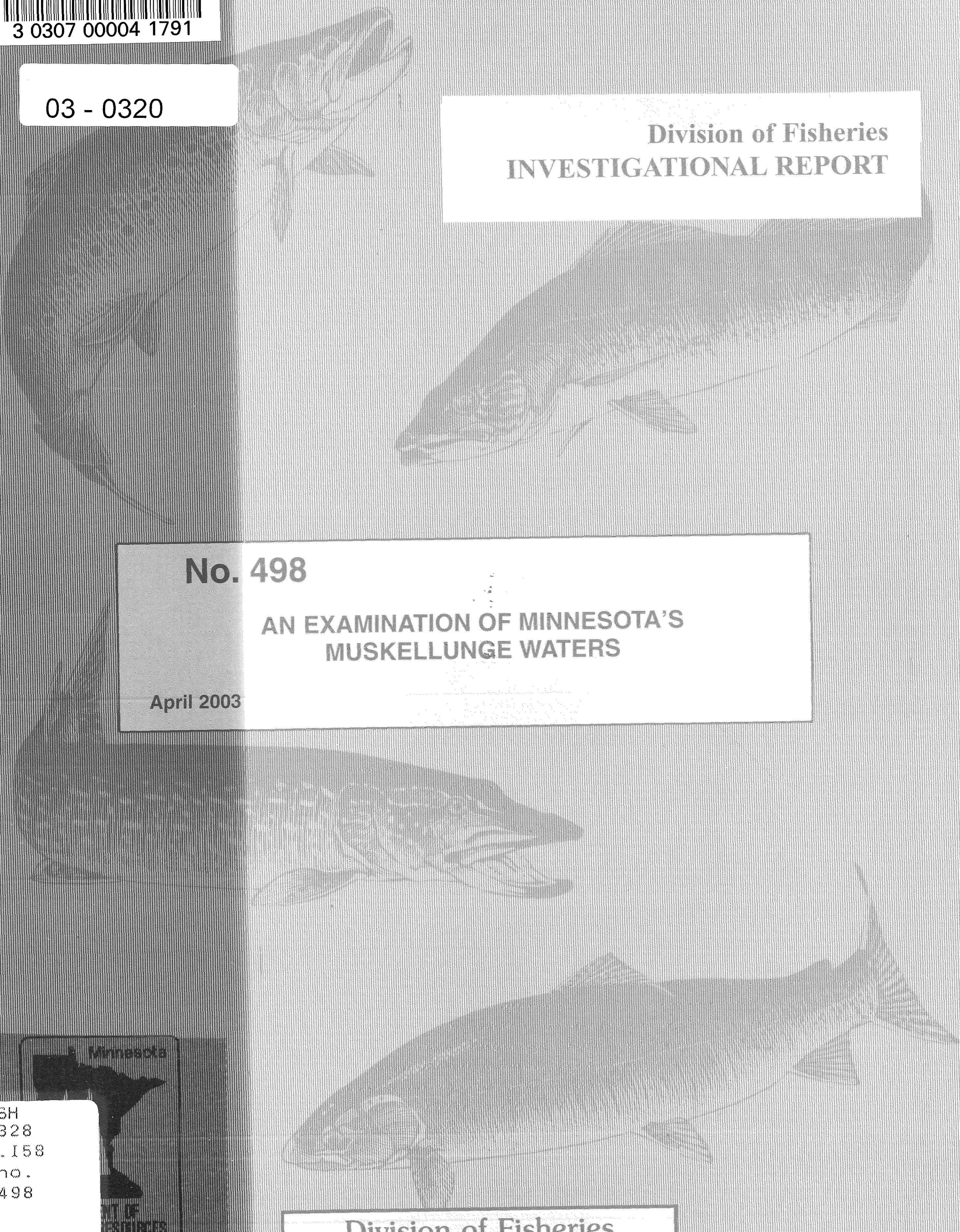

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AN EXAMINATION OF MINNESOTA'S MUSKELLUNGE WATERS[1]

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Abstract.-- We examined Minnesota's muskellunge *Esox masquinongy* waters using various data sets including spring trap net assessments, angler diary surveys, and stocking records. In many cases, data limitations prevented us from drawing strong conclusions. Currently, 107 lakes have been identified as muskellunge waters, of which 63 lakes have been created and maintained by stocking. Anglers averaged more muskellunge specific angling trips in 1996-98 than in 1986-89. Minimum size regulations have progressively increased over the past 10 years, while stocking numbers have been decreasing. It appears from trap net analysis that the abundance of 40 inch and larger muskellunge has been increasing over time. The proportion of successful anglers has increased over time, but catch rates remained the same. Both trap net and angler data provide some indications that size of muskellunge caught has also increased over time. Age, size, and growth potential of muskellunge from Minnesota waters was estimated from 564 cleithra collected from taxidermists and other sources. Angler-caught muskellunge averaged 11 years of age and 45.1 inches total length. Von Bertalanffy ultimate length estimates averaged 54.2 inches for females and 46.1 inches for males. All evidence, although limited by inconsistent data sampling sets, appears to indicate a successful management program.

Introduction

The muskellunge *Esox masquinongy* is regarded as a prized game fish and is the largest of the esocids found in Minnesota. Minnesota's Muskellunge Long Range Plan (MN DNR 1994) established a goal of managing natural and introduced populations of muskellunge for a range of quality angling experiences, while maintaining trophy opportunities and preserving genetic integrity. However, as muskellunge angling popularity grows, so has the demand for more muskellunge waters and larger minimum size limits.

Muskellunge size is perceived as the key component of a quality fishery, and the use of harvest regulations (i.e., bag and size limits, restricted seasons) are viewed as tools to improve fishing quality. Leitch and Baltezore (1987) illustrated the importance of trophy an-

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gling opportunities from an angler attitude survey of Minnesota anglers. Cunningham and Anderson (1992) found that anglers typically associated with chartered fishing organizations favored quality-sized fish and regulatory restrictions that accompany this management activity. Anglers fishing muskellunge in Wisconsin defined a trophy as at least 40 inches, but preferably greater than 45 inches in total length (Margenau et al. 1994). The practice of catch and release is also testimony to the significance size plays in muskellunge angling. More than just an ethic, catch and release has been viewed as a tool in managing a "trophy" muskellunge resource.

Evidence of increased exploitation coupled with changes in population size structure was documented for muskellunge in the Park Rapids area over a 58-year period (Olson and Cunningham 1989). The historical qualities of these fisheries have not been restored, although stocking and size restrictions were applied as corrective measures. Hanson (1986) attributed limited trophy potential and poor quality size structure in some Wisconsin lakes to exploitation. Highly variable muskellunge population characteristics were found in these eight study lakes. In contrast, a 36-year experiment with liberal angling regulations in Escanaba Lake failed to alter muskellunge population trends as theoretically predicted (Hoff and Serns 1986). It is apparent that exploitation has played a role in changing the quality size structure of muskellunge populations in some waters. These cases exemplify the need to more closely examine Minnesota's muskellunge waters and better define the trophy potential as it relates to each lake.

Although muskellunge are one of the few fish in Minnesota managed exclusively for trophy purposes, the definition of a "trophy" muskellunge is as diverse as the experience of the anglers who pursue this fish. As anglers' experience and catch (numbers and size) increase, so does their perspective of what constitutes a "trophy" fish (Wingate 1986). Confounding this issue is the inherent difference between biological and social definitions of "trophy" management. Both resource managers and muskellunge anglers must recognize the biological limitations and associated social issues accompanying muskellunge management, and react accordingly.

When addressing muskellunge issues, another problem surfaces that impacts how we approach management. Basic biological data necessary to effectively refine our muskellunge management strategies is either lacking, decentralized, or not readily available. Standard fisheries sampling techniques and monitoring methods have failed to provide adequate information on muskellunge population characteristics (Strand 1986). Statewide, Area Fisheries Offices are now more frequently conducting muskellunge special assessments. However, this information needs to be integrated into a centralized database that encompasses all of the state's muskellunge waters. The number of anglers fishing for muskellunge, fishing pressure specifically directed at muskellunge, and the statewide harvest are all unknown. The age and size structure of the harvest, and population characteristics and trends in the premier Minnesota muskellunge waters are also poorly described. Use and harvest of the introduced populations are also unknown. This type of basic biological information is necessary to effectively guide this relatively young management program.

Part of this project was to develop and foster a working relationship between the Division of Fisheries and other parties interested in the muskellunge resource (including both muskellunge anglers and taxidermists). The primary objective of this study was to collect and compile existing muskellunge assessment data, and create a database that will allow us to begin describing lake specific population characteristics and trophy potential. We summarized and conducted analyses on angler diary and trap net information, and age and growth data. A general description of the muskellunge program provided in this report includes stocking and regulation reviews, and distribution and classification of muskellunge waters.

Data

Minnesota's muskellunge program is relatively young and doesn't have the advantage of a large database to provide management direction. Spring special trap netting assessments have been the primary means of collecting population information since 1976. A total of 210 spring trap net assessments conducted on 47 lakes were available for analysis. This indicates that 45% of the muskellunge waters have never been assessed with spring trap netting. Netting data is either lacking or unavailable for four of the premier muskellunge lakes (Cass, Leech, Mille Lacs, and Winnibigoshish) in the state. The Mississippi River has angler diary information, but lacks netting information. In addition, no statewide design was used for selecting lakes to sample. Some muskellunge waters, such as brood stock lakes, are netted every year, while other lakes have sampling intervals ranging from two to five years. This resulted in our inability to describe statewide or long-term trends on individual lakes.

We pooled lake data by Lake Class (Schupp 1992) to increase sample size, however, lack of randomization and unequal distribution between lakes and among Lake Classes complicated the analysis. Muskellunge waters are present in 23 Lake Classes, of which any one Lake Class could contain from one to 23 lakes (Table 1). Special assessments have been conducted on muskellunge lakes present in 13 Lake Classes. Lake Classes containing the greatest numbers of muskellunge waters have also been sampled proportionately more often (Table 1). Lake Classes 22 and 24 have a similar number of lakes with netting data, however, most lakes in Lake Class 24 have been sampled more frequently than lakes in Lake Class 22 (Table 2). Lake Classes 25 and 27 have both stocked and native populations, but are infrequently surveyed. Special assessments are lacking for most muskellunge lakes in the Lake Classes ranging from 29 to 43. All river information collected was assigned to Lake Class 50 for analytical purposes.

Table 1. Spring trap net assessments conducted on muskellunge waters from 1976 - 2002. Lakes were grouped by Lake Class.

Lake Class	Number of lakes	Number of lakes surveyed	Percent of class surveyed	Total number of surveys	Number of lakes - muskellunge	Number of lakes - hybrids	Acres
2	2	1	50	6	2		47,892
5	1	1	100	2	1		437
12	1	0	0	0	1		123
13	2	0	0	0	2		362
20	1	1	100	4	1		86
22	16	9	56	43	16		72,239
23	8	2	25	10	7	1	2,792
24	23	9	39	70	13	10	12,984
25	17	7	41	29	17		17,598
26	3	1	33	2	3		301,587
27	11	5	45	15	11		24,822
28	2	0	0	0	2		153
29	2	1	50	1	1	1	355
30	3	0	0	0		3	283
31	4	2	50	12	4		1,264
32	1	1	100	10	1		510
34	2	0	0	0	1	1	368
35	2	1	50	2	2		596
38	2	1	50	2	1	1	739
40	2	0	0	0		2	156
41	1	1	100	2		1	780
42	1	0	0	0		1	60
43	1	0	0	0		1	233

Table 2. Description of Lake Classes used in analysis of muskellunge angler diary and trap net survey data sets.

Lake Class	Comments
2	Two muskullunge lakes are in this Lake Class. Lake Vermilion is the only lake in this Lake Class with netting data; first stocked in 1985 and netted in 1993; eight years between stocking and first netting event; will probably show slightly larger fish than those lakes sampled 3-4 years after stocking; takes 2 years to net the whole lake - east end one year and west end the following year. Limited angler diary data.
22	Sixteen muskullunge lakes are in Lake Class 22 of which 8 have data available including Alexander (4 years), Bemidji (1 year), Big Detroit (4 years), Deer (4 years), Little Boy (9 years), Miltona (3 years), Plantagenette (6 years), and Wabedo (8 years). Two Lake Class 22 lakes are metro lakes. Plantagenette is a brood stock and 48 inch minimum size lake; first stocked in 1982 and sampled in 1989; sampling was done every year until 1993. Over half of the lakes in Lake Class 22 are native waters. Data was not available for Cass Lake. Angler diary data available for 11 lakes.
23	Eight muskullunge lakes are in this Lake Class. Baby and Elk are the only lakes that have data available. Baby has one year of sampling and is known as a small fish lake (native lake that had Shoepack stocking). Elk is a brood stock and 48 inch minimum size lake, and has been netted 9 years. Angler diary data available for 3 lakes.
24	Twenty-four muskullunge lakes are in Lake Class 24 of which 9 have data available including Bald Eagle (10 years), Eagle (7 years), East Rush (2 years), French (6 years), Independence (10 yeas), Owasso (4 years), Rebecca (17 years), Forest (3 netting events and no data), and Sugar (10 years). Eagle, Owasso, and Rebecca are brood stock and 48 inch minimum size lakes. Bald Eagle also has a 48 inch minimum size regulation. All Lake Class 24 lakes are in the Twin Cities metropolitan area with the exception of Sugar, French, and East Rush Lakes. Angler diary data available for only 30% of the lakes.
25	Seventeen muskellunge lakes are in this Lake Class of which 7 have data available. Five of the lakes are from the Mantrap chain of lakes; Big Mantrap is the only one sampled. Big Mantrap has the most netting periods (8) followed by Lobster with 5 netting years. The remaining lakes (Beers, Cross, North Star, Spider, and West Rush) each have less than 5 years of netting. Angler diary data available for 9 lakes.
26	Lake Class 26 includes some of our large lakes. No netting data for Leech and 1 year for Mille Lacs. Diary data are present for both lakes. No net data and limited diary data for Winnibigoshish.
27	Eleven muskellunge lakes are in this Lake Class of which 5 have data available. Two lakes are native waters, Big and Moose. All lakes except for Moose Lake have less than 5 netting years of data. A number of the lakes are relatively new populations with netting periods first starting in 1995 or 1996. These lakes include Pelican, Shamineau, and West Battle all with 2 years of netting. Would expect some lakes in this Lake Class to show small fish with small sample sizes. Five lakes have angler diary data available.
30	Indian Lake is the only muskellunge lake in this Lake Class. The remaining lakes are hybrid waters. Indian Lake is no longer a muskellunge lake. It had 4 years of sampling starting in 1984. However, Indian is a relatively small, shallow lake that winterkilled one year and was removed from the designated muskellunge lake list. Some diary information collected prior to winterkill.
31	Four muskellunge lakes in this Lake Class. Little Moose and Little Wolf are the only lakes in this Class with netting data. Little Moose is a small, native lake (less than 300 acres), sample size during netting tends to be small (10 fish or less total). Little Moose has 3 good years of netting data. Little Wolf is a brood stock lake with a minimum size limit of 48 inches, frequent netting years early (1 a year until 1997); first stocked in 1982 and netted in 1986 would probably result in small fish in the sample. Little Wolf is the only introduced lake. Angler diary data available for Little Wolf only.
32	Island Lake (10 netting years) is the only muskellunge lake in this Lake Class. It is also a brood stock lake with frequent netting years early, 1 a year until 1994. The early netting years would probably be sampling small, young fish. Stocked in 1982 and first netted in 1985. Island Lake has limited diary data available.

Angler diary and taxidermist data also face some of the same limitations as the trap net data (Table 2). Both angler diary and taxidermist information were collected with the help of volunteers. The amount of data collected varied between lakes and spread across Lake Classes. Angler diary data were available for 44 muskellunge lakes spread across 12 Lake Classes. Taxidermist samples were primarily associated with two Lake Classes. Taxidermist and angler cooperation, and sample size were the limiting factors in performing lake specific analyses. Since both data sets depended on volunteers to collect information, lake and Lake Class data lacked randomization and balance.

Other confounding factors that complicate analysis of the trap net and diary data include changes in sampling gear, minimum size regulations, and stocking (Table 2). Sampling gear used during muskellunge assessments included big (5x6 foot frame) and small (3x6 foot frame) trap nets. With a few exceptions, most lakes during the early assessments were sampled using small trap nets. Starting in 1999, large trap nets became the standard muskellunge spring assessment net. Three regulation changes occurred over a 10-year period. In some cases these changes were lake specific and are reflected in individual Lake Classes (Table 2). The stocking variable only separates stocked lakes from native lakes. A more detailed assessment of stocking would have required additional information about stocking rates, frequency, size of fish stocked, and strain.

Due to nonrandom sampling by both anglers cooperating in the diary program, and in the trap net survey program, the inferences drawn from analyses of these data cannot be applied generally to all muskellunge waters. For example, trap net analyses may be heavily influenced by a small number of influential lakes, and angler diary data are strongly influenced by the behavior of the relatively avid anglers that participated in this program.

Methods

Numerous sources of information were used to characterize Minnesota's muskellunge fishery. Data sets contributing to this report included both biological and social information. A license point of sale angler survey technique using the Electronic Licensing System (ELS) was used to collect muskellunge information. The muskellunge specific question focused on determining the total number of anglers (resident and nonresident) who fish specifically for this species. Historical regulation information was compiled from annual fishing synopses. Stocking and special assessment information were collected from the MNDNR, Division of Fisheries DataBase Warehouse. Since the Data Base Warehouse did not contain a complete set of muskellunge spring assessment data, these data were supplemented with additional data from Area Fisheries Office's survey reports. The stocking database was also updated to include the most current muskellunge stocking records. The voluntary angler reporting system used diaries to obtain muskellunge angling trip information. The diary design was similar to the 1986-89 ***Project Muskie*** angler diary (Younk and Cook 1992). Angler diary data from this study was compared with the data from the earlier study (Younk and Cook 1992). We used cleithra as the primary structure for analysis of age and growth (Casselman and Crossman 1986). Cleithra from taxidermists were supplemented with cleithra from other sources to increase sample size including lake assessments and muskellunge found dead.

Analytical Methods

Stocking rates, expressed as mean annual fingerling rate per surface area, were calculated by linking the lakes and stocking databases. Total numbers of muskellunge fingerlings and number of years since the first stocking occurred were used to calculate mean annual stocking rates for each lake.

Angler diary and trap net length data were analyzed with standard parametric procedures, including analysis of variance (ANOVA) followed by multiple comparison of means using Tukey's HSD with a Type I error rate of 5% (SAS Institute 2002). Trap net length data were not available for individual fish, so we used mean length per survey with reciprocal variance weighting, where the mean and variance were for all fish sampled within one annual survey on one water body. For testing trends over time with angler diary data, time was arranged as a nominal variable with an early period from 1986 to 1989 and a later period from 1996 to 1998. Year was a continuous variable when testing trends over time with trap net data.

Both angler diary and trap net CPUE data contained large numbers of zero values (i.e., anglers that were not successful in catching at least one fish, and trap net surveys where no fish were captured), and thus could not be subjected to standard parametric procedures based on the normal or lognormal distribution. For these data, we applied analytical procedures appropriate for the delta distribution to contend with the large number of zero observations (Syrjala 2000). To achieve this, we first categorized each observation (i.e., an angler's fishing trip or a trap net survey) as successful (i.e., caught at least one fish), or not (i.e., no fish were caught). These binomial data sets were then analyzed using nominal logistic methods or logistic regression to identify significant independent variables. We then took a subset of both angler diary and trap net data that included only angler trips or trap net surveys that caught one or more fish. These data were then analyzed with standard general linear model procedures, where the dependent variable was $\log_e$ CPUE. Where appropriate, we applied Tukey's HSD with a Type I error rate of 5% to identify homogenous subsets for the nominal, independent variable analyzed.

When applying linear model analyses for both length and CPUE data, we did not use standard model selection procedures such as best subset regression because several independent variables were confounded over time. Instead, we simply subsetted the data over time to accommodate independent variables that were not confounded. For trap net data, we had to separate analyses for gear type, since the dimensions and design of trap nets changed over time. In addition to gear and time, other independent variables for both angler diary and trap nets included Lake Class and stocking (see description of these two factors above in the Data section, especially as it concerns study design limitations). Further description of limitations with these data is provided above in the Data section. We performed all analyses of length and CPUE data for both angler diary and trap net surveys using JMP software (SAS Institute 2002).

The analysis of cleithra has provided a direction for defining trophy muskellunge growth parameters (Casselman and Crossman 1986). Population characteristics described include mean age and size of harvest, and age and size frequency distributions. Additional length-based analysis (Pauly 1984) used the von Bertalanffy growth formula (VBGF) fit with nonlinear least squares (Prager et al. 1989) for determining growth parameters k and asymptotic length (L_∞).

Results and Discussion

Distribution of Muskellunge Waters, Angler Use, and Management

A key management issue is to increase the number of muskellunge angling opportunities by expanding the number of lakes managed for muskellunge. Currently, 107 lakes with a combined area of 486,419 acres, and 6 river systems have been identified as muskellunge waters (Table 2, includes hybrid muskellunge). Muskellunge waters are present in all three major drainage basins: Hudson Bay; Mississippi River; and Lake Superior. The majority of these muskellunge waters are found in the north-central and Twin Cities metropolitan areas, although angling opportunities for muskellunge are available in all regions of the state (Figure 1). Forty-four lakes and all six rivers are recognized as native muskellunge water. In addition, muskellunge are present in the following border waters with Canada and Wisconsin: Lake of the Woods; Rainy River; Rainy Lake; St. Louis River Estuary; and St. Croix River. Introduced populations have been developed statewide, and are maintained by a stocking program. The stocking program has created and continues to maintain 247,192 acres (41 lakes) and 4,481 acres (22 lakes) of muskellunge and hybrid muskellunge waters, respectively. Although hybrid muskellunge occur naturally in some waters, the managed hybrid lakes are maintained by stocking, and are located only in the Twin Cities metropolitan area. This represents a sizable resource base that supports an important but unquantified trophy fishery.

Muskellunge waters are found in 23 Lake Classes ranging from Class 2 to 43 (Table 3). Lakes in Lake Classes 2, 22, 24, 25, 26, and 27 account for 67 and 98% of the total number and acreage of muskellunge lakes, respectively. Native muskellunge waters are

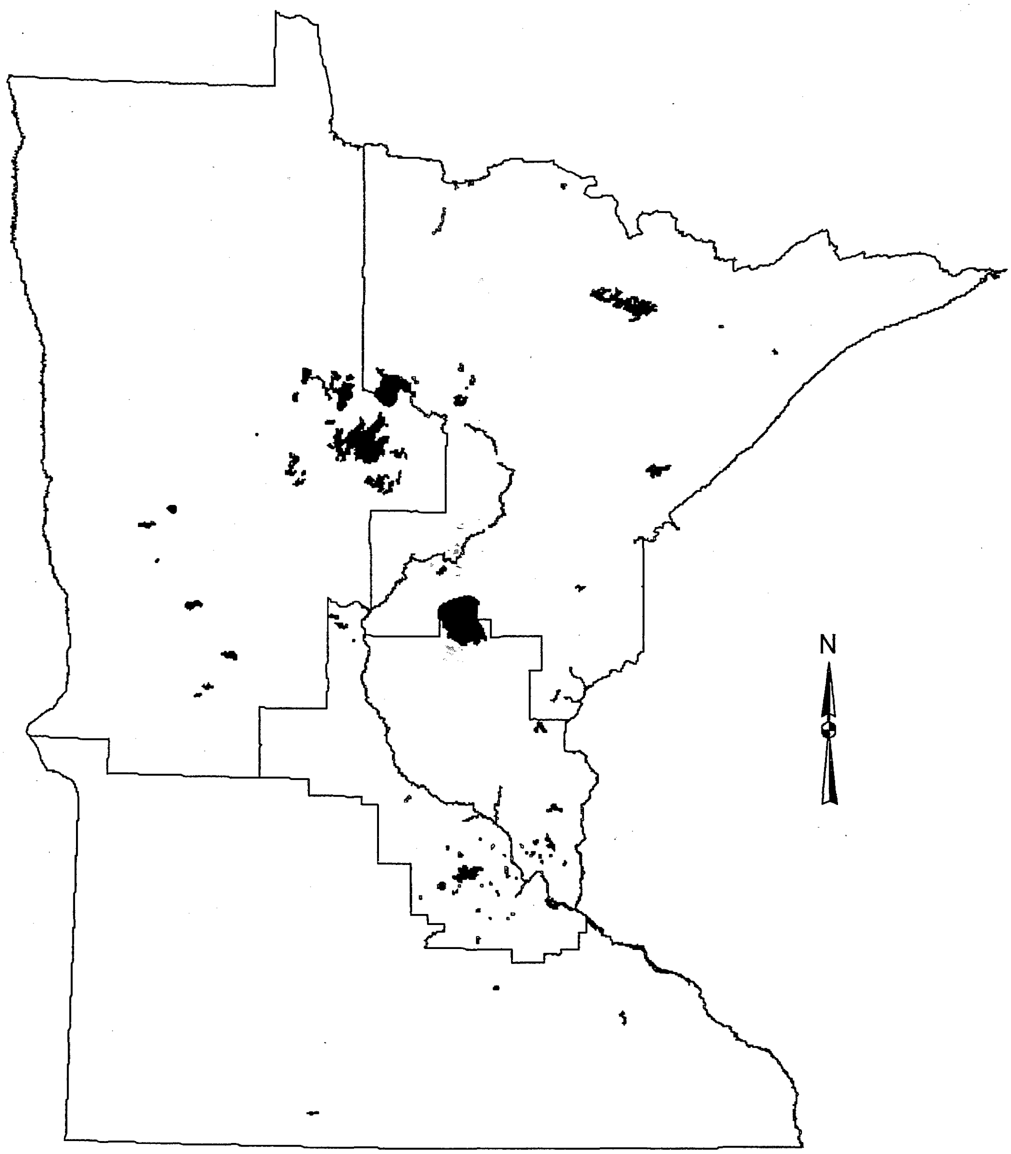


Figure 1. Statewide distribution of muskellunge waters. Lines represent the four regional boundaries.

Table 3. Current listing of Minnesota's muskellunge waters.

Water body	Lake ID number	Status[1]	Acres	Water body	Lake ID number	Status[1]	Acres
Alexander	49007900	I	2,763	Island	62007500	I/H	60
Andrusia	04003800	N	1,510	Island	58006200	I	510
Baby	11028300	N	705	Island	69037200	I	7,335
Bad Axe	29020800	N	271	Isles	27004000	I/H	109
Bald Eagle	62000200	I	1,268	Johanna	62007800	I/H	213
Beers	56072400	I	195	Kettle River	River	N	
Belle Taine	29014600	N	1,185	Kid	11026200	N	167
Bemidji	04013000	N	6,420	Kitchi	04000700	N	1,785
Big	04004900	N	3,533	Lake St. Croix	82000100	I	8,209
Big Detroit	03038100	I	2,967	Leech	11020300	N	110,527
Big Fork River	River	N		Little Boy	11016700	N	1,372
Big Mantrap	29015100	N	1,556	Little Fork River	River	N	
Big Sand	29018500	N	1,659	Little Moose	31061000	N	271
Big Wolf	04007900	N	1,094	Little Sand	29015000	N	386
Blandin Reservoir	31053300	N	449	Little Shoepack	69086800	N	56
Boy	11014300	N	3,186	Little Winnibigoshish	31085000	N	938
Bryant	27006700	I/H	161	Little Wolf	11050500	I	490
Buck	04004200	N	271	Lobster	21014400	I	1,308
Bush	27004700	I/H	172	Long	11048000	N	271
Calhoun	27003100	I	401	Lower Bottle	29018000	N	652
Cass	04003000	N	15,596	Mann	11028200	N	445
Cedar	01020900	I	1,769	May	11048200	N	187
Cedar	27003900	I/H	169	Mckeown	11026100	N	147
Cedar	70009100	I/H	780	Mille Lacs	48000200	I	132,516
Child	11026300	N	316	Miltona	21008300	I	5838
Clear	82016300	I/H	424	Minnetonka	27013300	I	13,834
Cross	58011900	I	943	Mississippi River	River	N	
Crystal	19002700	I/H	280	Moose	31072200	N	1,265
Crystal	27003400	I/H	78	Mule	11020000	N	456
Deer	31071900	N	3,691	Nokomis	27001900	I/H	204
Dumbbell	38039300	I	437	North Star	31065300	I	1,059
Eagle	27011100	I	291	Orange	31058700	I	86
Eagle	10012100	I/H	233	Orchard	19003100	I/H	234
Elk	15001000	I	271	Oscar	21025700	I	630
Elmo	82010600	I/H	206	Owasso	62005600	I	384
Emma	29018600	N	77	Pelican	56078600	I	3,986
Forest	82015900	I	2,251	Phalen	62001300	I/H	198
Fox	46010900	I	1,041	Pierson	10005300	I/H	235
French	66003800	I	816	Pike Bay	11041500	N	4,760
Gervis	62000700	I/H	234	Plantaganette	29015600	I	2,529
Girl	11017400	N	348	Pleasant	62004600	I	585
Harriet	27001600	I	335	Praire River	River	N	
Harris	38073600	I	123	Rainy River	River	N	
Hyland	27004800	I/H	84	Rebecca	27019200	I	254
Ida	29017000	N	76	Round	27007100	I/H	33
Independence	27017600	I	844	Round	49005600	I	121
Inguadona	11012000	N	1,077	Winnibigoshish	11014700	N	58,544

Table 3 Continued.

Water body	Lake ID #	Status[1]	Acres
Rush	13006900	I	2,823
Shamineau	49012700	I	1,626
Shoepack	69087000	N	306
Silver	62000100	I/H	72
Snake River	River	N	
Spider	29011700	N	544
Spider	31053800	N	1,349
St. Croix River	River	N	
St.Louis Bay	69129100	N	11,550
Steamboat	11050400	N	1,775
Stocking	29017200	N	88
Sugar	86023300	I	1,015
Swift	11013300	N	352
Upper Bottle	29014800	N	465
Vermilion	69037800	I	40,557
Wabedo	11017100	N	1,185
Waconia	10005900	I	2,996
Wasserman	10004800	I/H	153
Weaver	27011700	I/H	149
West Battle	56023900	I	5,624
White Bear Lake	82016700	I	2,416
Woman	11020100	N	4,782
Zumbro Reservoir	55000400	I	606

[1] I=Introduced waters; N=Native waters; I/H = Introduced hybrids waters

found most frequently in Lake Classes 22, 23, 25, 26, and 27. Although introduced muskellunge lakes are distributed among 15 Lake Classes ranging from Lake Class 2 to 38, these lakes are primarily located in Lake Classes 22, 24, and 25. Fifty-nine percent of the hybrid muskellunge lakes are found in Lake Classes 24 and 30. The remaining eight hybrid lakes are found in seven Lake Classes.

The muskellunge resource is relatively limited and frequently viewed as a nonconsumptive angling activity, thus detracting from its value when compared to other species present in Minnesota. An estimated 31,100 anglers, answering an Electronic Licensing System (ELS) survey question, indicated that they specifically fished for muskellunge during the 2001 angling season. This initial attempt at quantifying the number of anglers who fish for muskellunge should be viewed cautiously. Numerous problems associated with the survey may have underestimated the number of anglers specifically fishing for muskellunge. In comparison, the United States Fish and Wildlife Service (1988) estimated that 78,900 anglers (55,800 resident anglers) spent 876,000 angling days (741,600 resident angling days) in pursuit of muskellunge. Again, sample bias (small sample size) may cause these estimates to be inflated. Younk and Cook (1992) found that resident muskellunge anglers averaged 14.5 trips (median 11.0 trips) per season with an average trip length of 5.6 hours. Results from the 1996-98 angler diary study were slightly higher with anglers averaging 17.6 trips (median 12.0 trips) per season and 6.5 hours per trip. Although muskellunge angling is not widespread, interest and participation appears to be growing.

A historical review of muskellunge regulations indicates increasingly conservative regulations over time (Table 4). The earliest

Table 4. Summary of historical muskellunge regulations for inland waters of Minnesota, 1914 to 2002.

Year	Open season	Possession/Daily limit	Size limit
1914-18	1 May to 1 March	na/25 fish combined	Minimum size 30"
1921-24	15 May to 1 March	na/5	Minimum size 30"
1925	15 May to 1February	na/2	Minimum size 30"
1930-38	15 May to 1 February	na/2	None
1939-47	15 May to 15 February	2/2	None
1948	15 June to 15 February	2/2	None
1949-55	Mid-May to 15 February	2/2	None
1956-60	Mid-May to 15 February	1/1	None
1961-67	Mid-May to 15 February	1/1	[1]Minimum size 30"
1968-72	Mid-May to 15 February	1/1	Minimum size 30"
1973-81	Mid-May to 15 February	1/1	[1]Minimum size 30"
1982	5 June to 15 February	1/1	[1]Minimum size 30"
1983	4 June to 15 February	1/1	Minimum size 36" and 30" north/south division
1984-86	Early June to 15 February	1/1	[2]Minimum size 36" and 30" north/south division
1987	6 June to 15 February	1/1	[3]Minimum size 36"
1988-91	Early June to 15 February	1/1	[4,5]Minimum size 36"
1992	6 June to 15 February	1/1	[5,6]Minimum size 36"
1993-02	Early June to 15 February	1/1	[5,6]Minimum size 40"

[1]Exception: minimum size limit is 26" in Shoepack and Little Shoepack Lakes.
[2]Exception: minimum size limit is 30" in Cook, Hubbard, Lake, Otter Tail, & St. Louis counties.
[3]Exception: minimum size limit is 30" in Cook, Lake, Rice, Yellow Medicine, Steele, & Lyon counties.
[4]Exception: minimum size limit is 30" in Cook, Lake, Rice, Yellow Medicine, Steele, & Lyon counties. Also included are Shoepack & Little Shoepack Lakes.
[5]Exception: minimum size limit of 48" in 7 brood stock lakes.
[6]Exception: minimum size limit is 30" in Shoepack Lake.

series of changes resulted in reducing the bag limit from 25 fish (all species combined) during the early 1900s to our present species-specific harvest regulation of one muskellunge first implemented in 1956. Seasons have stayed relatively constant, although the start or end of season time intervals have periodically changed. The most recent change in the muskellunge season occurred in 1982 when recommendations were made to move the muskellunge opener to a later date than the traditional statewide fishing opener near mid-May. This change reflects the desire to protect mature fish from being harvested during the spawning season. Size limit regulations have alternated between no minimum size limit and a minimum size limit of 30 inches from the early 1900s to 1982. During the four-year period 1983-86, regional rather than statewide minimum size regulations were implemented (Table 4). A progressive increase in the minimum size limit occurred statewide between 1986 and 1993, resulting in our present statewide minimum size regulation of 40 inches. Exceptions to this regulation include a minimum size limit of 30 inches in Shoepack Lake and 48 inches in 7 brood stock lakes. Again, these changes were directed at protecting mature females through at least one spawning season.

Earliest documented efforts at propagating and stocking muskellunge occurred in 1911 (Minnesota 1912), and continued with limited success throughout the early 1900s. Shoepack strain muskellunge were the main source of fish used in the stocking program from the 1950s through the early 1980s. The stocking program first used Wisconsin strain in 1978 and Leech Lake strain muskellunge in 1982 (Table 5). Today, only the Leech Lake strain is used for stocking.

Table 5. Mean annual muskellunge fingerling stocking rates. Leech and Wisconsin strain muskellunge stocking data were combined. Shoepack strain muskellunge stocking data was excluded from analysis.

Water body	Lake ID number	First year each strain was stocked		Number years stocked	Number/acre	Number/littoral acre
		Leech	Wisconsin			
Lake Class 2						
Island	69037200	1992		7	0.32	1.07
Vermilion	69037800	1987	1985	12	0.10	0.27
Lake Class Mean					0.21	0.67
Lake Class 5						
Dumbbell	38039300	1989	1986	7	0.42	0.91
Lake Class 22						
Alexander	49007900	1988		4	0.06	0.20
Bemidji	4013000	1982	1978	9	0.12	0.40
Big Detroit	3038100	1989		10	0.82	1.33
Deer[1]	31071900		1985	1	0.14	0.76
Little Boy[1]	11016700	1987		4	0.13	0.39
Miltona	21008300	1989	1982	11	0.11	0.22
Minnetonka	27013300	1989	1987	8	0.07	0.17
Pelican	56078600	1989	1983	9	0.10	0.25
Plantaganette	29015600	1982		11	0.77	1.97
Wabedo[1]	11017100	1987		1	0.24	0.98
Lake Class Mean					0.26	0.67
Lake Class 23						
Elk	15001000	1982		14	0.82	3.03
Lake Class 24						
Bald Eagle	62000200	1994	1981	15	0.48	0.78
Calhoun	27003100	1994		2	0.19	0.65
Cedar	27003900	1998		1	0.59	1.58
Clear	82016300	2000		1	0.90	1.27
Eagle	27011100	1982		10	0.61	1.83
Forest	82015900	1989	1985	9	0.30	0.44
French	66003800	1989	1986	14	0.84	1.71
Gervis[1]	62000700	2000	1984	2	0.05	0.13
Harriet	27001600	1989	1982	13	0.22	0.87
Independence	27017600	1989	1982	14	0.58	1.16
Owasso	62005600	1982		10	0.40	0.50
Pleasant[1]	62004600	1988	1978	8	0.17	0.37
Rebecca	27019200	1982		13	0.81	1.50
Sugar	86023300	1989	1983	16	0.48	1.36
Lake Class Mean					0.47	1.01
Lake Class 25						
Beers	56072400	1990	1981	9	0.44	0.90
Big Mantrap	29015100	1988	1987	9	0.33	0.69

Table 5. Continued

Water body	Lake ID number	First year each strain was stocked: Leech	Wisconsin	Number years stocked	Number/acre	Number/littoral acre
Cedar	01020900	1994		7	0.24	1.05
Cross	58011900	1989	1983	11	0.41	0.59
Lobster	21014400	1990	1983	14	0.32	0.62
North Star[1]	31065300	1989		3	0.15	0.49
Zumbro Reservoir	55000400	1994		4	0.29	0.67
Lake Class Mean					0.31	0.72
			Lake Class 26			
Leech[1]	11020300	1982		8	0.004	0.01
Mille Lacs	48000200	1989	1984	12	0.02	0.09
Lake Class Mean					0.012	0.05
			Lake Class 27			
Big	4004900	1987		10	0.62	1.05
Moose[1]	31072200	1985		1	0.27	1.01
Shamineau	49012700	1988		5	0.19	0.42
Waconia	10005900	1984	1984	9	0.15	0.28
West Battle	56023900	1990	1979	11	0.10	0.23
Lake Class Mean					0.27	0.60
			Lake Class 29			
Round	49005600	1990		2	0.60	0.76
			Lake Class 30			
Indian[1]	2103600	1990	1979	10	1.07	1.77
			Lake Class 31			
Little Moose[1]	31061000	1988		1	0.30	0.66
Little Wolf	11050500	1982		9	0.45	0.91
Lake Class Mean					0.38	0.78
			Lake Class 32			
Island	58006200	1982		13	0.93	1.87
			Lake Class 35			
Blandin Reservoir[1]	31053300	1988		3	0.36	0.44
			Lake Class 38			
Oscar	21025700	1990	1985	5	0.34	0.43
			Other Waters			
Lake St. Croix	82000100	1992	1989	7	0.17	
Rush	13006900	1989	1983	14	0.32	0.51
St. Louis Bay	69000000	1989	1986	7	0.15	
			Statewide			
Mean					0.37	0.83
Median					0.31	0.68
SE					0.038	0.087

[1] No longer stocked

Muskellunge stocking averaged 28,932 (se 2,777) fingerlings annually during the period 1982-2001 (Figure 2). Prior to 1982, the stocking program was in transition, switching from Shoepack to Leech Lake strain muskellunge. Production and stocking during the early years (1982-1989) of the Leech Lake strain program, averaged 20,098 (se 3,596) fingerlings annually. Several strong production years in 1990 and 1994 were followed by a decrease in production and stocking during the period 1995-2001 (Figure 2). Although stocking during this later period has gradually declined, the average number of fingerlings stocked still remains above the overall average.

Stocking rates have also varied among lakes and Lake Classes, primarily resulting from differences in stocking frequency and numbers (Table 5). Individual lake management plans outlining specific objectives (i.e., brood stock lakes) also were responsible for some of these differences. Thirty-eight percent of the lakes exceeded the statewide average stocking rate of 0.37 fingerlings/acre (Table 5). Lake Class 26, consisting of two large lakes (Leech and Mille Lacs), exhibited the lowest stocking rate. Leech Lake strain brood stock lake stocking rates varied from 0.40 to 0.93 fingerlings/acre (mean 0.68 fingerlings/acre).

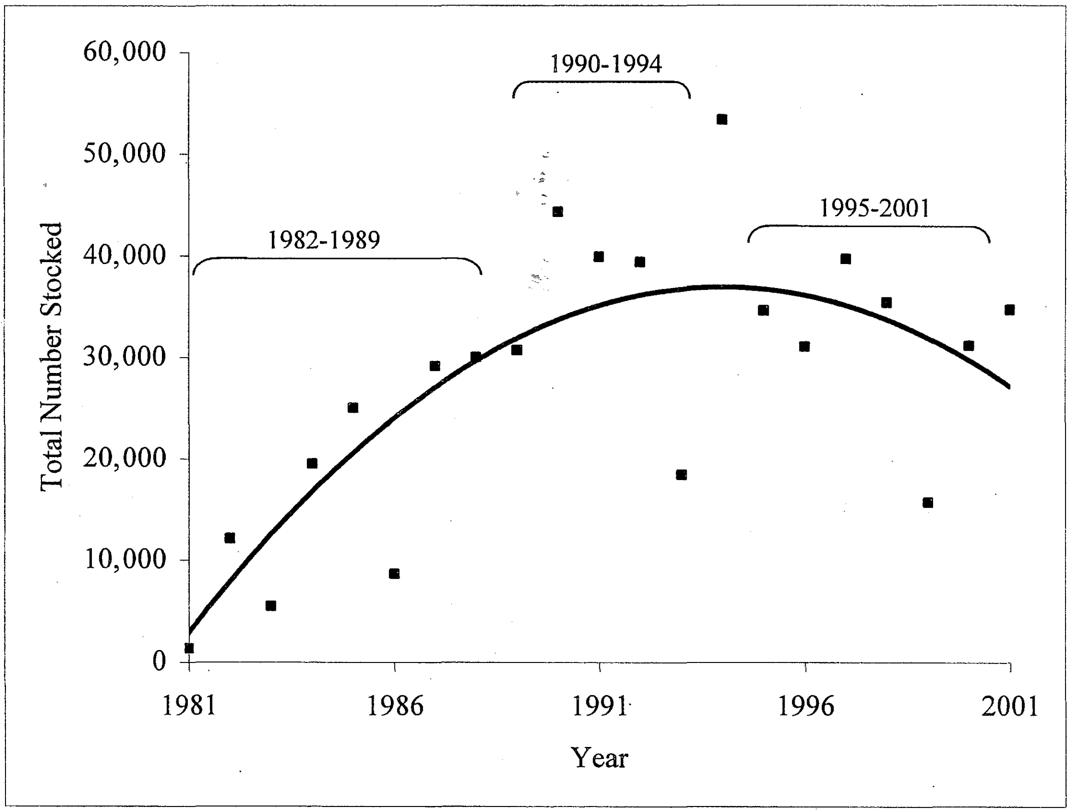


Figure 2. Examination of muskellunge fingerling stocking over time using a smoothing spline fit, 1981-2001. Leech Lake and Wisconsin strain muskellunge are combined.

Analysis of Relative Abundance

Relative abundance data included angler diary and trap net surveys. Both data were analyzed independently, and then compared to see if the results led to similar conclusions.

We analyzed trap net survey data using logistic regression after arranging the data in a binomial format for surveys that did not catch any fish and surveys that caught one or more fish. Independent variables included year of survey and gear (small and large nets). For trap net survey data, year was a continuous variable, as compared to diary data where time was a dichotomous, nominal variable (early or late periods). We report the Year*Gear interaction only when parameter estimates were unbiased. We could not include Lake Class or stocking in this analysis due to the severe imbalance in the data. We did this analysis for three size classes of fish: fish greater than or equal to 25 inches, 30 inches, and 40 inches. The only effect in all three size classes that was significant was the Year effect for the 40 inch size-class (Table 6A). This indicates that the odds of catching at least one fish 40 inches or larger in a survey are increasing over time (Figure 3). We also do not know if this is a true trend over time or an artifact arising because various Lake Classes were not sampled evenly over time. We could not reliably fit a Lake Class effect, so we cannot test this alternative hypothesis with these data.

We also applied ANOVA to trap net surveys that had caught at least one fish (i.e., CPUE greater than zero). These data required $\log_e$ transformation to conform to normality assumptions. Independent variables included Year, Gear, and Lake Class (Table 6B). The Lake Classes included Lake Classes 22 through 25, 27, 31 and 32. We did this analysis for the same three size classes used for logistic regression analysis of the trap net data (greater than or equal to 25, 30, and 40 inches). There was no evidence of a trend over time for the 25 and 30 inch size classes; the only significant main effect for both of these size classes was Lake Class (Table 6B). Based on multiple comparisons with Tukey's HSD, Lake Classes 24 and 25 have higher CPUE than Lake Class 27 for the 25 inch data set, and Lake Class 24 had higher CPUE than Lake Class 27 for the 30 inch data set. For the 40 inch data set, the only significant main effects were Year and Class, while none of the interactions were significant. The estimated year parameter was positive, indicating that Log_eCPUE of muskellunge 40 inches and larger has been increasing over time. Based on multiple comparisons with Tukey's HSD, Lake Class 24 had higher CPUE than Lake Classes 27 and 32. Again, we urge caution in interpreting results from analysis of Lake Class. Though the interaction for Year*Class was not significant, the power of this test was weak. Due to low statistical power in combination with the inadequate distribution of surveys across Lake Classes, there is nothing that we can conclude regarding trends in abundance by Lake Class. We can only conclude that the Year effect for 40 inch and larger fish was only significant and increasing for all of the lakes pooled in this analysis. However, both types of analyses that we applied to the trap net survey data (logistic regression of presence/absence binomial data and ANOVA of Log_eCPUE) indicate that the abundance of 40 inch and larger muskellunge in the included lakes has been increasing over time. We also examined separate plots and simple linear regressions of Log_eCPUE against Year for the seven Lake Classes included here (Figure 4). All had positive slopes and only those with small sample sizes (Lake Classes 23, 27, 31, and 32) were not significant. This suggests that the increasing trend in abundance over time is consistent across the classes examined here.

We fit nominal logistic models to angler diary data after arranging data in a binomial format for anglers that did not catch any fish during a trip (unsuccessful anglers) and anglers that caught one or more fish during a trip (successful anglers). We did this analysis for all reported fish caught, and for fish that were 40 inches and larger. Independent variables included two time periods (early and late), stocked or native waters, and several

Table 6. Analysis of trap net survey CPUE data: A. Logistic regression for binomial data (surveys where muskellunge were present or absent); B. ANOVA of Log_eCPUE for trap net surveys catching one or more fish.

A. Logistic regression analysis of binomial response.

Size of fish (inches)	Source	df	Chi square	Prob. > Chi square
25	Year	1	2.932	0.0868
	Gear	1	0.050	0.8235
30	Year	1	2.086	0.1486
	Gear	1	0.301	0.5834
40	Year	1	14.066	0.0002
	Gear	1	0.430	0.5120
	Year*Gear	1	0.028	0.8674

B. ANOVA of Log_eCPUE for trap net surveys catching one or more fish.

Size of fish (inches)	Source	df	Sum of squares	Mean square	Prob. > F
25	Year	1	0.5	0.5	0.5048
	Class	6	27.7	4.6	0.0004
	Gear	1	1.4	1.4	0.2558
	Year*Class	6	14.3	2.4	0.0395
	Year*Gear	1	2.1	2.1	0.1619
	Class*Gear	6	5.4	0.9	0.5258
	Error	117	121.3	1.0	
	Corrected Total	138	219.0		
30	Year	1	1.8	1.8	0.1939
	Class	6	26.1	4.4	0.0009
	Gear	1	0.6	0.6	0.4382
	Year*Class	6	14.5	2.4	0.0403
	Year*Gear	1	1.7	1.7	0.2072
	Class*Gear	6	5.7	0.9	0.4994
	Error	116	122.7	1.1	
	Corrected Total	137	221.9		
40	Year	1	8.8	8.8	0.0013
	Class	6	18.0	3.0	0.0022
	Gear	1	1.6	1.6	0.1623
	Year*Class	6	4.8	0.8	0.4246
	Year*Gear	1	0.2	0.2	0.5963
	Class*Gear	6	3.6	0.6	0.5990
	Error	88	69.9	0.8	
	Corrected Total	109	171.9		

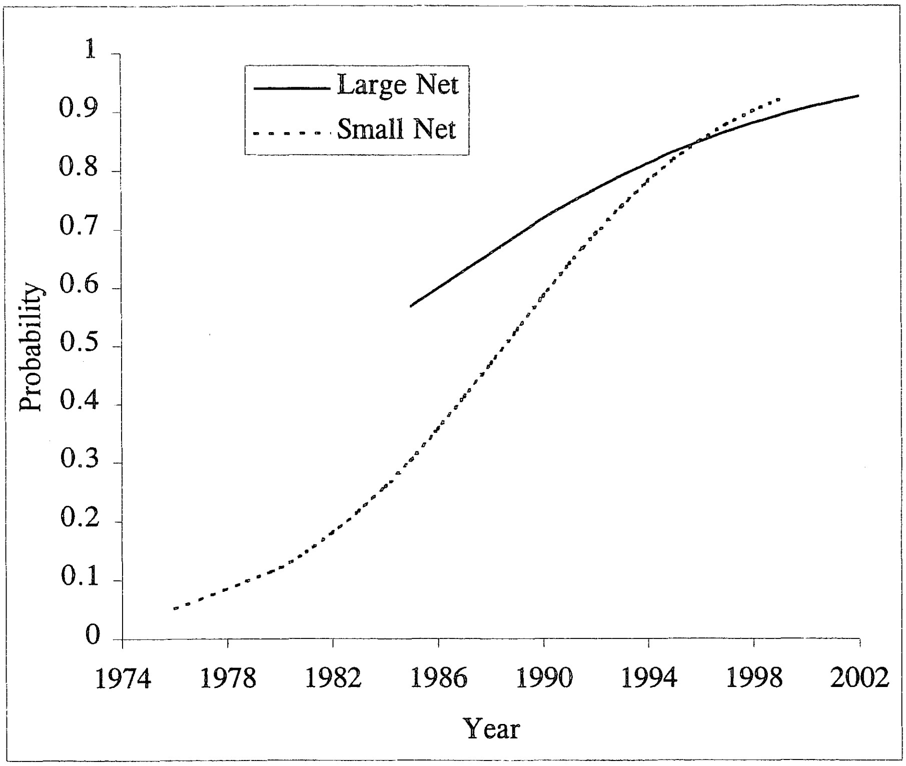


Figure 3. The probability of catching at least one muskellunge 40 inches or larger in a survey. Since the gear effect was not significant, the two lines for small and large nets are not significantly different.

Lake Classes. Proportion of successful anglers increased from the early to the late time period for both size classes of fish (Table 7A; from 20.7% up to 27.8% for all fish and from 3.8% up to 9.3% for fish 40 inches and larger). Anglers fishing stocked lakes were more successful (29.8% caught one or more fish) than those fishing native waters (18.4% caught one or more fish), but only for all fish caught; this test was not significant (P = 0.81) for fish 40 inches and larger (Table 7A). The test for Lake Class and the Time*Class interaction were significant for both size classes (Table 7A). There was a more consistent increase across Lake Classes in percent successful anglers for larger fish (greater than 40") than for all fish (Figure 5). However, we again urge caution in interpretation of analysis by Lake Classification due to data limitations.

We fit general linear models to log transformed CPUE for successful anglers, for all fish caught, and for fish that were 40 inches and larger (Table 7B). We used the same independent variables as used for the binomial data above. Catch rates did not change significantly between the two time periods for all fish caught (0.142 fish per hour for the early period and 0.137 for the later period, least square means), but did appear to decrease significantly for 40" and larger fish (from 0.167 fish per hour during the first period down to 0.113 during the second period). Stocked lakes had higher catch rates in the second period compared to the first for both size classes. The

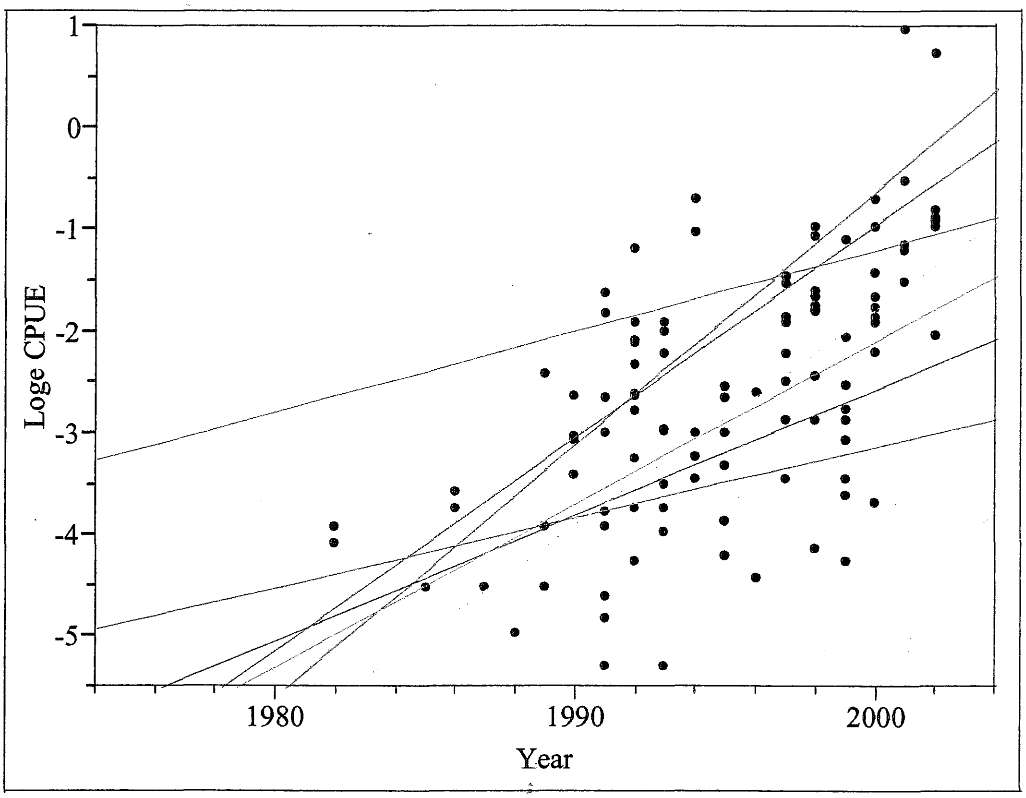


Figure 4. Individual regressions for Lake Classes using trap net CPUE for fish 40 inches or larger. The two shallower slopes are for Lake Classes 23 and 32, with sample sizes of only 6 and 7, respectively.

Time*Class interaction was significant for all fish caught, and for fish 40 inches and larger (Table 7B). Tukey's HSD indicated that the only Lake Classes that had significant changes in catch rates between time periods were Lake Class 31 waters for all fish, and Lake Class 23 waters for fish 40 inches and larger (Figure 6). After removing Lake Class 23 waters from the data for fish 40 inches and larger, the test for a Time effect was no longer significant ($P = 0.42$). The influences of Lake Classes 31 and 23 are unique since both contain brood stock lakes with minimum size limits of 48 inches. Both Lake Classes are also unique because they each are dominated by one lake with frequent netting events. Little Wolf Lake (Lake Class 31) is known as a lake with high catches, but small fish. Elk Lake (Lake Class 23) has a reputation of being a trophy fish lake. We conclude that there is little evidence for any change in angler catch rates between the two periods. This analysis further illustrates the shortcomings of these data due to distribution of fishing across various Lake Classes.

Although the proportion of successful anglers increased over time, we found no evidence for an increase in CPUE. The differences between these two results may reflect the nature of muskellunge angling, where very few anglers will catch more than one fish per trip. We could also attribute these differences to a limited resource being pursued by an increasing number of anglers. Based on increasing license sales (Cook et al. 1997), we can assume that the number of muskellunge anglers has also increased over time. Coupled with the increase in fishable muskellunge waters, it appears that the catch is distributed over more anglers, and the catch rate is indicating no change. Simonson and Hewett (1999) reported

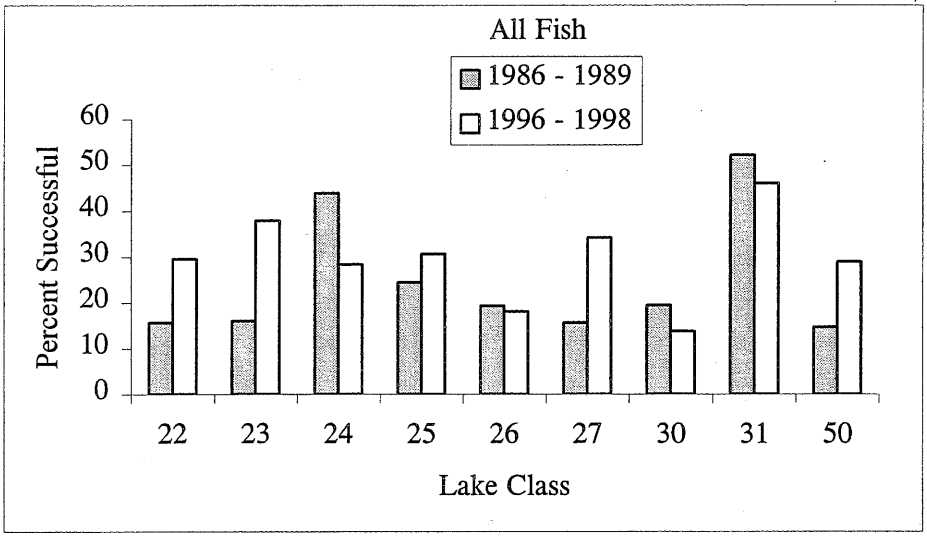
Table 7. Analysis of angler diary CPUE data: A. Nominal logistic fit for binomial data (successful and unsuccessful anglers); B. ANOVA of Log_eCPUE for anglers catching one or more fish.

A. Nominal logistic analysis of binomial response.

Size of fish (inches)	Source	df	Chi square	Prob. > Chi square
All Fish	Time	1	5.8	0.0164
	Class	8	73.8	0
	Stocked	1	25.7	0
	Time*Class	8	84.5	0
	Time*Stocked	1	0.4	0.5342
Fish ≥ 40	Time	1	49.7	0
	Class	8	30.4	0.0002
	Stocked	1	0.1	0.8066
	Time*Class	8	32.0	0.0001
	Time*Stocked	1	0.7	0.3897

B. ANOVA of Log_eCPUE for anglers catching one or more fish.

Size of fish (inches)	Source	df	Sum of squares	Mean square	Prob. > F
All Fish	Time	1	0.3	0.3	0.458
	Class	8	21.9	2.7	<.0001
	Stocked	1	24.8	24.8	<.0001
	Time*Class	8	21.7	2.7	<.0001
	Time*Stocked	1	1.0	1.0	0.1695
	Error	3051	1674.4	0.5	
	Corrected Total	3070	1867.3		
Fish ≥ 40	Time	1	4.0	4.0	0.006
	Class	8	9.6	1.2	0.018
	Stocked	1	10.1	10.1	<.0001
	Time*Class	8	16.7	2.1	0.0001
	Time*Stocked	1	0.9	0.9	0.1889
	Error	902	467.1	0.5	
	Corrected Total	921	533.2		



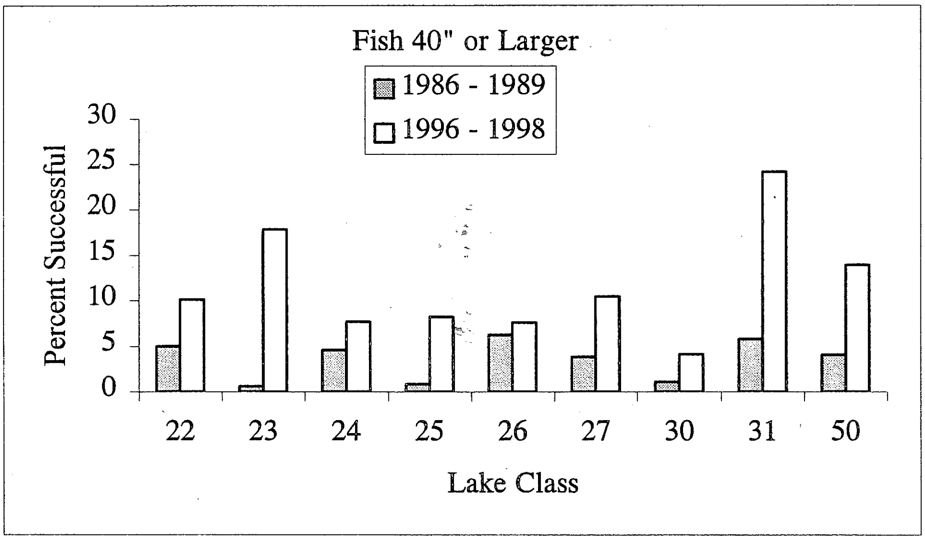


Figure 5. Percent successful anglers by Lake Class, early and later periods, and for all fish and fish larger than or equal to 40 inches.

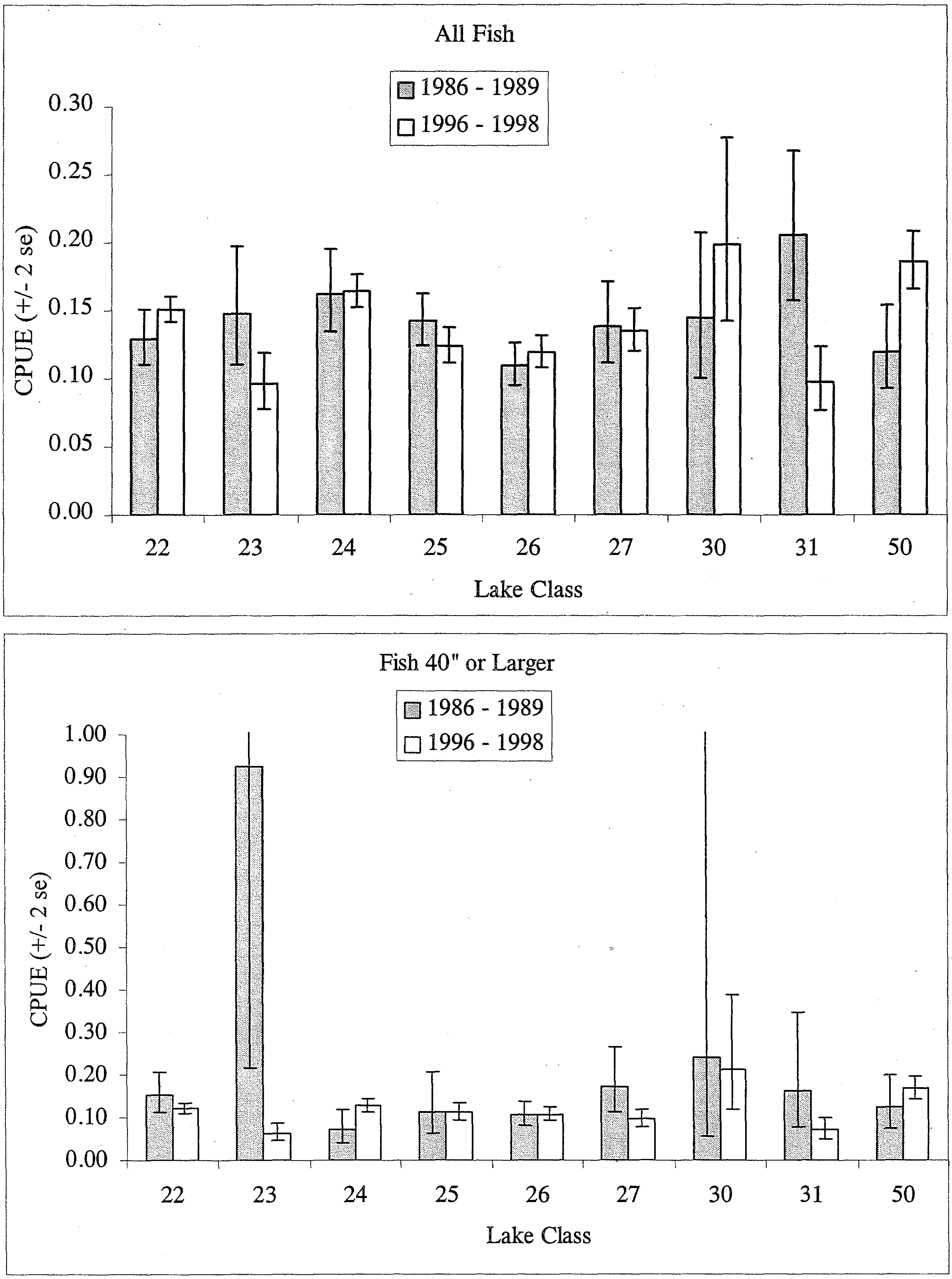


Figure 6. CPUE least square means for the Time*Lake Class interaction after back-transforming, for all fish and for fish larger than or equal to 40 inches. These were generated for successful anglers with the model that included the following effects: Time, Lake Class, Stocked, Time*Lake Class, and Time*Stocked. Vertical line represents +/- 2 se.

that angling effort targeting muskellunge in six Wisconsin lakes during the 1990s was higher than during the 1980s. During these same two time periods catch rates were similar and harvest rates declined, but total muskellunge catch remained the same.

Analysis of Length Data

Analysis of angler diary length data indicates that size of muskellunge caught by anglers has increased over time (Table 8A). There was no significant difference between size caught in stocked and native waters, though native waters had larger fish (35.3 versus 34.7 inches). Time, Class and Time*Class interaction were all significant. However, the interaction was primarily due to Lake Class 27, the only class to decrease in size from period one to period two (Figure 7). When Lake Class 27 was removed, the interaction was no longer significant (P = 0.108). Mean size of muskellunge reported in angler diaries increased from 33.8 inches in the early period to 36.2 inches in the later period. Considering only the later period, Lake Class 50 (Mississippi River) had larger sizes reported than for all other Lake Classes except for Lake Class 26. Lake Class 26 produced larger fish than all remaining Lake Classes with the exception of Lake Classes 23 and 31 (Figure 7; refer to Tables 2 and 5 for specific lakes in these Lake Classes).

Trap net length data were analyzed separately for small and large trap nets. The time period covered by trap net surveys extended from 1980 to 2002. Small trap nets were used mostly during the earlier years and were not used after 1999, and use of large trap nets did not begin until 1990. Mean length in trap net surveys increased over time in small trap nets, but no significant year effect was detected in large trap nets (Table 8B). One reason for these inconsistent results may be related to the initial unfamiliarity with the

Table 8. Analysis of variance for angler diary (A) and trap net (B) length data.

A. Angler Diary.

Source	df	Sum of squares	Mean square	Prob. > F
Time	1	2113.3	2113.3	<.0001
Class	7	1967.7	281.1	<.0001
Stocked	1	108.4	108.4	0.0940
Time*Class	7	1098.9	157.0	0.0002
Time*Stocked	1	15.0	15.0	0.5326
Error	4090	157916.4	38.6	
Corrected Total	4107	166534.4		

B. Trap Net.

Net size	Source	df	Sum of squares	Mean square	Prob. > F
Small	Year	1	1239.1	1239.1	<.0001
	Class	5	266.3	53.3	0.0068
	Error	55	811.5	14.8	
	Corrected Total	61	2641.8		
Large	Year	1	20.0	20.0	0.0945
	Class	6	261.3	43.6	0.0001
	Error	33	222.1	6.7	
	Corrected Total	40	573.8		

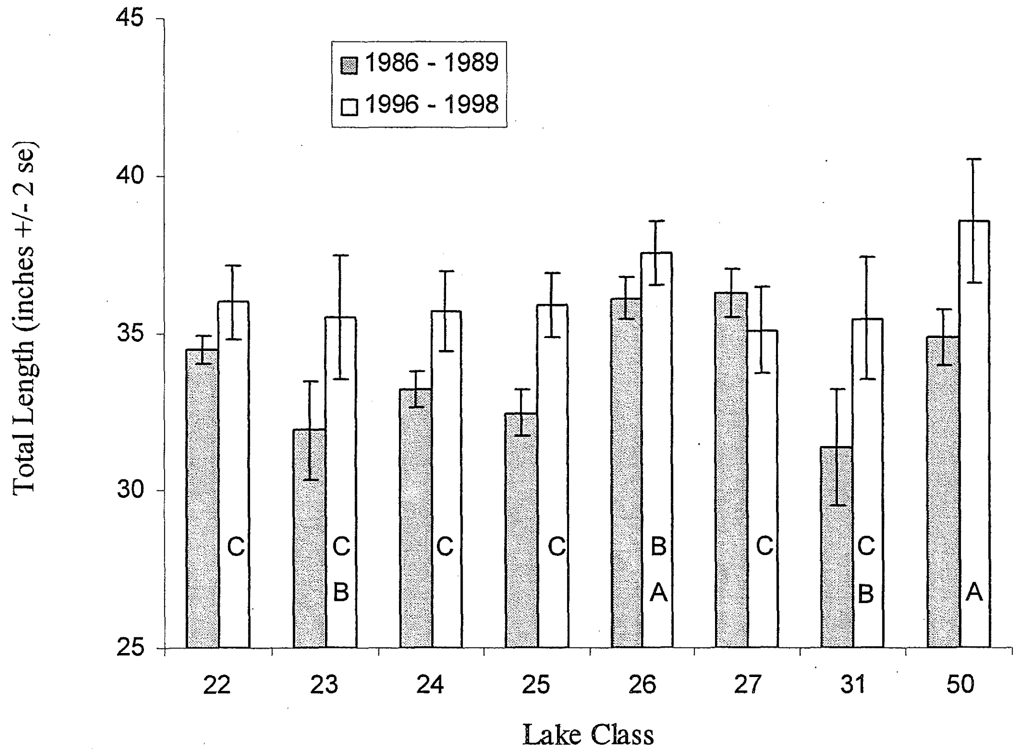


Figure 7. Angler diary length least square means for the Time*Lake Class interaction. Common subsets for the second time period are indicated with a letter (A, B, or C). The interaction was due primarily to Lake Class 27, which was the only class that decreased in size from period one to period two. This interaction was not significant after data for this Lake Class were excluded from the analysis (P = 0.108). Vertical line represents +/- 2 se.

deployment of large trap nets. Site selection and net deployment procedures needed to be modified because of the larger frame and hoops. Net deployment was one of several factors listed by Hubert (1996) as having an influence on catch. However, change in minimum size regulation from 36 to 40 inches in 1993 is the more likely reason for these differences. Any effect the regulation change had on the size structure of the population could have occurred during the 6-year period prior to the full-scale use of the large trap nets. We could not test for differences in time trends across different Lake Classes due to data limitations. Also, while Lake Class effects were significant for both sizes of trap nets (Table 8B), we urge caution in interpretation because surveys in different Lake Classes were not distributed evenly over time.

Age and Growth Parameters

A total of 564 muskellunge cleithra were collected, however, not all were available for use in analyzing all growth parameters.

Taxidermist samples (N=389) accounted for 69% of the cleithra aged, with the remaining samples (N=175) coming from other sources (Table 9). Muskellunge reported by taxidermists averaged 11 years old, but showed a broad range of ages (range 4-22 years). Although females averaged 1 year older than males, results showed a modal age of 9 years for females and 11 years for males. Forty-two percent of the females and 23% of the males caught by anglers exceeded 11 years of age. When cleithra from all sources were combined, a broader range of ages (range 1-22) were available, but skewed towards younger fish (Table 9). In contrast to taxidermist samples, only 37% of the females and 16% of the males exceeded 11 years of age in these pooled sampled. This would not be unusual, since muskellunge anglers tend to harvest the older and larger individuals. Mean age of muskellunge from all sources was 10 years, with a modal age of 9 years for females and 11 years for males (similar to results from taxidermist samples).

Minimum size regulations, coupled with angler preferences and harvest ethics, probably have the greatest influences on the harvest of trophy muskellunge. Taxidermist reported muskellunge averaged 45.1 inches with a modal length-class of 47.0 inches (Table 10). Sex ratio of taxidermist reported muskellunge was skewed toward females (2.9:1), as would be expected. This disproportionate number of females reflects the selective harvest of the larger individuals by anglers. Reports of skewed sex ratios of angler harvested muskellunge have ranged from 2.7:1 (Casselman et al 1999) to 6.3:1 (Casselman and Crossman

Table 9. Age frequency distributions (%) of taxidermist muskellunge and muskellunge collected from other sources.

	Taxidermist			All sources combined		
Age	All	Female	Male	All	Female	Male
1				4.4		
2				3.0	2.0	4.6
3				3.9	4.3	2.3
4	0.8	0.4		4.6	2.3	7.6
5	2.8	2.5	6.2	5.0	4.3	9.2
6	3.1	2.5	4.9	3.0	2.3	6.1
7	8.0	8.4	8.6	6.4	7.3	6.9
8	11.1	11.8	12.3	9.6	11.2	10.7
9	11.8	13.5	13.6	9.2	11.6	10.7
10	8.2	6.8	13.6	7.8	6.6	12.2
11	12.3	12.2	17.3	10.1	10.9	13.7
12	8.5	9.3	3.7	6.6	8.3	2.3
13	8.5	9.3	4.9	6.6	7.9	3.8
14	7.5	7.6	6.2	6.0	6.9	3.8
15	4.4	4.2	2.5	3.2	3.3	1.5
16	4.4	2.5	3.7	3.4	2.3	2.3
17	2.6	3.4		2.1	3.0	0.8
18	1.5	0.4	1.2	1.4	0.7	0.8
19	1.5	1.7	1.2	1.4	2.0	0.8
20	1.3	1.3		0.9	1.0	
21	1.5	1.7		1.2	1.7	
22	0.3	0.4		0.2	0.3	
N	389	237	81	564	303	131
Mean	11	11	10	10	10	9
Median	11	11	10	10	10	9
25 percentile	8	8	8	7	8	6
75 percentile	13	13	11	13	13	11

Table 10. Length frequency distributions (%) of taxidermist muskellunge and muskellunge collected from other sources.

Length (inches)	Taxidermist			All sources combined		
	All	Female	Male	All	Female	Male
<21				5.7		2.3
21-22.9				1.4	0.7	2.3
23-24.9				2.5	2.0	3.1
25-26.9				2.0	1.3	1.5
27-28.9	0.3	0.4		1.6	1.3	3.1
29-30.9				1.4	1.7	1.5
31-32.9				1.8	1.0	5.3
33-34.9	0.5		1.3	1.1	0.3	2.3
35-36.9	1.6	1.3	2.5	3.2	3.0	6.1
37-38.9	6.2	3.4	17.5	6.5	4.3	15.3
39-40.9	11.9	8.1	23.8	9.7	7.0	19.1
41-42.9	11.7	8.5	28.7	10.4	9.3	20.6
43-44.9	13.2	14.9	17.5	10.6	12.6	12.2
45-46.9	11.7	13.2	7.5	9.0	12.0	4.6
47-48.9	18.4	23.8		14.3	20.3	
49-50.9	13.5	16.2	1.3	10.4	14.3	0.8
51-52.9	6.5	5.5		5.0	5.0	
53-54.9	3.4	3.4		2.5	2.7	
55-56.9	1.0	1.3		0.9	1.0	
57-58.9						
N	385	235	80	558	301	131
Mean	45.1	45.9	41.0	40.9	44.0	37.8
Median	45.2	46.8	41.0	43.5	45.8	39.8
25 percentile	41.0	43.5	39.0	38.0	41.0	36.6
75 percentile	48.5	49.0	43.0	48.0	48.5	42.0

1986). Twenty-six percent of the females and 1% of the males exceeded the 47.0 inch length-class. The majority (53%) of females were from 45.0 to 51.0 inches in length. Fifty-two percent of the males ranged from 39.0 to 43.0 inches in length. Mean length of females was 5.0 inches longer than males. Other sources of muskellunge provided an additional 173 samples, resulting in a broader length distribution (Table 10). Mean length was 40.9 inches with the modal length-class remaining at 47.0 inches. The increase in smaller fish in the sample reduced the average size of females and males to 44.0 and 37.8 inches, respectively. Considering that the majority of fish from other sources were found dead along lakeshores, this information could provide some insight into the size of fish associated with either natural or hooking mortality.

A total of 362 cleithra were available for calculating von Bertalanffy growth estimates, of which 81% were from taxidermists (Table 11). Estimated ultimate lengths averaged 54.2 inches for females and 46.1 inches for males using taxidermist samples. For Ontario populations, average ultimate length ranged from 32.0-55.1 inches for females and 27.8-45.6 inches for males (Casselman et al 1999). Forty-seven percent of the harvested muskellunge exceeded the 51.0 inch size-interval (Table 11). All estimates exceeding the 51.0 inch size-interval were female. The modal size-interval was 51.0 to 52.9 inches for females and 45.0 to 46.9 inches for males. A box plot of female and male growth parameters further illustrates the growth potential differences that exist between them (Figure 8). The plot also seems to indicate that the majority of taxidermist fish of unknown sex are female. Values outside the interquartile range should be viewed cautiously, especially those exceeding 60.0 inches. The largest muskellunge ever sampled during spring trap net assessments was 57.0 inches. Although combining all sources

Table 11. L∞ growth parameter frequency distributions (%) of taxidermist muskellunge and muskellunge collected from other sources.

Length (inches)	Taxidermist			All sources combined		
	All	Female	Male	All	Female	Male
<39				0.6		2.6
39-40.9				1.1		5.1
41-42.9	1.4	1.0	1.8	3.3	2.7	5.1
43-44.9	6.1		29.1	6.4		26.6
45-46.9	8.2	2.6	32.7	8.6	3.1	27.8
47-48.9	9.2	7.3	21.8	10.2	8.5	19.0
49-50.9	10.5	10.5	12.7	9.9	11.2	8.9
51-52.9	17.3	20.4	1.8	18.0	21.4	5.1
53-54.9	14.6	18.3		13.0	17.0	
55-56.9	13.9	13.6		11.9	11.6	
57-58.9	8.8	13.1		7.7	11.6	
59-60.9	3.7	4.2		3.9	4.9	
61-62.9	1.7	2.1		1.7	1.8	
63-64.9	2.4	3.7		1.9	3.1	
>65	2.0	3.1		1.9	3.1	
N	294	191	55	362	224	79
Mean	52.6	54.2	46.1	51.9	53.7	45.5
Median	52.5	53.8	45.8	51.9	53.2	45.4
25 percentile	48.9	51.1	44.2	47.8	50.8	43.8
75 percentile	55.9	57.3	47.7	55.5	56.8	47.4

of muskellunge increased the number of samples for both females and males, ultimate length averages and modes did not change (Table 11). However, the increased samples did broaden the range (<39.0 to 52.9 inches) for males and reduced the frequency of females exceeding the 51.0 size-interval from 58% to 53%.

Examination of growth potential for Lake Classes was limited due to small sample sizes. With 23 Lake Classes representing muskellunge waters, only 7 have samples. Of these seven Lake Classes, the majority of the samples are in Lake Classes 22 and 26 (Tables 12 and 13). The majority of samples in Lake Classes 22 and 26 were collected from Cass and Leech lakes, respectively. No samples were either collected or provided for Lake Class 24, the Lake Class with the largest assemblage of muskellunge waters. For taxidermist reported females, the overall ultimate length averaged 51.9 inches. An ultimate length of 53.9 inches was associated with an average age of 12 years and length of 46.6 inches for females in Lake Class 22. In comparison, females from Lake Class 26 with a projected ultimate length of 55.0 inches, averaged 11 years old, and 45.7 inches in length. Males collected from these two Lake Classes (22 and 26) followed a similar pattern (Table 12). Because of taxidermist reported samples of less than five observations in some Lake Classes, this may not be a true picture of Lake Class growth potential. Muskellunge collected from all sources combined showed that most Lake Class specific age and growth estimates were smaller than taxidermist only samples (Table 13). This again reflects the addition of smaller and younger fish to the sample.

Summary and Management Implications

Muskellunge angling opportunities in Minnesota have been increased and enhanced through lake expansion, stocking, and the use of conservative, but progressive regulations. Evaluation of data utilizing trap net and angler

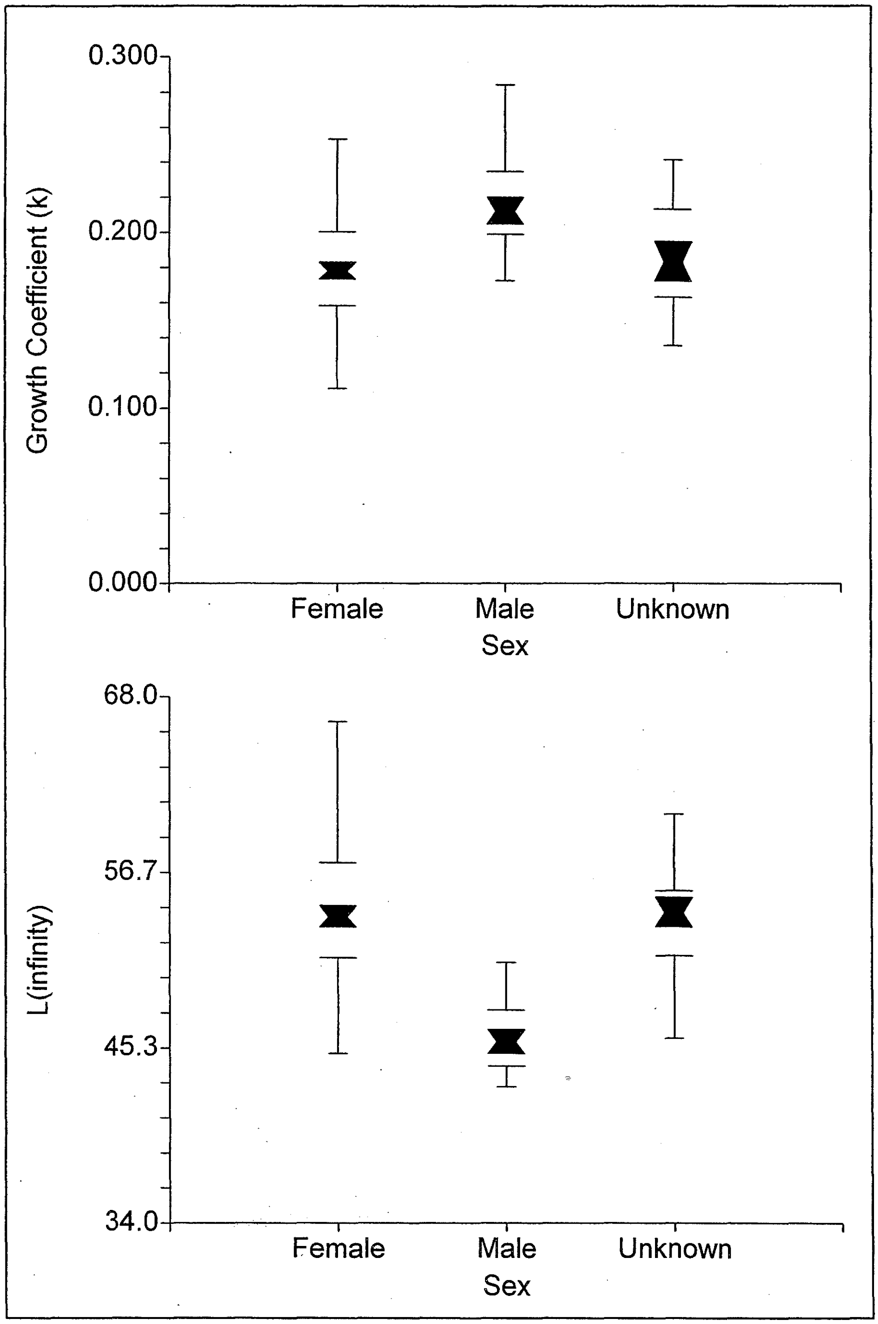


Figure 8. Box plots of von Bertalanffy growth parameters k and L∞ (inches) for male and female muskellunge collected from taxidermists. The median is represented by the notch. The horizontal line immediately above and below the notch marks the box and defines the 75th and 25th percentiles. Adjacent values are shown as T-shaped lines extending from each end of the box.

Table 12. Mean age and growth values as determined from muskellunge cleithra collected from taxidermist. All sexes combined include fish of unknown sex.

Lake Class	N	Age	Length (inches)	$L\infty$ (inches)	k
			Female		
22	84	12	46.6	53.9	0.181
23	11	11	42.4	50.3	0.175
25	3	8	43.2	52.0	0.201
26	129	11	45.7	55.0	0.177
27	5	14	48.1	55.9	0.166
28	1	13	43.0	45.8	0.188
31	2	11	45.7	50.0	0.198
50	3	13	49.7	52.2	0.238
Mean (Median)		12 (12)	45.6 (45.7)	51.9 (52.1)	0.191 (0.184)
			Male		
22	29	10	40.7	46.7	0.212
23	0				
25	1	7	38.0	43.3	0.28
26	47	10	41.1	46.2	0.215
27	4	12	42.9	45.9	0.213
28	0				
31	0				
50	1	11	42.0	42.8	0.289
Mean (Median)		10 (10)	40.9 (41.1)	45.0 (45.9)	0.242 (0.215)
			All Sexes Combined		
22	139	12	45.5	52.6	0.187
23	14	12	42.2	49.4	0.180
25	5	8	41.5	51.3	0.215
26	207	11	45.0	52.9	0.185
27	14	13	46.4	52.6	0.181
28	2	10	43.0	45.8	0.188
31	3	9	42.8	52.0	0.205
50	8	13	48.4	49.8	0.251
Mean (Median)		11 (12)	44.4 (44.0)	50.8 (51.7)	0.199 (0.188)

diary information suggests that size and catch of muskellunge have increased over time. We can also show that a number of the state's muskellunge waters are capable of producing 55 inch and larger fish. Although limitations of the data prevent us from presenting more specific results about Minnesota's muskellunge waters, the problematic data sets do provide us with some insight into data collection and retrieval needs.

We need to incorporate a better sampling design into the statewide muskellunge assessment program. The sampling design must take into consideration both short-term and long-term data needs. To improve our sampling design, we need to address questions about which lakes to sample and how frequently they will be sampled. This may be a difficult challenge to accomplish when examining both statewide and management area needs. Issues about when and how long to conduct the netting must also be addressed. The success of muskellunge trap net assessments depends on movement and behavior of spawning fish, which in turn are influenced by water temperatures. Water temperatures should be recorded daily, prior to and during netting operations, and used to gauge the duration of the netting period. Lake specific netting sites and deployment techniques should be standardized to reduce sampling variability. Data collection needs to be comprehensive and consistent from one water body to the next. Information should include both netting site and fish data. We need to determine the best way to summarize and report the data so that we can maxi-

Table 13. Mean age and growth values as determined from muskellunge cleithra collected from all sources combined. All sexes combined include fish of unknown sex.

Lake Class	N	Age	Length (inches)	L∞ (inches)	k
			Female		
22	109	11	44.2	53.3	0.184
23	17	10	39.8	50.8	0.172
25	7	7	35.7	52.0	0.201
26	136	11	45.5	54.9	0.177
27	17	9	41.9	52.1	0.199
28	1	13	43.0	45.8	0.188
31	9	8	37.8	48.8	0.208
50	8	10	45.0	55.2	0.203
Mean (Median)		10 (10)	41.6 (45.0)	51.6 (55.2)	0.192 (0.203)
			Male		
22	47	8	37.3	46.1	0.219
23	2	5	26.5		
25	1	7	38.0	43.3	0.282
26	51	10	40.6	46.2	0.216
27	12	8	35.2	44.4	0.231
28	0				
31	11	6	32.7	43.1	0.237
50	7	9	36.8	43.3	0.231
Mean (Median)		8 (8)	35.3 (36.8)	44.4 (43.9)	0.236 (0.231)
			All Sexes Combined		
22	199	10	40.8	51.9	0.191
23	31	8	32.4	51.1	0.173
25	14	6	33.6	49.8	0.212
26	223	11	44.4	52.9	0.186
27	40	9	39.4	51.0	0.202
28	2	10	43.0	45.8	0.188
31	31	5	29.8	46.7	0.222
50	27	9	40.8	49.1	0.220
Mean (Median)		9 (9)	38.0 (40.1)	49.8 (50.4)	0.199 (0.196)

mize use of this information. Both summarized and raw data should be maintained in a centralized database. Since muskellunge netting is considered a special assessment with unique sampling needs, outlining sampling design and protocol may best be accomplished by establishing a users guide.

The overall number and acreage of muskellunge waters will continue to change as we continue to evaluate both our introduced and historically important native muskellunge waters. However, we still face numerous gaps in information that could help in managing the state's muskellunge waters. Some of these information needs include but are not limited to: estimating muskellunge angling effort; vital population parameters including mortality rates for both stocked and native waters; defining and maintaining sustainable catch rates; and evaluating hooking mortality. We also need to examine socio-economic factors as it relates to angler attitudes, and the economic value of the muskellunge fishery. When these data become available, they can be synthesized in an evaluation system that will define sustainable muskellunge fishery management goals and facilitate future management decisions required to pursue these goals.

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