Section of Fisheries

INVESTIGATIONAL REPORT

No. 418

PERFORMANCE EVALUATION OF FOUR MUSKELLUNGE *ESOX MASQUINONGY* STRAINS IN TWO MINNESOTA LAKES

September 1992

Minnesota Department of Natural Resources

Division of Fish and Wildlife

Minnesota Department of Natural Resources
Investigational Report 418

PERFORMANCE EVALUATION OF FOUR MUSKELLUNGE *Esox masquinongy* STRAINS IN TWO MINNESOTA LAKES[1]

Jerry A. Younk and Robert F. Strand

Minnesota Department of Natural Resources
Section of Fisheries
500 Lafayette Road
St. Paul, MN 55155-4012

Abstract.--Performance of four muskellunge strains (Mississippi, Shoepack, Court Oreilles, and Minocqua) were evaluated in two Minnesota lakes. Shoepack strain matured earlier and at a smaller size than the Mississippi strain. Although temporal spawning periods tended to overlap, Mississippi strain spawned at significantly higher water temperatures than the Shoepack strain. After six growing seasons the Mississippi strain was longer and heavier than the other strains. Weight-length relationships were significantly different, with Shoepack and Wisconsin strains exhibiting a more robust body shape. Ultimate growth potential was greatest for the Mississippi and Court Oreilles strains, and least for the Minocqua and Shoepack strains. Mortality rates were similar except for the Shoepack strain, which had the highest mortality rate. The superior growth performance of the Mississippi strain suggests that it should be the strain of choice for muskellunge culture in Minnesota.

[1] This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingel-Johnson) Program. Completion Report, Study 603 (126), D-J Project F-26-R Minnesota.

Introduction

Historically, some of Minnesota's native muskellunge *Esox masquinongy* populations have undergone a period of declining abundance. Of most concern were populations found in the Park Rapids area, lower Mississippi River, and St. Louis River estuary of Lake Superior. Beginning in the 1930s, an expanded management program was started in direct response to the precipitous decline in native muskellunge stocks in the Park Rapids area in northwestern Minnesota (Olson and Cunningham 1989). Based on sport fishing trends, trophy-sized muskellunge declined during a 30 year period (1930-1959) followed by a slight increase during 1960-1987. Management measures applied during this period involved regulation changes, and stocking for reestablishment and expansion of naturally reproducing populations.

Before 1953, muskellunge spawn taking efforts were directed at the geographic region encompassing the upper Mississippi River drainage basin. Initial spawn taking efforts on Leech Lake and the Big Mantrap chain of lakes (Park Rapids area) met with mixed results. Due to the limited success in locating a reliable egg source from this region, Minnesota Department of Natural Resources (MNDNR) fisheries personnel sought alternative sources.

The search for a candidate brood lake ended with the selection of Shoepack Lake, located near International Falls in northeastern Minnesota, and within the Hudson Bay drainage. Fish from this source were described as exhibiting characteristics typical of native Minnesota muskellunge (Eddy and Surber 1943; Eddy and Underhill 1974). Eggs were collected and fertilized at Shoepack Lake, and later transported to the Park Rapids hatchery for rearing and distribution. For over 30 years progeny with origins from Shoepack Lake were propagated and liberated in Minnesota waters. As a result of radio-telemetry work on Leech Lake, a second source of muskellunge eggs (Mississippi strain) was obtained for propagation (Strand 1986).

Naturally occurring muskellunge populations are present in 29 lakes and 4 river systems. Culture efforts have established populations in an additional 50 lakes. Evidence accumulated from MNDNR lake survey data revealed differential growth patterns between those lakes with introduced Shoepack muskellunge and lakes with naturally occurring populations. Angler reports supported these observations. Questions were raised concerning habitat limitations, and the possibility of genetically distinct strains.

In 1982, Minnesota participated in a study aimed at analyzing genetic variation of various muskellunge stocks. Results from the analysis of two Minnesota muskellunge stocks revealed genetic differences between Shoepack and Leech (Mississippi) strains (Hanson et al. 1983). Although a direct relationship between genetic variation and growth rates was never established, the results provided a basis for additional evaluation. The present study was designed to examine the performance of four muskellunge strains under similar environmental conditions.

Study Area

Selection of study lakes was based on four criteria: 1) geographic location; 2) no previous record of muskellunge; 3) an abundance of prey; and 4) relatively low northern pike *Esox lucius* populations. Candidate lakes were selected from waters within and outside the muskellunge's native range (Figure 1). Physical and chemical characteristics describing the two study lakes were based on lake survey data (Table 1).

Grace Lake is a moderately shallow 359 hectare mesotrophic lake located in the forested zone of northwestern Minnesota. Shoreline development and recreational use are moderate. Waconia Lake is larger, shallower, and more eutrophic with abundant growths of submerged vegetation. Located in the transitional (forest-agricultur-

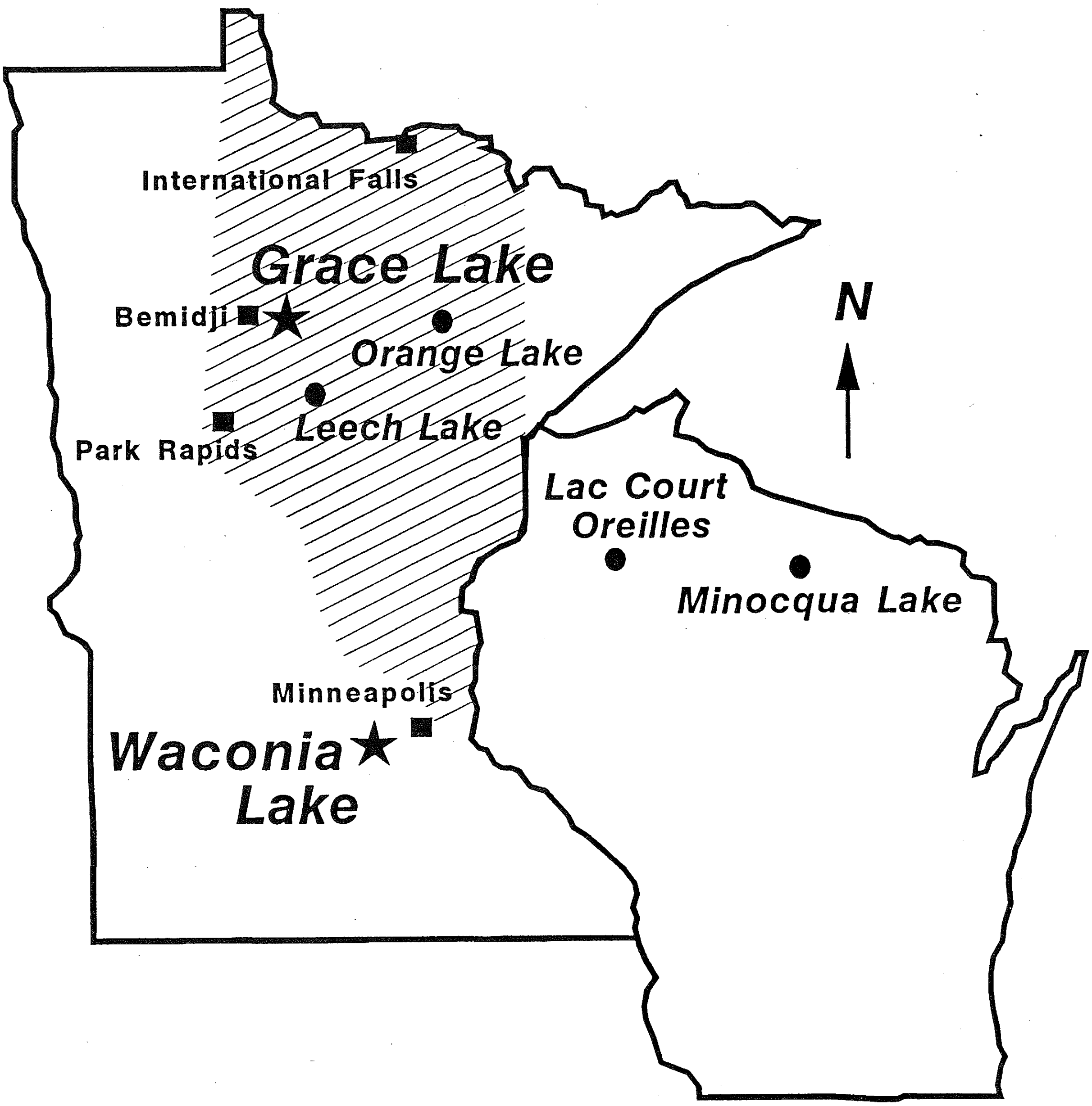

Figure 1. Muskellunge strain evaluation study lakes, 1984-1990. Shaded area indicates Minnesota's native muskellunge range.

Table 1. Summary of selected physical and chemical characteristics of muskellunge strain evaluation lakes.

	Grace Lake	Waconia Lake
Area (ha)	359	1256
Maximum depth (m)	12.8	11.2
Littoral area (%)	38	54
Total alkalinity (ppm)	102.0	167.5
Secchi disk (m)	2.9	1.3
SDF	1.05	1.01

al) zone of southeastern Minnesota, it has a highly developed shoreline and heavy recreational use. Both Grace and Waconia lakes are hardwater lakes with fish assemblages dominated by centrarchid-percid complexes (Schupp *In* Press). Grace Lake has an extremely high population of yellow perch *Perca flavescens*, while Waconia Lake supports abundant populations of both yellow perch and freshwater drum *Aplodinotus grunniens*. Major predator fish present in both lakes include walleye *Stizostedion vitreum*, largemouth bass *Micropterus salmoides*, and northern pike.

Methods

Strain origin and stocking

Two native Minnesota muskellunge strains were available for performance evaluation: (1) Mississippi (MS) strain were progeny of muskellunge reared from Leech Lake parental stock, and (2) Shoepack (SP) strain eggs were obtained from Orange Lake where a muskellunge population had been established with progeny originating from Shoepack Lake (Table 2). In addition, two Wisconsin strains were made available to Minnesota as fall fingerlings. Court Oreilles (CO) and Minocqua (MQ) strains originated from Lac Court Oreilles and Minocqua Lakes (Wisconsin), respectively.

Eggs of each strain were hatched either at Park Rapids, or Woodruff and Spooner (Wisconsin) state hatcheries. Fry were transplanted to separate rearing ponds at Park Rapids, New London (Minnesota), Hinckley (Minnesota), Woodruff, and Spooner hatcheries. Ponds were harvested, and equal numbers of three strains were stocked in each study lake on 18-20 September 1984 (Table 2). Before stocking, 100-150 fish from each strain were measured for total length (TL). Each strain was given a unique fin clip for future identification.

Assessment

Study lakes were intensively sampled during two periods; shortly after ice-out (April) and again in fall (September-October). Assessment periods were kept consistent by sampling at water temperatures ranging from 7.2-12.7°C. During the 6 year evaluation (1985-1990), muskellunge were caught using a combination of two gear types: (1) 24 mm bar measure trap nets (1 x 2 m double frame), and (2) DC electrofishing unit (Coffelt model VVP15). Captured muskellunge were anaesthetized using tricaine methanesulfonate (MS-222), measured for TL, and examined for a fin clip. Individual fish weights were recorded starting in fall 1986. Sex was determined either by external characteristics (Lebeau and Pageau 1989) or by the extrusion of gametes. Although fish were of known age, scales were collected from the area below the origin of the dorsal fin and above the lateral line for determining growth. Study lakes were closed to the harvest of muskellunge until the opening of the Minnesota fishing season in 1990.

Table 2. Stocking summary of four muskellunge strains stocked in Grace and Waconia lakes, 1984.

Strain (Code)	Lake of stock origin	Number stocked	Date stocked	Fin clip
		Grace Lake		
Mississippi (MS)	Leech	500	20 Sep.	L.Pelvic
Shoepack (SP)	Orange	500	19 Sep.	R.Pelvic
Minocqua (MQ)[a]	Minocqua	500	18 Sep.	L.Pectoral
		Waconia Lake		
Mississippi (MS)	Leech	1000	18 Sep.	L.Pelvic
Shoepack (SP)	Orange	1000	18 Sep.	R.Pelvic
Court Oreilles (CO)[a]	Court Oreilles	1000	18 Sep.	L.Pectoral

[a]Wisconsin strains

For each strain, individual back-calculated lengths and corresponding growth increments were determined using DISBCAL89 (Missouri Department of Conservation 1989). Scale samples from 311 muskellunge ranging in size from 400-1,070 mm were used in growth computations. Annual incremental growth at ages 1-6 was stratified by sex, and compared among strains and between lakes with the general linear model (GLM) - analysis of variance (ANOVA) (Hintze 1987). Multiple comparisons of significant effects were made using a Newman-Keul test at the P=0.05 significance level.

Growth was also described by the Von Bertalanffy growth formula (VBGF) using a nonlinear least squares method (Prager et al. 1989). The growth function was of the form:

$$l_t = L_\infty (1 - e^{-K_{(t-t_0)}})$$

where; l_t = length at time t, L_∞ = asymptotic length, K = growth constant, and t_0 = hypothetical age at which fish would have zero growth. Growth parameters were calculated for individual fish at ages 4-6, and presented as averages with 95% confidence intervals. A growth-index, as presented by Casselman and Crossman (1986), was calculated for ages 5-6 and compared with the growth standard developed by those authors.

Length-weight (L-W) relationships for both sexes combined were calculated by least squares regression:

$$\log w = \log a + b(\log l)$$

where; w = weight, l = length, and a and b are constants. Regressions were compared among strains by analysis of covariance (ANCOVA) (Snedecor and Cochran 1980). Weight at age relationships were derived by applying average length data for a given age to the corresponding L-W regression equation.

Mortality estimates for each strain were obtained by applying VBGF growth parameters to Pauly's (1980) instantaneous natural mortality (M) equation:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.463 \log \bar{T}$$

where; $\log M$ = instantaneous natural mortality, L_∞ = asymptotic length, K = growth constant, and $\bar{T}$ = annual mean environmental temperature. Mean temperatures used in the model were 9.6°C and 11.8°C for Grace and Waconia lakes, respectively. Conversion to an annual natural mortality rate (n)

was estimated by the method of Ricker (1975). The number of individuals of each strain remaining to a particular age was simulated from life-tables. An initial annual survival of 39% (Hanson et al. 1986) was applied to age 0 muskellunge. Survival at older ages was estimated from Pauly's (1980) model.

Historical information detailing muskellunge spawning activity was extracted from MNDNR culture records. Spawning time, duration, and water temperatures were summarized for one SP, and for pooled data from five MS strain lakes. Peak spawning activity was determined by the presence of ripe females. Spawning temperatures were averaged over the period 1953-1990 and compared using a two sample *T*-test ($P=0.05$).

Results

Catch Composition

Although sampling during the spring and fall assessments was intensive, averaging 352 net lifts/year, annual catches were small. Attempts to sample muskellunge 1-8 months after stocking resulted in the capture of one fish (Figure 2). Spring catches were consistently poor until fish reached 3 years of age and older. In contrast, nearly all the muskellunge sampled during the fall were 4 years old and younger.

All strains were represented, but frequency of capture varied among strains and between lakes (Figure 2). Court Oreilles strain accounted for 62% of the total catch in Waconia Lake, and has dominated the spring catch since 1987. In most years, Grace Lake catches were dominated by the SP strain. Throughout the study, MQ strain was recovered in numbers nearly equal to that of the MS strain (Figure 2). However, while MS and CO strains clearly dominated the 1990 spring catch, few SP and MQ strains were captured. Mississippi strain increased from 1% in 1987 to 22% and 11% of the 1990 spring catch in Grace and Waconia Lakes, respectively.

Reproduction

The onset of sexual maturity differed among strains and between sexes. Six years were required before all strains were fully mature (Table 3). Female maturation occurred at a later age than males. The first mature males occurred at age 3, with MS and MQ strains fully mature by age 4. Mississippi strain females reached full maturity at age 6, one year later than the other strains.

Size at maturity also varied among the strains. Earlier maturation was associated with slower growth. Mean length at maturity was largest for MS strain females, exceeding the present minimum size limit of 914 mm for Minnesota muskellunge waters (Table 3). The smallest mature fish of both sexes were SP strain. Length at maturity for SP strain ranged from 580 to 820 mm and averaged 680 mm (Table 3). Mature Wisconsin strain fish ranged in size from 625-975 mm (CO) to 615-885 mm (MQ). Generally, MS strain muskellunge were 11-25% longer at maturity than the other strains.

Spawning appeared to be influenced more by phenological than chronological events. No distinct difference in spawning time could be detected between MS and SP strains (Figure 3). Spawning dates for SP strain ranged from 26 April to 28 May, while MS strain spawn from mid-April to mid-May. The peak spawning period averaged 8 and 10 days for MS and SP, respectively. Although spawning dates overlapped, the corresponding water temperatures differed (Figure 4). Mississippi strain spawned at significantly ($t=8.15$, $P<0.001$) higher water temperatures than the SP strain. Mean spawning temperatures were 11.2°C (range 8-18°C) for MS strain, and 8.4°C (range 6-14°C) for SP strain.

Growth

Pond growth of each strain was highly variable (Figure 5). Mean lengths at stocking among strains differed significantly at

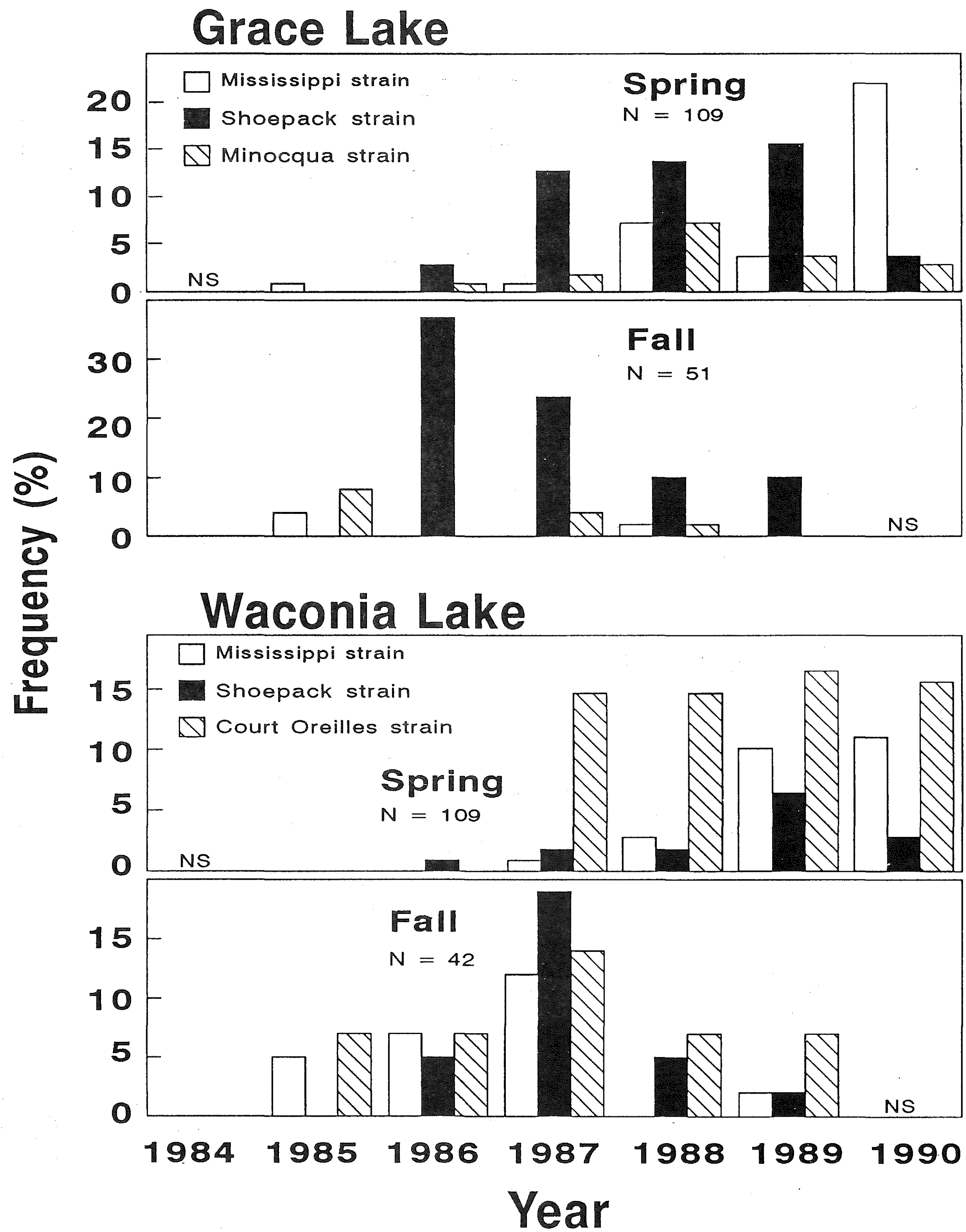

Figure 2. Percent contribution in spring and fall catches of four muskellunge strains, Grace and Waconia lakes, with NS representing non-sampling periods.

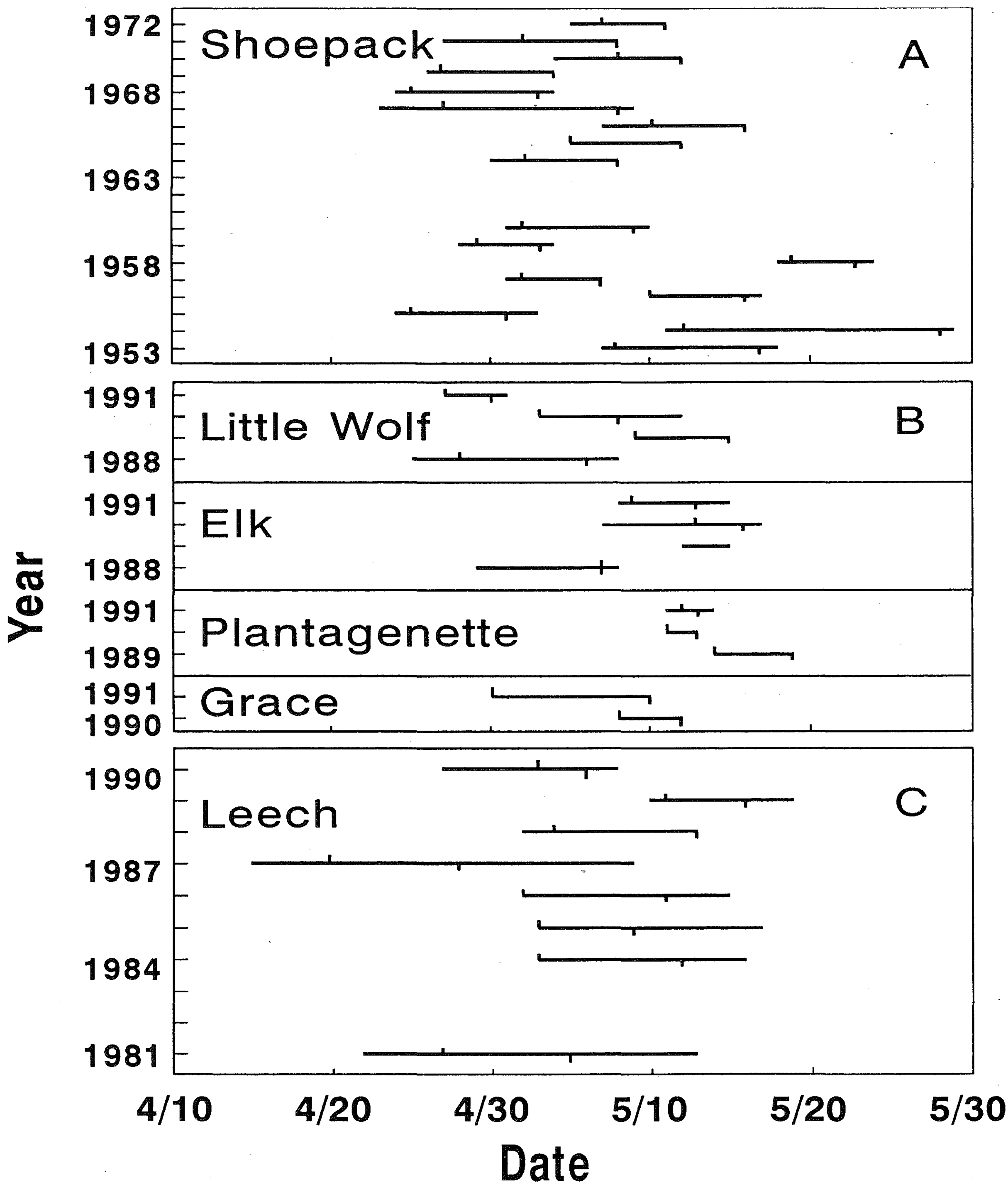

Figure 3. Historical summary of spawning periods for Shoepack strain (A) and Mississippi strain (B and C) muskellunge. The tic marks represent periods during which ripe females were captured.

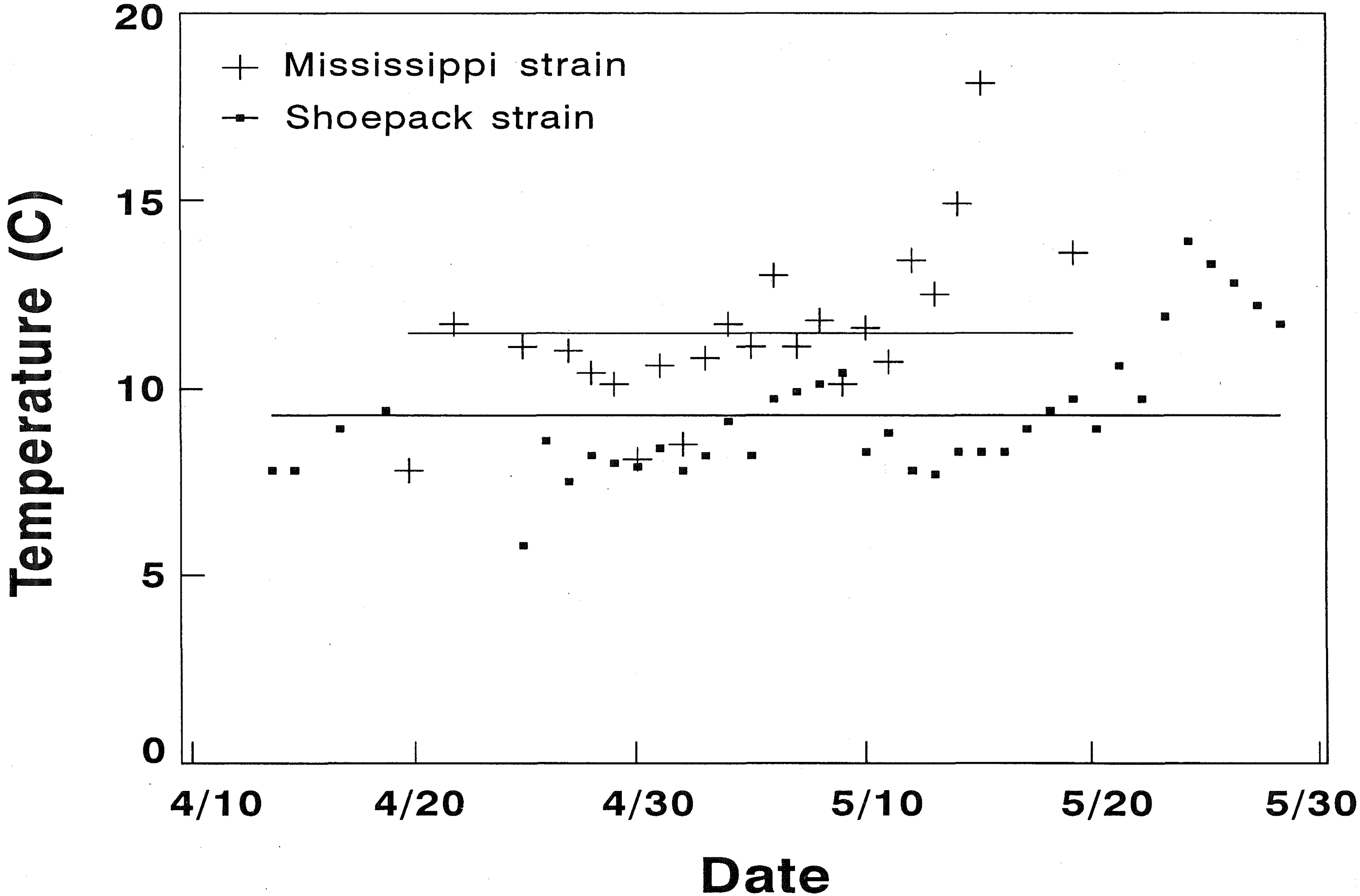

Figure 4. Mean spawning temperatures observed for Mississippi and Shoepack strain muskellunge. Data includes temperatures for Mississippi and Shoepack strains from 1988-91 and 1953-81, respectively. Horizontal lines represent a grand mean for the observation periods.

Table 3. Age and length at maturity of four muskellunge strains in Grace and Waconia lakes.

Strain/Sex	*N*	Age	Length (mm) Mean	Range
Mississippi				
Male	9	3-4	792	690-822
Female	24	5-6	1,029	925-1,070
Shoepack				
Male	12	3	591	580-605
Female	20	4-5	768	698-820
Court Oreilles				
Male	10	3	660	625-685
Female	12	5	915	860-975
Minocqua				
Male	7	3-4	678	615-733
Female	2	5	858	830-885

both Grace (F=26.81, P<0.001) and Waconia (F=103.25, P<0.0001) lakes. When mean lengths of the strains were ranked from largest to smallest, the order was MS > MQ > SP and MS > CO > SP for Grace and Waconia lakes, respectively.

In both study lakes, back-calculated growth was fastest for MS strain and slowest for SP strain (Figure 6). Court Oreilles growth closely paralleled that of the MS strain while MQ growth more closely matched that of SP strain. Divergence from this growth pattern began to develop with the approach of sexual maturation, although it was not as pronounced when comparing MS and CO strains (Figure 6C and D). The MQ strain continued to grow rapidly after ages 4 (females) and 2 (males) while the growth of SP strain began to decline (Figure 6A and B). Female and male SP strain averaged 216 and 248 mm, respectively, shorter than MS strain at age 6.

Examination of incremental lengths provided a comparative growth history among the strains. Annual growth increments were consistently longer for MS strain, although the differences were not always significant (P>0.05) (Table 4). Mean growth increments for MS strain were significantly larger than SP strain during 83% of the growth years. Differences between MS and SP strains averaged 34 mm for males, and 37 mm for females over all years. Minocqua strain grew significantly slower than MS strain during 82% of the growth years, and faster than SP strain during 55% of the growth years. Court Oreilles strain grew slower than MS strain, though the differences were significant only during the first (males only), fourth (both sexes), and fifth (females only) years (Table 4). Incremental differences between MS and CO strains never exceeded 21 mm, and averaged 12 mm for males and 9 mm for females during any given growth year. The first two years of growth accounted for 60-62% of the TL at age 6 for SP, and 53-56% of the TL (age 6) for MS and Wisconsin strains (Table 4, Figure 6).

Mississippi and SP were the only strains common to both Grace and Waconia lakes. Growth differences were evident between lakes for each strain, although these differences resulted in no distinct growth advantage through growth year 1989 (Table 5). Mean growth increments were larger for both MS and SP strains in Waconia Lake than in Grace Lake at growth years 1984 and 1987. Except for Waconia SP females, this pattern was reversed at growth years 1985 and 1986. Significant differences (P<0.05) were detected in 42% and 50% of

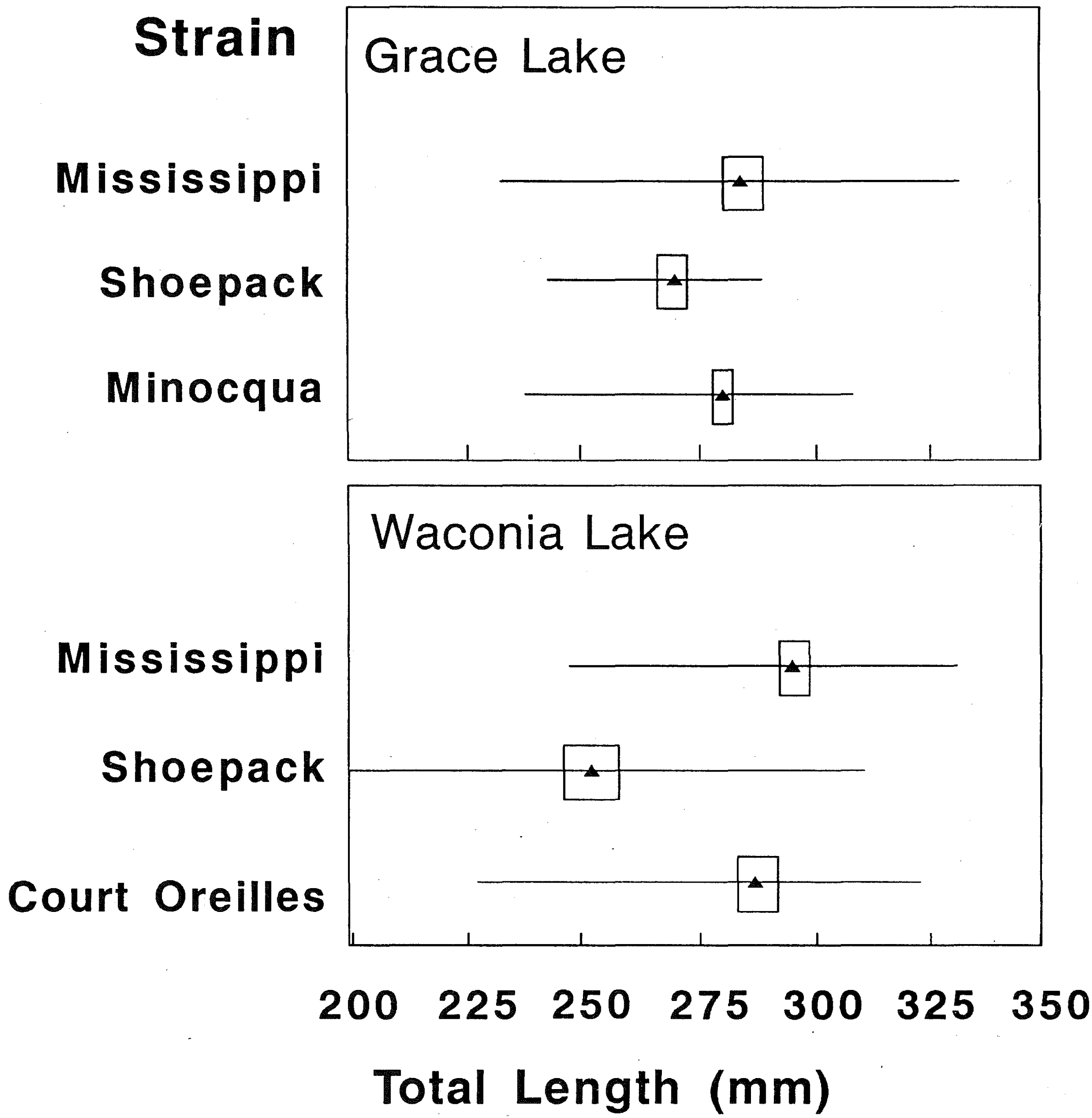

Figure 5. Horizontal box plot of pre-stocking lengths for four muskellunge strains, with mean (triangles), 95% confidence interval (boxes) and range (solid line) presented.

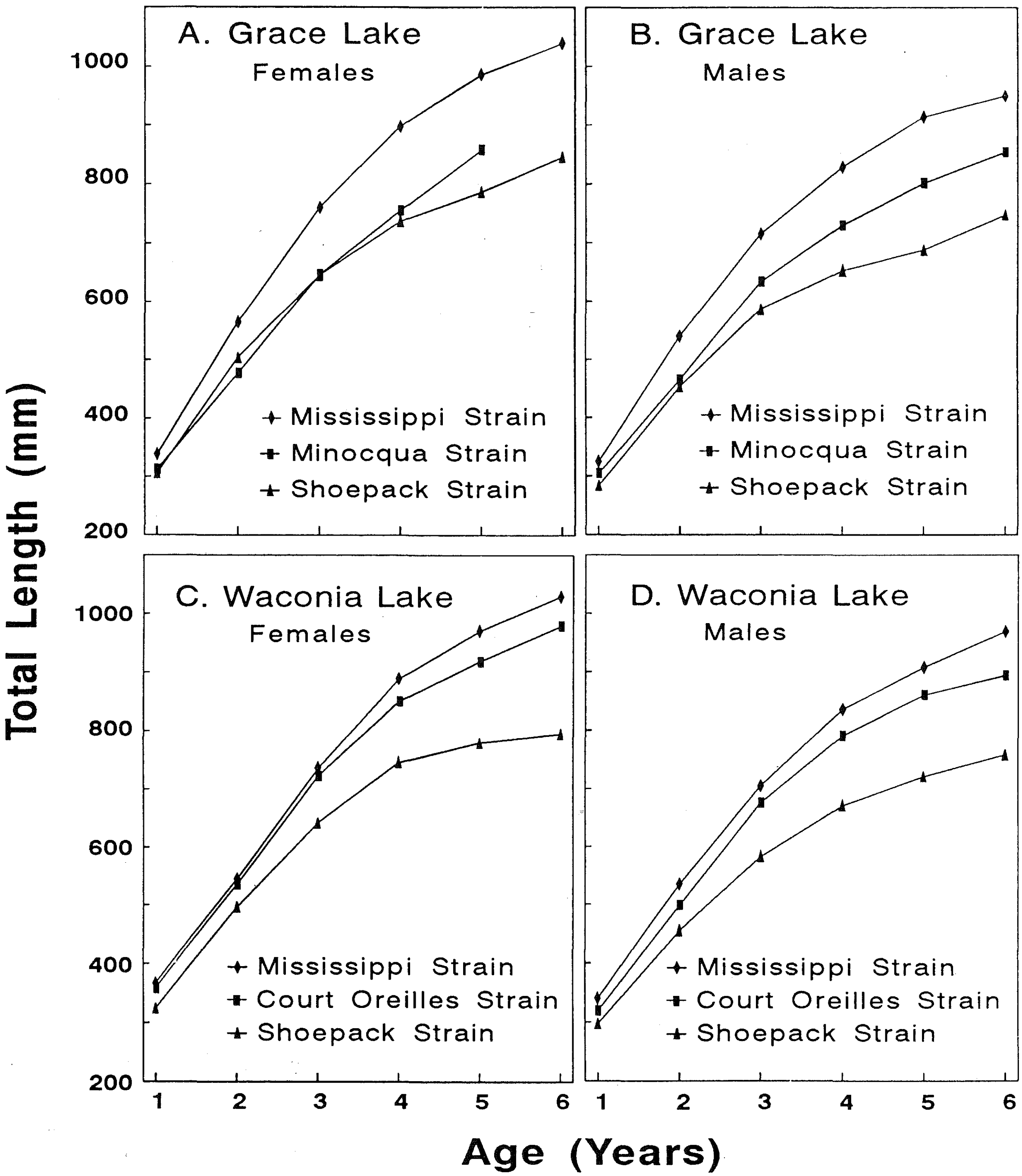

Figure 6. Average back-calculated lengths at age of four muskellunge strains in Grace and Waconia lakes.

Table 4. Back calculated mean incremental growth (mm) of four muskellunge strains in Grace and Waconia lakes. Similar pairs of growth values bracketed by vertical bars. (Fish were hatched and stocked in 1984.)

Strain/Sex	Year of Growth 1984	1985	1986	1987	1988	1989
Grace Lake						
Male						
Mississippi	325	215	176	112	75	39
Minocqua	305	161	186	92	43	48
Shoepack	284	169	133	65	36	25
Female						
Mississippi	346	225	195	132	83	54
Minocqua	312	165	169	107	52	NA
Shoepack	306	199	139	85	43	28
Waconia Lake						
Male						
Mississippi	340	195	164	117	60	41
Court Oreilles	319	180	175	101	55	35
Shoepack	298	157	128	80	46	25
Female						
Mississippi	367	178	189	139	80	52
Court Oreilles	358	176	186	119	61	53
Shoepack	324	172	145	96	43	NA

the compared growth years (Table 5).

The Shoepack strain exhibited the poorest growth potential as reflected by the low L_∞ values and high growth constants (Table 6). Shoepack strain reached 83-95% of their theoretical maximum TL by age 6. In contrast, MS strain exhibited the greatest growth potential followed by the CO strain. Mississippi and CO strain reached 78-88% and 82-84%, respectively, of their maximum growth potential by age 6. Growth parameters for the MQ strain were intermediate to those of CO and SP strains (Table 6). Only the MS and CO strains approached the theoretical maximum TL (1,393 mm) estimated for trophy muskellunge by Casselman and Crossman (1986). Differences between their theoretical maximum TL and those values projected for the strains from this study ranged from 266-588 mm (Table 6). Additional evidence that growth differences are present among the four strains is demonstrated by the growth-index:

Growth-Index (%)	Strain (Lake)
83.5	Shoepack (Waconia)
83.8	Shoepack (Grace)
92.0	Minocqua (Grace)
99.8	Court Oreilles (Waconia)
106.0	Mississippi (Grace)
106.3	Mississippi (Waconia)

The Wisconsin strains exhibited intermediate growth and were bounded by the faster growing MS strain and the slower growing SP strain. Furthermore, the growth-index compares favorably with the growth standard presented by Casselman and Crossman (1986). Of the six sets of data examined, MS strain exceeded the standard length while CO was nearly equal, and SP and MQ were less.

Table 5. Back calculated between lake comparison of yearly growth increments (mm) of Mississippi and Shoepack strain muskellunge.

Year of growth	Male Grace	Male Waconia	Male *P*	Female Grace	Female Waconia	Female *P*
			Mississippi strain			
1984	325	340	0.046	346	367	0.012
1985	215	195	0.007	225	178	0.000
1986	176	164	0.088	195	189	0.494
1987	112	117	0.266	132	139	0.314
1988	75	60	0.027	83	80	0.738
1989	39	41	0.833	54	52	0.632
			Shoepack strain			
1984	284	298	0.008	306	324	0.003
1985	169	157	0.111	199	172	0.011
1986	133	128	0.404	139	145	0.449
1987	65	80	0.053	85	96	0.100
1988	36	46	0.150	43	43	0.941

Table 6. Mean and 95% confidence intervals of Von Bertalanffy growth parameters for four muskellunge strains from Grace and Waconia lakes.

Strain/Sex	*N*	L_∞ (mm)	95% C.I. Limit Upper	95% C.I. Limit Lower	*K*	95% C.I. Limit Upper	95% C.I. Limit Lower
			Grace Lake				
Mississippi							
Male	26	1,092	1,119	1,066	0.362	0.387	0.338
Female	23	1,201	1,228	1,173	0.344	0.362	0.326
Shoepack							
Male	20	805	833	777	0.438	0.483	0.394
Female	20	889	914	865	0.466	0.523	0.409
Minocqua							
Male	7	966	992	940	0.359	0.392	0.325
Female	5	1,127	1,204	1,051	0.272	0.349	0.195
			Waconia Lake				
Mississippi							
Male	9	1,105	1,181	1,028	0.348	0.392	0.304
Female	16	1,341	1,411	1,271	0.244	0.266	0.222
Shoepack							
Male	8	846	887	805	0.384	0.448	0.320
Female	7	955	1,014	896	0.381	0.486	0.276
Court Oreilles							
Male	22	1,057	1,097	1,016	0.346	0.376	0.316
Female	31	1,194	1,234	1,153	0.299	0.325	0.274

Table 7. Length-weight relationship for four muskellunge strains from Grace and Waconia lakes.

Strain	N	Regression Coefficient	Intercept	R^2
		Grace Lake		
Mississippi	39	3.406	-6.422	0.978
Shoepack	86	3.501	-6.609	0.982
Minocqua	20	3.169	-5.682	0.963
		Waconia Lake		
Mississippi	38	3.576	-6.894	0.974
Shoepack	27	3.252	-5.908	0.944
Court Oreilles	75	3.263	-5.921	0.979

The MS strain appeared to have a less robust body shape than the other strains. Predicted weights from length-weight regressions supported this impression (Table 7). Differences in slopes among regressions in both Grace (F=3.26, P=0.05) and Waconia (F=4.58, P=0.05) lakes precluded additional statistical testing within lakes. For a given length, SP strain tended to be heavier than MQ, but lighter than CO strains. The relatively high regression coefficients, ranging from 3.169 to 3.576, can be attributed to samples taken during the spring spawning period.

Between lakes, there was no significant difference ($P \geq 0.10$) in adjusted mean weights for SP strain. There was, however, a significant difference (F=15.43, $P \leq 0.05$) for MS strain. Compared to Grace Lake, Waconia Lake MS strain were progressively heavier at lengths greater than 700 mm.

Individual strains were neither abundant nor were they sampled equally during similar periods so direct comparisons of empirical weights were limited (Table 8). In general, mean weights were greatest for MS and CO strains. The maximum recorded weights were 9.4 and 6.8 kg for an age 6 MS strain female and male, respectively. Shoepack strain grew more slowly, requiring 5 or more years to attain a weight of 4.5 kg compared to a maximum of 5 years for MS and CO strains. Minocqua strain averaged 4.6 kg (females) and 3.9 kg (males) at ages 5 and 6, respectively (Table 8).

Predicted weights at age followed a similar pattern to that of length at age. Mississippi was the largest strain followed by the CO, MQ, and SP strains (Figure 7). Weights were similar for all strains at ages 1 and 2. Predicted weights of MS and CO strains were nearly equal through age 5. After that, weight differences were influenced by the sexual maturation of female MS strain. Minocqua strain maintained a growth rate parallel to SP strain, though heavier for most ages.

Mortality

Restrictions imposed on muskellunge harvest conveniently confined mortality to a single component, natural mortality. Natural mortality rates (n) were slightly higher for males than females, independent of strain (Table 9). Natural mortality rates of SP strain were the highest of the four muskellunge strains, averaging 38% for Grace and Waconia lakes. Natural mortality rates for the remaining strains were similar, averaging 31% (MS), 31% (MQ), and 33% (CO). Between lake differences of common strains were negligible (Table 9). Mortality estimates from a moderately exploited MS strain population (Leech Lake) were n=22% and m=14%, resulting in a 33% total annual mortality (Younk, unpublished data).

Simulated survival estimates appeared to be reasonable, although the differences between the actual and simulated values were unknown (Table 10). Assuming an initial post-stocking mortality of 61%, projected survival to age 1 was 195 and 390 muskellunge per strain in Grace and Waconia lakes, respectively. By age 6, we would expect 78 (Grace Lake) and 152 (Waconia Lake) muskellunge of all strains to remain from the initial stockings (Table 10). This represents a survival of 4-6%, by strain, for each lake.

Table 8. Seasonal mean weights (kg) of four muskellunge strains in Grace and Waconia lakes. Sample size represented in parenthesis.

Year (age)/ Season	Strain					
	Mississippi		Shoepack		Wisconsin[a]	
	Male	Female	Male	Female	Male	Female
			Grace Lake			
1987 (3)						
Spring	-	1.98(1)	1.24(13)	1.38(2)	1.53(2)	-
Fall	-	2.36(5)	1.89(7)	2.36(5)	2.50(1)	2.50(1)
1988 (4)						
Spring	2.93(8)	3.00(1)	1.64(10)	2.48(5)	2.13(5)	2.62(3)
Fall	4.40(1)	3.65(1)	2.33(3)	3.65(1)	-	3.20(1)
1989 (5)						
Spring	4.36(3)	6.00(1)	2.02(6)	3.48(11)	3.00(2)	4.55(2)
Fall	-	-	2.15(3)	4.78(2)	-	-
1990 (6)						
Spring	5.23(10)	7.25(14)	2.35(3)	4.30(1)	3.92(3)	-
			Waconia Lake			
1987 (3)						
Spring	1.80(1)	-	1.40(1)	1.65(1)	1.95(14)	2.23(2)
Fall	3.08(4)	3.68(2)	1.77(3)	2.81(5)	3.15(4)	3.30(2)
1988 (4)						
Spring	3.03(3)	-	1.65(1)	2.33(1)	3.18(10)	4.42(6)
Fall	-	-	1.70(1)	3.90(1)	5.00(1)	5.98(2)
1989 (5)						
Spring	4.18(4)	5.81(7)	2.33(5)	3.63(3)	4.57(5)	5.80(12)
Fall	-	8.20(1)	-	2.60(1)	-	7.07(3)
1990 (6)						
Spring	5.53(5)	7.71(7)	3.06(2)	3.10(1)	4.97(9)	7.25(8)

[a] Court Oreilles strain in Waconia, Minocqua strain in Grace.

Table 9. Comparison of conditional natural mortality rates (*SE*) for various muskellunge strains from Grace and Waconia lakes, 1988-91.

Strain	Grace Lake		Waconia Lake	
	Male	Female	Male	Female
Mississippi	0.32 (0.01)	0.30 (0.01)	0.34 (0.01)	0.27 (0.01)
Shoepack	0.39 (0.02)	0.37 (0.01)	0.39 (0.01)	0.35 (0.03)
Minocqua	0.33 (0.01)	0.28 (NA)	- -	- -
Court Oreilles	- -	- -	0.34 (0.02)	0.31 (0.01)

Table 10. Simulated survival of four stocked muskellunge strains in Grace and Waconia lakes.

Age	Mississippi	Shoepack	Minocqua
	Grace Lake		
Initial stocking (0+)	500	500	500
1	195	195	195
2	135	121	135
3	93	75	93
4	64	47	64
5	44	29	44
6	30	18	30
	Waconia Lake		
Initial stocking (0+)	1000	1000	1000
1	390	390	390
2	269	246	261
3	186	155	175
4	128	98	117
5	88	62	78
6	61	39	52

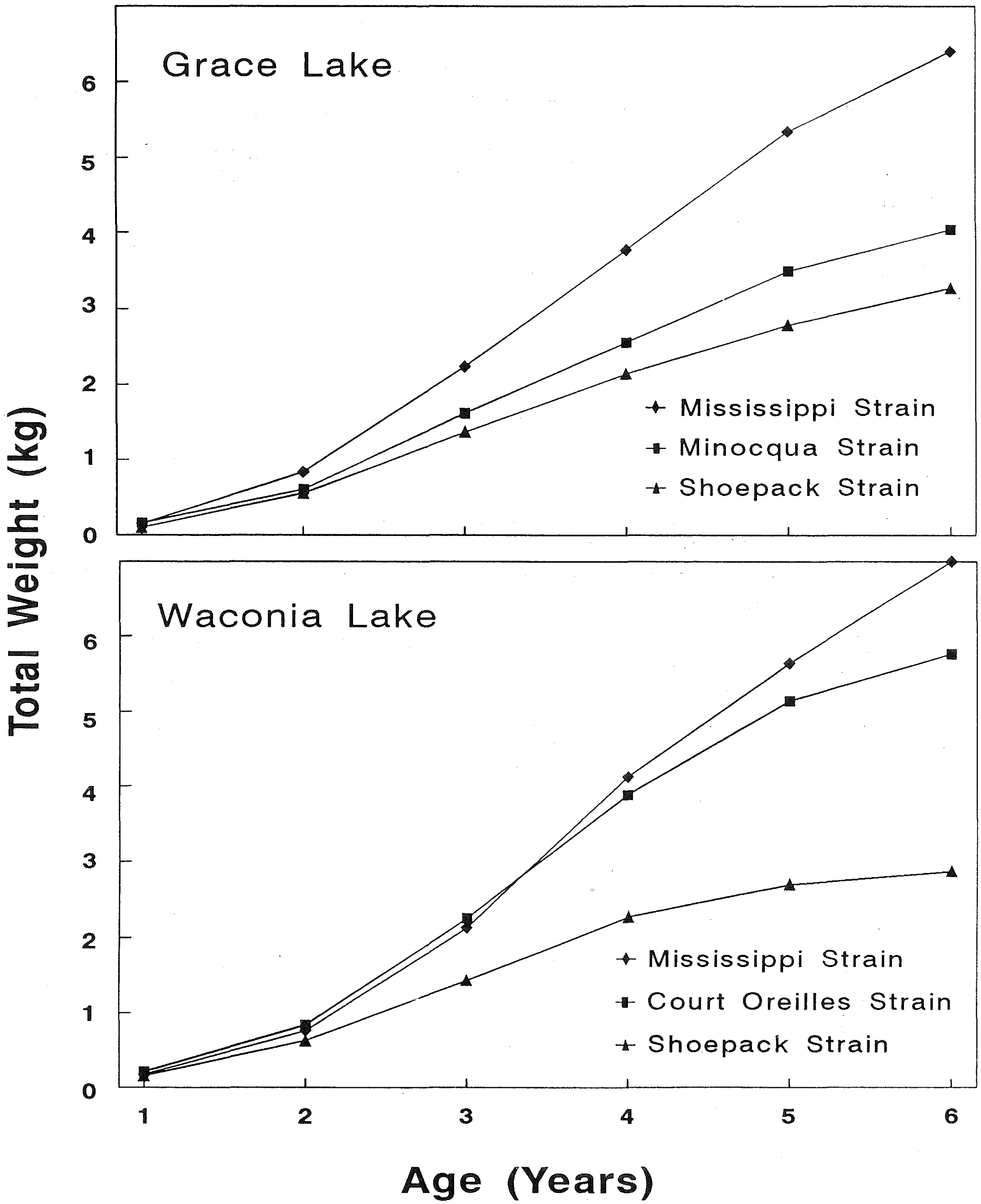

Figure 7. Age-weight relationships (sexes combined) of four muskellunge strains in Grace and Waconia lakes.

Discussion

The MS strain muskellunge were consistently longer and heavier at any given age than the other strains in this study. Considering the common habitats, these differences appear inherent to the strains and not the result of environment. Slight growth differences were also observed between common strains in both Grace and Waconia lakes. These differences were highly variable, reflecting in various degrees the effect of latitude (length of growing season), and prey quantity and quality.

Other studies have documented differences in growth characteristics of various muskellunge populations (Schloemer 1936; Hourston 1952; Johnson 1971). Most of these comparisons were intended to examine growth (slow, average, or rapid) differences among lakes. These results must be interpreted cautiously, considering the confounding effects of habitat and population genetics. Johnson (1971) speculated that some unknown genetic factor may have caused the growth differences observed among three study lakes in northern Wisconsin. Results from this study support his contention.

The age of maturation greatly influenced growth differences. The greatest divergence in growth occurred with the onset of maturity. This was particularly evident in the length-weight relationships. The earlier maturing strains were heavier than the later maturing MS strain at any given length. This would not be unexpected since earlier maturing individuals would be increasing gonadal growth while decreasing somatic growth. An extended somatic growth period would be advantageous for the potential growth of trophy fish.

Growth potential is of particular interest for the management of muskellunge sport fisheries. Most anglers in pursuit of muskellunge have expectations of catching a trophy fish. Mississippi strain exhibited the best potential for trophy management in Minnesota waters. Both the growth-index and the projected size of MS strain were higher than the other strains. The theoretical maximum TL of the MS strain is nearly identical to that of Escanaba Lake males (1,115 mm) and females (1,303 mm) (Hoff and Serns 1986). The theoretical maximum TL of Chautauqua Lake muskellunge males (1,100 mm) was also similar, but for Chautauqua Lake females (1,540 mm) was considerably larger (Bimber 1982). The low theoretical maximum TL of the SP strain coupled with a high growth coefficient suggests a relatively short life span, qualities not conducive to managing for trophy fish.

The greatest differences in reproductive characteristics were between the MS and SP strains. Mississippi strain reached full maturity at an older age and larger size than the SP strain. Both Wisconsin strains matured at ages comparable to those reported for Wisconsin waters (Johnson 1971), but size at maturity was larger in Grace and Waconia lakes. Growth is typically faster in introduced populations than in native populations (Muir 1960). Spawning begins at a higher water temperature for the MS strain, and physical characteristics of the spawning areas differ (Strand 1986, MNDNR unpublished data). Strand (1986) described spawning areas used by MS strain in Leech Lake as spatially and temporally different from areas used by northern pike. Shoepack strain have been netted while spawning in heavily vegetated near-shore areas in Shoepack and Orange Lakes which have no northern pike. Wisconsin strain muskellunge typically spawn from mid-April to mid-May at water temperatures ranging from 9.4 to 15.6°C, and over muck bottom covered with dead vegetation (Becker 1983). Except for spawning temperatures, Wisconsin and SP strains appear to have similar spawning habits.

Although size at stocking was significantly different, we don't believe later growth was markedly influenced. The magnitude of the differences between age 0 and age 6 were great enough to overcome any initial concerns. Several reasons for these differences may be inherent, and include variation in pond growth due to environmental effects or to maternal genetic effects. Five widely dispersed ponds in Minnesota and Wisconsin were used for rearing study fish. The study design precluded any evaluation of pond growth except post-harvest lengths. The question of maternal genetic effects relates to the relationship of egg size to female size. Johnson (1958) described muskellunge egg sizes as variable and independent of female size. Any differences in egg size could possibly influence later life stages resulting in different size fingerlings.

Observed differences in the capture frequency of various strains should be viewed cautiously. The confounding factors of availability and vulnerability to capture were evident for all strains, especially during the first 2-3 years after stocking. Once each strain reached sexual maturity, spring catches increased.

Except for a higher rate for the SP strain, natural mortality rates were similar for other studied strains. The rates estimated for this study are high compared to natural mortality rates estimated by several other authors. Comparable values calculated from various studies (Muir 1964; Spangler 1968, Harrison and Hadley 1979) ranged from 13-25% (Lyons and Margenau 1986). Under the restrictive harvest regulations imposed on the study lakes, however, natural mortality equaled total mortality. Estimates were similar to those for total mortality of exploited populations reported in the literature (Lyons and Margenau 1986). At Nogies Creek, Ontario, Crossman (1956) estimated a total mortality rate of 70% with no fishing.

The survival simulation assumed that fingerlings of all strains survived at the same rate through the first fall. This assumption may be unrealistic and a source of error in the simulation. The lack of an adequate sample size prevented assessment of this factor. Past studies, however, have shown that first year survival is highly variable (Johnson 1978; Hanson et al. 1986), and dependent on several factors such as predator and prey abundance (Serns and Andrews 1986). An estimated mortality rate from ages 4-6 was applied to ages 1-6, since mortality estimates for ages 1-3 were unknown. The rates estimated for this study are similar to those reported by Hoff and Serns (1986). They estimated a total annual mortality rate of 0.345 and 0.320 for ages 2-13 and ages 5-13 muskellunge, respectively.

Although both the MS and SP strains are native to Minnesota, each exhibit distinct growth, longevity, and reproductive characteristics. Compared to MS strain, the natural distribution of SP strain is limited. Both Wisconsin strains exhibit characteristics intermediate to those of the MS and SP strains. Many of the characteristics of the SP strain may be linked to their original environment. Shoepack Lake is a small (120 hectare) isolated lake located between Kabetogama and Rainy lakes in northern Minnesota. The lake was described as having a dense population (0.51 fish/hectare) of small (range 411-724 mm) muskellunge, limited forage, and no northern pike (Eddy and Underhill 1974; MNDNR unpublished data). The SP strain may have evolved certain traits enabling the population to thrive under the limitations imposed by this isolated environment.

Management Implications

As a result of the findings in this study, MNDNR fisheries managers have discontinued propagating Shoepack strain, and implemented a culture program using the Mississippi strain muskellunge. The superior growth characteristics of the Mississippi strain should provide the trophy fishery most anglers prefer. In addition, the differences observed between the two Minnesota strains provide evidence of the potential problems associated with stocking programs using fish of unknown genetic qualities. Although both are native to Minnesota, each has its own unique characteristics well adapted to a local environment.

References

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison.

Bimber, D.L. 1982. Longevity, growth and mortality of muskellunge in Chautauqua Lake, New York. New York Fish and Game Journal 29:134-141.

Casselman, J.M., and E.J. Crossman. 1986. Size, age, and growth of trophy muskellunge and muskellunge-northern pike hybrids -- the cleithrum project, 1929-1983. American Fisheries Society Special Publication 15:93-110.

Crossman, E.J. 1956. Growth, mortality and movements of a sanctuary population of maskinonge (*Esox masquinongy* Mitchell). Journal of Fisheries Research Board Canada 13:599-612.

Eddy, S., and T. Surber. 1943. Northern Fishes. The University of Minnesota Press, Minneapolis.

Eddy, S., and J.C. Underhill. 1974. Northern Fishes, 3rd edition. University of Minnesota Press, Minneapolis.

Hanson, D.A., M.D. Staggs, S.L. Serns, L.D. Johnson, and L.M. Andrews. 1986. Survival of stocked muskellunge eggs, fry, and fingerlings in Wisconsin lakes. American Fisheries Society Special Publication 15:216-218.

Hanson, D., B. Strand, D.D. Post, W.H. LeGrande, and S. Fillbach. 1983. Muskellunge electrophoresis study. Muskie 17(4):9-13.

Harrison, E.J., and W.F. Hadley. 1979. Biology of muskellunge (*Esox masquinongy*) in the Upper Niagara River. Transactions of the American Fisheries Society 108:444-451.

Hintze, J.L. 1987. Number cruncher statistical system. Kaysville, Utah.

Hoff, M.H., and S.L. Serns. 1986. The muskellunge fishery of Escanaba Lake, Wisconsin under liberalized angling regulations, 1946-1981. American Fisheries Society Special Publication 15:249-256.

Hourston, A.S. 1952. The food and growth of muskellunge (*Esox masquinongy* Mitchell) in Canadian waters. Journal of Fisheries Research Board of Canada 8:247-268.

Johnson, L.D. 1958. Pond culture of muskellunge in Wisconsin. Wisconsin Department of Natural Resources, Technical Bulletin 17, Madison.

Johnson, L.D. 1971. Growth of known-age muskellunge in Wisconsin and validation of age and growth determination methods. Wisconsin Department of Natural Resources, Technical Bulletin 49, Madison.

Johnson, L.D. 1978. Evaluation of esocid stocking program in Wisconsin. American Fisheries Society Special Publication 11:298-301.

Lebeau, B., and G. Pageau. 1989. Comparative urogenital morphology and external sex determination in muskellunge, *Esox masquinongy* Mitchill. Canadian Journal of Zoology 67:1053-1060.

Lyons, J., and T. Margenau. 1986. Population dynamics of stocked adult muskellunge (*Esox masquinongy*) in Lac Court Oreilles, Wisconsin 1961-1977. Wisconsin Department of Natural Resources, Technical Bulletin 160, Madison.

Missouri Department of Conservation. 1989. Fishery analysis tools - reference and users' guide to FishCalc89 and DisBCal89 microcomputer software packages. Jefferson City.

Muir, B.S. 1960. Comparison of growth rates for native and hatchery stocked populations of *Esox masquinongy* in Nogies Creek, Ontario. Journal of Fisheries Research Board Canada 17(6):919-927.

Muir, B.S. 1964. Vital statistics of *Esox masquinongy* in Nogies Creek, Ontario II. Population size, natural mortality, and the effect of fishing. Journal of Fisheries Research Board Canada

21:727-746.
Olson, D.E., and P.K. Cunningham. 1989. Sport-fisheries trends shown by an annual Minnesota fishing contest over a 58-year period. North American Journal of Fisheries Management 9:287-297.
Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal Conseil International pour l'Exploration de la Mer 39:175-192.
Prager, M.H., S.B. Saila, and C.W. Recksiek. 1989. FISHPARM: a microcomputer program for parameter estimation of nonlinear models in fishery science, 2nd edition. Old Dominion University, Oceanography Technical Report 87-10, Norfolk, Virginia.
Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191.
Schloemer, C.L. 1936. The growth of muskellunge *Esox masquinongy immaculatus* (Garrard) in various lakes and drainage areas of northern Wisconsin. Copeia 1936:185-193.
Schupp, D.H. *In* Press. An ecological classification of Minnesota lakes with associated fish communities. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report, St. Paul.
Serns, S.L., and L.M. Andrews. 1986. Comparative survival and growth of three sizes of muskellunge fingerlings stocked in four northern Wisconsin lakes. American Fisheries Society Special Publication 15:229-237.
Snedecor, G.W., and W.G. Cochran. 1980. Statistical methods, 7th edition. Iowa State University Press, Ames.
Spangler, G.R. 1968. Angler harvest and mortality of *Esox masquinongy* in Pigeon and Sturgeon Lakes, Ontario. Journal Fisheries Research Board of Canada 25:1145-1154.
Strand, R.F. 1986. Identification of principal spawning areas and seasonal distribution and movements of muskellunge in Leech Lake Minnesota. American Fisheries Society Special Publication 15:62-73.

ACKNOWLEDGMENTS

Numerous individuals from the Fisheries Research Unit provided electrofishing assistance. We also appreciate the assistance provided by the Bemidji and Metro Area Fisheries Management Stations. A special thanks to J. and C. Mase for providing the use of their facilities at Intowne Marina, Waconia. M. Cook assisted with field work and manuscript preparation. D. Schupp provided valuable comments on earlier versions of the manuscript.

SH 328 .I58 no. 418
Younk, Jerry A.
Performance evaluation of
four muskellunge esox

Edited by:
D. H. Schupp, Warmwater Fisheries Research Supervisor
P.J. Wingate, Fisheries Research Manager

INVESTIGATIONAL REPORTS*

No. 408 Fluorescent Chemical Marking of Walleye Larva with a Selected Literature Review of Similar Investigations, by J. Younk and M. Cook. June 1991.

No. 409 Walleye Mortality During a Live-Release Tournament on Mille Lacs, Minnesota, by T. Goeman. Reprint from North American Journal of Fisheries Management, Vol. 11, No. 1, Winter 1991.

No. 410 Sex Ratios of Young-of-the-Year Walleye from Rearing Ponds and Lakes in Minnesota, by P. Eiler. November 1991.

No. 411 Genetic Description of Walleye Stocks in Minnesota, by M. McInerny, R. Glazer, G. Zarling, J. Fulton, J. Otis, and K. Guise. March 1992.

No. 412 The Walleye Sport Fishery of the St. Louis River Estuary, 1980-1982, by T. Osborn, T. Close, S. Colvin, and D. Pereira. March 1992.

No. 413 The Role of Research in Minnesota Fisheries Management: An Update, by P. Jacobson and R. Davis. November 1991.

No. 414 Evaluation of Bioenergetics Modeling in the Study of Predator-Prey Dynamics in Minnesota Waters of Lake Superior, by Mary T. Negus. March 1992.

No. 415 Macrophyte Removal to Enhance Bluegill, Largemouth and Northern Pike Populations, by T. Cross, M. McInerny, and R. Davis. June 1992.

No. 416 Fish Community Responses to Manipulation of Northern Pike and Yellow Perch Densities in a Minnesota Centrarchid Lake, by T. Goeman and P. Spencer. July 1992.

No. 417 An Ecological Classification of Minnesota Lakes with Associated Fish Communities, by D.H. Schupp, August 1992.

*Complete list of all publications in the series available from Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Box 12, 500 Lafayette Road, St. Paul, Minnesota 55155-4012.