	1,060	55		1		T64NR37WS1	S	LSW	42-167
89	Empire Mine Tailings B	Marquette	1,058			18		T46NR27WS11	M	LMN	52-1813
90	Moss Lake	Delta	1,054	5		1		T40NR19WS3	M	LMN	21-105
91	Manistee Lake	Manistee	1,051		E	1	Yes	T21NR16WS6	M	LMC	51-43
92	Diamond Lake	Cass	1,041	64	M	1	Yes	T6SR14WS30	M	LMS	14-223
93	Perch Lake	Iron	1,038	14	M	1	Yes	T46NR35WS22	S	LSW	36-1529
94	Kent Lake	Livingston	1,015	38	E	3		T1NR6ES1	E	LE	63-2
95	East Unit, Crow Is. R. A.	Saginaw	1,009			7		T13NR5ES28	H	LHS	73-75
96	Thousand Island Lake	Gogebic	1,009	81	M	2	Yes	T44NR41WS1	S	LSW	27-265

[1] Lac Vieux Desert, 4370 acres in area, is on the Michigan-Wisconsin border, with approximately 1,532 acres in Michigan and 2,838 acres in Wisconsin.

Table 3.–Codes and descriptions for types of lake origin for 6,298 inland lakes. Also shown are the number of water bodies, by Fisheries Management Unit (Table 4), for which codes have been assigned for lakes 10 acres and larger. Almost all assignments were done by Humphrys and Green (1962), who developed the coding system.

Origin code	Description	State Number	LE	LHN	LHS	LMC	LMN	LMS	LSE	LSW
1	Natural lakes and ponds	4974	421	519	442	788	916	1159	252	477
2	Natural lake with a dam	264	44	22	38	48	48	35	9	20
3	Artificial lake	378	113	33	77	50	23	71	2	9
4	Artificial pond	5	0	3	0	0	0	1	0	1
5	Hydro-electric reservoir	91	11	16	14	17	11	10	1	11
6	Municipal water supply reservoir	20	4	0	6	2	2	1	0	5
7	Fish and wildlife flooding	120	4	19	21	21	37	11	4	3
8	Mill pond	43	15	1	7	2	0	18	0	0
9	Gravel pit or quarry pond	251	95	12	44	11	7	73	0	9
10	Marl lake - dredging has created or enlarged the lake	14	3	0	0	0	0	11	0	0
11	Fish hatchery pond	3	0	1	0	0	0	2	0	0
12	Underwater borrow pit	37	14	2	11	1	0	9	0	0
13	Recharge basin	1	0	0	0	0	0	1	0	0
14	Settling pond	26	2	0	3	2	16	1	0	2
15	Beaver pond	4	0	0	1	1	0	1	1	0
16	Sewage disposal basin	55	4	3	6	14	0	26	0	2
17	Fish breeding pond	4	1	1	0	1	0	1	0	0
18	Flood control reservoir	1	0	0	0	0	1	0	0	0
19	Brine storage basin	1	0	0	1	0	0	0	0	0
20	Swamp	2	0	0	0	2	0	0	0	0
21	Tailings pond	3	0	0	0	0	3	0	0	0
22	Marsh	1	0	0	0	1	0	0	0	0
23	Canal	0	0	0	0	0	0	0	0	0
24	Drain	0	0	0	0	0	0	0	0	0
25	Bog	0	0	0	0	0	0	0	0	0

Table 4.–Description of codes for Great Lakes Basin (GB) and Fisheries Management Unit (FMU).

GB code	Great Lakes Basin	FMU code	Fisheries Management Unit
E	Lake Erie	LE	Lake Erie Management Unit
H	Lake Huron	LHN	Northern Lake Huron Management Unit
		LHS	Southern Lake Huron Management Unit
M	Lake Michigan	LMN	Northern Lake Michigan Management Unit
		LMC	Central Lake Michigan Management Unit
		LMS	Southern Lake Michigan Management Unit
S	Lake Superior	LSW	Western Lake Superior Management Unit
		LSE	Eastern Lake Superior Management Unit

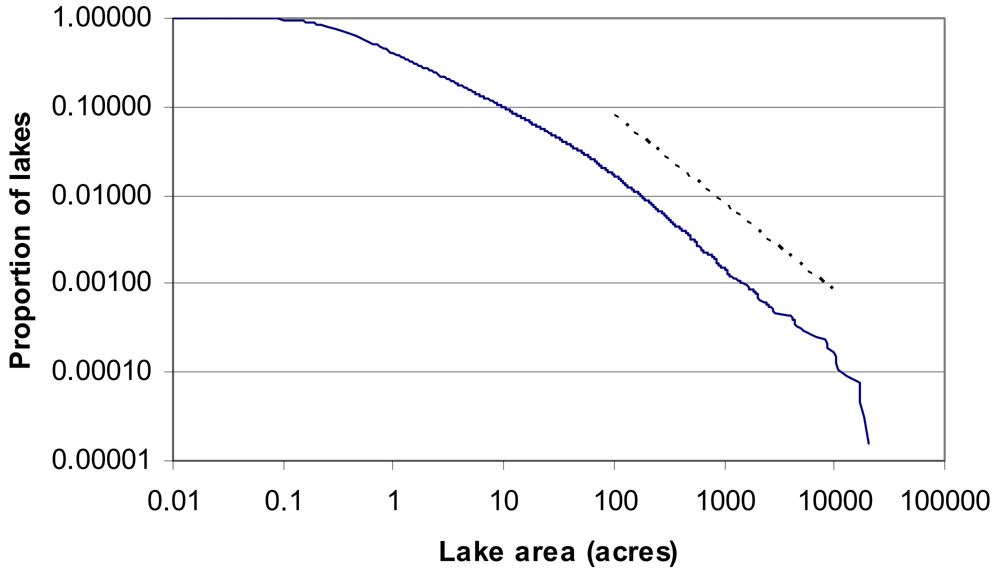

Figure 1.–The size distribution of Michigan lakes follows a power-law distribution. There are many small lakes and few large lakes. The solid line indicates the proportion of lakes larger than a given size. The reference dotted line has a slope of -1.

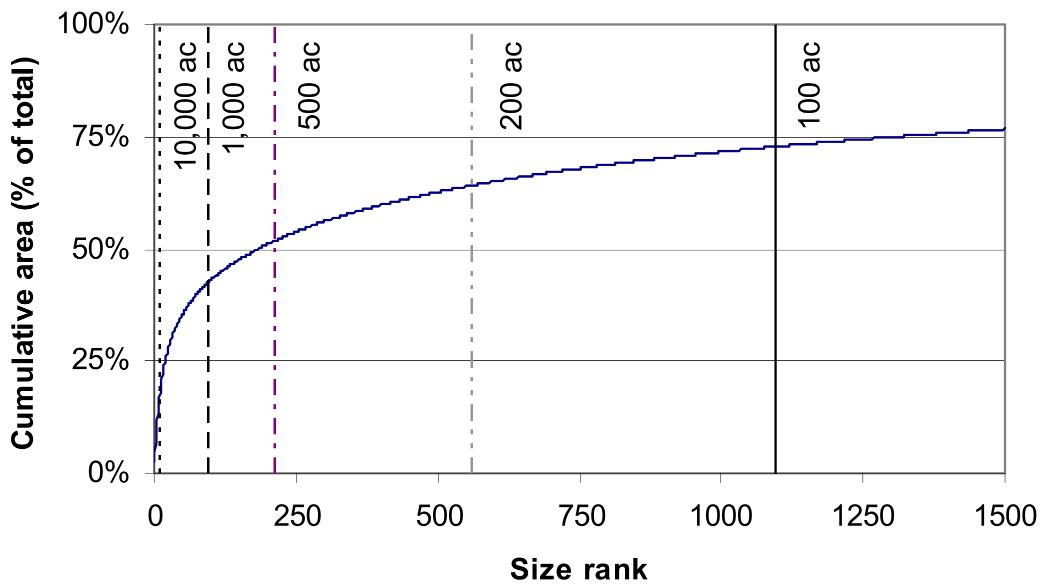

Figure 2.–Cumulative lake area versus lake-size rank. Total surface area for 64,797 inland lakes is 864,334 acres, according to GIS information used in this study. The largest inland lake (rank 1) is Houghton Lake, with a surface area of 20,075 acres, representing 2.3% of the total for the State. Vertical lines indicate rank for lakes of a specified size. The 10 lakes ≥ 10,000 acres are 16.7% of total surface area; 96 lakes ≥ 1,000 acres are 43% of total surface area; 213 lakes ≥ 500 acres are 52% of total surface area; 561 lakes ≥ 200 acres are 64% of total surface area; 1,095 lakes ≥ 100 acres are 72.8% of total surface area. The 6,341 lakes ≥ 10.0 acres (only some of which are shown) represent 91.1% of total surface area; 26,055 lakes ≥ 1.0 acres represent 98.2% of total surface area.

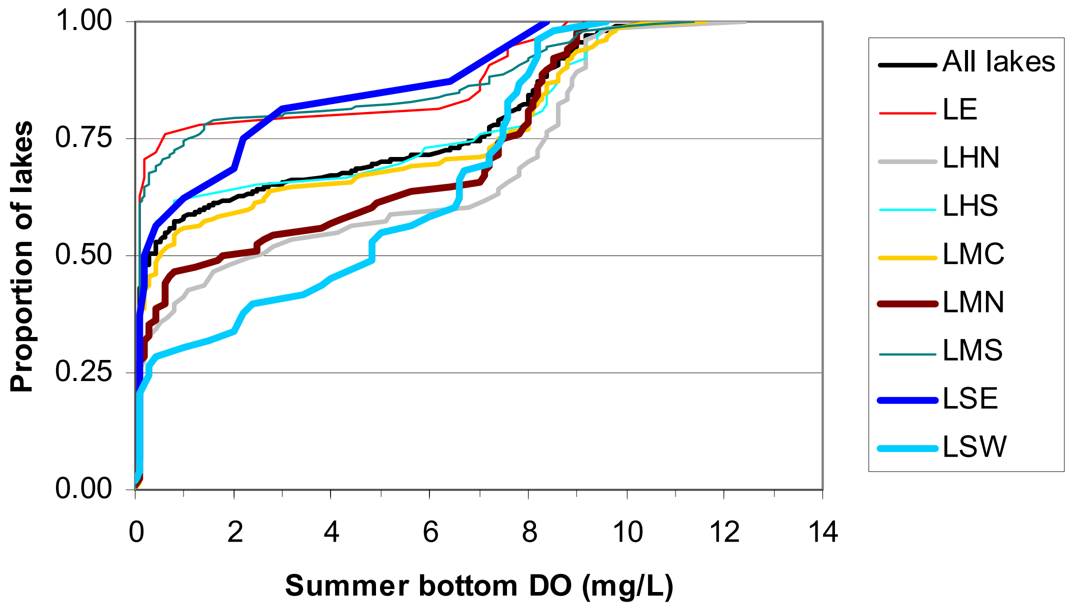

Figure 3.–Cumulative distribution functions for summer dissolved oxygen concentration (DO, mg/L) at the bottom of Michigan lakes, by Fisheries Management Unit. The lines represent the proportion of lakes having average summer DO concentrations less than or equal to a particular value. Measurements made by MI DEQ for each of 688 lakes were obtained from the U.S. EPA, STORET database. All measurements for a given lake at the bottom in August or September were averaged.

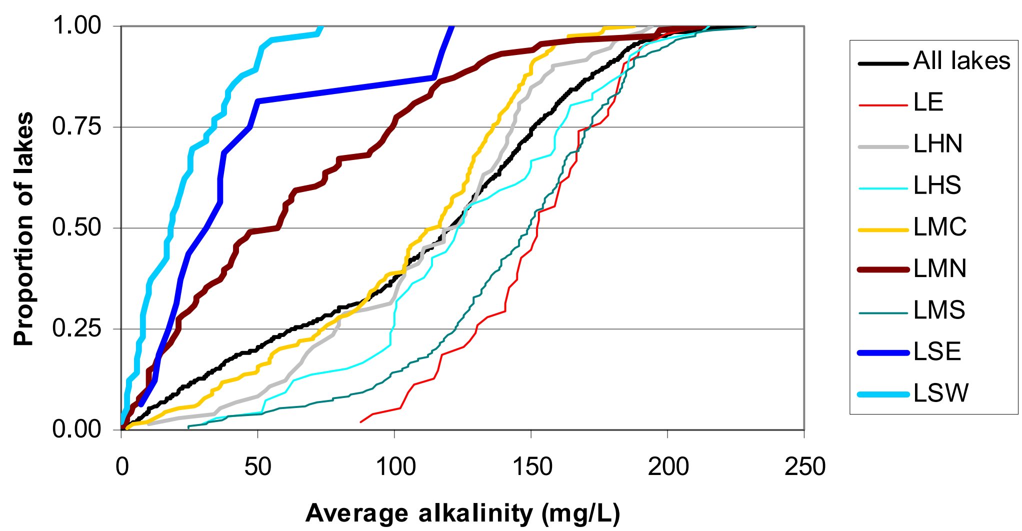

Figure 4.–Cumulative distribution functions for alkalinity in 719 Michigan lakes, by Fisheries Management Unit. Lines represent the proportion of lakes having average alkalinity less than or equal to a particular value. Alkalinity (mg/L as $CaCO_3$) indicates the concentration of compounds (typically, bicarbonates, carbonates, and hydroxides) that shift pH to the alkaline side of neutrality (Wetzel 1975). Measurements made by MI DEQ for each of 719 lakes were obtained from U.S. EPA STORET database. All measurements for a given lake were averaged.