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ILLINOIS
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EVALUATION OF MUSKELLUNGE AND TIGER MUSKELLUNGE STOCKING PROGRAM

Project F-113-R

Annual Report to
Illinois Department of Conservation

Center for Aquatic Ecology

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EVALUATION OF MUSKELLUNGE AND TIGER MUSKELLUNGE STOCKING PROGRAM

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STUDY 101. Evaluation of muskellunge and tiger muskellunge stocking program.

JOB 101.1 Size-specific survival of muskellunge and tiger muskellunge.

OBJECTIVE: To compare survival and conduct benefit/cost analyses using a bioeconomic model for various sizes of muskellunge and tiger muskellunge stocked in Illinois impoundments.

INTRODUCTION: Stocking is a popular management tool to provide sport fishing opportunities and to supplement existing sport fish populations (Keith 1986). The success of fish stocking programs is largely dependant upon the ensuing survival rates. Stockings of esocid fingerlings have displayed extremely variable survival rates (Wahl and Stein 1989; Stein et al 1981; Johnson 1982). The sizes to which esocids must be reared to attain acceptable rates of survival is largely dependant upon system specific characteristics such as forage species abundance and size, predator density and size distribution, and thermal regime.

Survival of esocid fingerlings in impoundments has been shown to be largely dependant upon predation by resident largemouth bass (Stein et al. 1981) and the composition and abundance of forage fishes (Wahl and Stein 1988). Sizes to which esocids must be reared will vary according to the predator population and forage base of a specific system. The success of various size stockings need to be correlated with these factors to develop guidelines for impoundment stockings. These results will be used to improve and test a bioeconomic model developed by Wahl and Stein (1990) to compare the factors influencing survival of various sizes of esocids as a function of cost of rearing. In this job, we evaluate the relative survival of 4, 8 and 10 inch muskellunge and tiger muskellunge with impoundment stockings, and assess the effects of predator populations and prey resources on survival. These data will be used to help develop guidelines for future esocid stockings in Illinois.

METHODS and RESULTS: Results of experiments evaluating factors influencing relative survival of 4, 8, and 10 inch muskellunge have been presented in previous annual reports and a manuscript by T.A. Szendrey and D.H. Wahl entitled, "Size-specific survival and growth of stocked muskellunge" has been submitted to the *North American Journal of Fisheries Management.*

Thus far, we have identified several factors that can influence esocid stocking success including thermal regime, density and size structure of resident predators, and availability of appropriate size forage. These data are being summarized for development of an bioeconomic that compares trade-offs between survival as a function of size and relative costs of rearing for both muskellunge and tiger muskellunge. The model incorporates each of these factors we have identified as affecting esocid survival. In addition, we will include alternative costs of rearing, such as those used in Illinois hatcheries, that were not included in the original development of the model. With additional model development and incorporation of data collected in our work, the bioeconomic model can be used to determine the most appropriate size and time of year for stocking esocids in a particular system in order to maximize survival as a function of costs of rearing. The model will be useful in making system specific stocking recommendations.

The current version of the bioeconomic model allows evaluation of the effects of bass density and size distribution, thermal stress at stocking, forage base and, thermal regime on survival costs of stocked esocids. Preliminary simulations evaluated the effects of largemouth bass density on these relationships. Model simulations suggest bass density effects stocking strategies for tiger muskellunge more than for muskellunge (Figure 1). Tiger muskellunge can be economically stocked at small sizes only at low bass densities (< 5/ha) whereas small size muskellunge can be economically stocked at all largemouth bass densities. Future simulations will evaluate the effects of each of the other factors on esocid stocking strategies.

RECOMMENDATIONS: Results from the 1990-1992 stockings indicate that survival of fish less than 10 inches is poor, and no survival has been observed for stockings of fish less than 8 inches during all three years. Sampling of fish stocked in 1990-1992 should continue in order to monitor the effect of size at stocking on survival and growth rates through the second, third and fourth years. We have begun to incorporate data collected in this job into the esocid bioeconomic model. Simulations from this improved model will be useful in determining trade-offs between costs of rearing and size at stocking for individidual impoundment characteristics. These simulations will then be used to make mangagement recommendations regarding stocking of esocids in lakes throughout Illinois. The current version of the bioeconomic model allows evaluation of the effects of bass density and size distribution, thermal stress at stocking, forage base and, thermal regime on survival/cost of stocked esocids.

JOB 101.2 Effect of rearing technique on esocid survival

OBJECTIVE: To compare survival of minnow and pellet reared muskellunge and tiger muskellunge, and extensive and intensive reared muskellunge in impoundments.

INTRODUCTION: In addition to size at stocking, another factor which hatcheries can control which may potentially impact stocking success is rearing method. Extensive rearing of esocid fingerlings on minnows has been utilized for most stocking programs, however intensive rearing on pellets has been found to be a less expensive alternative (Klingbiel 1986). However, the survival and behavioral characteristics of esocids reared on minnows and dry diets should be evaluated before the implementation of large-scale use of artificial diets (Hanson et al 1986; Carline et al 1986). Similarly, survival of extensively and intensively reared esocids may also differ, as extensively reared tiger muskellunge have shown higher survival and faster growth than pellet fed fish (Johnson 1978; Andrews 1983; Beyerle 1984). However, size at stocking, number stocked, and time of stocking were not sufficiently controlled in these studies. Differential susceptibility to predation and conversion to available prey sources may greatly influence the survival and growth rates of fingerling esocids reared by different methods. In this job, we compare survival and growth rates of minnow versus pellet reared and intensively versus extensively reared muskellunge and tiger muskellunge and evaluate potential mechanisms causing observed differences in growth and survival.

METHODS: Paradise Lake (Coles Co.) was stocked with equal numbers (N = 1000; 15/ha) and similar sizes (10 inch) of extensively reared muskellunge (mean length = 256 mm; mean weight= 76.6 g) and tiger muskellunge (258 mm; 80.9 g) on August

17 (Table 1). Fish were reared in ponds at the Jake Wolf Memorial fish hatchery in Manito, Illinois, by the Illinois Department of Conservation. Unique fin clips were given to each species. Fish were tempered to within 2°C of lake temperature before stocking to avoid thermally stressing the fish (Mather and Wahl 1989). A sub-sample of each stocked group was held in three predator-free cages (N=15/cage) for 48 hours to monitor mortality associated with stress due to transport and stocking. Temperature and dissolved oxygen measurements were recorded on each sampling date in order to determine their influence on survival rates.

Susceptibility to predation by largemouth bass was determined as in Job 101.1. The number of tiger muskellunge and muskellunge collected from largemouth bass stomachs on each date was combined with largemouth bass population estimates (Table 2) to compute the total number of each rearing species eaten daily. These values were then summmed to compute total predatory mortality.

Population estimates (Schnabel mark-recapture) and catch-per-unit-effort of muskellunge and tiger muskellunge were computed in the fall and spring to determine survival rates. The entire perimeter of each lake was sampled at weekly intervals by electrofishing. All esocids collected were given a caudal fin clip to determine mark-recapture population estimates of each species.

RESULTS: Bass predation on muskellunge and tiger muskellunge was low. No mortaility was observed in cages after stocking for either species in Paradise Lake. Catch rates after stocking were consistently higher for muskellunge until late fall, when tiger muskellunge became higher (Table 3). Based on catch-per-unit-effort (CPUE), survival was higher through spring for muskellunge than for tiger muskellunge (Table 4). Electrofishing mark-recapture population estimates during fall in Paradise Lake revealed survival was slightly higher for muskellunge (23.5%) than for tiger muskellunge (22.3%) (Table 2). Spring population estimates were also higher for muskellunge (11.7%) than for tiger muskellunge (5.4%) (Table 2).

RECOMMENDATIONS: Stockings of extensive and intensive reared muskellunge should be repeated in 1994. Additional stockings are required to increase sample sizes for comparison of survival and vulnerability to predation between esocids reared by the two methods. Results from the 1993 stocking suggest that even though extensively reared muskellunge grow slower than tiger muskellunge, they do have higher survival. These experiments should also be repeated in 1994. Laboratory experiments are being conducted to determine if there are behavioral differences between the two species that might account for the higher survival of muskellunge. The experiments are focused on habitat selection, response to falling objects through the water column, and movement. Preliminary data shows that tiger muskellunge spend greater time in open water, are more likely to chase after objects falling through the water column, and move around more than muskellunge. Each of these behavioral traits may make tiger muskellunge more vunerable to predation and will be examined further.

JOB 101.3 Laboratory and pond experiments.

OBJECTIVE: To evaluate growth and survival rates of various sizes, minnow versus pellet reared, intensively versus extensively reared and genetic stocks of esocids in laboratory and pond experiments.

INTRODUCTION: Pond and laboratory experiments have been used often to determine the mechanisms that cause differences observed in field studies (Wahl and Stein 1989, Werner et al. 1983, Savino and Stein 1982). In comparing survival of muskellunge, tiger muskellunge and northern pike, Wahl and Stein (1989) used both experimental ponds and laboratory pools to compare vulnerability of esocids to largemouth bass predation. These experiments were extremely useful in evaluating mechanisms of differential survival. Differences in susceptibility to predation among pellet and forage reared esocids may have dramatic influences on survival. In this job, we employ the use of experimental ponds and laboratory pools to examine the susceptibility to largemouth bass predation of intensively and extensively reared muskellunge and tiger muskellunge.

METHODS: Six 1/10 acre ponds were used to examine survival, growth, and susceptibility to largemouth bass predation of intensively and extensively reared muskellunge. Three of the ponds were control, the other three were experimental. The experimental ponds had 4 bass, while the control did not. Twenty extensively and 20 intensively reared muskies were stocked into each of the six ponds. Minnows were placed in the control pond to provide food; the density of minnows was considered *ad* *libitum*. After two weeks, all ponds were seined and drained. The number of survivors of both rearing type were counted and the survivors in the control ponds were weighed and measured.

RESULTS: In control ponds without predators, extensively reared fish had higher survival than intensively reared fish (P=0.003). In the presence largemouth bass, extensively reared fish again had higher survival. Combining these results we conclude that extensively reared fish are similar in thier ability to avoid largemouth bass predation as intensive reared fish on minnows (Figure2). In control ponds, extensively and intensively reared muskellunge had similar growth (Figure 3).

RECOMMENDATIONS: From reservoir experiments, rearing technique influences vulnerability to predation. However, the mechanism for these differences is not clear. Future work should examine whether differences in color quantified for minnow and pellet reared tiger muskellunge directly affects vulnerability to predation. In addition, pond and laboratory experiments will be used to evaluate factors influencing survival of intensively versus extensively reared fish. Pond experiments should also be conducted to examine performance of different muskellunge stocks, to compare with laboratory findings (see Job 101.5).

JOB 101.4 Growth and food habits of muskellunge and tiger muskellunge.

OBJECTIVE: To determine the effect of stocking size and rearing technique on growth rates and food habits of muskellunge and tiger muskellunge.

INTRODUCTION: The relative success of muskellunge and tiger muskellunge in utilizing prey resources in impoundments after introduction can play a large role in the overall success of a particular stocking. Differences in conversion to available prey in the field can significantly influence survival and growth rates (Wahl and Stein 1988 ; Tomcko et al 1984). These differences are primarily the result of foraging efficiency of the fish and characteristics of the individual prey species. Gillen et al. (1981) examined the effect of the diet history (minnow vs pellet fed) of tiger muskellunge on foraging success, and found pellet reared fish to require longer capture times and more strikes per capture than minnow reared fish. These differences may be attributable to behavioral differences between the two rearing methods. The availability of adequate sizes of forage fish to various sizes of stocked esocids can also influence survival. In this job, we examine the effect of rearing method and size at stocking on the prey utilization and growth rates of muskellunge and tiger muskellunge in impoundments.

METHODS: Each group of esocids stocked was sub-sampled for length (nearest mm) and weight (nearest g) prior to stocking (Table 1). Esocids were then collected weekly or bi-weekly by electrofishing the entire perimeter of each impoundment. Esocids were measured and weighed at each collection date to determine relative growth rates of minnow and pellet reared, extensive and intensive reared, and various sizes of stocked esocids. Stomach contents of all esocids collected were removed by stomach flushing (Foster 1977) to determine food habits and to examine differences in diet conversion between minnow and pellet reared and extensive and intensive reared esocids. Five stations were seined with 75 foot hauls every month to determine inshore species composition, densities and size distribution of prey fishes available in each impoundment. Prey were identified to species and counted. These data will be used to evaluate the role of forage base in affecting growth and survival of stocked esocids.

RESULTS: Growth and food habits data were collected during fall and spring sampling after stockings of muskellunge and tiger muskellunge. Growth and food habits data were obtained from both esocids stocked in Paradise Lake. Both muskellunge and tiger muskellunge grew during the fall and spring months, however; tiger muskellunge grew faster and were larger by the end of the fall ($P=0.007$) (Figures 4 and 5).

High percentages of muskellunge and tiger muskellunge collected contained food in both fall and spring. Gizzard shad were consumed almost exclusively (Table 5). As in previous years, supplementary electrofishing samples showed gizzard shad to be exceedingly abundant, with large numbers of appropriately sized gizzard shad available as forage.

RECOMMENDATIONS: All esocids stocked in 1990-93 should continue to be sampled by electrofishing at monthly intervals to monitor growth and food habits.

JOB 101.5. Assessment of different stocks of muskellunge.

OBJECTIVE: To identify different genetic stocks of muskellunge and to evaluate their performance characteristics for stocking in Illinois impoundments.

INTRODUCTION: Different stocks of muskellunge have evolved under different ecological conditions, and as a result have acquired different performance characteristics. Growth rates, maximum size, longevity, and survival are among the traits that will affect an individual stock's value to Illinois fisheries. Preliminary work has shown that genetic techniques will be useful for identification of geographically distinct stocks. The purpose of this job is to use genetic techniques to identify different genetic stocks of muskellunge and then to evaluate their performance characteristics for stocking in Illinois impoundments. Several molecular techniques are being evaluated for their ability to detect genetic variation in this species. During this segment of the study, we completed laboratory evaluations of performance characteristics of the muskellunge populations identified through our genetic work. We compared consumption, conversion efficiency, growth, and metabolic rates of these populations as a function of water temperature to examine how each population might survive and grow in the thermal regimes present in Illinois. Additionally, we began pond evaluations to determine the long-term variation in growth that might occur among these same muskellunge populations.

METHODS AND RESULTS:

Laboratory tests of food consumption, conversion efficiency, and growth.- Experiments were completed examining temperature effects on food consumption, conversion efficiency, and growth of muskellunge stocks from Kentucky, Minnesota, New York, Ohio, the St. Lawrence River, and Wisconsin (Table 6). Test temperatures included 5, 10, 15, 25, and 27.5°C and experiments were completed in appropriate seasons to correspond to environmental water temperatures. We tested stocks in a recirculating system that allowed separation of fish into individual aquaria (35 L) while maintaining both constant temperatures and water quality. Ten muskellunge per stock were used for a total of 40 fish per temperature. Two weeks prior to consumption experiments, muskellunge were randomly assigned to aquaria and acclimated to test temperatures. Muskellunge were starved from 1-3 d depending on temperature to empty stomach contents and were then measured in weight (g) and length (mm). Muskellunge were fed fathead minnows ad libitum, and wet weights of minnows fed to each fish were recorded to determine 24-h consumption rates. Experiments lasted two weeks, after which muskellunge were again starved and measured to determine growth.

We compared food consumption (g food consumed/g fish/d), conversion efficiency (g food/growth), and relative growth (growth/g fish/d) among muskellunge stocks and temperatures. Food consumption for fish from all muskellunge populations increased with temperature from a low of less than 0.04 g/g/d at 5°C to a maximum of almost 0.14 g/g/d at 25°C, then declined at 27.5°C (Table 7). As with consumption, growth of fish from most populations was lowest at 5°C (less than 0.01 g/g/d), peaked at 25°C (0.05 g/g/d), and declined slightly at 27.5°C (Table 7). Growth of fish from the Kentucky population increased continuously with temperature from 5°C to 27.5°C. Conversion efficiency varied inconsistently across temperatures and among populations of muskellunge and differences observed were not statistically significant.

Differences in food consumption were related to population, temperature, and a population x temperature interaction. However, there were few consistent patterns in food consumption among populations of muskellunge across temperatures. At 5°C, Kentucky and St. Lawrence River fish consumed less food than fish from Minnesota, New York, Ohio, and Wisconsin populations. At temperatures higher than 10°C, fish from Wisconsin and Ohio populations had higher consumption rates than muskellunge from the other populations, but specific significant differences among populations varied with temperature (Table 7). When data from individual populations were grouped according to previously described stocks, differences were observed related to stock, temperature, and a stock x temperature interaction. Muskellunge from the _E. m. immaculatus_ group consistently had the highest consumption rates, followed by those from _E. m. ohioensis_ and _E. m. masquinongy_ groups (Figure 7).

Relative growth followed similar patterns to consumption for these populations. Differences in relative growth were again related to population, temperature, and a population x temperature interaction. There were no significant differences in growth among populations at 5°C or 10°C. As with maximum consumption, at temperatures higher than 10°C, fish from

Wisconsin and Ohio populations had higher growth rates than muskellunge from the other populations. Again, specific significant differences in growth among populations varied with temperature (Table 7). Differences in growth were also observed related to stock, temperature, and a stock x temperature interaction. Growth of muskellunge stocks followed a pattern similar to that seen for consumption, with fish from the E. m. immaculatus group growing faster than those from E. m. ohioensis and E. m. masquinongy groups (Figure 6).

Laboratory tests of metabolic rate. - Tests of resting metabolic rate were completed on fingerling muskellunge from the same six populations used in feeding and growth evaluations (Table 7). Metabolic rate tests were conducted in an environmental chamber which allowed for control of temperature and photoperiod. Tests involved evaluation of resting metabolic rate at five temperatures (5OC, 10°C, 15°C, 25°, and 27.5°C). Photoperiod was held constant at 14 h daylight and 10 h dark at 25°C and 27.5°C, and 12 h:12 h at each of the other three temperatures. Four to nine fish from each stock were tested at each temperature; two to three replicate tests were performed on each fish.

Static as opposed to flow-through chambers were used to measure metabolic rate (Bevelheimer et al. 1985). Measurements were made by sealing each fish in a glass bowl (2.3 l) covered by a plexiglass lid fitted with a polarographic dissolved oxygen probe. Chambers were filled from an aerated head tank and flushed of waste products before and after each test. Fish were starved for 1-3 d prior to each test (depending on temperature), and were transferred to static test chambers the day before tests were conducted. Once a fish was sealed inside the test chamber, records of oxygen levels inside the chamber were output to a computer at 30 second intervals. Tests were designed to measure resting metabolic rate, and records of oxygen levels during the tests were also used as a measure of activity. Muskellunge were anesthetized, weighed, and measured at the end of each set of tests. Seven to fourteen blanks were run at each temperature to correct for any oxygen demand of the system other than from the fish. Metabolic rate was calculated as the drop in dissolved oxygen content of the water during the test multiplied by the volume of the test chamber. Values were expressed as a function of the weight of the fish (g) and time (h). Tests lasted for 0.75 h to 1.5 h.

Standard metabolic rate increased with temperature for all muskellunge populations tested (Table 7). Metabolic rate ranged from near 0.1 mg O g/h at 5°C to near 0.25 mg O and 27.5°C. As with consumption and growth, differences in metabolic rate were related to population, temperature, and a population x temperature interaction, but overall there were fewer differences in metabolic rate among populations than there were in consumption and growth. Metabolic rates of fish from Minnesota and Wisconsin populations were significantly higher than those of St. Lawrence River fish at 10°C, and Wisconsin fish had higher metabolic rates than St. Lawrence River fish at 27.5°C. There were no significant differences in metabolic rate among muskellunge populations at 5°, 15°, or 25°C. Differences in metabolic rate were observed related to stock, temperature, and a stock x temperature interaction, but these differences were not consistent with those observed for maximum consumption and growth. At temperatures below 25°C, metabolic rates of fish from the *E. m. immaculatus* group were higher than those of fish from *E. m. ohioensis* and *E. m. masquinongy* groups (Figure 7). At 25° 27, *E. m. ohioensis* fish had the highest metabolic rate, although differences among stocks at these higher temperatures were not significant.

Intraspecific population differences in food consumption, conversion efficiency, growth, and metabolic rate were substantial. While we observed differences among six muskellunge populations in three of four dependent variables tested across a range of temperatures, the differences were not consistent across variables and could not be explained based on a hypothesis of thermal adaptation or on previous genetic groupings. We expected Minnesota and Wisconsin fish to consume more food and grow faster at lower temperatures than fish adapted to warmer temperature regimes. Conversely, Kentucky, New York, and Ohio fish were expected to consume more food and grow more quickly at higher temperatures. These expected relationships were observed in only a few instances. For example, at 27.5°C, Ohio fish did have the highest rate of food consumption, but Wisconsin fish had similarly high rates, and New York fish consumed less food than fish from any other population. At 5°C, Wisconsin fish had the highest growth rate (as expected), but growth of Minnesota fish was relatively slow. Similarly variable results were observed when groupings of populations (stocks) were analyzed. These results suggest that, at least for muskellunge, thermal adaptation may not be observable at the population or stock level. Lack of agreement between physiological characters and genetic groupings is additional evidence supporting the alternative hypothesis that significant adaptation to local environments has not occurred for muskellunge populations.

The physiological differences we observed among muskellunge populations, while not consistent with genetic analyses, still support the point that supplementing natural populations with hatchery-produced individuals may compromise the genetic integrity of those populations (Koppelman and Philipp 1986); the long-term consequences of supplementing natural populations with hatchery fish need to be considered before such introductions are made. Muskellunge are also increasingly being introduced in areas where they have not previously occurred, and the differences we observed among young-of-year muskellunge could be extremely important. For example, with a given temperature regime, we might see important differences in growth among fish from these populations after the first summer following stocking (Bevelheimer et al. 1985). Growth differences have important implications for survival, both that influenced by losses to predation (Wahl and Stein 1989) and overwinter (Bevelheimer et al. 1985, Carline et al. 1986). Differences among populations in growth and food consumption suggest that the thermal regimes of recipient waters should be considered in determining the most appropriate population for use in introductions outside the native range of the muskellunge.

Pond Tests of Muskellunge Growth. - Additional sampling was conducted to evaluate long-term differences in growth among muskellunge stocks. Evaluations were conducted in 1/10th-acre ponds stocked with populations of muskellunge used previously in laboratory tests of food consumption, growth, and metabolic rate. Ponds were periodically stocked with fathead minnows *Pimephales promelas* as forage. Total length and weight of muskellunge from Kentucky, Minnesota, Ohio, and Wisconsin were measured on nine sampling dates since fish were stocked to ponds in August 1993. Minnesota muskellunge have shown consistently slower growth than fish from the other stocks; growth of fish from Kentucky, Ohio, and Wisconsin was not different (Figure 7). Fish were transferred to a 1-acre pond for long-term monitoring in May 1994.

RECOMMENDATIONS: The physiological differences we observed among muskellunge populations, while not consistent with genetic analyses, still have important implications for growth and survival of muskellunge stocked in Illinois impoundments and reservoirs. Pond experiments will continue to assess long-term growth among the different muskellunge populations, allowing us to examine whether small differences in growth observed in laboratory experiments are also observed in the field. In addition, bioenergetics models will be modified using data obtained in laboratory experiments. Predicted growth using these revised models will then be compared to that observed among pond populations of muskellunge. With modification, these models will allow us to predict first year growth rates of different muskellunge populations in thermal regimes present in waters throughout Illinois.

Our work on performance evaluation has emphasized differences among young-of-year fish. After pond experiments are completed, differences among muskellunge stocks need to be determined in reservoir experiments, to fully evaluate the potential for use of different muskellunge populations for Illinois management applications. Reservoir evaluations should address differences among stocks that can be observed in young-of-year through adult fish. Parameters including temperature tolerance (preferred and lethal), growth rates (time to reach trophy size, maximum final size, size at first reproduction), distribution of energy intake to reproductive versus somatic growth, and longevity/survival need to be evaluated in both pond and field studies. Knowledge concerning all of these traits will help to better define individual populations and their potential value to Illinois fisheries.

JOB 101.6 Analysis and reporting

OBJECTIVE: To prepare annual and final reports which develop management guidelines for stocking esocids in Illinois impoundments.

RESULTS AND RECOMMENDATIONS: Relevant data were analyzed and reported in individual job of this report (see Job 101.1-101.5).

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ble 1. Summary of esocid stocking in Paradise Lake in 1993.
tal length (nearest mm) and weight (nearest 0.1 g) were
asured prior to stocking (N=50). Paradise Lake was stocked
th both extensively reared muskellunge (MU) and tiger
skellunge (TM).

ke	Taxa	Stocking Date	Number of Fish	Number per Hectare	Mean Length (mm)	Mean Weight (g)
radise	MU	Aug 17	1000	15	256	76.6
	TM	Aug 17	1000	15	258	80.9

Table 2. Schnabel population estimates and relative survival through fall 1993 and spring 1994 of stocked esocids and largemouth bass determined by electrofishing mark-recapture estimates. Extensively reared muskellunge and tiger muskellunge were stocked in Paradise Lake.

		Population Estimate		
Lake	Taxa	Point Estimate	95% C.I.	% Survival
Paradise Fall 1993	MU	235	190-450	23.5
	TM	223	124-453	22.3
Paradise Spring 1994	MU	117	70-273	11.7
	TM	54	27-273	5.4
Paradise Fall 1994	LMB	354	225-656	

ble 3. Catch-per-unit-effort from electrofishing on ccessive weeks after stocking during fall for extensively ared muskellunge (MU) and tiger muskellunge (TM) in Paradise ke, 1993.

		Catch (c)		CPUE (c/hr)	
ek	Effort (hrs)	MU	TM	MU	TM
	1.57	15	8	9.6	5.1
	1.58	14	7	8.9	4.4
	1.63	32	8	19.6	4.9
	1.50	18	7	12.0	4.7
	1.58	12	3	7.6	1.9
	1.47	4	3	2.7	2.0
	2.55	9	2	3.5	0.8
	1.58	8	1	5.1	0.6
	1.55	18	17	11.6	11.0
	1.75	8	15	4.6	8.6

Table 4. Catch-per-unit-effort from electrofishing on successive weeks after stocking during spring for extensively reared muskellunge (MU) and tiger muskellunge (TM) in Paradise Lake, 1994.

Week	Effort (hrs)	Catch (c)		CPUE (c/hr)	
		MU	TM	MU	TM
March 22	3.10	3	1	1.0	0.3
March 29	2.65	30	11	11.3	4.2
April 6	1.28	8	5	6.3	3.9
April 13	2.78	12	6	4.3	2.2
April 20	1.18	3	1	1.0	0.3
April 27	.75	3	0	4.0	0.0

Table 5. Monthly food habits of extensively reared muskellunge and tiger muskellunge stocked in Paradise Lake through fall and spring sampling periods.

			Prey species composition				
Date	% with food	N	Gizzard shad	Brook Silverside	Bluegill	Cyprinid spp.	Unidentified
			Muskellunge				
Aug	10	29	3	0	0	0	0
Sept	55	55	32	0	0	0	0
Oct	85	21	17	0	0	0	0
Nov	61	36	21	0	1	0	0
Dec	20	20	2	0	0	0	0
Mar	75	28	20	0	1	0	1
Apr	63	24	13	0	1	0	1
May	100	4	4	0	0	0	0
			Tiger Muskellunge				
Aug	20	15	3	0	0	0	0
Sept	67	18	13	0	0	0	0
Oct	67	6	6	0	0	0	0
Nov	71	38	25	0	0	0	0
Dec	71	7	4	0	0	0	0
Mar	57	14	14	0	0	0	0
Apr	33	12	12	0	0	0	0
May	0	2	0	0	0	0	0

Table 6. Sources for young-of-year muskellunge used in tests of food consumption, conversion efficiency, growth, and metabolic rate. Stocks are semi-discrete groups of fish from the muskellunge complex. Esox masquinongy ohioensis (EMO) includes muskellunge from the Ohio River and tributaries, and is represented here by populations from Kentucky, New York, and Ohio. Esox masquinongy immaculatus (EMI) includes muskellunge from lakes in Wisconsin, Minnesota, northwestern Ontario, and southeastern Manitoba, and is represented by populations from Wisconsin and Minnesota. Esox masquinongy masquinongy (EMM) includes fish from the St. Lawrence River-Great Lakes and tributaries, and is represented by a single population.

State	Hatchery	Source Water	Population	Stock
Kentucky	Minor Clark	Cave Run Lake	KY	EMO
Minnesota	New London	Leech Lake	MN	EMI
New York	Mayville	Lake Chautauqua	NY	EMO
	NYDEC/SUNY	St. Lawrence River	STL	EMM
Ohio	Kincaid	Clear Fork Lake	OH	EMO
Wisconsin	Woodruff	Minaqua Lake	WI	EMI

Table 7. Maximum food consumption, food conversion efficiency, relative growth and standard metabolic rate of muskellunge from six populations. Population refers to muskellunge populations described in the text and Table 6. Values are averages for all fish ± 95% confidence intervals. Within each column (temperature) and variable combination, values that do not share a common letter are significantly different from one another (P<0.05).

Population	Temperature				
	5	10	15	25	27.5
			Maximum food consumption ($g \cdot g^{-1} \cdot d^{-1}$)		
KY	0.016±0.004$_{ab}$	0.035±0.006$_{a}$	0.068±0.010$_{ac}$	0.104±0.011$_{a}$	0.100±0.012$_{ab}$
MN	0.021±0.006$_{ab}$	0.043±0.009$_{a}$	0.061±0.006$_{a}$	0.129±0.006$_{b}$	0.098±0.008$_{a}$
NY	0.022±0.006$_{ab}$	0.040±0.006$_{a}$	0.073±0.008$_{ab}$	0.130±0.007$_{b}$	0.095±0.014$_{a}$
OH	0.021±0.004$_{ab}$	0.045±0.005$_{a}$	0.078±0.007$_{bc}$	0.130±0.012$_{b}$	0.119±0.004$_{b}$
STL	0.015±0.002$_{b}$	0.045±0.008$_{a}$	0.058±0.016$_{a}$	0.108±0.007$_{a}$	-----
WI	0.033±0.006$_{a}$	0.043±0.004$_{a}$	0.086±0.007$_{b}$	0.136±0.006$_{b}$	0.107±0.009$_{ab}$
			Food conversion efficiency ($g \cdot g^{-1}$)		
KY	0.195±0.155$_{a}$	0.286±0.044$_{a}$	0.330±0.088$_{a}$	0.281±0.116$_{a}$	0.309±0.031$_{a}$
MN	0.128±0.283$_{a}$	0.306±0.041$_{a}$	0.374±0.023$_{a}$	0.340±0.034$_{a}$	0.294±0.032$_{a}$
NY	-0.058±0.708$_{a}$	0.290±0.053$_{a}$	0.366±0.024$_{a}$	0.416±0.029$_{a}$	0.242±0.125$_{a}$
OH	0.198±0.116$_{a}$	0.315±0.033$_{a}$	0.353±0.030$_{a}$	0.396±0.052$_{a}$	0.374±0.020$_{a}$
STL	0.106±0.167$_{a}$	0.268±0.047$_{a}$	0.265±0.101$_{a}$	0.321±0.067$_{a}$	-----
WI	0.293±0.048$_{a}$	0.291±0.030$_{a}$	0.372±0.030$_{a}$	0.400±0.069$_{a}$	0.354±0.038$_{a}$

Table 7. continued.

Population	Temperature				
	5	10	15	25	27.5
			Relative growth $(g \cdot g^{-1} \cdot d^{-1}) \cdot 100$		
KY	$0.34\pm0.28_{a}$	$1.01\pm0.26_{a}$	$2.16\pm0.55_{ab}$	$3.09\pm1.43_{a}$	$3.11\pm0.63_{ab}$
MN	$0.45\pm0.32_{a}$	$1.34\pm0.35_{a}$	$2.28\pm0.34_{ab}$	$4.36\pm0.34_{bc}$	$2.96\pm0.44_{a}$
NY	$0.56\pm0.48_{a}$	$1.17\pm0.30_{a}$	$2.68\pm0.34_{ab}$	$5.40\pm0.54_{b}$	$2.58\pm1.37_{a}$
OH	$0.47\pm0.22_{a}$	$1.42\pm0.21_{a}$	$2.77\pm0.34_{ab}$	$5.17\pm0.78_{b}$	$4.45\pm0.31_{b}$
STL	$0.25\pm0.16_{a}$	$1.22\pm0.38_{a}$	$1.53\pm0.57_{b}$	$3.47\pm0.73_{ac}$	-----
WI	$0.98\pm0.31_{a}$	$1.26\pm0.17_{a}$	$3.19\pm0.37_{a}$	$5.46\pm1.06_{b}$	$3.70\pm0.34_{ab}$
			Standard metabolic rate $(mg\ O_2 \cdot g^{-1} \cdot h^{-1})$		
KY	$0.08\pm0.02_{a}$	$0.13\pm0.03_{ab}$	$0.16\pm0.02_{a}$	$0.24\pm0.03_{a}$	$0.26\pm0.04_{ab}$
MN	$0.08\pm0.02_{a}$	$0.21\pm0.02_{b}$	$0.22\pm0.01_{a}$	$0.25\pm0.01_{a}$	$0.24\pm0.05_{ab}$
NY	$0.08\pm0.03_{a}$	$0.16\pm0.04_{ab}$	$0.21\pm0.02_{a}$	$0.26\pm0.04_{a}$	-----
OH	$0.09\pm0.02_{a}$	$0.14\pm0.03_{ab}$	$0.21\pm0.02_{a}$	$0.24\pm0.03_{a}$	$0.24\pm0.06_{ab}$
STL	$0.08\pm0.03_{a}$	$0.09\pm0.02_{a}$	$0.16\pm0.06_{a}$	$0.21\pm0.02_{a}$	$0.20\pm0.05_{a}$
WI	$0.09\pm0.03_{a}$	$0.18\pm0.04_{b}$	$0.22\pm0.04_{a}$	$0.23\pm0.03_{a}$	$0.30\pm0.06_{b}$

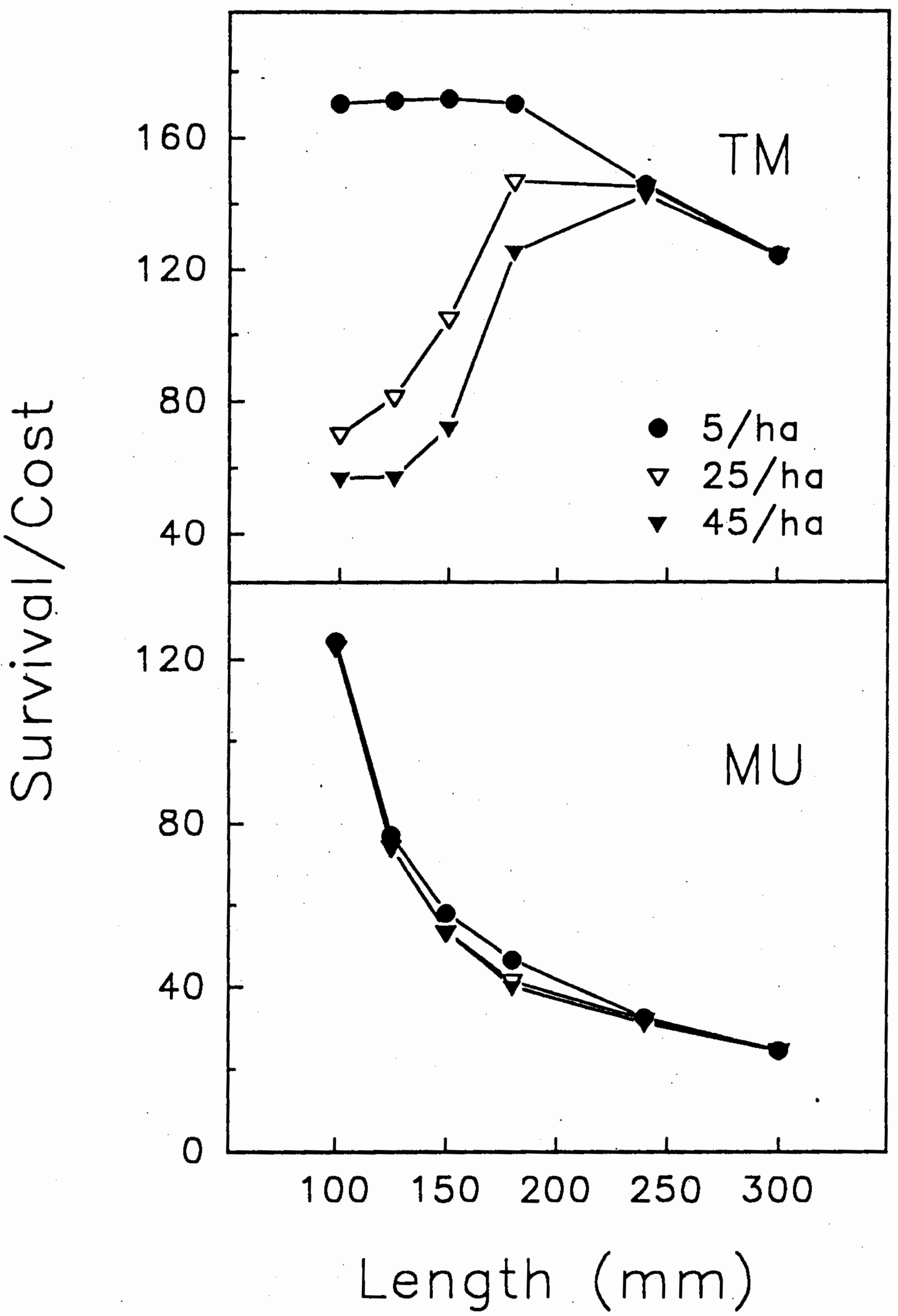

Figure 1. Comparison of survival per unit cost as a function of length for tiger muskellunge and muskellunge stocked into lakes with three different largemouth bass densities.

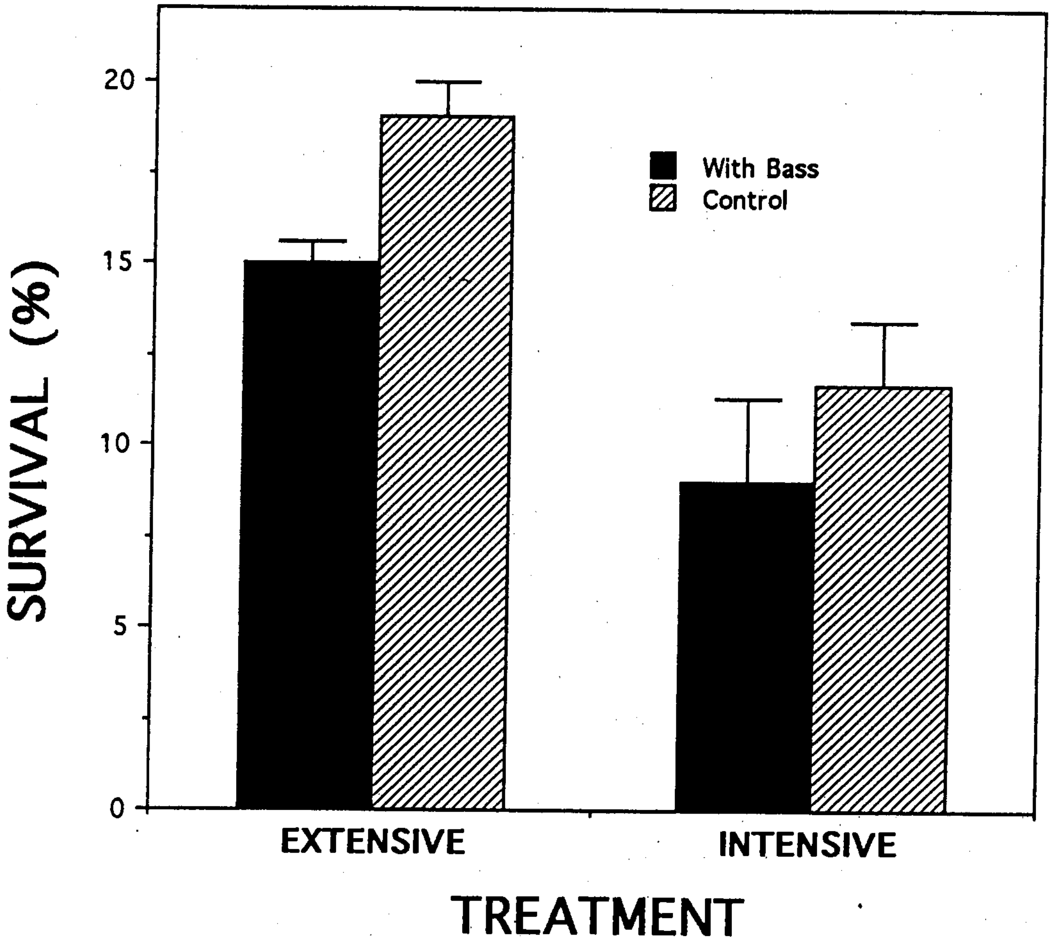

Figure 2. Survival of extensively and intensively reared muskellunge in experimental and control ponds.

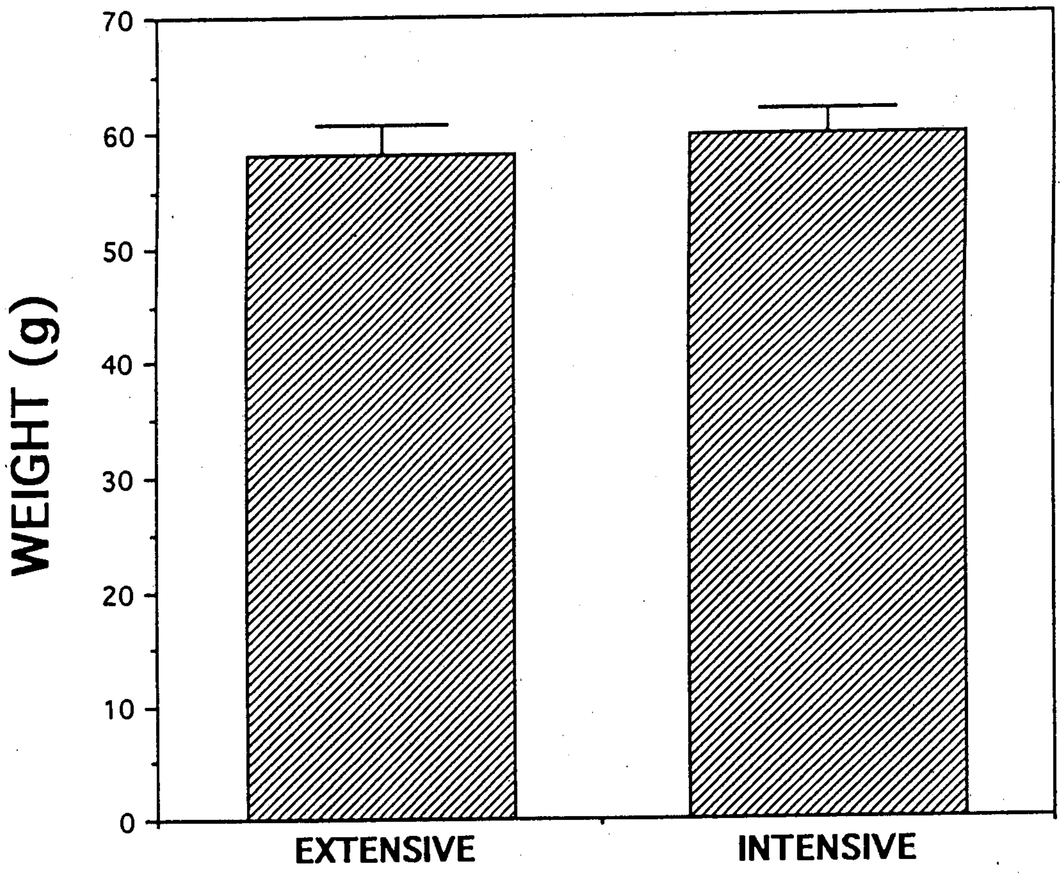

Figure 3. Growth of extensively and intensively reared muskellunge in control ponds.

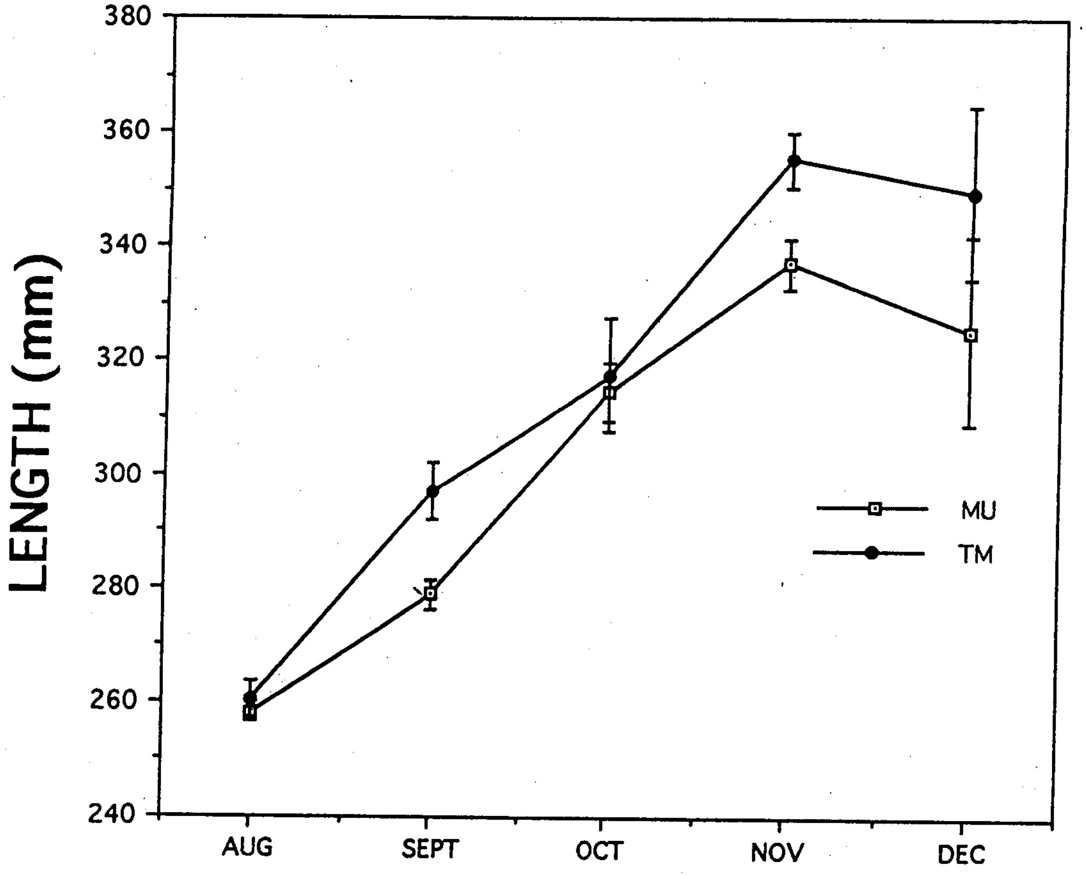

Figure 4. Growth of extensively reared muskellunge and tiger muskellunge in Paradise Lake through Fall 1993.

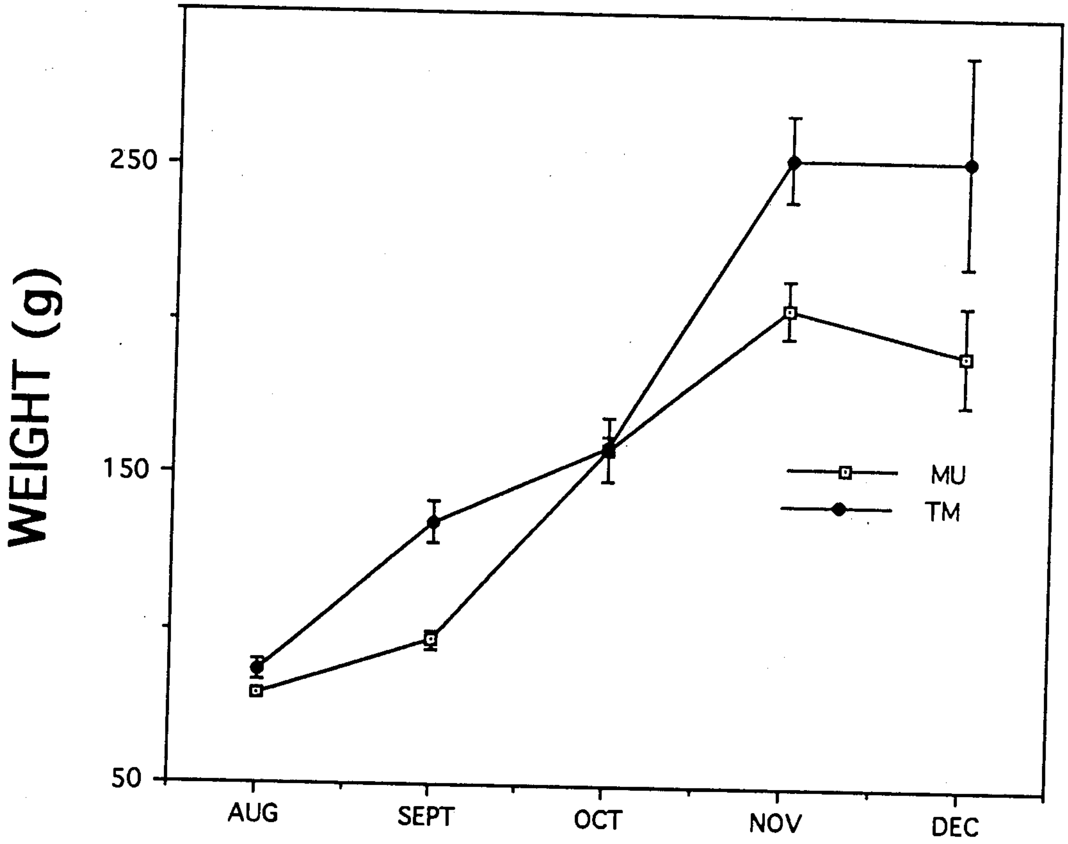

Figure 5. Growth of extensively muskellunge and tiger muskellunge in Paradise Lake through Fall 1993.

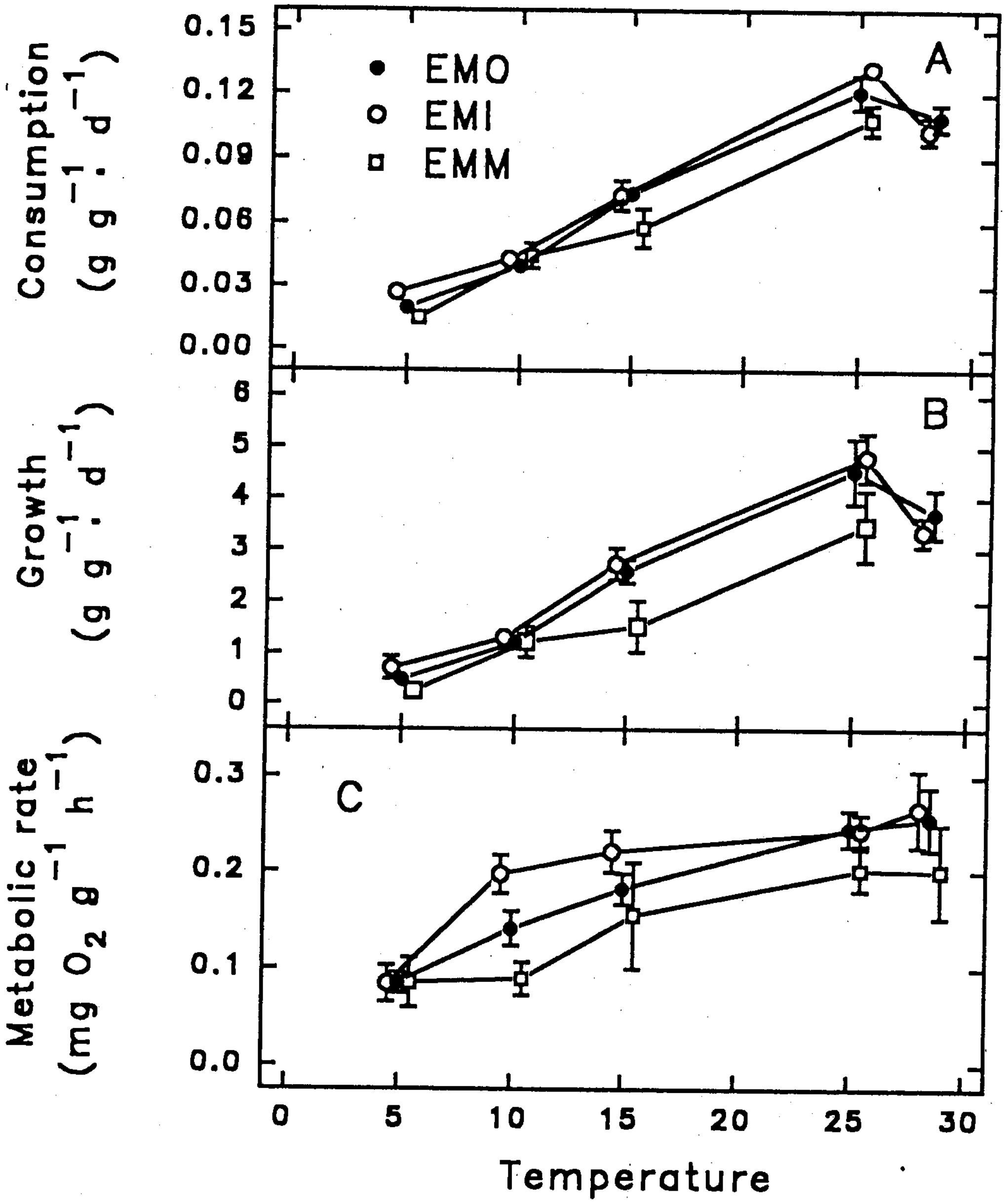

Figure 6. Maximum food consumption (A), relative growth (B), and standard metabolic rate (C) of three stocks of muskellunge at five temperatures. Stocks correspond to muskellunge stocks described in the text and Table 1. Vertical bars are 95% confidence intervals. Within each temperature, values that do not share a common letter are significantly different from one another ($P<0.05$).

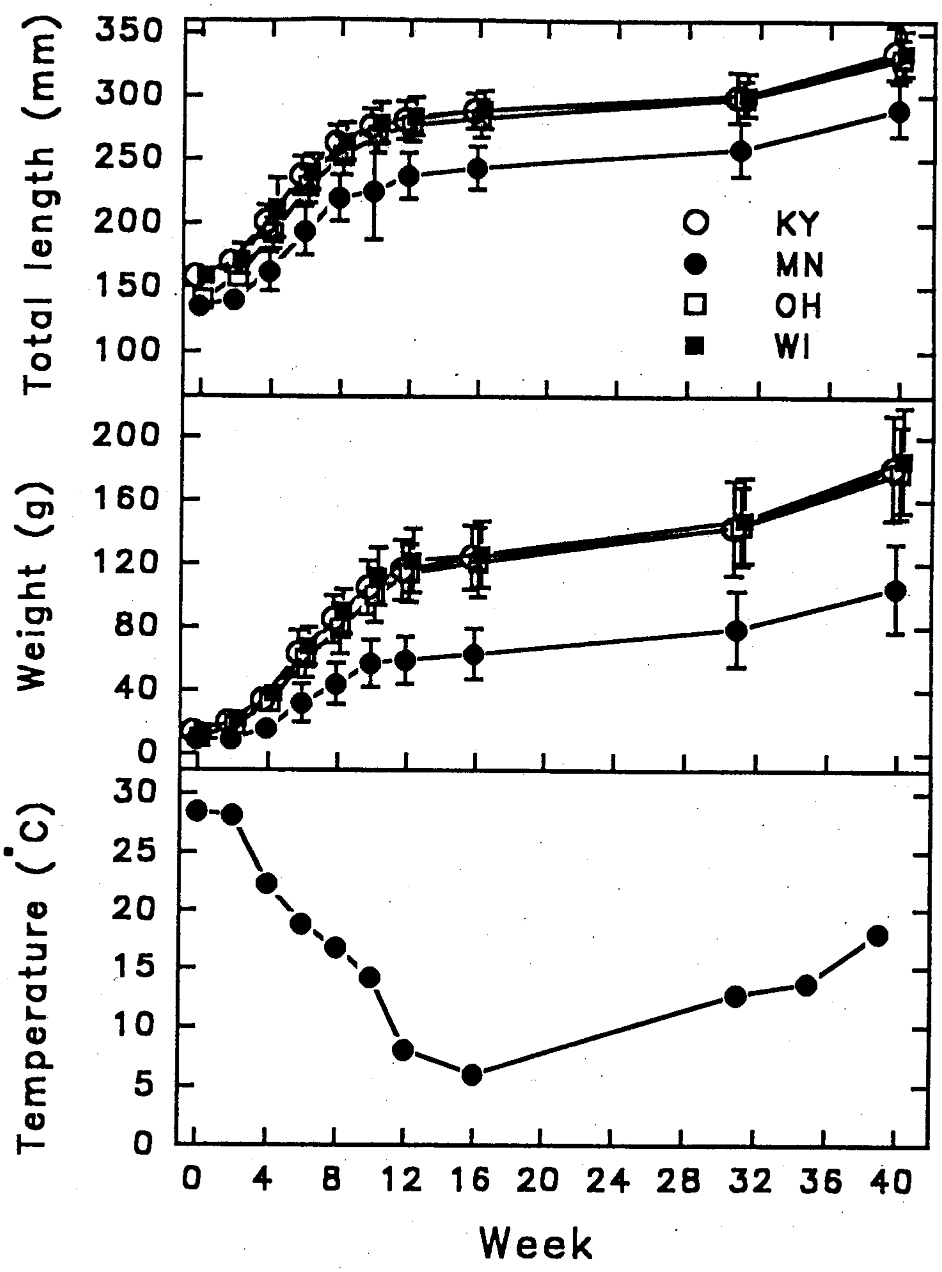

Figure 7. Total length and weight of muskellunge from four populations stocked into three hatchery ponds. Week refers to time since stocking. Vertical bars are 95% confidence intervals. Temperature is the average of temperature readings across ponds during each week.