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July 1, 2004 through June 30, 2005

EVALUATION OF GROWTH AND SURVIVAL OF DIFFERENT GENETIC STOCKS OF MUSKELLUNGE: IMPLICATIONS FOR STOCKING PROGRAMS IN ILLINOIS AND THE MIDWEST

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David H. Wahl	John Epifanio, Director
Principal Investigator	Center for Aquatic Ecology

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EXECUTIVE SUMMARY: Muskellunge *Esox masquinongy* are an important sportsfish that are commonly stocked throughout Illinois and much of the Midwestern United States. In Illinois, as in many other states, the demand for these fishes far exceeds the supply. Stocking has become the primary management tool for establishing and maintaining muskellunge populations. The high costs associated with producing these fishes create the need for efficient management practices. Previous research efforts have determined the size of fish and timing of stocking to maximize growth and survival. However, additional information on muskellunge stocking strategies is needed. Specifically, more biological data on different genetic stocks of muskellunge is needed to determine the best population to stock in a particular body of water to maximize growth and survival.

Morphological and geographic characteristics have suggested multiple distinct groups of muskellunge. More recently, genetic analysis identified several different genetic stocks of muskellunge (Ohio River drainage, Upper Mississippi River drainage, and the Great Lakes drainage stocks), each with multiple populations. Previous work with young-of-year from these populations found differences in growth and food consumption as a function of temperature. As a trophy species, anglers and managers are interested in utilizing populations of fish that grow the fastest, live longest, and obtain a largest maximum size. Because muskellunge populations are either not naturally found or have been eliminated in many Illinois lakes and reservoirs, it is not clear which population to use in stocking efforts. The muskellunge population currently used as brood stock for the stocking program in Illinois is of an unknown origin and may be made up of several different populations. Muskellunge stocks from various populations may perform differently in Illinois waters in terms of growth and survival. Additional information is needed on differences in growth and survival among stocks in waters at varying latitudes in Illinois before management recommendations can be made on which stock is most appropriate. Determining which stock has the highest levels of growth and survival under the various conditions found in Illinois waters will increase stocking success and angler satisfaction. This study examines differences in growth and survival among different stocks of muskellunge in order to make recommendations regarding stocking in Illinois.

During segment three, all activities outlined in the annual work plan were accomplished and were completed within the specified budget. During this segment, two jobs related to muskellunge stock evaluation were completed. Those jobs are (1) evaluation of growth and (2) evaluation of survival among stocks of muskellunge. In this segment of the study, we compare growth and survival of muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois North Spring Lake progeny in three lakes throughout Illinois. Muskellunge fingerlings from each of the stocks were introduced into Pierce Lake, Lake Mingo, and Forbes Lake at rates ranging from 0.3 – 4.9 fish per hectare during fall 2004. Initial stocking mortality due to transport and stocking was assessed using three 3-m deep predator-free cages for 48-h. Mortality from stocking stress was generally low for most populations, ranging from 0 – 40% (40% occurred at a surface temperature of 26.1 °C in September 2004). Across years and reservoirs, the Ohio River drainage stock muskellunge appear to have higher mean daily growth and mean relative growth rates than the Upper Mississippi River drainage stock or the Illinois population. The Illinois population typically expresses intermediate growth while the Upper Mississippi River drainage stock generally has the lowest growth rates. Initial results from reservoir introductions suggest that the Ohio River drainage stock and the Illinois population have somewhat higher survival than the Upper Mississippi River drainage stock.

These, and future introductions will need to be monitored over several years to further assess growth and survival differences among stocks.

In pond experiments at the Sam Parr Biological Station, Marion County, Illinois, three 0.4-ha ponds were also used to evaluate growth and survival differences among muskellunge stocks. At draining in April 2005, the Ohio River drainage stock and Illinois population had similar mean daily growth rates over the 6-mo overwinter interval, and both were higher than the mean daily growth rate of the Upper Mississippi River drainage stock. The Ohio River drainage stock muskellunge exhibited a significantly higher mean relative growth rate than both the Illinois population and the Upper Mississippi River drainage stock. Upon draining in April 2005, no significant differences in survival over the 6-mo period from stocking until draining were observed among muskellunge stocks.

These same, and additional, populations of muskellunge will be evaluated for growth and survival differences in future years of the study. The results obtained from these first three years will be combined with those from future years to identify the long-term growth and survival differences among genetic stocks of muskellunge. These results will be used to develop guidelines for future muskellunge stockings that maximize growth, survival, and angler satisfaction in reservoirs throughout Illinois.

Job 101.1. Evaluating growth of different stocks of muskellunge.

OBJECTIVE: To determine differences in growth among various stocks and populations of muskellunge in Illinois waters.

INTRODUCTION: The taxonomy of the muskellunge has undergone substantial revision over the last century (Crossman 1978; Crossman 1986). During the late 1800's and early 1900's, apparent correlations between markings and location led to the establishment of three separate species for a short time (Crossman 1978). As interpretation of the color and marking distinctions progressed, the idea of subspecies was introduced (Hubbs and Lagler 1958; McClane 1974; Smith 1979). By the late 1970's the idea that all variations were indeed one single species, without enough evidence to warrant subspecies classifications, had been established (Crossman 1978). More recent genetic analysis of various populations revealed three distinct clusters that were found to be related to major river drainage origins, suggesting the existence of divergent stocks (Koppelman and Philipp 1986). Existing information indicates muskellunge persisted through the Wisconsin glacier period in the Mississippi refugium and upon glacial recession, moved north up the Mississippi valley and established its current range via the Mississippi and Ohio River systems, as well as precursors to tributaries of the Great Lakes (Crossman 1978; Crossman 1986). Muskellunge were isolated by major river drainages and experienced different environmental conditions and thermal histories. As these isolated groups diverged through recolonizatoin, genetic processes, such as natural selection, resulted in stocks of muskellunge that are genetically dissimilar, and likely physiologically and behaviorally different from one another (Altukhov 1981; MacLean and Evans 1981; Ihssen et al. 1981; Clapp and Wahl 1996; Begg et al. 1999). The currently identified genetically distinct muskellunge stocks are the Upper Mississippi River drainage stock, the Great Lakes/St. Lawrence River drainage stock, and the Ohio River drainage stock (Koppelman and Philipp 1986; Clapp and Wahl 1996).

Stocks and populations of muskellunge have evolved under different ecological conditions, and as a result, have likely developed physiological differences through selection processes and genetic drift. Such differences could affect performance characteristics, such as growth rates at various temperatures, as has been demonstrated with other freshwater fishes. Luey and Adelman (1984) found significant differences in growth among groups of rainbow smelt *Osmerus mordax* sampled from three zones in Lake Michigan. These findings were consistent with previous genetic evidence suggesting three distinct stocks of rainbow smelt. Studies directed towards evaluating adaptability and differences between northern largemouth bass *Micropterus salmoides salmoides* and Florida largemouth bass *M. s. floridanus* (at the time considered sub-species) in central Illinois found significant growth differences, both overwinter and during the first growing season (Isely et al. 1987; Philipp and Whitt 1991). Growth differences were even observed between two stocks from different river drainages within Illinois (Philipp and Claussen 1995). In addition, a study of life history and electrophoretic characteristics of five allopatric stocks of lake whitefish *Coregonus clupeaformis* found differences in growth rate, as well as other traits, among stocks (Ihssen et al. 1981). As demonstrated by these studies, considerable physiological and/or behavioral differences can be observed among stocks of fish perceived to be very similar and it is important to incorporate this knowledge of stocks into management plans. Differences in growth among genetically distinct muskellunge stocks and populations may prove to be a critical factor in management decisions, such as determining the appropriateness of a population for developing various Illinois fisheries.

Evolutionary theory predicts that organisms adapt, over generations, to the conditions experienced in their specific environment. However, the actual mechanisms and response clines of this adaptation are poorly understood for ectotherms, specifically freshwater fishes. Arguably, the most influential source of environmental variation is the latitudinal gradient and corresponding thermal regime conditions experienced by many temperate fishes. Currently, two competing models exist to explain the nature in which intraspecific growth rates vary across a latitudinal gradient (i.e. among stocks). Thermal adaptation, also termed local adaptation, predicts that growth rates are adapted to the local thermal regime (Levinton 1983; Yamahira and Conover 2002). Physiological rates are expected to operate most efficiently (e.g. highest growth rates) at the temperatures most commonly experienced in the native environment (Levinton 1983; Levinton and Monahan 1983; Lonsdale and Levinton 1985). Studies of marine invertebrates (Levinton 1983; Levinton and Monahan 1983), crustaceans (Lonsdale and Levinton 1985), and fish (Galarowicz and Wahl 2003; Belk et al. 2005) have supported the idea of thermal adaptation.

The second model, countergradient variation, focuses on differences in length of the growing season across latitudes (Conover and Present 1990; Yamahira and Conover 2002). There exists a latitudinal gradient with regards to length of the growing season, with lower latitudes having longer growing seasons than higher latitudes. Countergradient variation predicts relatively high growth rates for individuals experiencing environments that impose relatively strong detrimental effects on growth, such as high latitudes (Conover and Schultz 1995; Belk et al. 2005). The mechanism proposed to direct species towards a countergradient variation response is selective pressure in relation to overwinter survival. In regions with growing seasons of short duration and long winters, it is hypothesized that individuals must be large enough to have the energy reserves necessary to survive winter as well as to decrease predation risk. Over time, the selection via survival towards phenotypes with a propensity for faster growth rates would structure a population, and species group, to display countergradient variation in growth rates. A growing body of literature for several fishes supports the concept of countergradient variation in physiological rates, specifically growth rates (Conover and Present 1990; Nicieza et al. 1994; Schultz et al. 1996; Conover et al. 1997; DiMichele and Westerman 1997; Jonassen et al. 2000).

A commonly used and straight-forward method to explore growth responses across a latitudinal gradient, or among stocks and populations, is a common garden (or common environment) experiment. One such experiment compared food consumption, metabolism, and growth among populations of muskellunge (Clapp and Wahl 1996). These laboratory studies evaluated six populations of young-of-year (YOY) muskellunge (Kentucky's Cave Run Lake, Minnesota's Leech Lake, New York's Lake Chautauqua, Ohio's Clear Fork Lake, St. Lawrence River, and Wisconsin's Minocqua Chain) at varying temperatures (5 – 27.5°C). The populations investigated represented muskellunge from each of the three identified muskellunge stocks, the Ohio River drainage stock, the Upper Mississippi River drainage stock, and the Great Lakes drainage stock (Table 1). Differences in growth and food consumption of YOY among populations were observed at higher temperatures (15 – 27.5°C). However, no significant differences in metabolism were observed at any temperature. Although results of these laboratory experiments showed bioenergetic differences among populations of muskellunge, they could not be explained solely in terms of thermal adaptation or countergradient variation among the established genetic groupings.

Based on the model of thermal adaptation, it would be expected that muskellunge from higher latitudes (Minnesota's Leech Lake and Wisconsin's Minocqua populations) would exhibit higher food consumption, greater conversion efficiency, and faster growth at lower temperatures than muskellunge from lower latitudes (Kentucky's Cave Run Lake population, for example) and conversely, muskellunge from lower latitudes were expected to exhibit greater rates and efficiency at higher temperatures. These relationships, although observed in a few instances, were not consistent in previous work with muskellunge (Clapp and Wahl 1996). If countergradient variation explained growth rate variation, it would be expected that across all temperatures comprising the growing season, muskellunge from the northern populations would exhibit higher food consumption, greater conversion efficiency, and faster growth than muskellunge from lower latitudes. Although not statistically significant, muskellunge from the Upper Mississippi River drainage stock had slightly higher consumption, growth, and metabolic rates from 15 – 25 C than muskellunge from the Ohio River drainage stock (Clapp and Wahl 1996). This pattern, although not significant, warrants further investigation.

In this study, we investigate population differentiation of muskellunge in the field from the YOY stage to adults. Long-term growth of muskellunge will be evaluated in pond and lake experiments. Identifying growth differences among muskellunge populations at these scales is important in defining these populations and in determining the most appropriate populations for specific management applications. Populations may vary in long-term growth, age-at-maturity, and maximum size. In this job, we assessed variation in growth among newly stocked YOY muskellunge from different populations and continued assessment of growth differences among previously introduced populations of muskellunge.

PROCEDURES: In the first two years of the study, as described in previous annual reports, we began by comparing growth between different stocks and populations of muskellunge in Lake Mingo, Vermillion County, Illinois, as well as in Pierce Lake, Winnebago County, and Forbes Lake, Marion County (Figure 1, Table 2). Temperature loggers verify that these reservoirs represent the climatic variation associated with latitude that exists throughout Illinois. In 2004, introductions were again made into Lake Mingo, Pierce Lake, and Forbes Lake (Table 3). Choice of stocks was dependent on availability of fish from each of the populations. Future segments of the project will include these same as well as additional stocks and populations.

Muskellunge from the Upper Mississippi River drainage stock included the Leech Lake population obtained from the Minnesota Department of Natural Resources and the Minocqua Chain population obtained from the Wisconsin Department of Natural Resources. Muskellunge from the Ohio River drainage stock included the Lake Chautauqua population obtained from the New York State Department of Environmental Conservation, the Pymatuning Lake population obtained from the Pennsylvania Fish and Boat Commission, the Clear Fork Lake population obtained from the Ohio Department of Natural Resources, and the Cave Run Lake population obtained from the Kentucky Department of Fish and Wildlife. The mixed-stock Illinois population is the F1 progeny from North Spring Lake and was obtained from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Natural Resources. Attempts were made to stock as similar of sizes and condition of fish as possible in each lake. Subsamples of each stock were held in three 3-m deep predator-free cages (N=15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress. Muskellunge from each population were stocked at rates between 0.3 – 4.9 fish per hectare. A subsample of each population was measured in length (nearest mm) and weighed (nearest g) prior to each stocking (Table 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination) and freeze cauterization of the wound for later identification of the stock (Boxrucker 1982). Beginning with this segment, we freeze branded all stocked fish in an effort to better enable age determination, in combination with scale aging, in future years. The 2004 brand was a back-right vertical brand. The brand will be applied differentially by year, with 2005 fish receiving a front-left vertical brand, and so on.

To determine growth rates, nighttime pulse DC boat-electrofishing sampling was performed from October through December 2004 and from March through May 2005 on all study reservoirs. Length (nearest mm) and weight (nearest g) measurements were taken on sampled muskellunge. The pelvic fin clip was used to identify the stock and population and an upper caudal fin clip was used to conduct a Schnabel population estimate within each sampling season (Ricker 1975). Scales were taken from all sampled muskellunge older than YOY in order to determine age class (herein described as 2002 Year Class, 2003 Year Class, and 2004 Year Class). Upon capture, muskellunge from the 2002 and 2003 Year Classes in Lake Mingo and 2003 Year Classes in Pierce Lake and Forbes Lake were implanted with a Passive Integrated Transponder (PIT) tag prior to release to aid in future identification. These data were used to determine mean daily growth rates (g/d) and mean relative growth rates (standardizing by starting weight, g/g/d) among the stocks of muskellunge in the study reservoirs.

In addition to the evaluation of growth among muskellunge stocks in reservoirs, we conducted a pond experiment to evaluate growth among YOY stocks in a more controlled environment. Advantages of this approach include greater precision via increased sample sizes, individual fish growth measurements, and replication by means of using several ponds. Three 0.4-ha experimental ponds at the Sam Parr Biological Station, Kinmundy, Illinois, were used for this experiment. Muskellunge from the Upper Mississippi River drainage stock (Leech Lake population), the Ohio River drainage stock (Cave Run Lake population), and the North Spring Lake, Illinois progeny (obtained from the Jake Wolf Memorial Fish Hatchery, IDNR) were stocked into the experimental ponds in fall 2002 and drained in spring and fall of each subsequent year including 2004 (Table 4). This experiment will herein be referred to as the 2002 Pond Experiment. The pond experiment was repeated with similar muskellunge stocks and populations introduced into experimental ponds during fall 2003 and will herein be referred to as the 2003 Pond Experiment. The 2003 Pond Experiment was drained in spring 2004, fall 2004, and spring 2005 (Table 5). In fall 2004, the pond experiment was again repeated with muskellunge from the Upper Mississippi River drainage stock (Minocqua Chain population), the Ohio River drainage stock (Chautauqua Lake population), and the Illinois population (Table 6). Thirty-three individuals from all populations were stocked into each of the three ponds (total N = 99 fish/pond). Immediately prior to stocking, each fish was anesthetized and implanted with a passive integrated transponder (PIT) tag in a similar manner as described by Harvey and Campbell (1989). Following the tagging, each fish was measured in length (nearest mm) and weighed (nearest g) and allowed to recover prior to being stocked into one of the ponds (Table 6). Hourly temperature readings were recorded using thermographs placed at 1-m depth and on the bottom.

Experimental ponds were drained in April 2005. Muskellunge were collected and identified by the PIT tag. All fish were measured in length (nearest mm) and weight (nearest g) and placed back into one of three 1-acre (0.4-ha) experimental ponds for future evaluations. These data were used to determine mean daily growth rates and mean relative growth rates among the stocks of muskellunge in experimental ponds. Mean daily growth rates were analyzed with an analysis of covariance (ANCOVA) with initial weight as the covariate and mean relative growth rates were analyzed using an analysis of variance (ANOVA) model. Results of the reservoir and pond evaluations will provide insight as to the fastest growing population in Illinois.

FINDINGS:

2002 Year Class

Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois, stocked into Lake Mingo during fall 2002 (Table 2) were monitored during fall 2004 and spring 2005 (Table 7). Unequal numbers were stocked due to limited availability of Cave Run Lake muskellunge. Mean initial lengths of the two populations were similar, but mean initial weights were higher for the Illinois population than the Cave Run Lake population (Table 2). Sampling in fall 2003 showed that the Ohio River drainage stock muskellunge had a significantly higher mean relative growth rate than the Illinois population one-year post-stocking (Figure 2, Table 8). In fall 2004, only one Illinois muskellunge from the 2002 Year Class was sampled, therefore meaningful statistical comparisons of growth rates are not possible. Despite unknown variation, the growth rates from fall 2003 through fall 2004 for the Ohio River drainage stock and Illinois population muskellunge appear to be similar over this time period (Figure 3). Two and a half years after stocking, the Illinois population appears to have maintained a slightly larger body length but similar body weight (Figure 4).

2003 Year Class

In fall 2003, three populations were introduced in Pierce Lake (Table 2). Unequal numbers were stocked (Leech Lake N = 100, Lake Chautauqua N = 234, and Illinois N = 500) due to limited availability of the populations. Some differences in stocking sizes existed with the Upper Mississippi River drainage stock having the lowest mean initial lengths and weights and the Illinois population having the highest mean initial lengths and weights (Table 2). Spring 2003 sampling (Table 9) showed significant overwinter differences in mean relative growth rates (ANOVA, $P = 0.0003$) among populations, with the Illinois population and the Ohio River drainage stock having similar mean relative growth rates, but both having significantly higher mean relative growth rates than the Upper Mississippi River drainage stock (Tukey, $P = 0.0004$, $P = 0.0003$, respectively). Sampling in fall 2004 resulted in only two recaptures of Ohio River drainage stock muskellunge and no recaptures of the Upper Mississippi River drainage stock (Table 9). Due to small samples sizes, growth rates could not be compared for the one-year post-stocking period from fall 2003 through fall 2004. Lengths and weights through time suggest the Illinois population and Ohio River drainage stock have similar growth rates in length whereas the Illinois population shows a potential trend towards faster growth in weight (Figure 5). No Upper Mississippi River drainage muskellunge were recaptured during fall 2004 and spring 2005 sampling.

Three populations of muskellunge were introduced in Lake Mingo in fall 2003. Unequal numbers were stocked (Leech Lake N = 285, Clear Fork Lake N = 288, and Illinois N = 500) due to limited availability of the populations. Stocking sizes were similar, with the Illinois population having only slightly higher mean initial lengths and weights (Table 2). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock and the Ohio River drainage stock exhibited 0% mortality and the Illinois population exhibited 13% mortality. This mortality was attributed to the warmer water temperatures (26.3 °C) when the Illinois muskellunge were stocked in late August (Mather and Wahl 1989; Wahl 1999). Subsequent analyses of survival will be adjusted to account for this initial mortality. Fall 2004 sampling (Table 10) revealed no differences in mean daily growth rates (Table 11; Figure 6; ANOVA, P = 0.65) nor mean relative growth rates (Table 11; Figure 6; ANOVA, P = 0.32) between the Ohio River drainage stock and the Illinois population one-year post-stocking. No Upper Mississippi River drainage stock muskellunge were recaptured during fall 2004 and spring 2005 sampling. A year and a half post-stocking, no differences are observed in body length or body weight (Figure 7) between the Ohio River drainage stock and Illinois population muskellunge.

Two populations of muskellunge were introduced in Forbes Lake in fall 2003. Unequal numbers were stocked (Minocqua Chain N = 217 and Illinois N = 500) due to limited availability of the populations. Stocking sizes were similar among populations (Table 2). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 27% mortality and the Illinois population exhibited 20% mortality. This mortality was attributed to the warmer water temperatures found at this latitude during late August and early September. Subsequent analyses of survival will be adjusted to account for these initial mortalities. No muskellunge were captured during spring 2004, fall 2004, or spring 2005 sampling seasons, despite 11, 8, and 6 hours of electrofishing effort, respectively. Therefore, no results of growth are reported.

2004 Year Class

Three populations were introduced in Pierce Lake during fall 2004 (Table 3). Unequal numbers were stocked (Leech Lake N = 200, Cave Run Lake N = 242, and Illinois N = 300) due to limited availability of the populations. Only slight differences in stocking size existed with the Upper Mississippi River drainage stock marginally longer and heavier than the Illinois population. In turn, the Illinois population was only an average of 11 mm and 12 g larger than the Ohio River drainage stock muskellunge (Table 3). Spring 2005 sampling (Table 12) revealed significant overwinter differences in mean daily growth rates (Table 13, ANOVA, P = 0.0001) and mean relative growth rates (Table 13, ANOVA, P = 0.0001) among populations, with the Ohio River drainage stock and Illinois population having similar growth rates, with both having significantly higher growth rates than the Upper Mississippi River drainage stock (Figure 8, Tukey, P = 0.0022, P = 0.0001, respectively for mean daily growth rates and Tukey, P = 0.0008, P = 0.0002, respectively for mean relative growth rates).

In fall 2004, three populations of muskellunge were introduced in Lake Mingo (Table 3). Unequal numbers were stocked (Leech Lake N = 193, Clear Fork Lake N = 245, and Illinois N = 300) due to limited availability of the populations. Negligible differences in stocking size existed among populations, with the Leech Lake and Illinois populations not differing in mean initial length or weight and the Leech Lake and Clear Fork Lake populations having similar mean initial weight. The Illinois population had a slightly higher mean initial length and weight than the Clear Fork Lake population that, in turn, had a modestly higher mean initial length than the Leech Lake population (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 0% mortality, the Ohio River drainage stock experienced 40% mortality, and the Illinois population had only a 2% mortality rate. The mortality experienced by the Ohio River drainage stock was attributed to the warm water and air temperatures (26.1 and 26.7 °C, respectively) experienced upon stocking in conjunction with the duration of the transport. Subsequent analyses of survival will be adjusted to account for this initial mortality. Spring 2005 sampling (Table 14) showed significant differences in overwinter growth rates (Table 15). The Illinois population exhibited a significantly higher mean daily growth rate than the Ohio River drainage stock (Figure 9, Tukey, P = .0106), and the Ohio River drainage stock had a significantly higher mean daily growth rate than the Upper Mississippi River drainage stock (Tukey, P = 0.0001). After adjusting for differences in initial stocking weight, no differences were observed in mean relative growth rates between the Illinois population and the Ohio River drainage stock (Figure 9, Tukey, P 0.2612); however, both populations had significantly higher mean relative growth rates than the Upper Mississippi River drainage stock (Tukey, P = 0.0001, P = 0.0001, respectively).

Three populations were introduced in Forbes Lake in fall 2004 (Table 3). Unequal numbers were stocked (Minocqua Chain N = 57, Chautauqua Lake N = 101, Pymatuning Lake N = 238, and Illinois N = 500) due to limited availability of the populations. Stocking sizes differed among populations, with the Upper Mississippi River drainage stock having the highest mean initial length and weight and the Pymatuning Lake population having the lowest mean initial length and weight (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. Initial mortality rates were 33% for the Illinois population, 7% each for the Minocqua Chain and Chautauqua Lake populations, and 0% for the Pymatuning Lake population. The mortality exhibited by the Illinois population was attributed to the warmer water temperatures (26.5 °C) found at this latitude at the time of stocking during late August. Subsequent analyses of survival will be adjusted to account for these initial mortalities. No muskellunge were captured during fall 2004 or spring 2005 sampling seasons, despite 8 and 6 hours of electrofishing effort, respectively. Therefore, no results of growth are reported.

2002 Pond Experiment

Three populations were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station in fall 2002 as described in previous annual reports. The ponds were drained in April 2003, October 2003, April 2004, and October 2004 (Table 4). At draining in spring 2003, no Leech Lake muskellunge were recovered from any of the ponds. Significant differences in mean daily growth rates (ANCOVA, P = 0.001) and mean relative growth rates (ANOVA, P < 0.0001) were observed between the Illinois population and the Ohio River drainage stock one-year post-stocking (Table 16). The Ohio River drainage stock had twice the mean daily growth rate than the Illinois muskellunge and about a four-fold higher mean relative growth rate (Figure 10).

2003 Pond Experiment

The pond experiment was repeated in fall 2003. Three populations of muskellunge were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological

Station in late October 2003 as described in the previous annual report. The ponds were drained in April 2004, October 2004, and April 2005 (Table 5, Figure 11). Significant differences in mean daily growth rates (ANCOVA, $P < 0.0001$) and mean relative growth rates (ANOVA, $P < 0.0001$) among populations were observed for the one-year post-stocking period (Table 17). The Illinois population and the Upper Mississippi River drainage stock exhibited similar mean daily growth rates (Figure 12, Tukey, $P = 0.1991$), while the Ohio River drainage stock had a significantly higher mean daily growth rate than both the Illinois population (Tukey, $P < 0.0001$) and the Upper Mississippi River drainage muskellunge (Tukey, $P < 0.0001$). The Ohio River drainage stock exhibited the highest mean relative growth rate (Figure 12, Tukey, $P < 0.001$), the Upper Mississippi River drainage stock intermediate (Tukey, $P < 0.0001$), and the Illinois muskellunge had the lowest mean relative growth rate (Tukey, $P < 0.0001$).

2004 Pond Experiment

Three populations of muskellunge were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station in late October 2004. The Upper Mississippi River drainage stock is represented by the Minocqua Chain population, the Ohio River drainage stock is represented by the Chautauqua Lake population, and the Illinois population is the progeny of the North Spring Lake. The initial mean lengths and weights were not significantly different between the Illinois muskellunge and the Upper Mississippi River drainage stock fish (Table 6). The initial mean length and weight for the Ohio River drainage stock was slightly lower (Table 6). Ponds were visually monitored for 48-hrs post-stocking to assess mortality due to PIT tagging and handling. No short-term mortality was observed. Ponds were drained in April 2005. Significant differences in overwinter mean daily growth rates (ANCOVA, $P = 0.006$) and mean relative growth rates (ANOVA, $P < 0.0001$) were observed among populations (Table 18). Similar mean daily growth rates were observed for the Illinois population and the Ohio River drainage stock (Figure 13, Tukey, $P = 0.43$). However, both the Illinois and Ohio River drainage muskellunge had significantly higher mean daily growth rates than the Upper Mississippi River drainage stock (Tukey, $P = 0.01$, $P = 0.045$, respectively). Examination of mean relative growth rates revealed that the Ohio River drainage stock had faster growth than the Illinois population and the Upper Mississippi River drainage stock (Figure 13, Tukey, $P < 0.0001$, $P < 0.0001$, respectively). No differences in mean relative growth were observed between the Illinois population and the Upper Mississippi River drainage muskellunge (Tukey, $P = 0.19$).

RECOMMENDATIONS: Any long-term differences among muskellunge populations we observe in reservoir and pond experiments will have important implications for conservation of native muskellunge populations, as well as for introduction of muskellunge into waters where they do not naturally occur. When muskellunge are introduced in areas where they have not previously occurred, such as Illinois impoundments, knowledge of population differentiation will be useful in planning stocking programs. Growth differences we observed among YOY and juvenile muskellunge during the first three years of this study can influence initial survival; both by loss to predation (Wahl and Stein 1989) and loss due to over-winter mortality (Bevelhimer et al. 1985; Carline et al. 1986). We have found initial growth differences among populations of muskellunge that will need to continue to be monitored as fish grow into adults.

In both the reservoir and pond experiments, the Ohio River drainage stock has thus far consistently exhibited the highest mean daily growth rate (g/d) and mean relative growth rate (g/g/d). The Illinois population typically exhibits intermediate growth, and the Upper Mississippi River drainage stock is almost always the slowest growing. However, examining the longest data set thus far, the 2002 Year Class in Lake Mingo, suggests that the growth trajectories vary only slightly over the longer term.

Thus far in this study, the thermal adaptation concept seems to explain growth of muskellunge stocks more closely than the countergradient variation theory. The climate of the Ohio River drainage is likely more similar to Illinois than is the climate of the Upper Mississippi River drainage. Under the assumptions of the thermal adaptation concept, it would be predicted that the Ohio River drainage stock would exhibit higher growth rates in Illinois than the Upper Mississippi River drainage stock. The North Spring Lake population used for broodstock in Illinois was first established in the early 1980's and has subsequently been stocked almost yearly with muskellunge from throughout the native range of the species. The actual progeny of broodstock from any particular year results in an unknown-origin population, or possibly, a mixed-origin population. Future years of data will be needed, with as similar of initial lengths and weights as possible among stocks and populations, to be able to determine if the current trend of faster growth of the Ohio River drainage stock is consistent.

Further fall and spring monitoring of the study reservoirs will be conducted, as well as additional introductions of the various stocks into the reservoirs for the purpose of growth evaluation. The three 0.4-ha experimental ponds will be drained in fall 2005 to evaluate growth of the muskellunge stocks in the experiment. In fall 2005, another trial of the pond experiment may be initiated with additional populations of muskellunge from each of the stocks. The results obtained from these initial three years will be combined with data from future years to identify differences among genetic stocks of juvenile and adult muskellunge and to develop guidelines for future stockings that maximize growth in impoundments throughout Illinois.

Job 101.2. Evaluating survival of different stocks of muskellunge.

OBJECTIVE: To determine differences in survival among various stocks and populations of muskellunge in Illinois waters.

INTRODUCTION: In addition to growth, survival differences among genetically distinct muskellunge stocks and populations may be important in determining the most appropriate populations for use in management applications. Survival and other population characteristics is the consequence of life history modes to which stocks have evolved (Begg et al. 1999). Physiological differences among stocks could affect survival rates at various temperatures and will affect the value of a population for stocking in various waters throughout Illinois.

Numerous studies have investigated differences in survival among stocks; however most of this work has been done with salmonids. Significant differences in survival were found between hatchery reared and wild steelhead trout *Salmo gairdneri* in stream and pond evaluations; however outcomes varied between systems (Reisenbichler and McIntyre 1977). Genetic origin has been shown to influence survival among stockings of lake trout *Salvelinus namaycush* in two lakes in Ontario (MacLean et al. 1981). In comparisons of survival of northern largemouth bass *Micropterus salmoides salmoides*, Florida largemouth bass *Micropterus salmoides floridanus,* and their F1 hybrids in central Illinois, the native northern largemouth bass was shown to have the highest survival rates (Philipp and Whitt 1991). Further work suggested significant survival differences between stocks of northern largemouth bass from two different river drainages within Illinois when both were stocked in northern and southern Illinois (Philipp and Claussen 1995). These studies suggest that geographic origin (stock) can have a substantial influence on survival in a given region.

Limited work has been done evaluating survival differences among muskellunge stocks and populations. In Minnesota, performance of four native muskellunge populations of the Mississippi River drainage stock showed similar survival, with the exception of the lower survival of the Shoepack population (Younk and Strand 1992). Performance differences were also evaluated among 5 local populations in Wisconsin and compared to the performance of the Leech Lake, Minnesota population (Margenau and Hanson 1996; Margenau and Hanson 1997). Short-term (<60 d) survival was higher for the Mud/Callahan Lake population compared to the other four Wisconsin populations (Maragenau and Hanson 1996). The remaining four populations all expressed similar short-term survival. Results showed that the Leech Lake population could be introduced into Wisconsin lakes and survive; however, there was no distinct advantage over the Wisconsin lake muskellunge populations (Margenau and Hanson 1997). All of these studies examined survival among populations of muskellunge from one stock, the Upper Mississippi River drainage stock. There exists a need to evaluate the survival differences among the three genetic stocks of muskellunge, the Ohio River drainage stock, the Upper Mississippi River drainage stock, and the Great Lakes drainage stock (Table 1). Many muskellunge fisheries, including those in Illinois, are sustained by stockings of muskellunge into waters where the species has been extirpated or for new introductions. In these scenarios, it would be beneficial to know which stock and populations have the highest survival in the thermal regime of the region to be stocked.

In this job, we are investigating population and stock differentiation in terms of survival for muskellunge in the field. Long-term survival of muskellunge is being evaluated in reservoir and pond experiments. Identifying survival differences among muskellunge populations at these scales is important in defining these populations and in determining the most appropriate populations for specific management applications. In this job, we continued assessment of variation in survival among different YOY and juvenile muskellunge populations. Future work will monitor survival of these populations through adults.

PROCEDURES: In the first two years of the study, as described in the previous annual reports, we began by comparing survival between different stocks and populations of muskellunge in Lake Mingo, Vermillion County, Illinois, as well as in Pierce Lake, Winnebago County, and Forbes Lake, Marion County (Figure 1, Table 2). These reservoirs represent the latitudinal climatic variation that exists throughout Illinois. In 2004, introductions were again made into Pierce Lake, Lake Mingo, and Forbes Lake (Table 3). Choice of stocks was dependent on availability of fish from each of the populations. Future segments of the project will include these same as well as additional stocks and populations.

As described in Job 101.1, we stocked muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois population into three study reservoirs in fall 2004 (Table 3). Muskellunge were stocked at a large fingerling size to increase initial survival across all populations as determined in previous studies (Carline et al. 1986; Szendrey and Wahl 1996; McKeown et al. 1999). Stocked fish were also reared under as similar conditions and feeding regimes as possible so as to eliminate any indirect biases on survival or vulnerability to predation (Szendrey and Wahl 1995). Subsamples of each stock were held in three 3-m deep predator-free cages (N = 15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress. Muskellunge from each population were stocked at rates between 0.3 – 4.9 fish per hectare (Table 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination) and freeze cauterization of the wound for later identification of the stock. Previous work has suggested that removal of any single paired fin is equally detrimental to short-term survival (3-mos) and the loss of a pelvic fin is less detrimental than loss of a pectoral fin over the long term (McNeil and Crossman 1979). Beginning with this segment, we freeze branded all stocked fish in an effort to better enable age-determination, in combination with scale aging, in future years. The 2004 brand was a back-right vertical brand. The brand will be applied differentially by year, such that each stocking year will have a different freeze brand location. The freeze brand, in conjunction with the pelvic fin clip, will allow accurate identification of both the major river drainage stock as well as the specific population under examination. To determine survival, nighttime pulse DC boat-electrofishing sampling was performed from October through December 2004 and from March through May 2005 on all study reservoirs. Electrofishing catch-per-unit-effort (CPUE) and Schnabel population estimates (Ricker 1975) were used to assess survival differences among stocks.

In addition to the evaluation of survival differences among muskellunge stocks in reservoirs, we conducted a pond experiment to evaluate survival among stocks in a more controlled environment. Advantages of this approach include the ability to obtain a direct measurement of relative survival via pond draining. Three 0.4-ha experimental ponds at the Sam Parr Biological Station, Kinmundy, Illinois, were used for this experiment. As described in previous annual reports, muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois population were stocked into the experimental ponds in fall 2002 and were drained each subsequent spring and fall, and again in fall 2004 (Table 4).
The pond experiment was repeated with similar muskellunge stocks and populations introduced into experimental ponds during fall 2003. The 2003 pond experiment was also drained in

subsequent spring and falls (Table 5). In fall 2004, the pond experiment was again repeated with muskellunge from the Upper Mississippi River drainage stock (Minocqua Chain population), the Ohio River drainage stock (Chautauqua Lake population), and the Illinois population (Table 6). Thirty-three individuals from all populations were stocked into each of the three ponds (total N = 99 fish/pond).

Experimental ponds were drained in April 2005. Muskellunge were collected and population identified by the PIT tag. All surviving fish were placed back into one of three 0.4-ha experimental ponds for future evaluations. These data were used to determine survival among the stocks of muskellunge in experimental ponds using a maximum likelihood estimation approach. Results of the reservoir and pond evaluations will provide insight as to the best surviving population in Illinois.

FINDINGS:

2002 Year Class

Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois (Table 1), stocked into Lake Mingo during fall 2002 (Table 2) were monitored during fall 2004 and spring 2005. Unequal numbers were stocked due to limited availability of Cave Run Lake muskellunge. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Both populations showed 0% mortality after the 48-hr monitoring period. Mark-recapture sampling during fall 2003 was used to determine a Schnabel population estimate for both populations. CPUE was also calculated for each sampling event. Schnabel population estimates were lower for the Ohio River drainage muskellunge (N = 48) than for the Illinois population (N = 94) (Table 19). Survival one-year post-stocking is estimated at 28% for the Ohio River drainage stock and 24% for the Illinois population (Table 19). Adjusted CPUE was calculated to account for unequal stocking numbers among stocks and populations. During fall 2003, the adjusted CPUE increased over time for both populations, suggesting increasing capture efficiency as water temperatures become cooler (Figure 14). Although the adjusted CPUE was higher for the Ohio River drainage stock muskellunge on all sampling dates except one, analysis of variance (ANOVA) showed no significant difference in adjusted CPUE (P = 0.53) between the Ohio River drainage stock and the Illinois population during the fall 2003 sampling season. Recapture numbers of both populations were too low during the fall 2004 sampling season to draw accurate survival conclusions.

2003 Year Class

In fall 2003, three populations were introduced in Pierce Lake (Table 2). Too few recaptures of Illinois and Ohio River drainage stock muskellunge during fall 2004 sampling prevented analysis of survival for the one-year post-stocking period for the populations. No Upper Mississippi River drainage stock muskellunge were recaptured during fall 2004 and spring 2005 sampling. As reported in the previous annual report, overwinter survival was evaluated via sampling during spring 2004 with Schnabel population estimates. Schnabel population estimates found a point estimate of N = 58 for the Ohio River drainage stock and N = 5 for the Illinois population (Table 20). No population estimates were calculated for the Upper Mississippi River drainage stock due to low number of recaptures (Table 20). Survival over the 6-mo interval from stocking through spring 2004 was estimated to be 25% for the Ohio River drainage stock and 1% for the Illinois population (Table 20).

Three populations of muskellunge were introduced in Lake Mingo in fall 2003 (Table 2). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock and the Ohio River drainage stock exhibited 0% mortality and the Illinois population exhibited 13% mortality. Subsequent analyses of survival will be adjusted to account for this initial mortality. Sampling in fall 2004 was used to determine adjusted CPUE for each sampling event (low numbers of recaptures prevented calculation of Schnabel population estimations). No Upper Mississippi River drainage stock muskellunge were recaptured during fall 2004 sampling. There was no consistent trend in adjusted CPUE over the sampling season to indicate obvious survival differences between the Ohio River drainage stock and the Illinois population (Figure 15). No statistical difference in adjusted CPUE was observed between the Ohio River drainage muskellunge and the Illinois fish during the fall 2004 sampling season (ANOVA, P = 0.34), indicating no one-year post-stocking survival differences between the two populations.

Two populations of muskellunge were introduced in Forbes Lake in fall 2003 (Table 2). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 27% mortality and the Illinois population exhibited 20% mortality. No muskellunge were captured during the spring 2004, fall 2004, or spring 2005 sampling seasons despite 11, 8, and 6 hours of electrofishing effort, respectively. As a result, no one-year post-stocking survival estimates are reported for the period from stocking through fall 2004.

2004 Year Class

In fall 2004, three populations of muskellunge were introduced in Pierce Lake (Table 3). Unequal numbers were stocked (Leech Lake N = 200, Cave Run Lake N = 242, and Illinois N = 300) due to limited availability of the populations. Mortality cages were not utilized due to logistical constraints. Initial mortality was assumed minimal due to the late stocking dates for Leech Lake and Cave Run Lake muskellunge. The Illinois population was also assumed to be low given the low mortality observed of Illinois fish stocked at the same time in Lake Mingo. Overwinter survival was assessed during spring 2005 sampling by means of adjusted CPUE analysis, as low numbers of within season recaptures prevented calculation of Schnabel population estimates. Visual examination of the adjusted CPUE data reveals no distinct trend among stocks (Figure 16). This conclusion is confirmed by the analysis of variance test of the effect of stock on adjusted CPUE (P = 0.69). No differences in spring CPUE were observed among stocks (Figure 17), suggesting no difference in overwinter survival.

Three populations were introduced in Lake Mingo in fall 2004 (Table 3). Unequal numbers were stocked (Leech Lake N = 193, Clear Fork Lake N = 245, and Illinois N = 300) due to limited availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 0% mortality, the Ohio River drainage stock experienced 40% mortality, and the Illinois population had only a 2% mortality rate. Subsequent analyses of survival will be adjusted to account for this initial mortality. Spring 2005 sampling suggests differential survival among stocks of muskellunge (Table 21). Schnabel population estimates indicate that the Upper Mississippi River drainage stock had the highest survival (100%), followed by the Ohio River drainage stock (55%) and the Illinois population (19%) (Table 21). However, limited recaptures limit the precision of the Schnabel estimates. Visual examination of the adjusted CPUE over the spring 2005 sampling season also suggests that the Upper Mississippi River drainage stock exhibited the highest survival 6-mos post-stocking (Figure 18). Adjusted CPUE differed significantly among stocks (ANOVA, P = 0.04), with the Upper Mississippi River drainage muskellunge exhibiting significantly higher survival than the Illinois population (Figure 19, Tukey, P = 0.04). The Upper Mississippi River drainage stock had a similar mean adjusted CPUE as the Ohio River drainage stock (Figure 19, Tukey, P = 0.10), and in turn, the Ohio River drainage stock had a similar mean adjusted CPUE as the Illinois population (Tukey, P = 0.90). The combined survival analyses suggest that the Upper Mississippi River drainage muskellunge exhibited significantly higher survival compared to the Ohio River drainage stock and the Illinois population.

Three populations of muskellunge were introduced in Forbes Lake in fall 2004 (Table 3). Unequal numbers were stocked (Minocqua Chain N = 57, Chautauqua Lake N = 101, Pymatuning Lake N = 238, and Illinois N = 500). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 33% for the Illinois population, 7% each for the Minocqua Chain and Chautauqua Lake populations, and 0% for the Pymatuning Lake population. No muskellunge were captured during the fall 2004 or spring 2005 sampling seasons, despite 8 and 6 hours of electrofishing effort, respectively. Therefore, no results of overwinter survival are presented.

2002 Pond Experiment

Three populations were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station during fall 2002 as described in previous annual reports. The ponds were drained in subsequent springs and falls through October 2004. At draining in spring 2003, no Upper Mississippi River drainage stock muskellunge were recovered from any of the ponds. Significant differences in survival rate existed in spring 2003 following the 6-mo overwinter period post-stocking and differences remained through the completion of the experiment in fall 2004 (Figure 20). The Illinois population exhibited higher survival than the Ohio River drainage stock and the Upper Mississippi River drainage stock.

2003 Pond Experiment

Three populations of muskellunge were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station in late October 2003 as described in the previous annual report. The ponds were drained in April 2004, October 2004, and April 2005. No overwinter survival differences were observed following the first 6-mos post-stocking; however, differences were observed thereafter (Figure 21). One-year post-stocking, the Ohio River drainage stock exhibited higher survival than the Illinois and Upper Mississippi River drainage stock. The Illinois population, in turn, exhibited higher survival than the Upper Mississippi drainage stock. This pattern held constant through the spring 2005 draining (Figure 21).

2004 Pond Experiment

Three populations of muskellunge were also stocked in equal numbers into three 0.4-ha experimental ponds in October 2004. Ponds were visually monitored for 48-hrs post-stocking to assess mortality due to PIT tagging and handling. No short-term mortality was observed. Ponds were drained in April 2005. No significant overwinter survival differences were observed among stocks 6-mos post-stocking (Figure 22). All three muskellunge stocks had survival rates from 40 – 55%.

RECOMMENDATIONS: Any long-term differences in survival among muskellunge populations will have important implications for conservation and stocking of muskellunge. Survival differences we observed among YOY and juvenile muskellunge during the first three years of this study can influence the success and cost-effectiveness of a muskellunge stocking program (Margenau 1992). We have found initial survival differences among populations of muskellunge that will need to continue to be monitored as fish grow into adults.

Initial reservoir results suggest the Ohio River drainage stock and Illinois population muskellunge have a survival advantage over the Upper Mississippi River drainage stock throughout the latitudinal range of Illinois. In both Pierce and Mingo Lakes, the 2003 year class of the Upper Mississippi River drainage stock disappeared from the samples one-year post-stocking, suggesting poor survival. Overwinter survival varied, with results ranging from the Upper Mississippi River drainage stock having highest survival to exhibiting the lowest survival. The pond experiments support these general conclusions. In the 2002 pond experiment, the Upper Mississippi River drainage stock exhibited 0% survival 6-mos post stocking and the Illinois population had higher survival than the Ohio River drainage stock through the remainder of the experiment. Both the 2003 and 2004 pond experiments revealed no overwinter survival differences 6-mos post-stocking; however, 1-yr post-stocking survival indicates that the Ohio River drainage stock had the highest survival, the Illinois population intermediate, and the Upper Mississippi River drainage stock the lowest.

Further fall and spring monitoring of the study reservoirs will be conducted, as well as additional introductions of the various stocks into the three reservoirs for the purpose of evaluating survival differences among stocks. The three 0.4-ha experimental ponds will be drained in fall 2005 to evaluate survival of the muskellunge stocks in the experiment. In late October 2005, a fourth trial of the pond experiment may be initiated with additional populations of the major stocks. The results obtained from these past and future years will be used to identify long-term differences in survival and longevity among genetic stocks of muskellunge.

Job 101.3. Analysis and reporting.

OBJECTIVE: To prepare annual and final reports summarizing information and develop guidelines for proper selection of muskellunge populations for stocking in Illinois impoundments.

PROCEDURES and FINDINGS: Data collected in Jobs 101.1 – 101.2 were analyzed to begin developing guidelines regarding appropriate muskellunge populations for stocking throughout Illinois. In future segments, recommendations will be made that will allow hatchery and management biologists to make decisions that will maximize benefits for the muskellunge program in Illinois.

BUDGET TABLE:

Project Segment 3

Job	Proposed Cost	Actual Cost
Job 101.1	$21,857	$21,857
Job 101.2	$22,378	$22,378
Job 101.3	$7,806	$7,806

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Table 1. Sources of young-of-year muskellunge stocks used for evaluation of growth and survival. Kentucky, Ohio, Pennsylvania, and New York populations are from the Ohio River drainage (Ohio stock); Minnesota and Wisconsin populations are from the Upper Mississippi River drainage (Mississippi stock); St. Lawrence River muskellunge are from the Great Lakes drainage (Great Lakes stock). Cooling (CDD) and heating (HDD) degree days are calculated using a base temperature of 65° F, with 1961 - 1990 data from the National Oceanic and Atmospheric Administration, Midwest Climate Center, Pennsylvania State Climatologist, and the New York State Climate Office.

Population (abbreviation)	Source Water	Drainage (stock)	Latitude (north)	Cooling Degree Days (CDD)	Heating Degree Days (HDD)	Mean Annual Temp. (F)
Kentucky (KY)	Cave Run Lake	Ohio River	37° 35′	1154	4713	55.2
Ohio (OH)	Clear Fork Lake	Ohio River	39° 30′	703	6300	49.6
Pennsylvania (PA)	Pymatuning Reservoir	Ohio River	41° 30′	322	6934	47.4
New York (NY)	Lake Chautauqua	Ohio River	42° 07′	350	6279	49.4
St. Lawrence (SL)	St. Lawrence River	Great Lakes	42° 25′	551	6785	45.4
Wisconsin (WI)	Minocqua Chain	Mississippi River	45° 30′	215	9550	39.3
Minnesota (MN)	Leech Lake	Mississippi River	46° 35′	347	9495	39.9
Illinois (IL)	North Spring Lake	*	40° 40′	998	6097	50.8

Table 2. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH) and North Spring Lake, IL progeny (IL) introduced in Pierce Lake, Lake Mingo, and Forbes Lake during falls 2002 and 2003. Total length (nearest mm) and weight (nearest g) were measured prior to stocking. Values in parentheses represent 95% confidence intervals.

Lake	Stock	Population	Stocking Date	Number of Fish	Number per Hectare	Mean Length (mm)	Mean Weight (g)
			2002				
Mingo	OH	Cave Run Lake, KY	October 30, 2002	171	2.4	315 (±7.5)	155 (±8.2)
	IL	North Spring Lake, IL	October 24, 2002	400	5.6	336 (±5.6)	200 (±11.7)
			2003				
Pierce	MISS	Leech Lake, MN	November 7, 2003	100	1.6	197 (±5.0)	28 (±2.5)
	OH	Lake Chautauqua, NY	September 19, 2003	234	3.8	225 (±2.6)	44 (±1.7)
	IL	North Spring Lake, IL	August 29, 2003	500	8.2	258 (±3.3)	77 (±2.9)
Mingo	MISS	Leech Lake, MN	October 31, 2003	285	4.0	237 (±9.0)	60 (±7.7)
	OH	Clear Fork Lake, OH	September 4, 2003	288	4.0	227 (±2.5)	56 (±2.2)
	IL	North Spring Lake, IL	August 29, 2003	500	7.0	258 (±3.3)	77 (±2.9)
Forbes	MISS	Minocqua Chain, WI	September 9, 2003	217	1.0	248 (±4.8)	87 (±4.7)
	IL	North Spring Lake, IL	August 29, 2003	500	2.2	258 (±3.3)	77 (±2.9)

Table 3. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH) and North Spring Lake, IL progeny (IL) introduced in Pierce Lake, Lake Mingo, and Forbes Lake during fall 2004. Total length (nearest mm) and weight (nearest g) were measured prior to stocking. Values in parentheses represent 95% confidence intervals.

Lake	Stock	Population	Stocking Date	Number of Fish	Number per Hectare	Mean Length (mm)	Mean Weight (g)
Pierce	MISS	Leech Lake, MN	October 29, 2004	200	3.3	287 (±7.9)	96 (±9.7)
	OH	Cave Run Lake, KY	September 14, 2004	242	4.0	261 (±5.0)	76 (±5.1)
	IL	North Spring Lake, IL	August 26, 2004	300	4.9	272 (±4.7)	88 (±5.1)
Mingo	MISS	Leech Lake, MN	October 30, 2004	193	2.7	280 (±8.2)	85 (±9.1)
	OH	Clear Fork Lake, OH	September 14, 2004	245	3.4	261 (±5.6)	74 (±5.3)
	IL	North Spring Lake, IL	August 27, 2004	300	4.2	273 (±4.6)	88 (±5.3)
Forbes	MISS	Minocqua Chain, WI	October 6, 2004	57	0.3	303 (±6.5)	135 (±9.9)
	OH	Chautauqua Lake, NY*	October 5, 2004	101	0.4	233 (±2.8)	50 (±1.9)
	OH	Pymatuning Lake, PA*	October 5, 2004	238	1.1	187 (±3.3)	27 (±1.5)
	IL	North Spring Lake, IL	August 26, 2004	500	2.2	270 (±4.6)	89 (±5.4)

* Populations differentially marked with vertical vs. horizontal back-right freeze brand on side of body

Table 4. Summary of initial and subsequent lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002. Ponds were drained in spring and fall of each subsequent year. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population. No Mississippi River drainage stock muskellunge were recovered in any of the ponds. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Mississippi River Drainage	Illinois
		Length (mm)	
Fall 2002	245 (± 5.9)	199 (± 3.3)	334 (± 4.9)
Spring 2003	284 (± 6.2)	-	361 (± 6.9)
Fall 2003	406 (± 11.3)	-	450 (± 9.3)
Spring 2004	422 (± 13.1)	-	464 (± 9.7)
Fall 2004	-	-	469 (± 11.8)
		Weight (g)	
Fall 2002	58 (± 3.8)	26 (± 2.1)	191 (± 8.7)
Spring 2003	92 (± 7.3)	-	229 (± 12.4)
Fall 2003	304 (± 31.4)	-	420 (± 28.4)
Spring 2004	318 (± 33.2)	-	433 (± 29.8)
Fall 2004	-	-	450 (± 31.0)

Table 5. Summary of initial and subsequent lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003. Ponds were drained in spring and fall of each subsequent year. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population. Values in parentheses represent 95% confidence intervales.

Season	Ohio River Drainage	Mississippi River Drainage	Illinois
		Length (mm)	
Fall 2003	292 (± 4.5)	283 (± 7.2)	353 (± 3.9)
Spring 2004	338 (± 3.9)	323 (± 6.5)	386 (± 4.7)
Fall 2004	407 (± 5.5)	391 (± 8.1)	426 (± 6.7)
Spring 2005	422 (± 6.8)	411 (± 9.4)	439 (± 6.8)
		Weight (g)	
Fall 2003	96 (± 4.3)	98 (± 8.3)	190 (± 7.4)
Spring 2004	181 (± 7.4)	146 (± 9.6)	278 (± 11.1)
Fall 2004	302 (± 13.3)	251 (± 19.8)	334 (± 17.9)
Spring 2005	320 (± 18.1)	265 (± 30.5)	336 (± 15.9)

Table 6. Summary of initial and subsequent lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2004 and drained in April 2005. The Ohio River drainage stock is represented by the New York Lake Chautauqua population and the Upper Mississippi River drainage stock is represented by the Wisconsin Minocqua Chain population. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Mississippi River Drainage	Illinois
		Length (mm)	
Fall 2004	234 (± 1.9)	304 (± 2.5)	308 (± 3.5)
Spring 2005	289 (± 2.9)	336 (± 3.9)	340 (± 5.0)
		Weight (g)	
Fall 2004	51 (± 1.5)	137 (± 4.0)	128 (± 5.8)
Spring 2005	120 (± 5.3)	198 (± 7.4)	196 (± 9.6)

Table 7. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of two stocks of muskellunge introduced in Lake Mingo during fall 2002. Spring and fall sampling periods are comprised of multiple sampling events per season. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Illinois
	Length (mm)	
Fall 2002	315 (±7.5)	336 (±5.6)
Spring 2003	341 (±7.5)	365 (±6.9)
Fall 2003	623 (±16.3)	650 (±11.6)
Spring 2004	641 (±10.3)	647 (±46.5)
Fall 2004	818 (±35.4)	843 (±0.0)
Spring 2005	788 (±33.3)	808 (±29.7)
	Weight (g)	
Fall 2002	155 (±8.2)	200 (±11.7)
Spring 2003	184 (±15.6)	255 (±18.9)
Fall 2003	1457 (±106.4)	1735 (±118.3)
Spring 2004	1776 (±95.3)	1892 (±406.1)
Fall 2004	3983 (±592.2)	4639 (±0.0)
Spring 2005	3588 (±628.6)	4007 (±658.4.2)

Table 8. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. Growth is for the 1-yr interval from stocking through the following fall (October through December 2003). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	1	2.470	6.26	0.02
Error	38	14.990		
	Mean relative growth rate (g/g/d)			
Stock	1	0.0000575	5.09	0.03
Error	38	0.000429		

Table 9. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the New York Lake Chautauqua population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	197 (±5.0)	225 (±2.6)	258 (±3.3)
Spring 2004	202 (±46.2)	284 (±9.4)	347 (±11.4)
Fall 2004	-	471 (±324.0)	552 (±34.0)
Spring 2005	-	511 (±457.4)	580 (±163.2)
		Weight (g)	
Fall 2003	28 (±2.5)	44 (±1.7)	77 (±2.9)
Spring 2004	28 (±21.7)	102 (±11.6)	191 (±30.8)
Fall 2004	-	532 (±813.2)	931 (±251.4)
Spring 2005	-	839 (±3621.3)	1319 (±1572.3)

Table 10. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2003. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	237 (±9.0)	227 (±2.5)	258 (±3.3)
Spring 2004	301 (±18.0)	306 (±9.7)	349 (±9.3)
Fall 2004	-	541 (±34.1)	565 (±52.5)
Spring 2005	-	577 (±58.6)	611 (±972.0)
		Weight (g)	
Fall 2003	60 (±7.7)	56 (±2.2)	77 (±2.9)
Spring 2004	105 (±22.2)	128 (±17.1)	191 (±18.8)
Fall 2004	-	1011 (±287.5)	1128 (±425.8)
Spring 2005	-	1461 (±605.3)	1836 (±11486.4)

Table 11. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2003. Growth is for the 1-yr interval from stocking through the following fall (November through December 2004). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	1	0.200	0.22	0.65
Error	16	14.486		
	Mean relative growth rate (g/g/d)			
Stock	1	0.000245	1.05	0.32
Error	16	0.003725		

Table 12. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2004. Spring sampling was conducted from April 5 through May 10, 2005. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2004	287 (±7.9)	261 (±5.0)	272 (±4.7)
Spring 2005	292 (±14.4)	331 (±19.5)	360 (±18.5)
		Weight (g)	
Fall 2004	96 (±9.7)	76 (±5.1)	88 (±5.1)
Spring 2005	98 (±21.0)	188 (±63.9)	236 (±48.4)

Table 13. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Pierce Lake during fall 2004. Growth is for the 6-mo interval from stocking through the following spring (April through May 2005). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	2	1.990	14.11	0.0001
Error	23	1.623		
	Mean relative growth rate (g/g/d)			
Stock	2	0.000284	13.93	0.0001
Error	23	0.000235		

Table 14. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2004. Spring sampling was conducted from March 16 through April 25, 2005. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2004	280 (±8.2)	261 (±5.6)	273 (±4.6)
Spring 2005	297 (±9.2)	334 (±8.4)	371 (±9.9)
		Weight (g)	
Fall 2004	85 (±9.1)	74 (±5.3)	88 (±5.3)
Spring 2005	104 (±10.6)	179 (±16.7)	250 (±25.6)

Table 15. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2004. Growth is for the 6-mo interval from stocking through the following spring (March through April 2005). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	2	4.854	57.28	< 0.0001
Error	60	2.542		
	Mean relative growth rate (g/g/d)			
Stock	2	0.000685	57.77	< 0.0001
Error	60	0.000356		

Table 16. Analysis of covariance and variance tests of the effects of stock, initial weight, and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during October 2003. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	1	0.5271	12.06	0.001
Initial Weight	1	0.4023	9.21	0.004
Pond	2	0.7744	8.86	0.000
Error	60	2.6223		
	Mean relative growth rate (g/g/d)			
Stock	1	0.0006	252.05	<0.0001
Pond	2	0.0002	4.38	0.017
Error	61	0.0001		

Table 17. Analysis of variance tests of the effects of stock, initial weight, and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during October 2004. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	2	0.7130	30.35	<0.0001
Initial Weight	1	0.0106	0.90	0.344
Pond	2	1.1308	48.14	<0.0001
Error	134	1.5737		
		Mean relative growth rate (g/g/d)		
Stock	2	0.0006	173.43	<0.0001
Pond	2	0.0001	19.53	<0.0001
Error	135	0.0002		

Table 18. Analysis of variance tests of the effects of stock, initial weight, and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2004 and drained during April 2005. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
	Mean daily growth rate (g/d)			
Stock	2	0.0972	5.31	0.006
Initial Weight	1	0.0212	2.32	0.130
Pond	2	0.1757	9.59	<0.0001
Error	132	1.2089		
	Mean relative growth rate (g/g/d)			
Stock	2	0.0008	131.05	<0.0001
Pond	2	0.0000	5.99	0.003
Error	133	0.0004		

Table 19. Schnabel population estimates and relative survival of two stocks of muskellunge during the first year following stocking in Lake Mingo, fall 2002. Survival is calculated for the period from stocking through fall 2003 sampling (October 7 through December 4, 2003).

			Schnabel Population Estimate		
Stock	Total Number Captured	Total Number Recaptured	Point Estimate	95% C.I.	Survival (%)
OH	16	2	48	13-480	28
IL	24	2	94	26-945	24

Table 20. Schnabel population estimates and relative survival of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Sampling was conducted from March 10 through May 6, 2004.

			Schnabel Population Estimate		
Stock	Total Number Captured	Total Number Recaptured	Point Estimate	95% C.I.	Survival (%)
MISS	3	0	-	-	-
OH	13	1	58	10-580	25
IL	6	2	5	1-50	1

Table 21. Schnabel population estimates and relative survival of three stocks of muskellunge during the first winter following stocking in Lake Mingo, fall 2004. Survival is calculated for the period from stocking through spring 2005 sampling (March 16 through April 25, 2005).

			Schnabel Population Estimate		
Stock	Total Number Captured	Total Number Recaptured	Point Estimate	95% C.I.	Survival (%)
MISS	32	2	203	56-2030	100
OH	14	1	81	14-810	55
IL	17	2	56	16-560	19

Figure 1. Illinois reservoirs stocked for evaluation of growth and survival among muskellunge stocks.

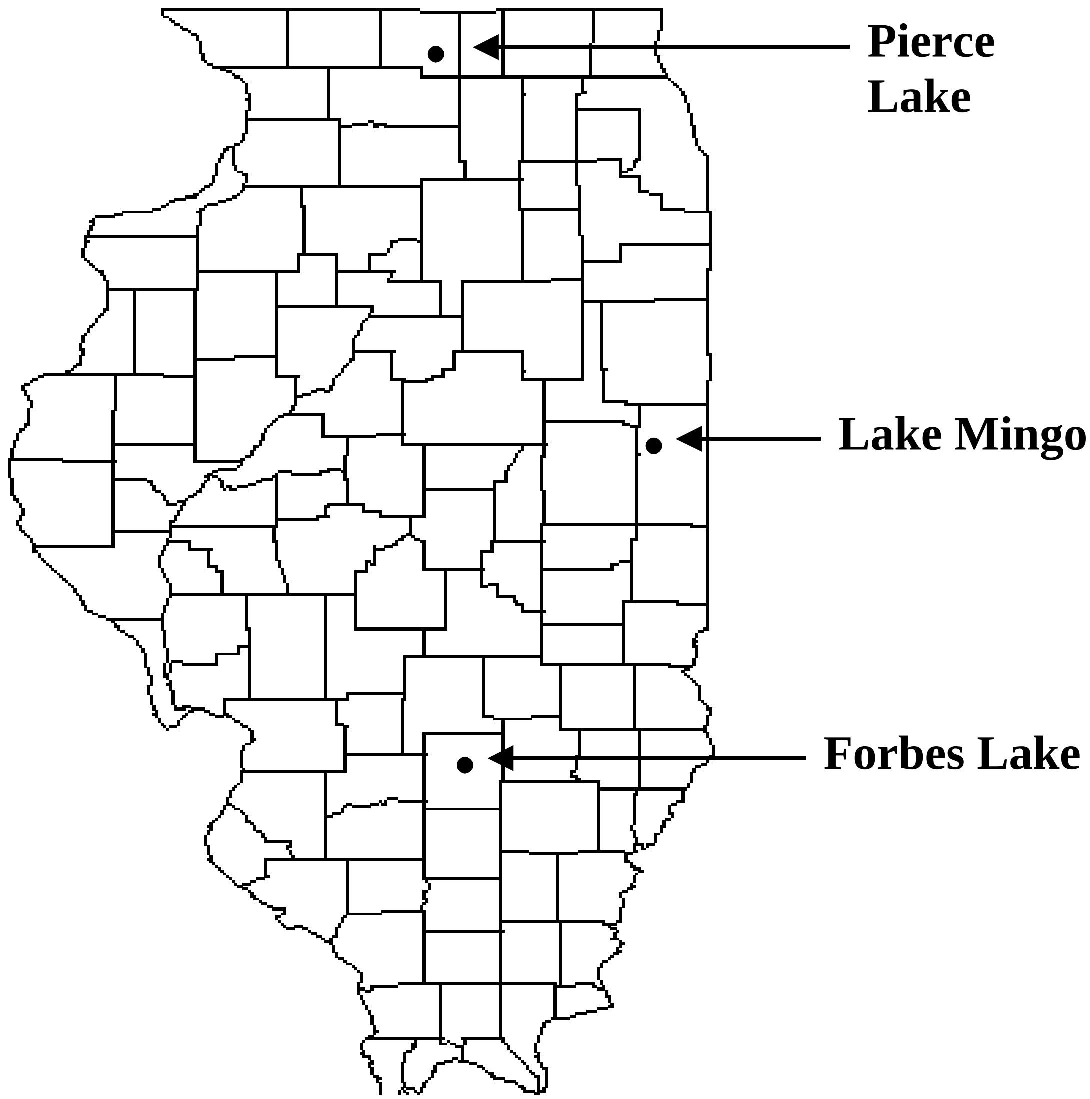

Figure 2. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. Growth is from the time of stocking through the first fall (October through December 2003). The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

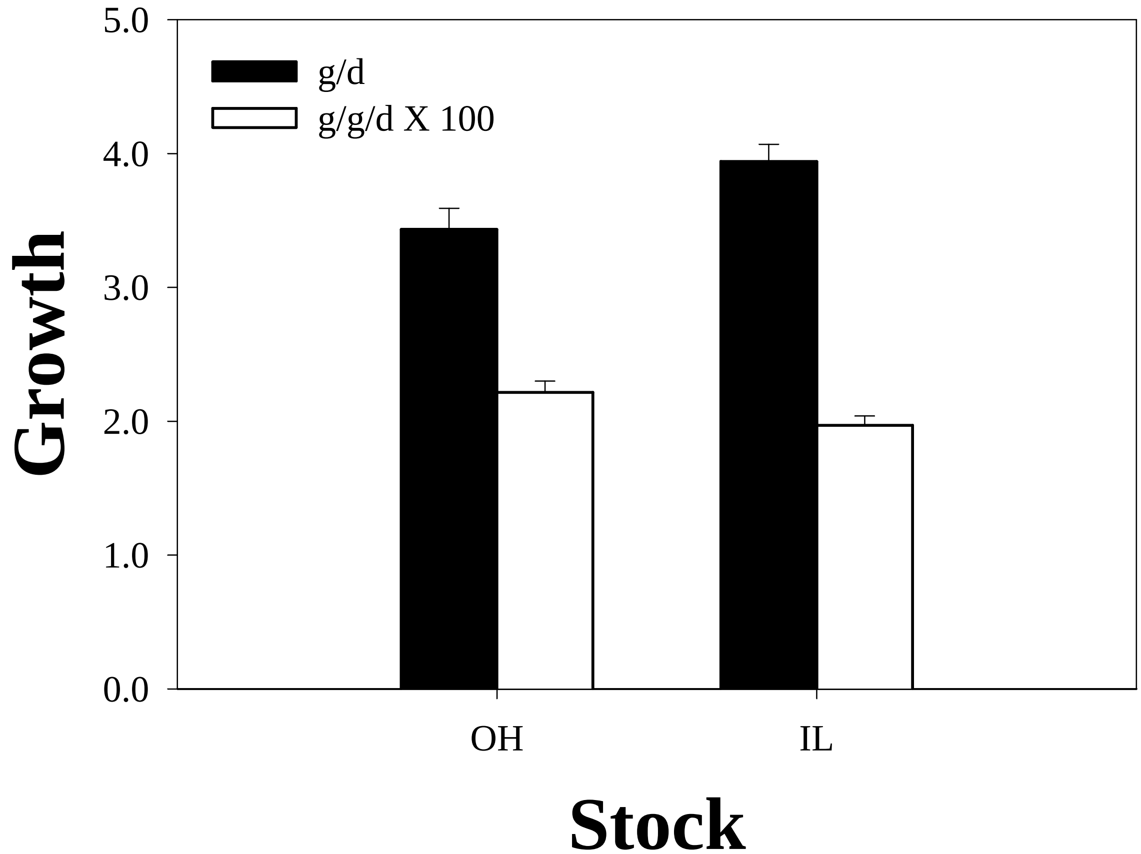

Figure 3. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 1000, open bars) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. Growth is from the fall 2003 sampling season through the fall 2004 sampling season (October through December 2004). The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

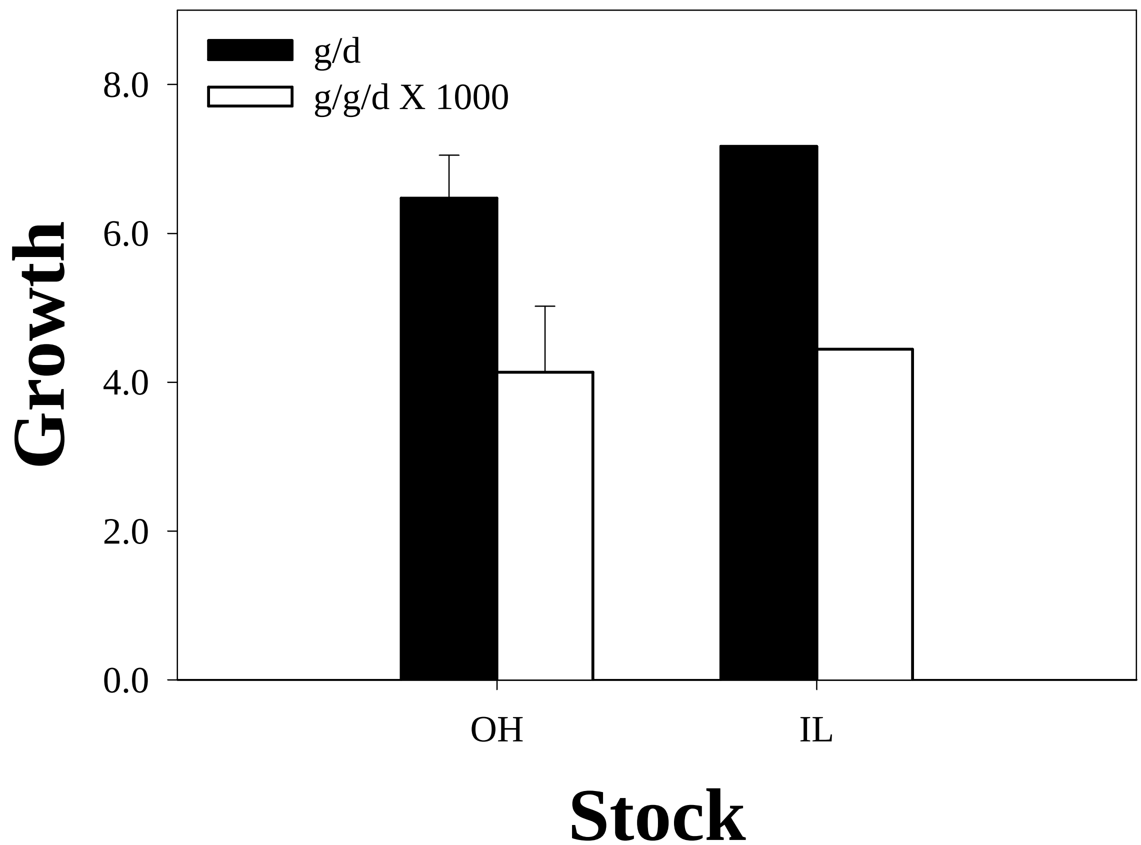

Figure 4. Stocking and subsequent sample mean lengths (nearest mm) and weights (nearest g) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

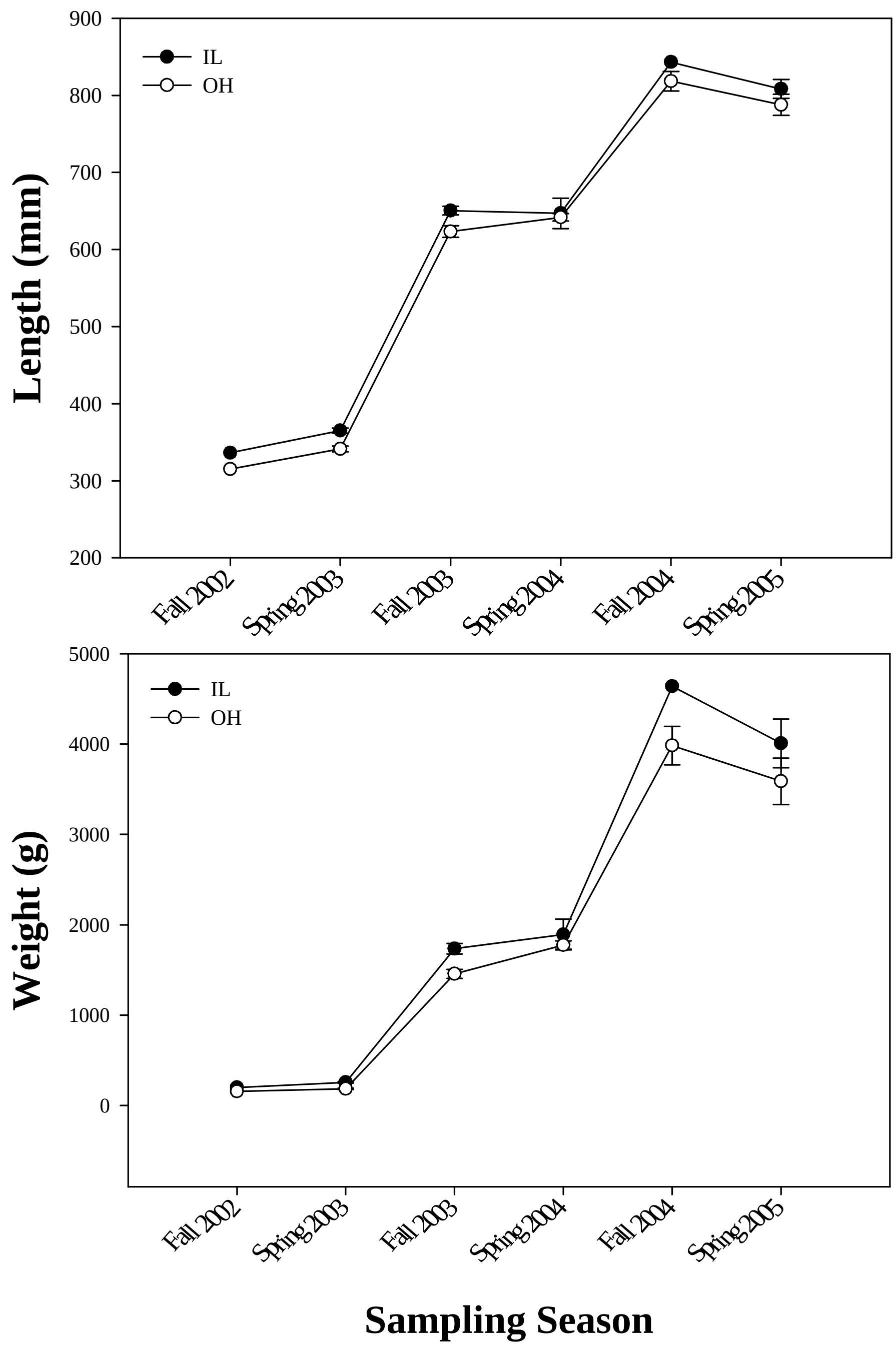

Figure 5. Stocking and subsequent sample mean lengths (nearest mm) and weights (nearest g) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Pierce Lake during fall 2003. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the New York Lake Chautauqua population, and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

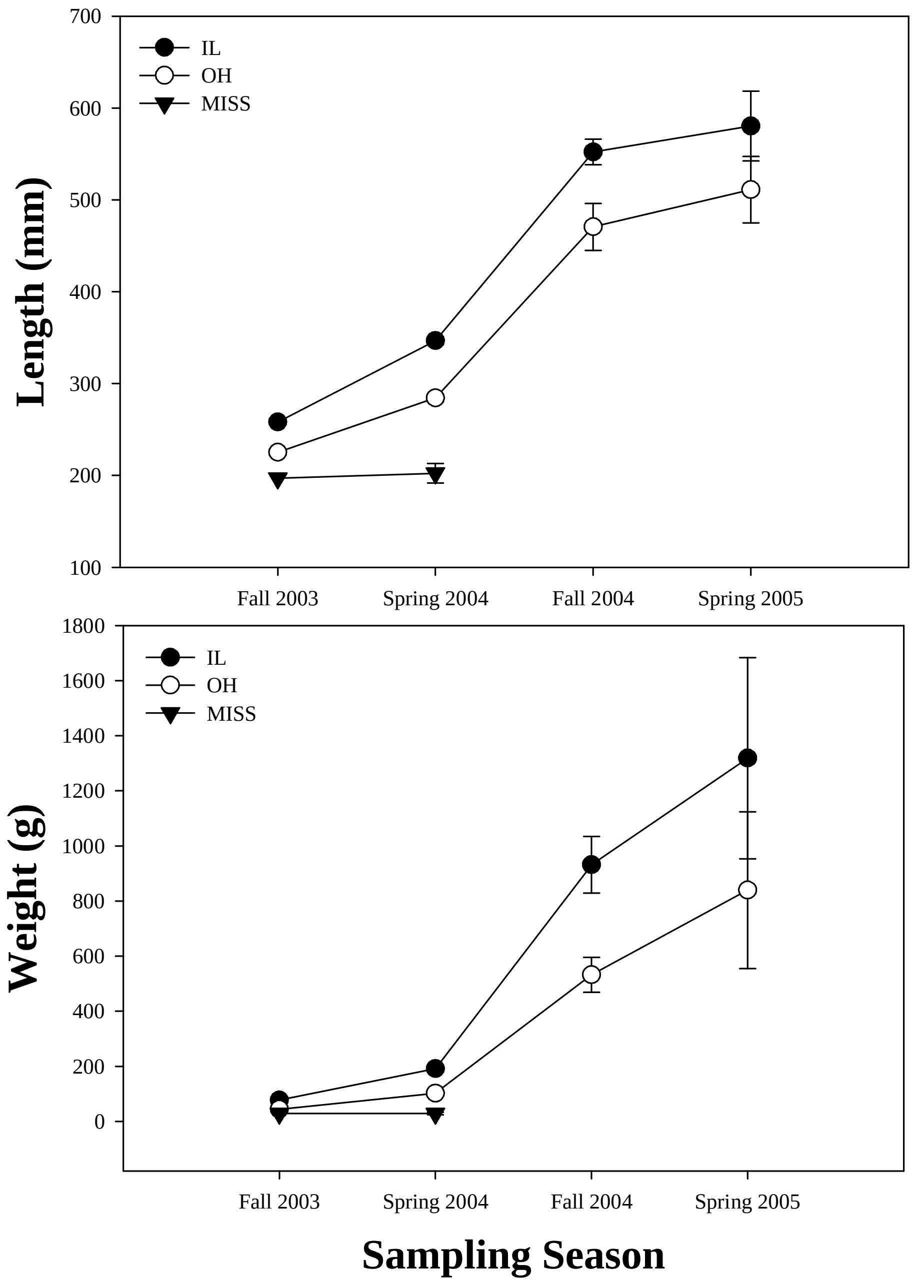

Figure 6. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2003. Growth is from the time of stocking through the first fall (November through December 2004). The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

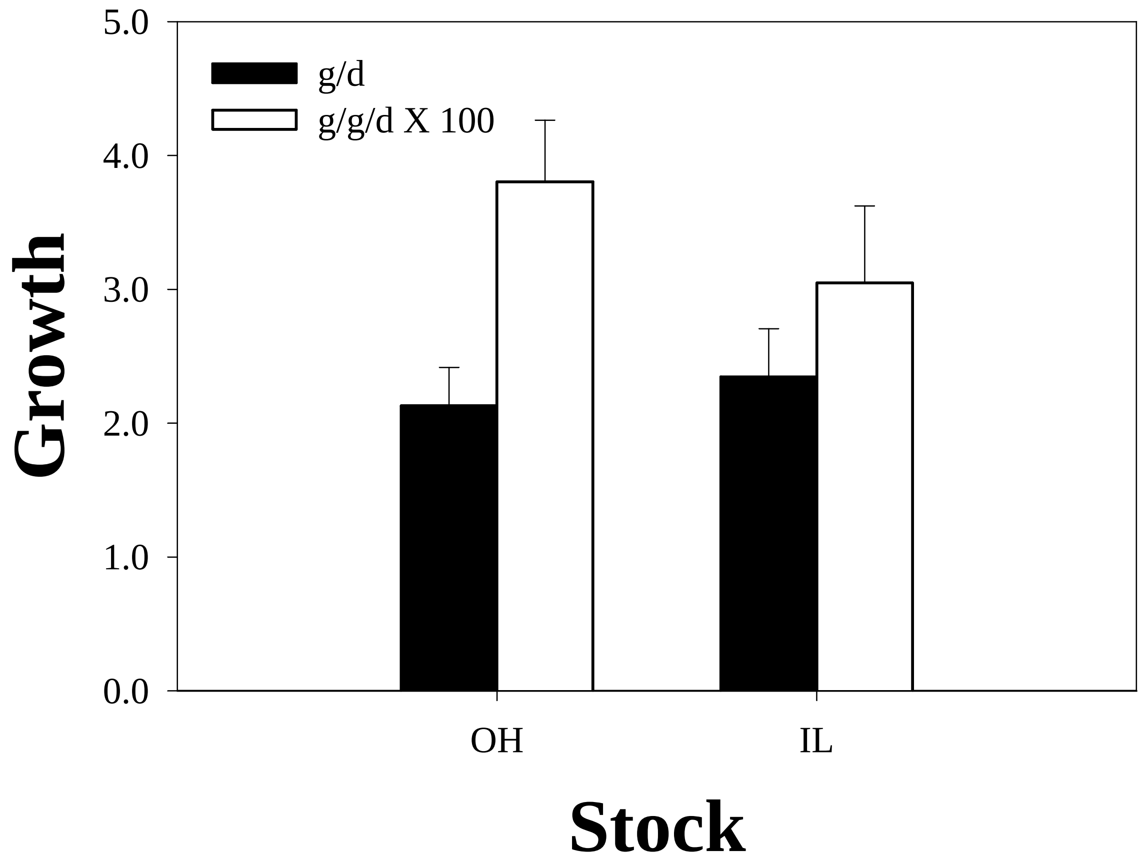

Figure 7. Stocking and subsequent sample mean lengths (nearest mm) and weights (nearest g) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2003. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

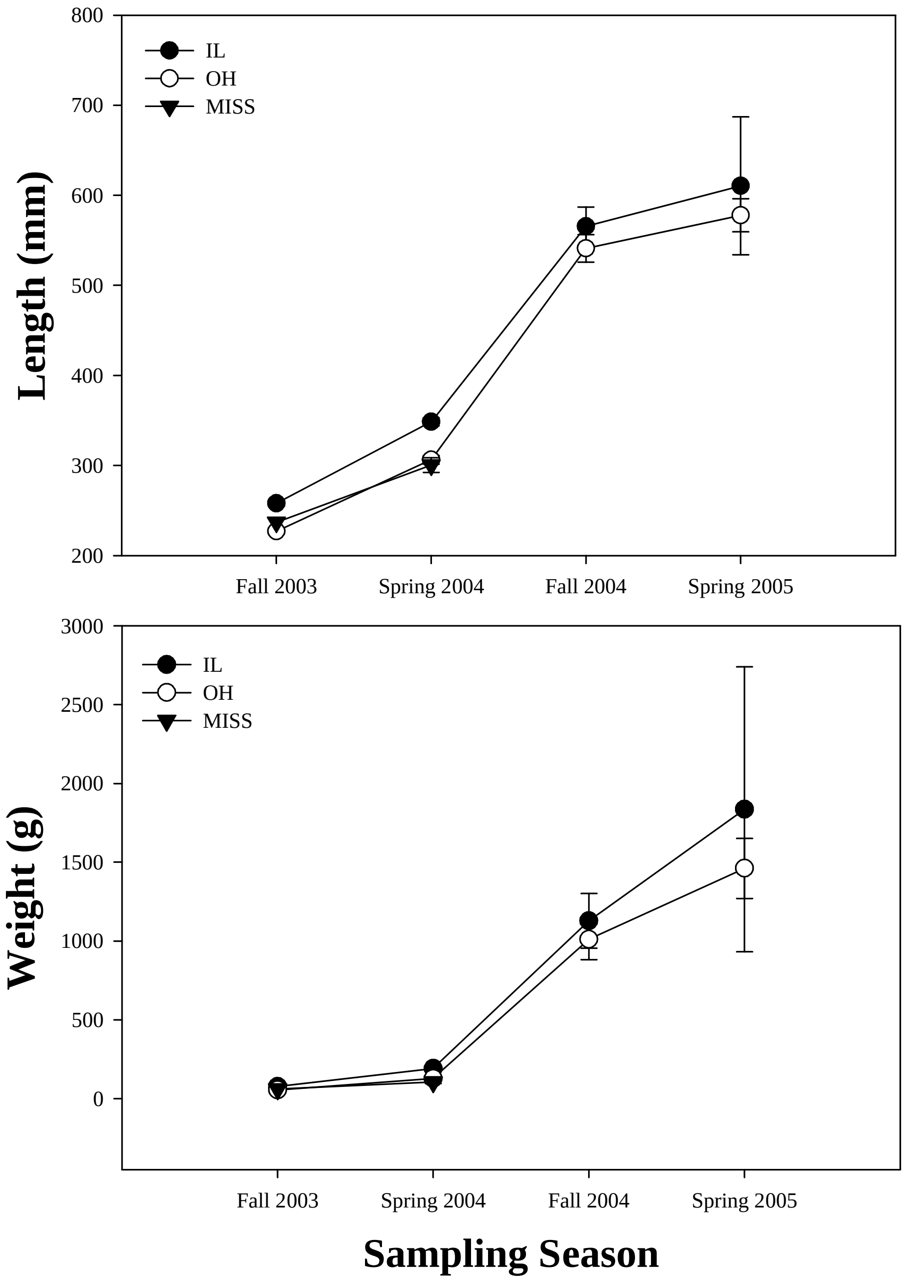

Figure 8. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Pierce Lake during fall 2004. Growth is from the time of stocking through spring (April through May 2005). The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

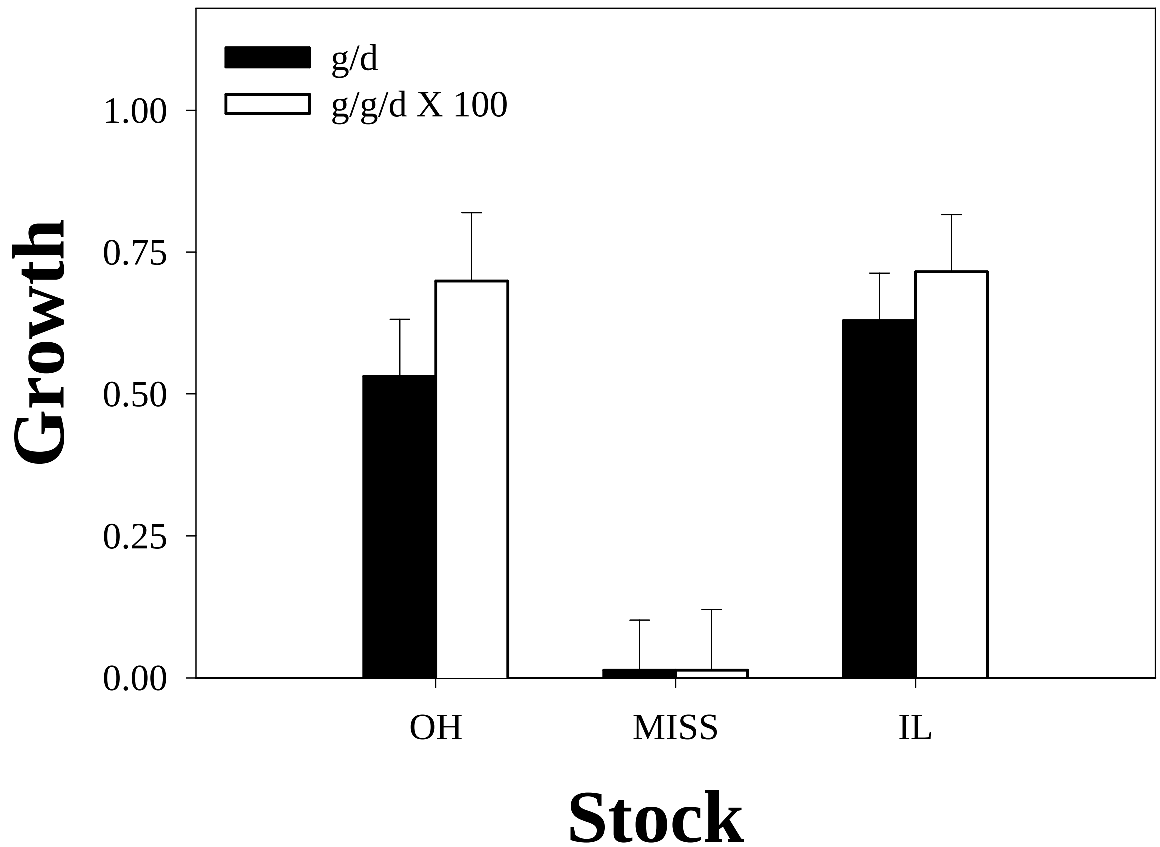

Figure 9. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2004. Growth is from the time of stocking through spring (March through April 2005). The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent ±1 standard error.

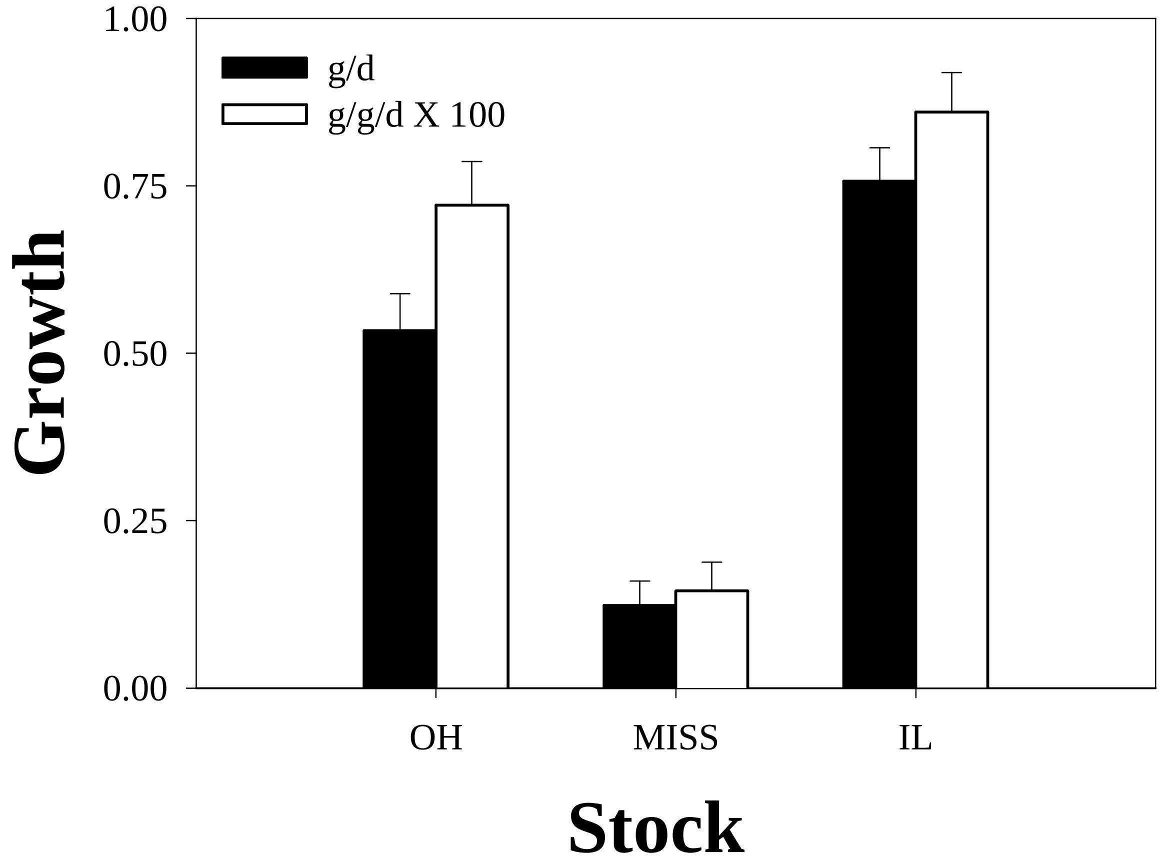

Figure 10. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during October 2003. One-year growth is from the time of stocking through the following October. No Upper Mississippi River drainage muskellunge were recovered in any of the ponds and therefore no growth values are given. Vertical lines represent ±1 standard error.

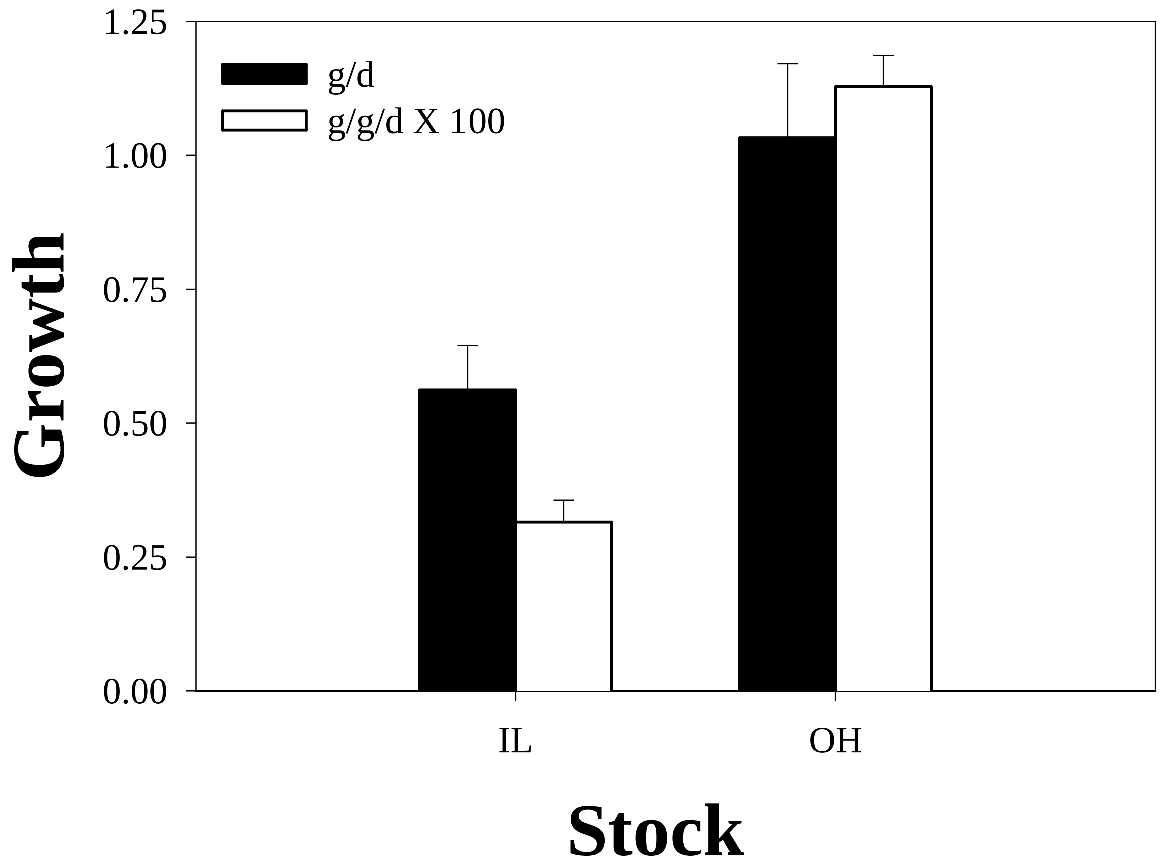

Figure 11. Stocking and subsequent sample mean weights (nearest g) of muskellunge populations introduced into 3, 0.4-ha ponds in October 2003 and drained during April 2004, October 2004, and April 2005. Vertical lines represent ±1 standard error.

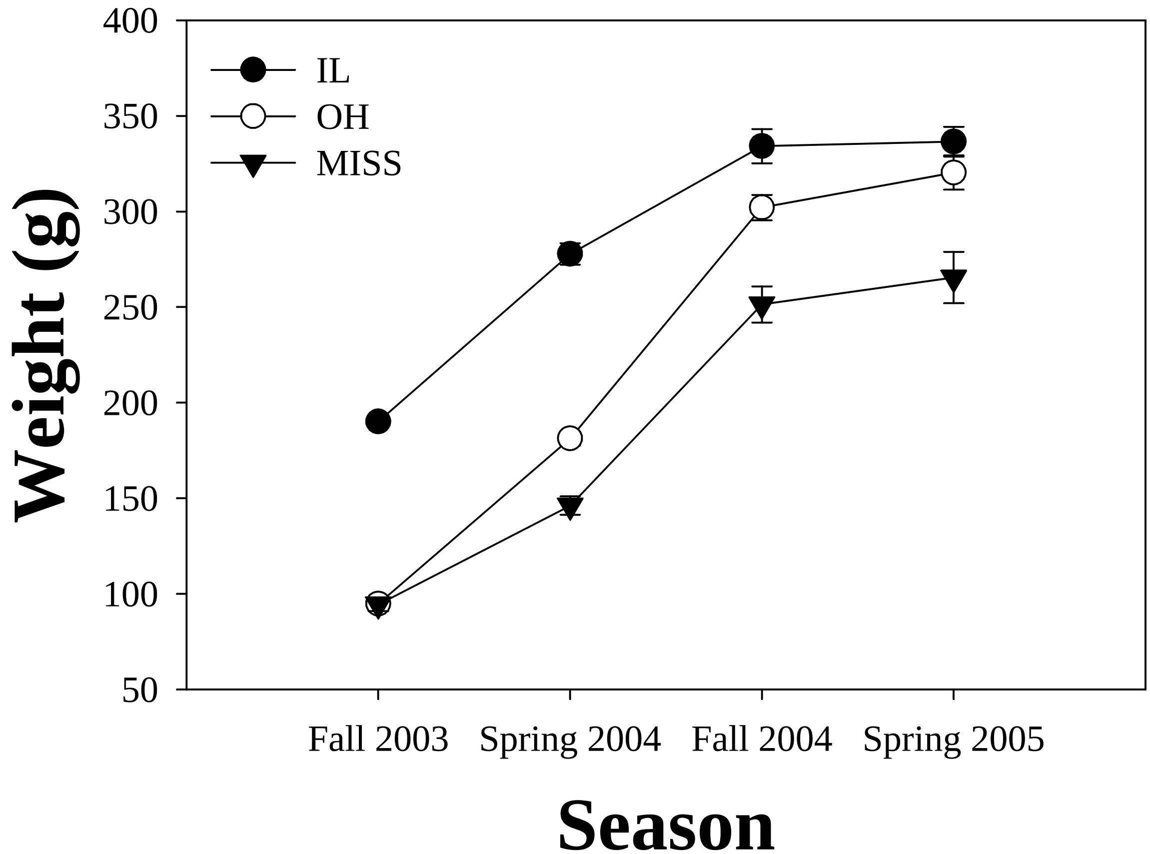

Figure 12. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during October 2004. One-year growth is from the time of stocking through the following October. Vertical lines represent ±1 standard error.

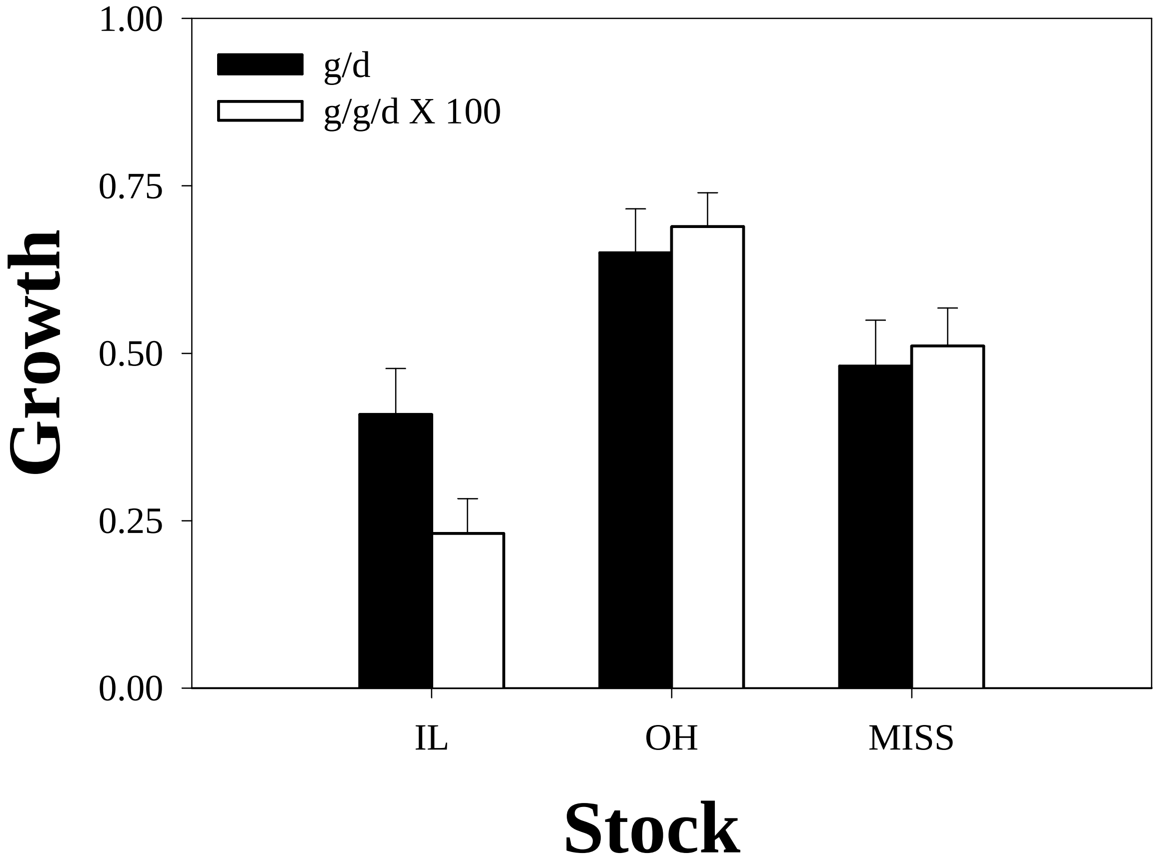

Figure 13. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2004 and drained during April 2005. Overwinter growth is from the time of stocking through the following April. Vertical lines represent ±1 standard error.

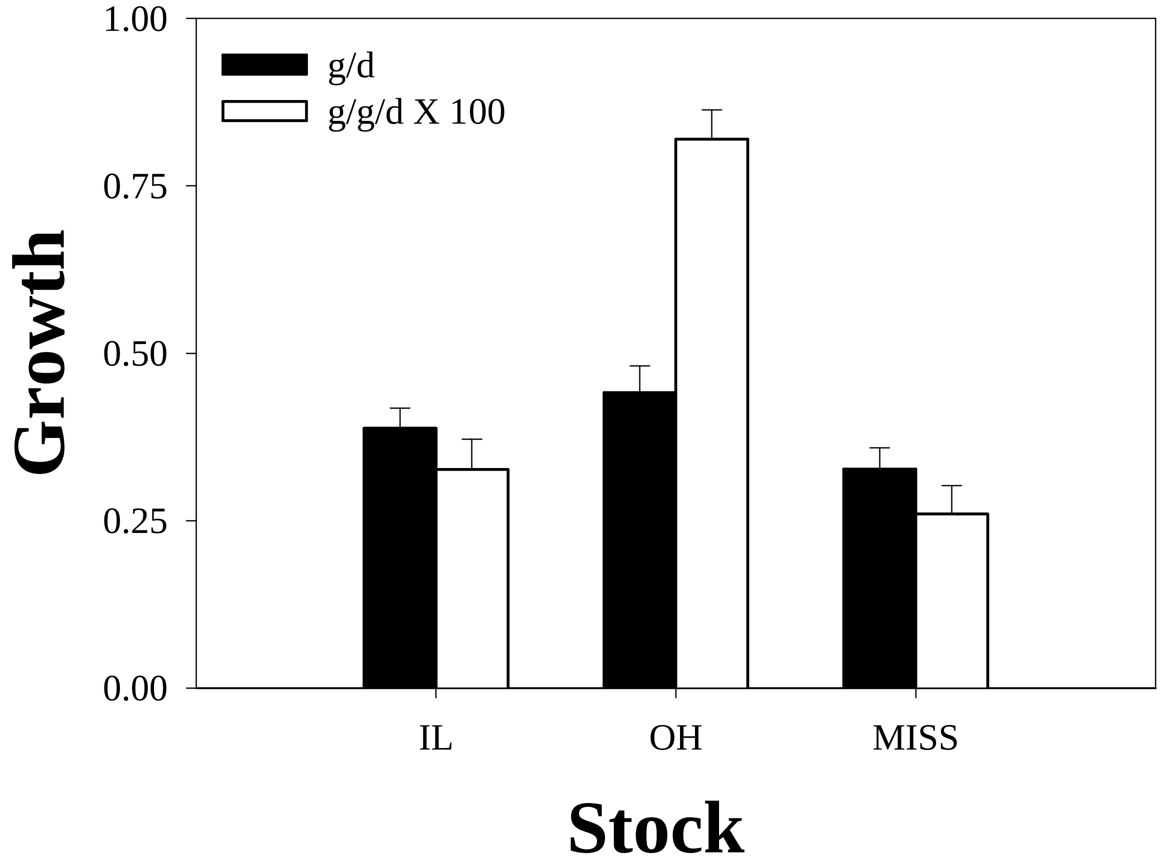

Figure 14. Adjusted catch-per-unit-effort (CPUE) through time for the Ohio River drainage stock (OH), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Lake Mingo during fall 2002. Sampling was conducted from October through December 2003. The CPUE of the Ohio River drainage stock is adjusted to account for varying stocking numbers (Adjusted CPUE).

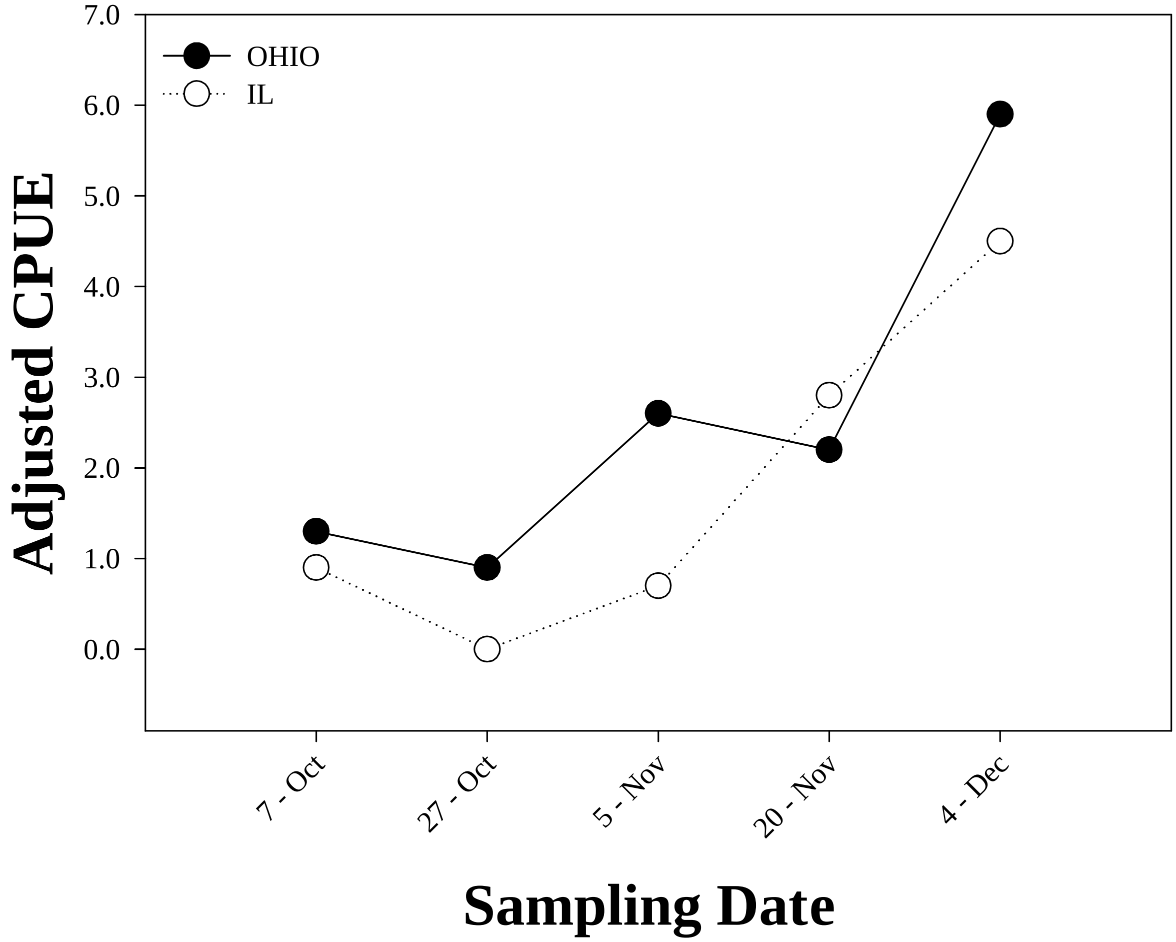

Figure 15. Adjusted catch-per-unit-effort (CPUE) through time for the Upper Mississippi River drainage stock, the Ohio River drainage stock (OH), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Lake Mingo during fall 2003. Sampling was conducted from November through December 2004. No Upper Mississippi River drainage muskellunge were recaptured in fall 2004. The CPUE of the Ohio River drainage stock is adjusted to account for varying stocking numbers (Adjusted CPUE).

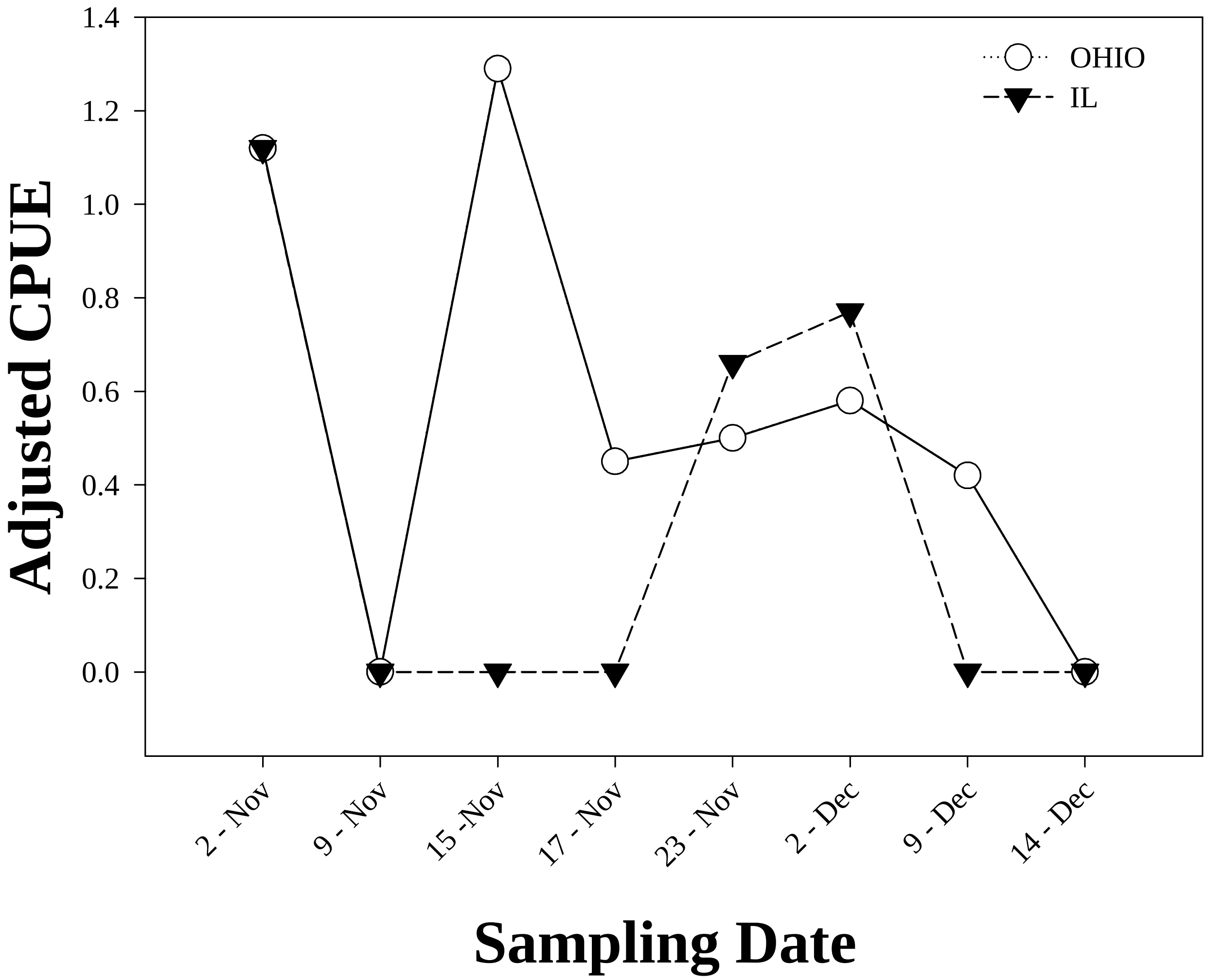

Figure 16. Adjusted catch-per-unit-effort (CPUE) through time for the Upper Mississippi River drainage stock (MISS), the Ohio River drainage stock (OHIO), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Pierce Lake during fall 2004. Sampling was conducted from April through May 2005.

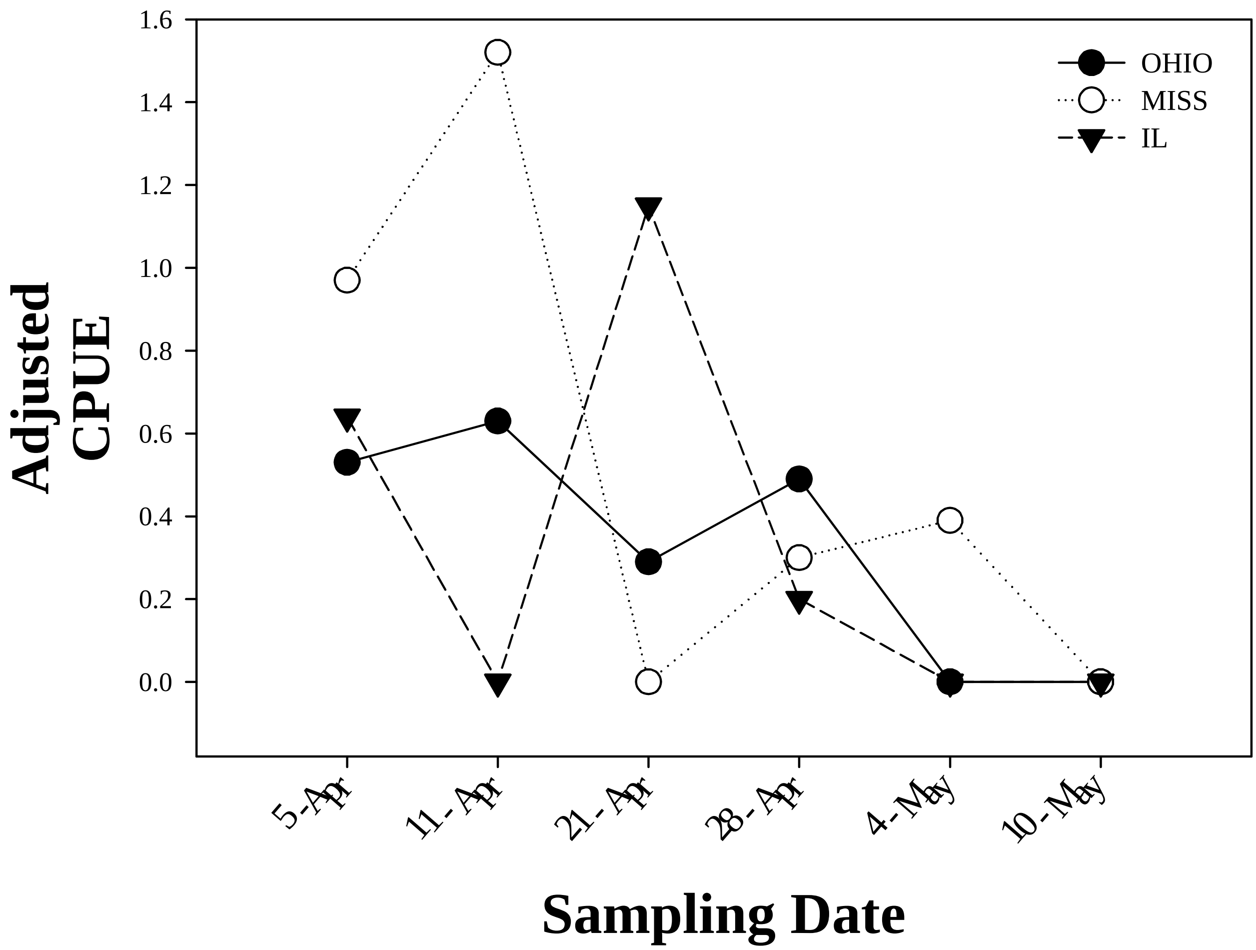

Figure 17. Adjusted catch-per-unit-effort (CPUE) during the spring 2005 sampling season for the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the North Spring Lake, IL progeny introduced in Pierce Lake in fall 2004. Vertical lines represent ±1 standard error.

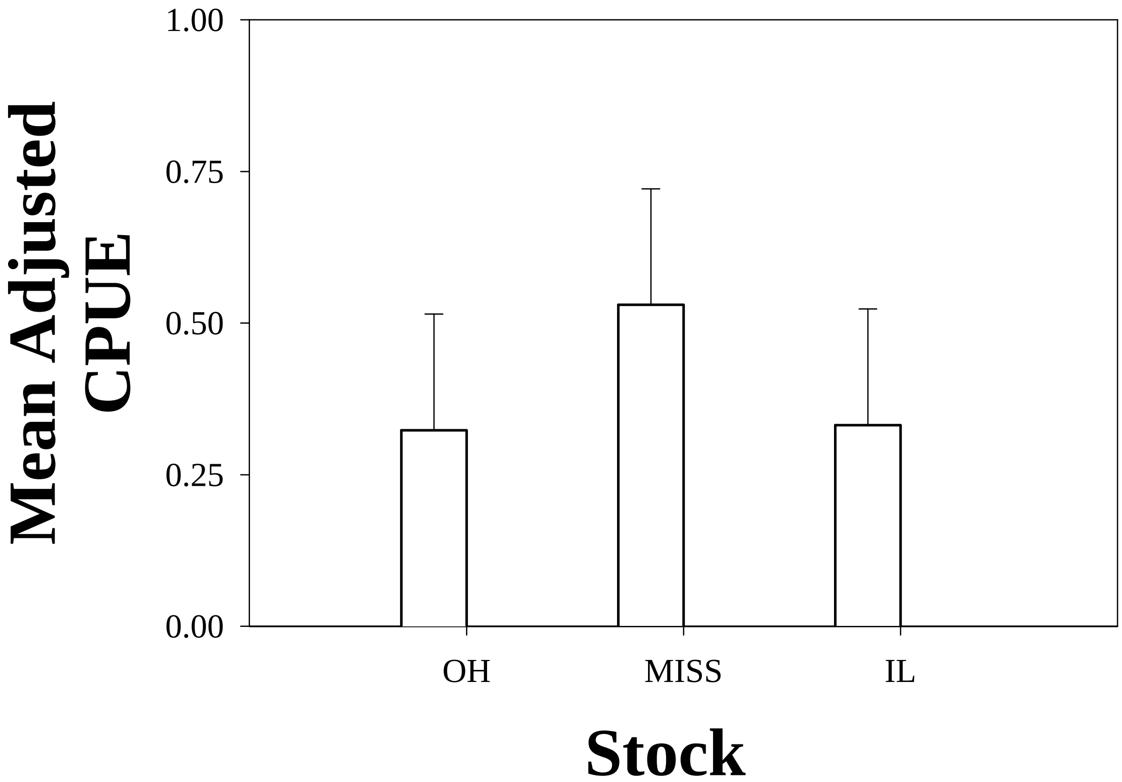

Figure 18. Adjusted catch-per-unit-effort (CPUE) through time for the Upper Mississippi River drainage stock (MISS), the Ohio River drainage stock (OHIO), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Lake Mingo during fall 2004. Sampling was conducted from March through April 2005.

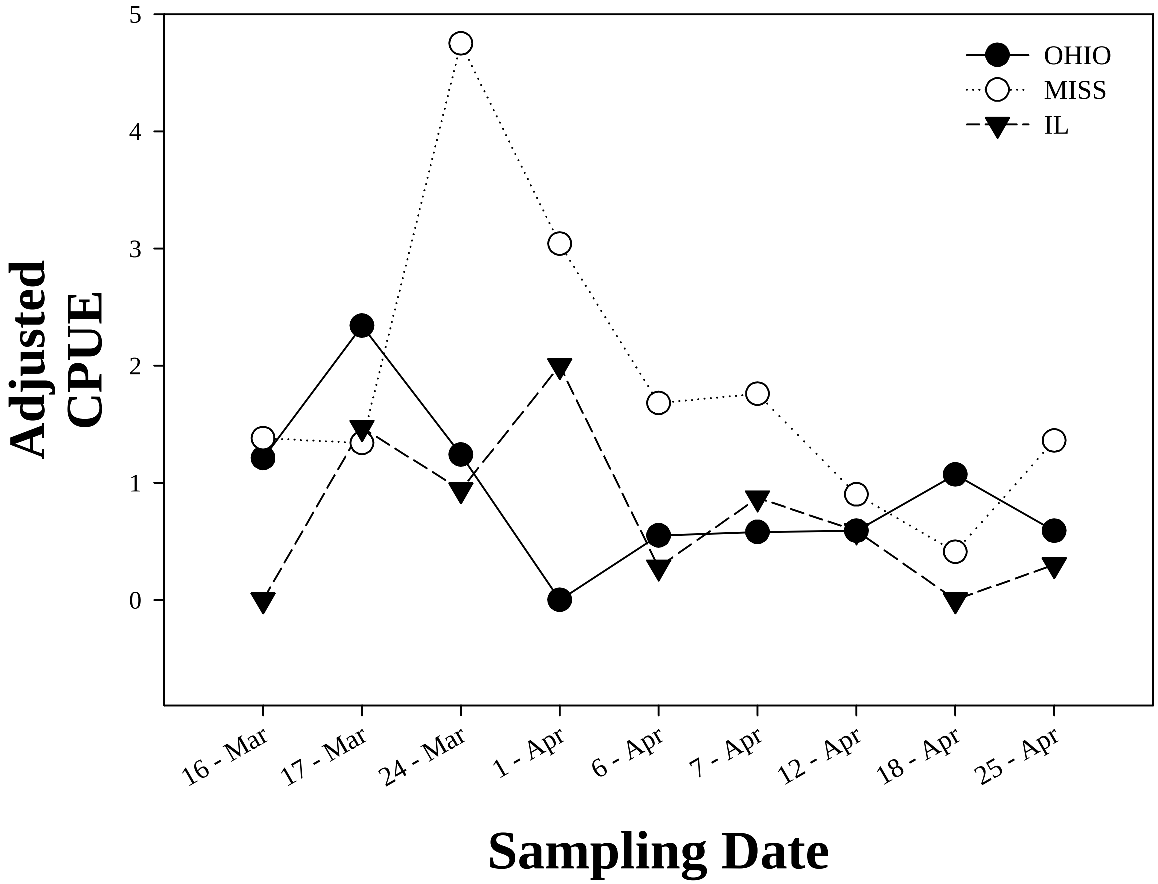

Figure 19. Adjusted catch-per-unit-effort (CPUE) during the spring 2005 sampling season for the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the North Spring Lake, IL progeny introduced in Lake Mingo in fall 2004. Vertical lines represent ±1 standard error.

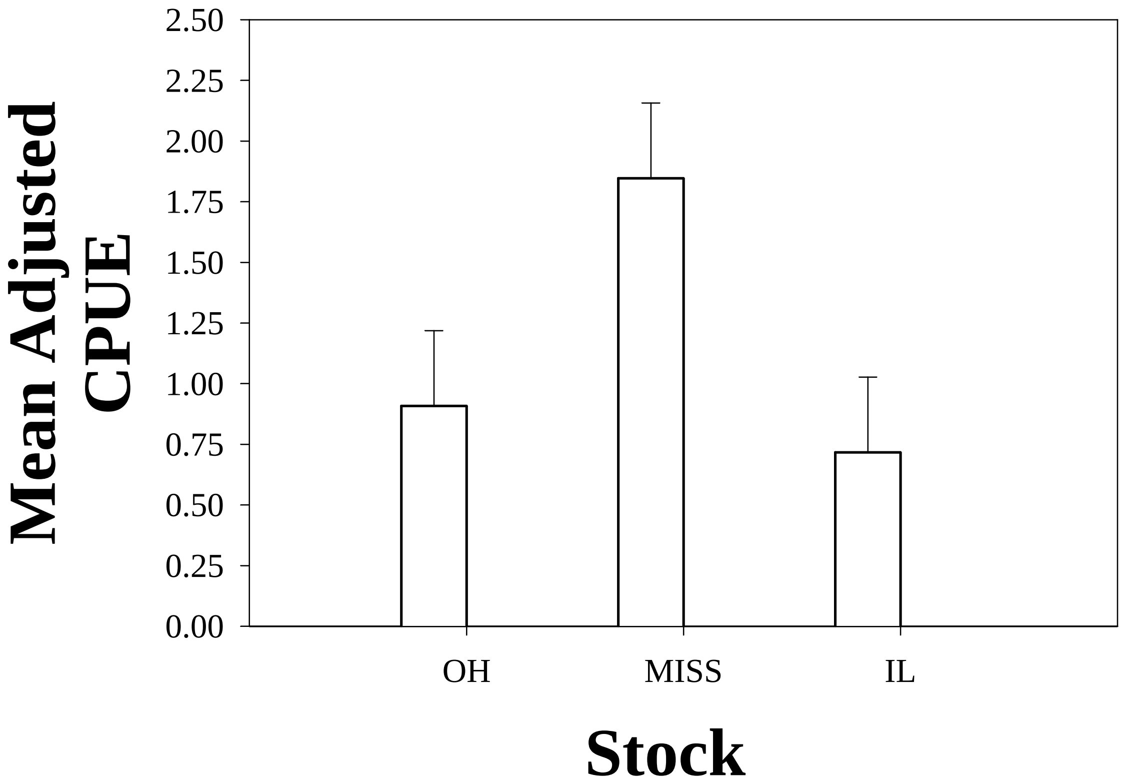

Figure 20. Survival of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during April 2003, October 2003, April 2004, and October 2004. Survival measurements for each season are calculated from the time of stocking. No Upper Mississippi River drainage muskellunge were recovered in any of the ponds. Vertical lines represent 95% confidence limits.

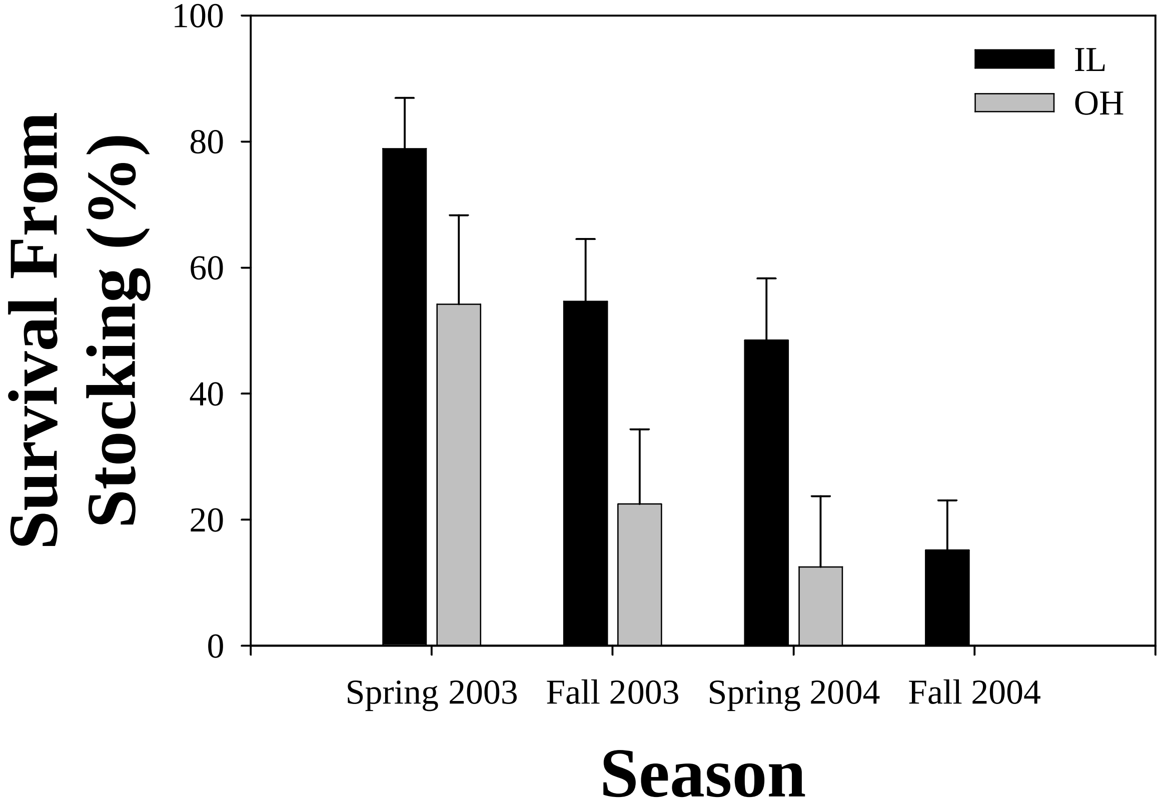

Figure 21. Survival of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during April 2004, October 2004, and April 2005. Survival measurements for each season are calculated from the time of stocking. Vertical lines represent 95% confidence limits.

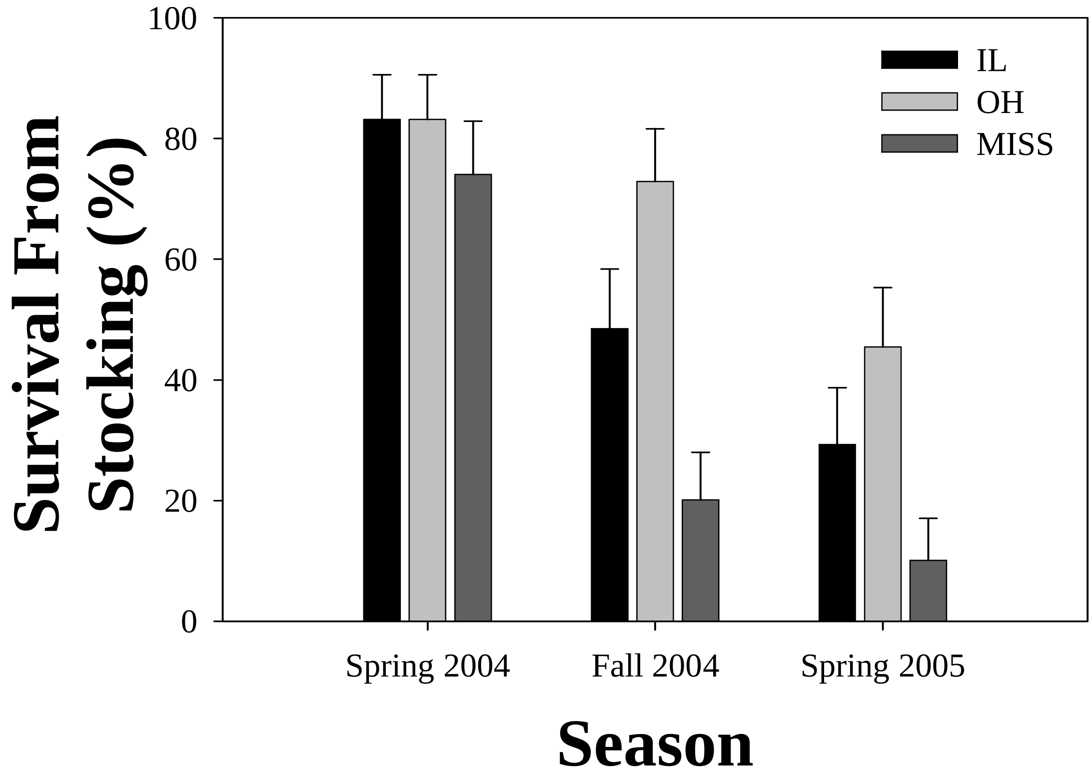

Figure 22. Survival of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2004 and drained during April 2005. Vertical lines represent 95% confidence limits.