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ANNUAL PROGRESS REPORT
July 1, 2008 through June 30, 2009

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

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Submitted to
Division of Fisheries
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Federal Aid Project F – 151 – R

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EXECUTIVE SUMMARY: Muskellunge *Esox masquinongy* are an important sportfish 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. In addition little research has focused on the response of fish communities and lake ecosystems to muskellunge stocking. As muskellunge increase in popularity and stocking becomes more widespread, potential impacts of muskellunge introduction on existing fisheries and aquatic communities must be considered.

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. 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 extirpated 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. 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. The first two jobs of this study examine differences in growth and survival among different stocks of muskellunge in order to make recommendations regarding stocking in Illinois.

Previous research on interactions of muskellunge with the aquatic community has been sparse and generally inconclusive. In addition, the existing literature on muskellunge diet focuses on natural lakes in northern states, which limits the utility of this information to managers in the lower Midwest. Few studies exist in the literature, which report fishery effects of muskellunge introductions. One study attributed muskellunge with the decline of largemouth bass populations in two Wisconsin lakes and another study documented a decline in black crappie and white sucker populations in Iron Lake, Michigan in response to muskellunge stocking. The utility of these studies to inform managers about the potential effects of muskellunge introduction in lakes of the lower Midwest is limited by a lack of replication or adequate comparison to control systems. The third job of this study will provide a rigorous evaluation of the diet and community effects of muskellunge across a number of Illinois lakes in order to inform managers about the potential effects of muskellunge introductions.

During segment seven, 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 and one job related to food habits and effects of muskellunge introduction were completed. In previous segments of the study, we compared initial 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 two Illinois lakes. In this segment electrofishing was conducted during fall 2008 and spring 2009, and combined with modified

fyke net surveys during spring 2009. Across years and lakes, the Ohio River drainage stock and the Illinois population appear to have similar growth rates; both consistently higher than the Upper Mississippi River drainage stock. Results from lake introductions suggest that after the first summer, the Ohio River drainage stock and Illinois population typically have similar survival and both are higher than the Upper Mississippi River drainage stock. These introductions will need to be monitored over additional years to further assess long-term growth and survival differences among stocks.

From summer 2007 to spring 2009 muskellunge diet samples have been collected from 591 fish across 6 Illinois lakes. These lakes included Lake Shelbyville, Lake Mingo, Ridge Lake, Pierce Lake, Lake of the Woods and Sam Dale Lake. Analysis of this data has shown that where present, gizzard shad dominated muskellunge diet in both numbers and biomass across all size classes and seasons. Diet of muskellunge in Ridge Lake consisted primarily of bluegill although a small percentage of the samples contained largemouth bass. Diet in this lake is limited by low species diversity and the absence of gizzard shad. Results thus far from diet analysis indicate that where available gizzard shad are the primary forage of muskellunge in Illinois lakes followed by bluegill. While this data provides a preliminary analysis of muskellunge diets in these lakes, more data is required to adequately characterize annual and seasonal fluctuations occurring over time. Specifically it is unclear how food habits of muskellunge may change in response to annual fluctuations in prey availability or whether consistent seasonal or size related trends are present.

In the current segment we continued two sets of analyses focused on the community and fishery effects of muskellunge introductions. The first analysis utilizes a community data set collected as part of previous Federal Aid in Sport Fish Restoration Projects (F-135-R, Factors influencing largemouth bass recruitment and stocking and F-128-R, Quality management of bluegill populations). Data from each trophic level including fish communities, zooplankton, larval fish, benthic macroinvertebrates, and nutrients has been collected on two reference lakes as well as lakes Mingo and Ridge, which have received muskellunge stockings. Lake Mingo has received muskellunge since fall of 2002 and Ridge Lake has been stocked since fall 2006. Data from Mingo and Ridge Lake is being compared to reference lakes before and after muskellunge introduction to determine if these stockings cause any changes in the aquatic communities of these two lakes. Preliminary results indicate that muskellunge stocking in Lake Mingo or Ridge Lake has not negatively affected largemouth bass and bluegill abundance and no significant effects on other parts of the aquatic food web have been detected.

The second set of analyses on effects of muskellunge stocking will involve a larger sample of lakes taken from the state Fishery Analysis System (FAS) database. Examination of muskellunge stocking records has identified a series of lakes that received concurrent initial stockings of muskellunge. To ensure that lakes selected for analysis have substantial muskellunge populations, we are comparing catch rates of muskellunge from candidate lakes to catch rates from lakes with known high-density populations (lakes Mingo and Pierce) based on both standardized electrofishing and spring trap netting surveys. This analysis will focus specifically on fish communities comparing trends before and after muskellunge introduction with a series of reference lakes. Reference lakes have been selected, which have similar geographic, physiochemical, morphometric and fishery characteristics to lakes receiving muskellunge stockings. This analysis will provide a more rigorous examination of muskellunge effects on existing fisheries due to a larger number of replicate lakes. Preliminary results based on three stocked and two reference lakes suggest that muskellunge introductions are having no effect on the size structure or relative abundance of largemouth bass populations.

In future years we will continue to monitor populations of muskellunge in lakes Mingo, Pierce and Sam Dale to evaluate long-term growth and survival differences between stocks and populations. The results obtained from initial years will be combined with those from future years to identify the long-term growth and survival differences among genetic stocks of muskellunge. Results will be used to develop guidelines for future muskellunge stockings that maximize growth, survival, and angler satisfaction in lakes throughout Illinois. As the management of muskellunge fisheries improves due to increased understanding of intraspecific variation, the effects of these highly predacious fishes on the existing aquatic community also needs to be considered. In future segments we will continue to examine the food habits and effects of muskellunge on existing fish populations. This information, combined with an increased understanding of appropriate stocks, will contribute to a more informed and holistic approach to muskellunge management in Illinois and the lower Midwest.

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 significant revisions over the last century (Crossman 1978; Crossman 1986). During the late 1800's and early 1900's, perceived correlations between muskellunge color patterns (spotted, clear, barred) and location led to the distinction 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) but this distinction lost favor by the late 1970's and all of these color variants are now considered the same species (Crossman 1978). Existing information indicates muskellunge survived 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). Genetic analysis of various populations from these major river drainages revealed three distinct clusters (separated by river drainage) suggesting the existence of divergent stocks (Koppelman and Philipp 1986). This divergence suggests that as these groups became geographically isolated within each river drainage processes such as natural selection, resulted in stocks of muskellunge that are genetically dissimilar, and are likely to display physiological and behavioral differences (Altukhov 1981; MacLean and Evans 1981; Ihssen et al. 1981; Clapp and Wahl 1996; Begg et al. 1999). Current delineation of muskellunge stocks recognizes three distinct groups, the Great Lakes/ St. Lawrence River drainage stock, the Ohio River drainage stock and the Upper Mississippi River drainage stock (Koppelman and Philipp 1986; Clapp and Wahl 1996).

Evolutionarily derived differences in physiology and behavior between stocks of muskellunge have been suggested by previous research and similar differences have been documented in a number of other fish species. Such differences have been shown to affect performance characteristics, measured in terms of growth rate and maximum body sizes. Past research comparing source populations of muskellunge in Minnesota found differences in growth rate and maximum size between two genetically divergent populations native to Shoepack Lake and Leech Lake Minnesota (Younk and Strand 1992, Wingate and Younk 2007). As a result of these findings the Minnesota Department of Natural Resources switched its hatchery brood source from Shoepack to Leech Lake muskellunge (Wingate and Younk 2007). A similar study focused on two populations of muskellunge from within Wisconsin found a difference in growth performance attributable to both environmental and genetic components (Margenau and Hanson 1996). Research conducted by the Illinois Natural History Survey compared food consumption, metabolism and growth among populations of YOY muskellunge from each of the major stocks and found differences in growth and food consumption at temperatures from 15-27.5˚C (Clapp and Wahl 1996). Research on other fish species in the Great Lakes region has found differences in growth between stocks of rainbow smelt *Osmerus mordax* (Luey and Adelman 1984), as well as Lake Whitefish *Coregonus clupeaformis* (Ihssen et al. 1981). In addition, research within Illinois has documented growth differences between stocks of largemouth bass *Micropterus salmoides* from major river drainages within the state (Philipp and Claussen 1995). These studies provide evidence that physiological and behavioral adaptations should be a significant factor in determining the source population for a stocking program such as the Illinois muskellunge program. Investigation of such variation will not only allow for selection of a broodstock which maximizes the growth potential for muskellunge fisheries within Illinois but the possibility that different stocks may be more appropriate for specific waters (for example if the latitudinal variation in local thermal regime displayed across the state is an important factor).

While differences in growth between genetically isolated fish stocks has been demonstrated, the ecological mechanisms for the evolution of growth rates are still in question and the lack of consensus makes it difficult to predict which stocks should perform best under a specified temperature regime. Two competing theories with empirical support exist to predict how poikilothermic organisms should respond to latitudinal variation in temperature regimes. These theories are based on the idea that selective agents such as winter severity, length of growing season and temperature can cause northern populations to express adaptive variation in somatic growth rates which may maintain physiological rates at levels as high or higher than southern populations (Levinton 1983). The first model called “local adaptation” focuses on temperature as the selective agent that organisms should evolve to grow best at the temperature regimes most commonly encountered in their environment (Lonsdale and Levinton 1985). If this model is correct then organisms from northern populations should adapt by both beginning growth and reaching maximal growth rates at lower temperatures than southern populations, which would result in comparable growth rates in their home environments. The trade off is that outside of their native temperature regime the locally adapted stocks would show poorer growth. This model has been supported by studies of marine invertebrates (Levinton 1983, crustaceans (Lonsdale and Levinton 1985) and fish (Galarowicz and Wahl 2003; Belk et al. 2005).

The second model focuses on the duration of the growing season as the selective agent. In northern latitudes where winters are more severe, a large body size is necessary to store sufficient energy to maintain metabolism through the long winter (Henderson et al. 1988, Post and Evans 1989). This model called “countergradient variation” states that size dependent overwinter survival in northern latitudes should select for higher maximum growth rates in northern populations which need to reach a large body size in a shorter period of time (Conover and Present 1990; Yamahira and Conover 2002). If this model is correct stocks should display an increase in growth rates with increasing latitude and should maintain this higher growth rate when introduced outside of their native range. This model has received empirical support for amphibians (Riha and Berven 1991), reptiles (Ferguson and Talent 1993), insects (Gotthard et al. 1994) and fishes (Conover and Present 1990, Nicieza et al. 1994, Schultz et al. 1996, Conover et al. 1997, DiMichele and Westerman 1997, Jonassen et al. 2000).

Based on the model of thermal adaptation, we would expect muskellunge from higher latitudes (Minnesota’s Leech Lake population) to exhibit higher growth rates at low temperatures and muskellunge from low latitudes (Kentucky’s Cave Run Lake population) to possess higher growth rates at high temperatures. In contrast, if countergradient variation is the mechanism driving growth rates of muskellunge stocks we would expect to see muskellunge from northern latitudes display higher growth rates than those from lower latitudes in all environments. Although not statistically significant the pattern observed for muskellunge in the experiments of Clapp and Wahl (1996) was for higher growth, metabolism and food conversion efficiency for fish from northern latitudes.

In this job, we investigate stock differentiation in growth for muskellunge in the field through adulthood. Long-term growth of muskellunge will be evaluated in three lakes covering the latitudinal range of Illinois. Identifying growth differences at this scale may be important in determining the appropriate brood sources for specific management applications. Populations from different latitudes may vary in long-term growth, longevity, size-at-maturity, and maximum size. In this job we continue to assess long-term growth and maximum sizes of previously introduced populations.

PROCEDURES: In previous annual reports we compared growth rates between different stocks and populations of muskellunge through age-1 by year class in both ponds and lakes including Lake Mingo (Vermillion County), Pierce Lake (Winnebago County), and Sam Dale Lake (Wayne County). This portion of the study has largely been completed and the results presented in previous annual reports. In this segment we focus on a global analysis of pooled year classes to examine general patterns for older age classes. Due to difficulty with mortality and availability of hatchery muskellunge, stockings were delayed in Sam Dale Lake. As a result, growth of age-1 fish is still being evaluated in Sam Dale and is included in this report. Introductions of muskellunge into Sam Dale Lake were continued in 2008, but not in the other lakes as we have established multiple year classes of adult muskellunge in Lakes Mingo and Pierce. Future stockings into study lakes will depend upon the availability of source populations and data requirements.

Stockings from various source populations (Table 1) representing each stock have been introduced into Lake Mingo since Fall of 2002, Pierce Lake since Fall of 2003 and Sam Dale Lake since 2005 (Table 2). At each stocking, attempts were made to stock as similar of sizes and condition of fish as possible in each lake. Subsamples of each source population 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 (Clapp et al. 1997). Muskellunge from each population were stocked at rates between 3.3-4.9 fish per hectare and a subsample of each population was measured in length (nearest mm) and weighed (nearest g) prior to each stocking (Table 2). Each fish was given an identifying complete pelvic fin clip and freeze cauterization of the wound for later identification of the stock (Boxrucker 1982). In the fall 2004 we began freeze branding all stocked fish in an effort to improve age determination (in combination with scale ageing). The brand location differs by year and the 2008 brand was a right-middle horizontal brand.

To determine growth rates of juvenile fish (ages 0-1) we conducted nighttime pulsed DC boat-electrofishing from October through November and March through April annually since 2002. Beginning in spring 2006 we began sampling adult muskellunge (ages 2+) with modified fyke net surveys in Lakes Mingo and Pierce. Nets (N=14) in Lake Mingo and (N=11) in Pierce Lake were 3.8 cm bar mesh (1.5 in) and frames were 1.2 X 1.8 m with six 0.75 m hoops. During a weeklong period each spring nets were checked between 0800 and 1200 hr each day over surface temperatures from 7.0 – 11.0 ˚C. Upon capture the pelvic fin clip was used to identify the stock and population and caudal fin clips were used to conduct Schnabel population estimates within each sampling season (Ricker 1975). Scales were taken from all sampled muskellunge older than YOY (age-0) to determine age class. Muskellunge older than YOY were implanted with a Passive Integrated Transponder (PIT) tags prior to release to aid in future identification (Wagner 2007). Data were used to determine mean daily growth rates (g/d) and mean relative daily growth rates standardized by weight (g/g/d) among the stocks through age-1. Growth rates were analyzed using analysis of variance (ANOVA) models. General patterns in size-at-age (length and weight) and growth trajectory between stocks were compared using ANOVA models including terms for stock and year class at each age and von Bertalanffy growth functions (Beverton and Holt 1957). Where sample sizes allowed all analyses of adult growth were stratified by lake and gender. All analyses were performed with the SAS® System and P-values less than 0.05 were considered significant.

FINDINGS:

Modified Fyke Net Surveys – Lake Mingo and Pierce Lake

In Lake Mingo a total of 63 muskellunge were captured during 6 nights of modified fyke net sampling during March and April 2009. Catch rates averaged approximately 0.83 fish per net-night (84 net-nights minus 8 bad sets). Daily average capture rates ranged from 0.25 fish per net-night to 1.81 fish per net-night. Of the 63 muskellunge captured 11 were Ohio River drainage stock, 52 were Illinois stock and none were Upper Mississippi River drainage stock. The smallest muskellunge captured was 511 mm and the largest was 985 mm; weights ranged from 680 g to 7870 g. Twelve muskellunge were age-2, 21 were age-3, 16 were age-4, 11 were age-5, 1 was age-6 and 2 were age-7. Of the 63 fish sampled 65% (N=40) were male and 35% (N=22) were female.

A total of 74 muskellunge were captured during the 4 nights of modified fyke net sampling (44 net-nights) in Pierce Lake during April 2009, yielding an average of 1.68 fish per net-night. Average daily capture rates ranged from 1.09 to 2.36 fish per net-night. Of the 74 muskellunge sampled, 21 were Ohio drainage stock, 53 were Illinois stock and none were Upper Mississippi River drainage stock. The smallest muskellunge captured was 568 mm and the largest was 989 mm; weights ranged from 1250 g to 8960 g. No age-1 muskellunge were sampled; however, 1 age-2, 16 age-3, 34 age-4, 10 age-5, and 13 age-6 fish were sampled. Males represented 72% (N=53) of the sampled muskellunge and females the other 28% (N=21). Data from modified fyke net surveys was integrated with electrofishing data for calculations of growth and survival.

Juvenile Growth Rate

In previous reports we compared relative daily growth rates (RDGR, standardized by weight) for age-1 muskellunge in Lake Mingo, Pierce Lake and Sam Dale Lake stratified by stocking year class. In addition we conducted multiple trials of a pond experiment to compare stocks in a more controlled environment. Results from the pond experiments have been presented in previous annual reports and are only summarized here for comparison to lake results. In the reservoir experiment overwinter RDGR was not significantly different between the Ohio River drainage stock and the Illinois stock for any of the year classes from 2003-2007. The Upper Mississippi river drainage stock exhibited a significantly lower overwinter RDGR than the Illinois stock for fish introduced in 2005 and a significantly lower RDGR than both the Ohio River drainage stock and the Illinois stock in 2007, overwinter growth for all other year classes were similar to the other two stocks. In Pierce Lake overwinter RDGR was not significantly different between the Ohio River Drainage stock and the Illinois stock for any of the year classes from 2003 through 2007 while the Upper Mississippi River drainage stock showed significantly lower rates than both of these stocks for the 2003 and 2004 year classes. The 2005 year class showed higher RDGR for Ohio River drainage muskellunge compared to Upper Mississippi River drainage muskellunge with Illinois stock being intermediate. Growth rates through age-1 in both Lake Mingo and Pierce Lake were similar between the Illinois stock and the Ohio River drainage stock for muskellunge introduced from 2003-2007. In general overwinter growth rates in the reservoirs were similar between Illinois stock and Ohio River drainage stock muskellunge through age-1 and lower for muskellunge from the Upper Mississippi River drainage. From 2003-2007 only two Upper Mississippi River drainage muskellunge were sampled at age-1 across year classes and reservoirs. This poor survival (see Job 101.2) limited our ability to make inferences on the juvenile growth rates for this stock through age-1 in the reservoirs.

In addition to the reservoir evaluation of juvenile growth rates, we conducted pond experiments comparing the growth rates of the muskellunge stocks. Equal numbers of muskellunge from each stock were introduced into three one-acre ponds at the Sam Parr Biological Station, Kinmundy, Illinois each fall from 2003-2005. The ponds were drained the subsequent spring (to assess overwinter growth) and fish were then restocked until draining the following fall (age-1) to determine growth rates through the first summer. The experiment was repeated three times. In two out of the three trials the Ohio River drainage muskellunge showed a higher overwinter RDGR than the Illinois stock or the Upper Mississippi River drainage stock. The Ohio River drainage stock also showed a higher RDGR than the other stocks in all three trials at age-1. The Illinois stock was generally intermediate between the Ohio River drainage stock and the Upper Mississippi River drainage stock. The Upper Mississippi River drainage stock generally exhibited the lowest RDGR at age-1. While these results provide an assessment of differences in growth rates through the first year of life, there may be other differences between stocks (e.g. age of maturation, maximum body size) that cause other differences for adult growth rates. Therefore in this segment we continue to examine long-term differences in growth through adulthood.

Juvenile Growth at Sam Dale Lake

Three populations were introduced into Sam Dale Lake in fall of 2008 (Table 2). Unequal numbers were stocked (300 Illinois population, 193 Ohio River Drainage stock, and 257 Upper Mississippi River drainage stock) due to limited availability of the populations. Illinois population muskellunge were from the Jake Wolf Fish Hatchery, the Upper Mississippi River drainage stock was represented by the Minnesota, Leech Lake population, and the Ohio River drainage stock was represented by the Kentucky, Cave Run Lake population. Three 3-m deep predator-free mortality cages were monitored for 48-hours post-stocking to evaluate mortality of each population. No deceased muskellunge were found for any of the stockings resulting in an initial post stocking mortality estimate of 0% across populations. Due to limited recaptures of muskellunge from the 2005-year class and a lack of available populations for stocking in 2006, growth rate comparisons were not possible for these year classes. The 2007 year class showed a significant difference in overwinter relative daily growth rates with the Illinois population having a higher rate of growth than the Upper Mississippi River drainage stock (Table 3). No Ohio River drainage stock or Upper Mississippi River drainage stock muskellunge from the 2007-year class were recovered during fall 2008 sampling preventing statistical comparisons of growth through age-1. The 2008-year class was sampled during spring 2009 electrofishing to assess overwinter growth rates. Two Ohio River drainage stock, one Illinois population and no Upper Mississippi River drainage stock muskellunge were sampled during eight hours of nighttime pulsed-DC electrofishing which preventing statistical comparisons of growth rates. In future segments we will begin monitoring long term growth of muskellunge stocks in Sam Dale Lake using spring modified fyke net surveys. These surveys are considerably more effective but do not capture muskellunge effectively until age-3.

Adult Size-at-Age

In Lake Mingo mean length-at-age was significantly different among stocks at age-2 (ANOVA, $P < 0.01$). At age-2 the Illinois stock was the longest of the three stocks and the Ohio River drainage stock was longer than the Upper Missississippi River stock (Table 4). For male muskellunge there was a significant difference in mean length at age-4 with the Illinois stock being significantly longer than the Ohio River drainage stock (ANOVA, $P < 0.05$). This difference was not evident at older age classes with male muskellunge being of similar length at age-5 (Table 4). No differences were found among the stocks for female muskellunge through age-6. In general all three stocks of muskellunge appear to be growing at similar rates in Lake Mingo although our inferences concerning the Upper Mississippi River drainage stock are limited to age-2, age-3 males, and age-5 females due to poor survival of this stock (Table 4).

Mean weights of muskellunge in Lake Mingo were significantly different among stocks at age-2 (ANOVA, $P < 0.01$) with the Illinois stock being significantly heavier than both the Ohio River Drainage stock and the Upper Mississippi River Drainage stock (Table 4). In addition there was a difference among stocks for age-4 female muskellunge with the Ohio River Drainage Stock being significantly heavier than the Illinois Drainage stock (ANOVA, $P < 0.01$, Table 4). This difference was not evident at older age classes with female muskellunge being of similar weight at age-5 (Table 4). The three stocks of muskellunge appear to be growing at similar rates measured by their average weights through time. No other differences in mean weight-at-age were found among the stocks although inferences concerning the Upper Mississippi River drainage stock were again limited by poor survival.

Examination of Von Bertalanffy growth functions fit to length-at-age data for each stock and gender of muskellunge in Lake Mingo revealed patterns in agreement with those based on mean length and weight. Male muskellunge from the Ohio River Drainage stock have lower lengths at ages 1-2 but these differences disappear by age-3 and growth trajectories are similar thereafter (Table 5, Figure 1). Female muskellunge showed similar growth trajectories as well with nearly identical asymptotic lengths and growth coefficients (Table 5, Figure 2). A growth function was also constructed for Upper Mississippi River drainage muskellunge pooling both genders. The Upper Mississippi River drainage function was based on limited samples but shows a growth trajectory very similar to the other two stocks with similar asymptotic lengths and growth coefficients (Table 5, Figure 2). Collectively these analyses show similar growth rates for these three different muskellunge stocks in Lake Mingo.

In Pierce Lake mean length-at-age was significantly different among stocks for adult male muskellunge. At age-4 mean length of male muskellunge from the Upper Mississippi River drainage stock was significantly longer than that of either of the other two stocks (ANOVA $P = 0.01$, Table 6). By age-5 the Illinois stock was significantly longer than the Ohio River drainage stock (ANOVA < 0.01, Table 6) and was still longer at age-6 but this difference was not statistically significant. No significant differences in length-at-age were found among stocks for adult female muskellunge although the average length of the Illinois stock was slightly greater at each age (Table 6). In Pierce Lake the Ohio River Drainage stock appears to be shorter than the Illinois stock at adult ages from 4-6. While the Upper Mississippi River Drainage stock was longest at age-4 this difference is based on a limited sample size of these fish

(N=2) and should be interpreted with caution. Interestingly these patterns were not evident in Lake Mingo and may be suggestive of a latitudinal effect present within the state. Further data will be required on size-at-age of adult fish from each lake (particularly from Sam Dale Lake in southern Illinois) to clarify whether this is a consistent pattern.

Few differences in weight-at-age were found among stocks in Pierce Lake. No differences were found among stocks at age-2, or for male muskellunge ages 3-6. Female muskellunge showed a significant difference in weight at age-3 with the Illinois stock being heavier than the Ohio River drainage stock (ANOVA $P < 0.01$) but there were no significant differences for ages 4-6 (Table 6). In Pierce Lake mean weight-at-age seems to be similar among stocks although inferences on the Upper Mississippi River drainage stock are limited to males at age-4 due to poor survival. Interestingly we found no differences in weight-at-age despite differences in length, which may suggest some differences in allometric length-weight relationships between stocks. These potential differences will be examined in future segments as sample sizes allow.

Examination of Von Bertalanffy growth functions fit to length-at-age data for each gender of muskellunge in Pierce Lake highlight differences in growth trajectory between stocks (Table 5, Figure 3). The asymptotic length (L_{∞}) of Ohio River Drainage males in Pierce Lake was significantly lower than that of the Illinois stock showing no overlap in 95% confidence intervals for this parameter (Table 5). In addition the growth coefficient (K) for Ohio River Drainage males was nearly twice that of the Illinois stock suggesting that the asymptotic length is reached more quickly by this stock. Male muskellunge from the Ohio River Drainage stock averaged 95% of asymptotic length at age-5 while the Illinois stock averaged 88% of asymptotic length at this age (Table 5). The growth trajectory of female muskellunge in Pierce Lake was generally similar among stocks (Figure 4). No differences in asymptotic length or growth coefficients were found although the Illinois stock was consistently longer across age-6 (Table 5, Figure 4). Poor survival of the Upper Mississippi River drainage stock did not allow us to generate a growth function for this stock in Pierce Lake, but will be incorporated in future segments as sample sizes allow.

RECOMMENDATIONS: In the pond experiments the Ohio River drainage stock had significantly higher growth rates through age-1 than the Illinois population and the Upper Mississippi River drainage stock. The Illinois population and the Upper Mississippi River Stock showed similar growth rates in these experiments. These growth differences among juvenile muskellunge could have an influence on survival; both by loss to predation (Wahl and Stein 1989) and overwinter mortality (Bevelhimer et al. 1985; Carline et al. 1986).

In Lake Mingo the Illinois population, the Ohio River drainage stock, and the Upper Mississippi River drainage stock generally exhibit similar growth trajectories and size-at-age. While the Illinois population seems to have a growth advantage at ages 1-2 this difference is not evident at older ages. In Pierce Lake however, growth differences between stocks are becoming apparent at adult sizes. Male Ohio River drainage stock muskellunge appear to reach smaller maximum sizes than the Illinois population in Pierce Lake and also reach this size more quickly. These growth differences between the two stocks results in lower size-at-age for male Ohio River drainage muskellunge at ages greater than 4 years. In addition there is some (although limited) evidence that the Upper Mississippi River drainage stock is longer than the other stocks at age-4 in this lake. Thus far these results support the hypothesis of thermal adaptation over the countergradient variation hypothesis. The natal climate of the Ohio River drainage stock is generally more similar to Lake Mingo than Pierce Lake. Under the assumptions of the thermal adaptation concept, it would be predicted that the Ohio River drainage stock would exhibit better performance in Lake Mingo than in Pierce Lake, which agrees with our results thus far. Future years of data and older age classes of muskellunge are needed to be able to determine if the current latitudinal trends continue. Modified fyke net surveys have proven more efficient than electrofishing for capturing adult muskellunge. In future segments we will increase netting effort by sampling over several weeks in an effort to further increase sample sizes. Of particular interest is the performance of the three stocks in Sam Dale Lake in southern Illinois, which will help to clarify potential within-state latitudinal effect on the growth performance of these three muskellunge stocks. Any long-term differences among muskellunge populations we observe in these experiments will have important implications for new introductions or maintenance stockings of muskellunge populations. When introducing muskellunge into areas where they have not naturally occurred, such as Illinois impoundments, knowledge of population differentiation will be a valuable tool in designing appropriate stocking programs.

Job 101.2. Evaluating survival of different stocks of muskellunge.

OBJECTIVE: To investigate survival of various stocks and populations of muskellunge in Illinois waters.

INTRODUCTION: Population survival rates are a consequence of life history modes to which stocks have evolved and are important determinants of the productivity and evolutionary potential of a species (Begg et al. 1999, Shaklee and Currens 2003). Differences in survival rates among distinct fish stocks in common environments have been demonstrated for recreationally important fish species such as largemouth bass (Leitner and Bulak 2008, Philipp and Claussen 1995), lake trout *Salvelinus namayacush* (MacLean 1981) and several others. In a recent paper Leitner and Bulak (2008) showed significant differences in survival rates between source populations of largemouth bass from the Piedmont and Coastal Plain regions of South Carolina with the Coastal Plain stock exhibiting higher survival to ages 3-4. Studies of stock specific survival of largemouth bass showed differences in survival between bass populations from two river drainages within Illinois (Phillip and Claussen 1995). These studies provide evidence that stock origin can influence survival rates of introduced sportfish and should be considered when selecting the appropriate stock for management purposes.

Muskellunge are long-lived (Cassellman and Crossman 1986), are commonly managed for trophy fisheries (Hanson et al. 1986) and naturally occur at low densities (Margenau and AveLallemant 2000) causing small fluctuations in mortality rates to have a relatively large influence on fishery quality (see Brenden et al. 2007 for an example of such sensitivity to mortality rates). Research focused on differences in mortality between muskellunge stocks has been limited to comparisons of populations from within the Upper Mississippi River drainage stock in Minnesota and Wisconsin. In a comparison of survival rates among four native muskellunge populations in Minnesota, Younk and Strand (1992) found that the Shoepack Lake population exhibited lower survival than populations from three other Minnesota waters. Survival was also compared among five local populations in Wisconsin as well as the Leech Lake, Minnesota population (Margenau and Hanson 1996). Survival was significantly higher for the Mud/Calahan Lake population compared to the other four Wisconsin populations and results demonstrated that the Leech Lake population could be introduced into Wisconsin waters and survive but this population showed no significant difference in survival rate compared to local muskellunge. Because these studies have focused on comparisons of populations within one muskellunge stock, there exists a need to evaluate potential survival differences among genetically divergent stocks (Table 1). Stockings of muskellunge into waters where the species has been extirpated or does not naturally occur sustain many muskellunge fisheries, including those in Illinois. In these scenarios, it would be beneficial to know which stocks and populations have the highest survival in the thermal regime of the region to be stocked. In this job, we are investigating differences in survival among stocks and populations of muskellunge in whole-lake, common garden experiments.

PROCEDURES: General stocking and sampling procedures for this job were identical to those presented in Job 101.1 and are therefore are not described here. Because muskellunge stocks were identified in the field by pelvic fin clips, we conducted a laboratory experiment to evaluate the potential for fin clipping to affect fitness characteristics (e.g. foraging, growth). Previous research has suggested that the loss of any single paired fin is equally detrimental to short-term survival (3-mos) and the loss of pelvic fins is less detrimental than loss of a pectoral fin (McNiel and Crossman 1979). Results from the laboratory experiment indicated that there are no significant negative effects of pelvic fin clips on foraging behavior or growth of juvenile muskellunge (Wagner et al. 2009). This information provides evidence that our clipping methods did not differentially affect fitness characteristics (and therefore survival) of the unique stocks.

In previous reports we compared survival rates among stocks by individual year class using adjusted catch-per-unit effort (CPUE) data (adjusted for stocking mortality) from electrofishing (juveniles to age-1) and spring modified fyke net surveys (adults ages 2+). Assessment of juvenile survival rates was also conducted in replicated pond experiments and reported in previous annual reports. The assessment of juvenile survival rates has been completed for Lake Mingo and Pierce Lake and these findings are summarized in this report. Assessment of survival rates of stocks of juvenile muskellunge in Sam Dale Lake is ongoing and in this segment we present comparisons based on CPUE data from nighttime pulse DC electrofishing conducted during fall 2008 and spring 2009.

In this segment we continue a global analysis of adult survival rates in lakes Mingo and Pierce. These analyses have been made possible by the establishment of multiple age classes in Lakes Mingo and Pierce combined with multiple years of catch data from spring modified fyke net surveys. To estimate annual survival and evaluate potential differences between stocks we utilized CPUE data from spring fyke net samples collected 2007-2009 (Lake Mingo) and 2008-2009 (Pierce Lake). Catch rates were used to compare both survival to adulthood and annual survival of adult fish after age 3. To compare survival of each stock to adulthood adjusted CPUE for each age class was calculated and compared among stocks within each lake using a blocked one way ANOVA (blocked by year class). Annual survival estimates for adult fish were calculated by the ratio of CPUE estimates in successive years for each age class (Ricker 1975). This analysis does not require the assumption of constant recruitment (violated in this study due to fluctuating availability of muskellunge source populations) common to many techniques designed for estimation of survival rates (e.g. catch-curves). Analysis was restricted to adult muskellunge year classes (ages 3-7) because these were the year classes fully recruited to the gear (Ricker 1975). Mean annual survival rates of adult fish were then compared between stocks using paired t-tests on pooled survival estimates from ages 3-7 in each lake.

FINDINGS:

Juvenile Survival Summary

In past reports we compared relative survival rates based on adjusted CPUE (adjusted for stocking related mortality) through age-1 of introduced muskellunge in Lake Mingo, Pierce Lake and Sam Dale Lake stratified by stocking year class. Results from year classes 2003 through 2007 in the reservoir experiment are presented in Table 7. Overwinter survival of juvenile muskellunge in Lake Mingo was significantly different among stocks for the 2004, 2006, and 2007-year classes. Overwinter survival of juvenile muskellunge in the 2004-year class was higher for the Upper Mississippi River drainage stock compared to the Illinois population and the Ohio River Drainage stock was intermediate. The 2006-year class in Lake Mingo showed significantly higher survival for Illinois population muskellunge compared to the Ohio River drainage stock and no Upper Mississippi River drainage muskellunge were recovered. The Upper Mississippi River drainage stock again showed higher overwinter survival as compared to the other two stocks for the 2007-year class while the Illinois population and the Ohio River drainage stock had similar survival rates. Overwinter survival was similar among all stocks for the 2003 and 2005-year classes in Lake Mingo.

For age-1 fish, survival in Lake Mingo was significantly different among stocks for the 2003-year class. The Ohio River drainage stock exhibited higher survival to age-1 than the Illinois population and no Upper Mississippi River drainage muskellunge were sampled. Survival to age-1 was similar between the Upper Mississippi River drainage stock and the Illinois population for the 2004-year class while no muskellunge from the Ohio River drainage stock were sampled. Comparisons of survival to age-1 among stocks in Lake Mingo were not possible for year classes 2005-2007 due to low survival of Upper Mississippi River drainage and Ohio River drainage stocks.

Juvenile survival in Pierce Lake was not statistically different either overwinter or through age-1 among stocks of muskellunge introduced from 2003-2007. Low survival of Upper Mississippi River drainage muskellunge to age-1 limited statistical comparisons of catch rates between the Illinois population and Ohio River drainage stock for all year classes except the 2005-year class. There were marginally significant differences in survival to age-1 between the Ohio River drainage stock and the Illinois population for muskellunge introduced in 2003 and 2004 with the Illinois population showing marginally higher survival in 2003 and the Ohio stock having the advantage in 2004.

Juvenile Survival Sam Dale Lake

Year classes of muskellunge were introduced into Sam Dale Lake each year from 2005-2008. The 2005-year class experienced significant stocking related mortality and no fish from this year class have been recovered to date. In 2006 only Illinois population muskellunge were introduced due to a limited availability of muskellunge source populations caused by concerns over the viral hemorrhagic septicemia virus (VHSV). Full introductions of each muskellunge stock were completed in 2007 and 2008. Muskellunge from the 2007-year class showed similar overwinter survival for fish from the Upper Mississippi River drainage stock and Illinois population while no Ohio River drainage muskellunge from this year class were captured. The 2008-year class sampled spring 2009 showed similar survival between the Illinois population and

Ohio River drainage stock and no Upper Mississippi River drainage stock muskellunge were recovered. To date no comparisons of survival to age-1 among stocks have been possible due to low numbers of recaptured muskellunge. In future segments we will begin spring modified fyke net sampling on this lake to assess survival to adulthood.

Adult CPUE and Survival in Lakes Mingo and Pierce

No Upper Mississippi River drainage stock muskellunge were captured in either Lake Mingo or Pierce Lake from summer 2008 through spring 2009. In contrast, CPUE was much higher and allowed survival comparisons for Ohio River drainage and Illinois population muskellunge. Adjusted CPUE of adult muskellunge in Lake Mingo was generally higher for Illinois population muskellunge (mean ± 95% CI = 0.14(±0.13)) compared to the Ohio River drainage stock (mean ± 95% CI = 0.03(±0.13)) but this difference was not statistically significant (ANOVA, Stock $F_{1,3} = 3.44$, $P = 0.16$). Similar to results from Lake Mingo, adjusted CPUE of adult muskellunge in Pierce Lake was not significantly different (ANOVA, Stock $F_{1,2} = 6.67$, $P = 0.12$) between the Illinois population (mean ± 95% CI = 0.30(±0.13)) and the Ohio River drainage stock (mean ± 95% CI = 0.17(±0.17)).

Data from spring fyke net surveys conducted on lakes Mingo and Pierce allowed estimation of annual survival rates for adult muskellunge ages 3-6+ in both lakes (Table 8-9). Due to low numbers of age-6 and greater muskellunge captured across lakes and years these fish were pooled and used to estimate an average survival rate of adult muskellunge after age-5. Average annual survival estimates for adult Illinois population muskellunge in Lake Mingo were 55% for the period from 2007-2008 and 32% from 2008-2009 (Table 8). Averages for the Ohio River drainage stock were 43% for the period from 2007-2008 and 19% from 2008-2009 (Table 8). Survival rates of each stock were compared using a paired t-test (paired by age and time period). No significant difference in average annual survival of adult muskellunge between the Illinois population and Ohio River drainage stock were found (Paired $t = –0.90$; $P = 0.41$) although the mean annual survival estimate for the Illinois population was slightly higher. Because our test indicated no differences in annual survival between the Illinois population and the Ohio River drainage stock we conducted a post hoc power analysis to assess the sensitivity of this test. A power curve (Figure 5) was generated using the pooled variance estimate (0.23), sample size (n =12) and alpha (0.05) from the t-test. Power was plotted against a range of effect sizes from .1 to .5 (stepped by .01) and examination of this curve indicated that the test had a high probability (> 0.80) of detecting a difference in survival greater than 0.25 or 25%. Based on this power analysis and our estimated difference of –0.12, we can be confident that the true difference in average annual survival between adult Illinois population and Ohio River drainage stock muskellunge in Lake Mingo is less than 25%.

Estimates of adult annual survival rates for muskellunge introduced into Pierce Lake were restricted to the period from 2008-2009 due to low numbers of muskellunge captured during spring 2007 fyke netting. The average annual survival estimate for the Illinois population for this time period was 38% while the average for the Ohio River drainage stock was 49% (Table 9). Paired analysis of adult survival found no significant difference between the two stocks (Paired $t = 0.75$; $P = 0.53$) although average survival of the Ohio River drainage stock was slightly higher. A post hoc power analysis was again conducted using the pooled variance estimate (0.17), sample size (n = 6) and alpha (0.05) from the t-test. A power curve (Figure 6) was constructed by plotting power vs. effect size (.1-.5 by 0.01). Examination of the power curve indicated that this test had low probability of detecting differences in survival between stocks of less than around 0.40 or 40%. Future years of data will be required to add precision to survival comparisons in this lake.

Recommendations: Thus far results from the reservoir experiment suggest similar survival between the Illinois population and Ohio River drainage muskellunge and much lower survival for the Upper Mississippi River drainage stock in all lakes. During spring netting surveys of adult muskellunge the Illinois population and the Ohio River drainage stock are consistently represented at similar levels in catches. In contrast only 7 Upper Mississippi River drainage muskellunge have been sampled beyond age-1 in Lake Mingo and 2 adults from this stock have been sampled to date in Pierce Lake. The recapture rate of Upper Mississippi River drainage stock muskellunge has been too low to allow quantitative comparisons with the other stocks and survival of this stock in both lakes is negligible. Results of pond experiments presented in previous reports showed a similar trend of equal survival between the Illinois population and Ohio River drainage stock and lower survival for the Upper Mississippi River drainage stock.

Further fall and spring monitoring of introduced muskellunge will be conducted in each of the three lakes. Of particular interest will be patterns of survival in Sam Dale Lake, the most southern of the lakes stocked in Illinois. Results from the lakes may reveal any latitudinal differences within the state among the introduced stocks. In future years we will begin spring fyke net surveys on Sam Dale Lake and increase spring netting efforts in Lakes Mingo and Pierce. Capturing additional year classes during these spring nettings will be vital for a more powerful assessment of differences between stocks, as current comparisons have had limited power to detect differences in survival of less than around 25%. This long-term data set will allow us to detect any biologically significant differences in longevity or survival between the distinct stocks of muskellunge in Illinois lakes.

Job 101.3. <u>Evaluating diet composition of muskellunge and potential direct and indirect interactions between muskellunge and other piscivorous fishes.</u>

OBJECTIVE: To evaluate diet composition of muskellunge and potential direct and indirect interactions between muskellunge and other piscivorous fishes.

INTRODUCTION: Muskellunge introductions in lakes Mingo, Pierce and Sam Dale have been successful and high density muskellunge fisheries are being developed in the study lakes. The establishment or enhancement of muskellunge fisheries requires not only an understanding of the appropriate source stock, but also the potential effects on the recipient aquatic community. Specifically, the rate that muskellunge populations feed on other ecologically and recreationally important fishes should be considered (Brenden et al 2004). In addition, an introduced top predator such as muskellunge may have important indirect effects by causing behavioral shifts in a common prey resource that can cascade through and alter the aquatic community. Such an effect was observed when introducing a new predator type (pikeperch *Sander lucioperca)* in a German reservoir containing northern pike *Esox lucius*. The introduction of the pelagic pikeperch resulted in a habitat shift of the primary prey (perch *Perca fluviatilis)* to the vegetated littoral zone, leading to an indirect increase in consumption by northern pike (Schulze et al 2006). There are a limited number of studies that have examined diet composition of introduced predators and even fewer have considered potential interactions between stocked game species and other piscivorous top predators (Eby 2006). These uncertainties have allowed angler groups targeting other species to develop antagonistic attitudes towards introduced muskellunge populations that may be unwarranted. Although muskellunge are providing new and exciting fisheries in Illinois waters, it is essential to consider their potential effects on other recreationally and ecologically important sportsfish populations; most notably largemouth bass populations.

Studies of interactions concerning muskellunge and other fish species have examined predatory effects and diet contents in river systems (Brenden et al 2004, Curry et al 2007) northern lakes, (Bozek et al 1999) or waters on the fringe of the native muskellunge range (Krska and Applegate 1982). A few studies exist in the literature, which report competitive or predatory effects in one or two lake systems. For example Becker (1983) attributed muskellunge with the decline of largemouth bass populations in two Wisconsin lakes. Another study documented a decline in black crappie and white sucker populations in Iron Lake, Michigan as a result of muskellunge introduction (Siler and Bayerle 1986). In northern Wisconsin lakes, yellow perch (*Perca flavescens),* catastomids (*Catastomus spp.*), sunfish (*Lepomis spp),* and crappie (*Pomoxis spp.)* dominated muskellunge diets across 34 waterbodies. Catastomid species also dominated the diets of large muskellunge from the New River, Virginia. An ontogenetic diet shift was noted in muskellunge from both the New River where fish switched from smaller prey fish to larger catastomids at around 800 mm (Brenden 2004). While these studies are useful to understanding muskellunge interactions in these respective regions they are of limited value to Illinois and other lower Midwestern fisheries managers working on systems with differing predator and prey assemblages. Published studies on muskellunge diet in southerly and lower midwestern reservoirs have been limited to a study of young-of-year diets in five Ohio reservoirs and fish up to age-3 in one reservoir (Wahl and Stein 1988, Wahl and Stein 1991). In Ohio reservoirs juvenile muskellunge diet was dominated by gizzard shad (*Dorosoma cepedianum)* in summer and early fall and sunfish and brook silverside (*Labidesthes sicculus*) in late fall and spring. In these Ohio reservoirs Wahl and Stein (1988) concluded that, where present, gizzard shad are a preferred prey of esocids in these systems. While these studies provide a beginning to understanding muskellunge interactions with other fish species there exists no rigorous evaluation of the broader community effects or fishery implications of muskellunge introduction in midwestern lakes.

In this job, we are investigating dietary habits, community effects, and fishery impacts of muskellunge introduction on a number of Illinois lakes with differing morphological and biotic characteristics. Knowledge of the preference and rate at which muskellunge feed upon recreationally valuable sport fish as well as their broader ecological effects on aquatic communities is vital information to fisheries managers considering the development of muskellunge fisheries in midwestern lakes. In this job, we continue investigation of the dietary habits and ecological consequences of muskellunge stocking. Future work will expand upon the analysis of lakes with muskellunge introductions utilizing additional data from the Illinois Fishery Analysis System (FAS) database and continued diet sampling.

PROCEDURES:

Muskellunge Food Habits

Diet samples were collected from 591 muskellunge between summer 2007 and spring 2009 across six Illinois lakes including Lakes Mingo, Pierce, Ridge, Sam Dale, Shelbyville, and Lake of the Woods. The majority of muskellunge were sampled using methods identical to those presented in Job 101.1. All sampling consisted of nighttime pulsed DC electrofishing with the exception of fish sampled during annual modified fyke netting surveys (spring 2008 and 2009) in lakes Mingo and Pierce and angled fish sampled as part of the long term creel on Ridge Lake (May – November 2007-2008). Diet contents were removed from all sizes of muskellunge sampled via pulsed gastric lavage (Foster 1977). Diet samples were labeled with the date, location, length and weight of muskellunge, stored in plastic bags and immediately frozen upon return from the field. Diet samples were later thawed, measured for total, fork, or backbone length, weighed and identified to species using scales and muscle tissue (Oates et al. 1993). Three muskellunge were sacrificed and later dissected to verify that lavage completely sampled all gut contents. Measurements of prey length were used to back-calculate wet weight of each item using regression equations from Wahl and Stein (1988), Anderson and Neuman (1996), and Bozek et al. (1999). Data were then used to calculate frequency of occurrence and proportion by weight of prey species found in muskellunge diets.

Community Effects of Muskellunge Stocking

The study sites for evaluation of community effects of muskellunge introduction include Lake Mingo, and Ridge Lake (Coles County), while reference waters include Homer Lake (Champaign County), and Lincoln Trail Lake (Clark County). These lakes have been monitored since fall of 1998 as part of ongoing or previous Federal Aid in Sport Fish Restoration Projects (F-135-R, Factors influencing largemouth bass recruitment and stocking and F-128-R, Quality management of bluegill populations). Data have been collected on relative abundance of fish species, larval fish density, benthic macroinvertebrate density, zooplankton density, chlorophyll a concentration, water clarity, total phosphorous, temperature and dissolved oxygen using standard methodologies (for specific sampling details see Diana et al. 2009). Lake Mingo was initially stocked with muskellunge in 2002 and Ridge Lake was initially stocked in 2005. Each lake has received annual stockings of 8-10 inch muskellunge each fall since the initial stockings. Changes to community parameters in Lakes Mingo and Ridge were analyzed using a paired before-after control-impact design (BACIP, Underwood 1994) due to a lack of replicates for some parameters. Paired analysis using waters from the same geographic area has been suggested as a better approach to whole lake studies when replicates of impacted locations are limited (Carpenter 1989).

In past reports we presented initial analysis of the effects of muskellunge introduction on the relative abundance of largemouth bass (a potential competitor) and size structure of gizzard shad (the primary prey species) in Lake Mingo; utilizing Homer Lake as a reference. In this segment we expand this analysis to include effects on bluegill relative abundance, zooplankton density and size, algal biomass, and total phosphorous concentration. In addition we present analysis of these parameters in response to muskellunge introduction in Ridge Lake using Lincoln Trail Lake as a reference. Data collection is ongoing and will continue to be collected in subsequent years. In this segment we present data through 2007, as data from 2008-2009 has not yet been processed. Data from fall (September-November, electrofishing CPUE) or summer (June-August, zooplankton, chlorophyll, total phosphorous) sample dates were averaged to produce a single measurement for each year. Data were analyzed using a paired BACI design suited to a repeated measures analysis of variance (Keough and Mapstone 1995) to test for impacts on each parameter in separate analyses.

Fishery Effects of Muskellunge Stocking

To provide a broader analysis of the potential impacts of muskellunge introductions on existing Illinois fisheries, an additional set of muskellunge lakes (N = 9) and reference waters (N = 7) have been identified for potential analysis by examination of stocking records from the Illinois DNR. These lakes received initial muskellunge introductions around the year 2000 and DNR biologists have conducted multiple pre and post introduction fisheries surveys on each lake. This data is being acquired and compiled using the Illinois Fisheries Analysis System (FAS) and will be used to evaluate trends for common fisheries parameters including CPUE (number/hr), and size structure (PSD) of important game species including largemouth bass, bluegill and black crappie before and after muskellunge introduction. In order to select candidate lakes for this analysis, we are comparing average CPUE of stock-length and larger muskellunge from standardized fall electrofishing surveys over the six-year period from 2002-2008 in candidate lakes to the catch rates of two lakes with known high-density populations (lakes Mingo and Pierce). By selecting lakes with electrofishing catch rates similar to these known established populations we can be confident that lakes selected for analysis also have significant muskellunge populations and are valid to use for comparisons. In this segment we present analysis of data from a subset of selected lakes including Shovel, Mill Creek and Staunton City. These treatment lakes had average electrofishing catch rates of stock length or greater muskellunge (2002-2008), which were not significantly different from lakes with known established populations (ANOVA, $F_{1,33} = 1.62$, $P = 0.21$). Reference lakes consisted of lakes monitored by the Illinois Natural History Survey as part of Federal Aid in Sport Fish Restoration Projects (F-135-R, Factors influencing largemouth bass recruitment and stocking and F-128-R, Quality management of bluegill populations) and included Lake Bloomington and Lake Leaquana. Fisheries surveys on these lakes were modeled after standard Illinois DNR electrofishing protocols and therefore were collected in a manner nearly identical to those of DNR biologists. In this segment we report analysis of responses of largemouth bass relative abundance (CPUE N/Hr) and size structure (PSD) from muskellunge stocking utilizing data from four years prior and four years after introduction.

Data analysis in the previous segment focused on community wide effects of muskellunge stocking in Lakes Mingo and Ridge using a paired design of waters from the same geographic region. The replicate stocked and reference waters available in this segment allowed the application of a more robust multiple before-after control-impact (MBACI) design. This experimental design is considered among the most scientifically sound methodologies of detecting impacts in natural systems (Kough and Quinn 2000) and was implemented by the fitting of a linear mixed model using SAS® software. Model terms included main factors of treatment (Trt; stocked or unstocked), and before-after (Period), with lakes (L) nested in Trt and years (Y) nested in Period followed by interactions. The three terms that included lakes were considered random (because lakes were considered a random effect in the model) and the remaining terms were considered fixed. The Trt*Period interaction measures any change associated with the onset of the muskellunge introduction.

FINDINGS:

Muskellunge Food Habits

Stomach contents of 234 muskellunge from six Illinois lakes were sampled between March 2008 and November 2009 yielding 88 diet items (151 fish had empty stomachs). Diet samples collected during this segment were pooled with data from previous years to greater describe the diet of muskellunge in each of the study lakes. Muskellunge sampled since summer 2007 ranged from 294-1119 mm and were collected via electrofishing (all lakes), spring fyke netting (lakes Mingo and Pierce), or creel survey (Ridge Lake). Gizzard shad were the dominant diet item by frequency and wet weight in Lakes Mingo (Figure 7) Pierce (Figure 8) and Sam Dale (Figure 9), whereas bluegill were the dominant diet item in Ridge Lake (Figure 10) Bluegill were a secondary prey species in Mingo and Pierce, while largemouth were the secondary species in Ridge Lake. Low sample sizes, multiple unidentifiable diet items, and a high percentage of fish with empty stomachs at the time of sampling limited our ability to describe the Lake Shelbyville and Lake of the Woods diets. Other species found included: brook silverside (Pierce and Sam Dale), yellow bullhead (Mingo), white bass (Shelbyville) and yellow perch (Pierce). Of all muskellunge captured, 55.8% had empty stomachs at the time of sampling. Findings from this segment were similar to those of the previous year. Gizzard shad are the most abundant prey item in lakes where they are present (Lakes Mingo, Sam Dale, and Pierce). In Ridge Lake, gizzard shad are not present and bluegills were found to be the dominant prey item. Largemouth bass comprised a very small percentage of the overall muskellunge diet but become a more important secondary diet item in the absence of gizzard shad (Figure 10). These findings are similar to other studies that have shown gizzard shad to be the dominant prey item in Ohio impoundments and that muskellunge prefer gizzard shad when present (Wahl and Stein 1988).

Community Effects of Muskellunge Stocking

We previously reported detecting no significant negative effects of muskellunge introduction on largemouth bass relative abundance in Lake Mingo utilizing data from four years before (1998-2001) and after muskellunge stocking (2002-2005). In this segment we reanalyzed largemouth bass and bluegill CPUE after including 2 additional years of data (2006-2007). We found no significant change in either largemouth bass or bluegill relative abundance in response to muskellunge introduction after six years of muskellunge stocking (Table 10). In addition we found no significant effects of muskellunge introduction on other important components of the aquatic food web including zooplankton (cladoceran density/size), phytoplankton (chl a) or nutrients (total phosphorous, Table 10). Thus far we have found few significant effects of muskellunge introduction on the aquatic food web of Lake Mingo. In future segments we will continue comparison of community parameters including larval fish density, littoral prey density and prey size structure before and after muskellunge introduction.

Effects of muskellunge on the aquatic community in Ridge Lake were similar to those from Lake Mingo. We found no significant effects of muskellunge introduction on the relative abundance of largemouth bass or bluegill sunfish in Ridge Lake based on data from three years before (2003-2005) and three years after (2006-2008) stocking. In addition we detected no significant changes in other food web components including zooplankton (cladoceran density), phytoplankton (chl a) or nutrients (total phosphorous, Table 10). We did find a significant change in cladoceran length ($t = 2.33$, $P = 0.05$); however after viewing the data, we determined that this effect was due to a change in the control lake (Lincoln Trail Lake) that was not present in Ridge Lake and is likely not due to any treatment effect. In future segments we will continue comparisons of additional community parameters and incorporate additional years of data as available.

Fishery Effects of Muskellunge Stocking

No significant effect of muskellunge introduction on the PSD of largemouth bass was found utilizing data from three stocked and two reference lakes four years before and after muskellunge stocking (ANOVA, Trt*Period $F_{1,3} = 0.01$, $P = 0.92$). The mean PSD values for both stocked and reference lakes were nearly unchanged after muskellunge introduction (Figure 11). Similarly, there was no significant effect of muskellunge introduction on the relative abundance (CPUE) of largemouth bass (ANOVA, Trt*Period $F_{1,3} = 0.28$, $P = 0.63$). Mean CPUE increased slightly for both stocked and reference lakes after muskellunge introduction and the increases were of similar magnitude for both sets of lakes (Figure 12). In future segments we will expand our analysis of abundance and size structure of important game species in response to muskellunge introduction by increasing the number of lakes included in the dataset and including additional species and size structure metrics.

Recommendations: The second year of muskellunge diet information has continued to show a consistent pattern of little predation on largemouth bass or other game species. Diet information from Lakes Mingo, Pierce, Sam Dale and Shelbyville indicates that gizzard shad make up the bulk of muskellunge diet wherever they are available. These findings suggest that muskellunge are not responsible for significant amounts of direct predation on most popular game species where gizzard shad are present. Diet composition from Ridge Lake shows that when gizzard shad or other soft rayed prey are not present, bluegill become the primary diet item making up more than 80 % of the diet. In these types of lakes largemouth bass become a more common prey item (although still less than 15 % of the total diet). Despite the heavy reliance of the Ridge Lake muskellunge population on bluegill prey, there has not been a significant effect on population abundance or cascading effects on other parts of the aquatic community. As sample sizes increase in future years we will begin to examine seasonal trends in muskellunge diet both within and across lakes. Of particular interest to management is the potential for seasonal or annual declines in the abundance of preferred prey, which may increase predation pressure on game species and/or increase competition with other top predators such as largemouth bass. Past diet information on muskellunge in Ohio reservoirs found that low abundance of gizzard shad in spring resulted in diversification of prey and may lead to seasonal increases in predation on game species like bluegill and largemouth bass (Wahl and Stein 1988). In addition, future analyses will examine diet data by size class of muskellunge to allow for detection of any ontogenetic changes in diet composition. Examination of multiple years and seasons of muskellunge diet will enhance our ability to detect possible changes in diet composition in response to fluctuations in abundances of preferred prey species such as gizzard shad. Knowledge of seasonal and annual patterns in muskellunge diet will provide insight into responses to fluctuations in primary prey species, which may alter both direct (predation) and indirect (competition) interactions with established recreational species. This information will provide evidence of the potential for muskellunge to impact established fisheries through predation which will enable managers to better respond to angler concerns about muskellunge introductions into their local waters.

Examination of community responses of Lake Mingo and Ridge Lake to muskellunge introduction has shown little effects of stocking this predator. In addition we found no significant effects of muskellunge introduction on the abundance of largemouth bass across five Illinois lakes or on the proportional stock density of largemouth bass across three lakes. Aquatic food webs of Illinois lakes appear to be resilient to perturbations of top predator biomass. While the specific reasons for this resilience are not completely clear, the most obvious hypothesis is that prey production (especially gizzard shad) outpaces piscivore demand in these highly productive lakes. Other possible mechanisms include compensatory reproductive output by prey species, and low diet overlap between muskellunge and other piscivorous fishes. Largemouth bass are known to draw a significant portion of their energy from macroinvertebrates and other benthic resources (Vander Zanden et al. 2005), which may reduce the potential for competition with muskellunge. In future segments additional replicate lakes will be added to these analyses which will allow us to make strong inferences concerning the potential effects of muskellunge introduction on important recreational species of Illinois Lakes.

Job 101.4. 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 – 101.3 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.

LITERATURE CITED

Anderson, R.O., Neumann, R.M. 1996. Length, weight and associated structural indices. Pages 447-482 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland

Altukhov, Y.P. 1981. The stock concept from the viewpoint of population genetics. Canadian Journal of Fisheries and Aquatic Sciences 38: 1523-1538.

Begg, G.A., K.D. Friedland, and J.B. Pearce. 1999. Stock identification and its role in stock assessment and fisheries management: an overview. Fisheries Research 43: 1-8.

Belk, M.C., J.B. Johnson, K.W. Wilson, M.E. Smith, and D.D. Houston. 2005. Variation in intrinsic individual growth rate among populations of leatherside chub (*Snyderichthys copei* Jordan & Gilbert): adaptation to temperature or length of growing season? Ecology of Freshwater Fish 14: 177-184.

Bevelhimer, M.R., R.A. Stein, and R.F. Carline. 1985. Assessing significance of physiological differences among three esocids with a bioenergetics model. Canadian Journal of Fisheries and Aquatic Sciences 42: 57-69.

Beverton, R..J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fishery Invest. Lond. Ser. 2. 19: 533 pp.

Brenden, T.O., E.M. Hallerman, and B.R. Murphy. 2004. Predatory impact of muskellunge on New River, Virginia, smallmouth bass. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 58:12-22.

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

Boxrucker, J.C. 1982. Mass marking of fingerling largemouth bass by fin-clipping followed by freeze-cauterization of the wound. North American Journal of Fisheries Management 2: 94-96.

Bozek, M.A., T.M. Burri, and R.V. Frie. 1999. Diets of muskellunge in northern Wisconsin lakes. North American Journal of Fisheries Management 19:258-270.

Brenden, T.O., E.M. Hallerman, B.R. Murphy, J.R. Copeland, and J.A. Williams. 2007. The New River, Virginia, muskellunge fishery: population dynamics, harvest regulation modeling, and angler attitudes. Environmental Biology of Fishes 79:1-2, 11-25.

Carline, R.F., R.A. Stein, and L.M. Riley. 1986. Effects of size at stocking, season, largemouth bass predation, and forage abundance on survival of tiger muskellunge, Pages 151-167 *in*

G. E. Hall, editor. Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland, USA.

Carpenter S.R. 1989. Replication and treatment strength in whole-lake experiments. Ecology 70(2): 453-463.

Casselman, J.M. and E.J. Crossman. 1986. Size, age, and growth of trophy muskellunge and muskellunge-northern pike hybrids—the cleithrum project, 1979-1983. American Fisheries Society Special Publication 15:93-110.

Clapp, D.F., Y. Bhagwat, and D.H. Wahl. 1997. The effect of thermal stress on walleye fry and fingerling mortality. North American Journal of Fisheries Management 17: 429-437.

Clapp, D.F. and D.H. Wahl. 1996. Comparison of food consumption, growth, and metabolism among muskellunge – an investigation of population differentiation. Transactions of the American Fisheries Society 125: 402-410.

Conover, D.O. and T.M.C. Present. 1990. Countergradient variation in growth rate: compensation for length of the growing season among Atlantic silversides from different latitudes. Oecologia 83: 316-324.

Conover, D.O., J.J. Brown, and A. Ehtisham. 1997. Countergradient variation in growth of young striped bass (*Morone saxatilis*) from different latitudes. Canadian Journal of Fisheries and Aquatic Sciences 54: 2401-2409.

Crossman, E.J. 1978. Taxonomy and distribution of North American esocids. Pages 13-26 *in* R.L. Kendall, editor. Selected coolwater fishes of North America. American Fisheries Society, Special Publication 11, Washington, D.C., USA.

Crossman, E.J. 1986. The noble muskellunge: a review. Pages 1-13 *in* G.E. Hall, editor. Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland, USA.

Curry, A.R., 2007. Using movements and diet analyses to assess effects of introd muskellunge (*Esox masquinongy)* on Atlantic salmon *(Salmo salar)* in the Saint John River, New Brunswick. Environmental Biology of Fish 79:49-60.

DiMichele, L. and M.E. Westerman. 1997. Geographic variation in development rate between populations of the teleost *Fundulus heteroclitus*. Marine Biology 128: 1-7.

Eby, L.A., W.J. Roach, L.B. Crowder, J.A. Stanford. 2006. Effects of stocking up freshwater food webs. Trends in Ecology and Evolution 21(10): 576-584.

Ferguson, G.W., and L.G. Talent. 1993. Life-history traits of the lizard *Sceloporus undulates* from two populations raised in a common laboratory environment. Oecologia 93:88-94.

Foster, J.R. 1977. Pulsed gastric lavage - efficient method of removing the stomach contents of live fish. The Progressive Fish-Culturist 39:166-169.

Galarowicz, T.L. and D.H. Wahl. 2003. Differences in growth, consumption, and metabolism among walleyes from different latitudes. Transactions of the American Fisheries Society 132: 425-437.

Gotthard, K., S. Nylin, and C. Wiklund. 1994. Adaptive variation in growth rate: life history costs and consequences in the speckled wood butterfly, *Pararge aegeria*. Oecologia 99:281-289.

Hanson, D.A. 1986. Population characteristics and angler use of muskellunge in eight northern Wisconsin lakes. American Fisheries Society Special Publication 15:238-248.

Henderson, P.A., R.H.A. Holmes, and R.N. Bamber. 1988. Size-selective overwintering mortality in the sand smelt, *Atherina boyeri* Risso, and its role in population regulation. Journal of Fish Biology 33:221-233.

Hubbs, C.L. and K.F. Lagler. 1958. Fishes of the Great Lakes region. Cranbrook Institute of Science Bulletin 26.

Hutchinson, G.E. 1958. Concluding remarks. Cold Spring Harbor Symposia on Quantitative Biology 22:415-427.

Ihssen, P.E., D.O. Evans, W.J. Christie, J.A. Reckahn, and R.L. DesJardine. 1981. Life history, morphology, and electrophoretic characteristics of five allopatric stocks of lake whitefish *Coregonus clupeaformis* in the Great Lakes region. Canadian Journal of Fisheries and Aquatic Sciences 38: 1790-1807.

Jonassen, T.M., A.K. Imsland, R. Fitzgerald, S.W. Bonga, E.V. Ham, G. Naevdal, M.O. Stefansson, and S.O. Stefansson. 2000. Geographic variation in growth and food consumption efficiency of juvenile Atlantic halibut related to latitude. Journal of Fish Biology 56: 279-294.

Keough, M.J. and B.D. Mapstone. 1995. Protocols for designing marine ecological monitoring programs associated with BEK Mills. National Pulp Mills Research Program Technical Report no. 11. Canberra, ACT: CSIRO.

Keough, M.J. and G. P. Quinn. 2000. Legislative vs. practical protection of an Intertidal shoreline in southeastern Australia. Ecological Applications 10:871-881.

Koppelman, J.B. and D.P. Philipp. 1986. Genetic applications in muskellunge management Pages 111-121 *in* G.E. Hall, editor. Managing Muskies. American Fisheries Society, SpecialPublication 15, Bethesda, Maryland, USA.

Krska, R.J. Jr., and R.L. Applegate. 1982. Food of young muskellunge in a power plant cooling reservoir. The Progressive Fish Culturist 44: 172-173.

Leitner, J., and Bulak, J. 2008. Performance differences between two endemic stocks of Largemouth Bass in South Carolina. North American Journal of Fisheries Management 28: 516-522.

Levinton, J.S. 1983. The latitudinal compensation hypothesis: growth data and a model of latitudinal growth differentiation based upon energy budgets. I. interspecific comparison of *Ophryotrocha* (Polychaeta: Dorvilleidae). Biological Bulletin (Woods Hole) 165: 686-698.

Levinton, J.S. and R.K. Monahan. 1983. The latitudinal compensation hypothesis: growth data and a model of latitudinal growth differentiation based upon energy budgets. II. intraspecific comparisons between subspecies of *Ophryotrocha puerilis* (Polychaeta: Dorvilleidae). Biological Bulletin (Woods Hole) 165: 699-707.

Lonsdale, D.J. and J.S. Levinton. 1985. Latitudinal differentiation in copepod growth: an adaptation to temperature. Ecology 66: 1397-1407.

Luey, J.E. and I.R. Adelman. 1984. Stock structure of rainbow smelt in western Lake Superior: population characteristics. Transactions of the American Fisheries Society 113: 709-715.

MacLean, J.A. and D.O. Evans. 1981. The stock concept, discreteness of fish stocks, and fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 38: 1889 1898.

MacLean, J.A., D.O. Evans, N.V. Martin, and R.L. DesJardine. 1981. Survival, growth, spawning distribution, and movements of introduced and native lake trout *Salvelinus namaycush* in two inland Ontario Lakes. Canadian Journal of Fisheries and Aquatic Sciences 38: 1685-1700.

Margenau, T.L. and S.P. AveLallemant. 2000. Effects of a 40-inch minimum length limit on muskellunge in Wisconsin. North American Journal of Fisheries Management 10:986 993.

Margenau, T.L. and D.A. Hanson. 1996. Survival and growth of stocked muskellunge: effects of genetic and environmental factors. Wisconsin Department of Natural Resources Research Report 172 172: 1-11.

McClane, A.J. 1974. McClane's field guide to freshwater fishes of North America. Holt, Rinehart, and Winston, New York, NY, USA.

McNeil, F.I. and E.J. Crossman. 1979. Fin clips in the evaluation of stocking programs for muskellunge *Esox masquinongy*. Transactions of the American Fisheries Society 108: 335-343.

Midwest Regional Climate Center (MRCC). 2004. http://mcc.sws.uiuc.edu/

National Oceanic and Atmospheric Administration (NOAA). 2004. http://www.noaa.gov/

New York State Climate Office (NYSCO). 2004. http://nysc.eas.cornell.edu/

Nicieza, A.G., F.G. Reyes-Gavilan, and F. Brana. 1994. Differentiation in juvenile growth and bimodality patterns between northern and southern populations of Atlantic salmon (*Salmo salar* L.). Canadian Journal of Zoology 72: 1603-1610.

Oates, D.W., L.M. Krings, and K.L. Ditz. 1993. Field manual for identification of selected North American freshwater fish by fillets and scales. Nebraska Game and Parks Commission, Nebraska Technical Series 19, Lincoln.

Pennsylvania State Climatologist (PSC). 2004. http://pasc.met.psu.edu/PA_Climatologist/index.php

Philipp, D.P. and J.E. Claussen. 1995. Fitness and performance differences between two stocks of largemouth bass from different river drainages within Illinois. American Fisheries Society Symposium 15: 236-243.

Post, J.R., and D.O. Evans. 1989. Size-dependent over-winter mortality of young-of-the-year yellow perch (*Perca flavescens*): laboratory, in situ enclosure, and field experiments. Canadian Journal of Fisheries and Aquatic Sciences 46:1958-1968.

Riha, V.F., and K.A. Berven. 1991. An analysis of latitudinal variation in the larval development of the Wood Frog (*Rana sylvatica*). Copeia 1991:209-221.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191. 382 pp.

Shaklee, J. B., and K. P. Currens. 2003. Genetic stock identification and risk assessment. Pages 291–328 in E. M. Hallerman, editor. Population genetics: principles and applications for fisheries scientists. American Fisheries Society, Bethesda, Maryland.

Schultz, E.T., K.E. Reynolds, and D.O. Conover. 1996. Countergradient variation in growth among newly hatched *Fundulus heteroclitus*: geographic differences revealed by common-environment experiments. Functional Ecology 10: 366-374.

Schulze, T., and coauthors. 2006. Response of the residential piscivorous fish community to introduction of a new predator type in a mesotrophic lake. Canadian Journal of Fisheries and Aquatic Sciences 63(10):2202-2212.

Siler, D. H. and G. B. Beyerle. 1986. Introduction and management of northern muskellunge in Iron Lake, Michigan. American Fisheries Society Special Publication 15: 257-262.

Smith, P.W. 1979. The fishes of Illinois. University of Illinois Press, Urbana, Illinois, USA.

Underwood, A. J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4(1):3-15.

Vander Zanden, M.J., T. E. Essington, and Y. Vadeboncoeur. 2005. Is pelagic top-down control in lakes augmented by benthic energy pathways? Canadian Journal of Fisheries and Aquatic Sciences 62: 1422-1431.

Wagner, C.P., M.J. Jennings, J.M. Kampa, and D.H. Wahl. 2007. Survival, growth, and tag retention in age-0 muskellunge implanted with passive integrated transponders. North American Journal of Fisheries Management 27: 873-877.

Wagner, C.P., L.M. Einfalt, A. Scimone, and D.H. Wahl. 2009. Effects of fin-clipping on the foraging behavior and growth of age-0 muskellunge. North American Journal of Fisheries Management. In Press.

Wahl, D.H. and Stein, R.A. 1991. Food consumption and growth of three esocids field tests of a bioenergetic model. Transactions of the American Fisheries Society 120: 230-246.

Wahl, D.H. and R.A. Stein. 1989. Comparative vulnerability of three esocids to largemouth bass *Micropterus salmoides* predation. Canadian Journal of Fisheries and Aquatic Sciences 46: 2095-2103.

Wahl, D.H., and R. A. Stein. 1988. Selective predation by three esocids: the role of prey behavior and morphology. Transactions of the American Fisheries Society 117(2): 142-151.

Wingate, P.J., and J.A. Younk. 2007. A program for successful muskellunge management -A Minnesota success story. Environmental Biology of Fishes 79: 163-169.

Yamahira, K. and D.O. Conover. 2002. Intra- vs. interspecific latitudinal variation in growth: adaptation to temperature or seasonality? Ecology 83: 1252-1262.

Younk, J.A. and R.F. Strand. 1992. Performance evaluation of four muskellunge *Esox* *masquinongy* strains in two Minnesota lakes. Minnesota Department of Natural Resources Section of Fisheries Investigational Report No. 418. pp 22.

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 Sam Dale Lake during falls 2002-2008. Adjusted number of fish and number per hectare account for initial mortality as determined by mortality cage estimates. 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: Stocked	Number of Fish: Adjusted	Number per Hectare: Stocked	Number per Hectare: Adjusted	Mean Length (mm)	Mean Weight (g)
			2002						
Mingo	OH	Cave Run Lake, KY	October 30, 2002	171	171	2.4	2.4	315 (±7.5)	155 (±8.2)
	IL	North Spring Lake, IL	October 24, 2002	400	400	5.6	5.6	336 (±5.6)	200 (±11.7)
			2003						
Pierce	MISS	Leech Lake, MN	November 7, 2003	100	100†	1.6	1.6	197 (±5.0)	28 (±2.5)
	OH	Lake Chautauqua, NY	September 19, 2003	234	234†	3.8	3.8	225 (±2.6)	44 (±1.7)
	IL	North Spring Lake, IL	August 29, 2003	500	500†	8.2	8.2	258 (±3.3)	77 (±2.9)
Mingo	MISS	Leech Lake, MN	October 31, 2003	285	285	4.0	4.0	237 (±9.0)	60 (±7.7)
	OH	Clear Fork Lake, OH	September 4, 2003	288	288	4.0	4.0	227 (±2.5)	56 (±2.2)
	IL	North Spring Lake, IL	August 29, 2003	500	433	7.0	6.0	258 (±3.3)	77 (±2.9)

Table 2. Continued.

Lake	Stock	Population	Stocking Date	Number of Fish		Number per Hectare		Mean Length (mm)	Mean Weight (g)
				Stocked	Adjusted	Stocked	Adjusted		
			2004						
Pierce	MISS	Leech Lake, MN	October 29, 2004	200	200†	3.3	3.3	287 (±7.9)	96 (±9.7)
	OH	Cave Run Lake, KY	September 14, 2004	242	242†	4.0	4.0	261 (±5.0)	76 (±5.1)
	IL	North Spring Lake, IL	August 26, 2004	300	300†	4.9	4.9	272 (±4.7)	88 (±5.1)
Mingo	MISS	Leech Lake, MN	October 30, 2004	193	193	2.7	2.7	280 (±8.2)	85 (±9.1)
	OH	Clear Fork Lake, OH	September 14, 2004	245	147	3.4	2.1	261 (±5.6)	74 (±5.3)
	IL	North Spring Lake, IL	August 27, 2004	300	293	4.2	4.1	273 (±4.6)	88 (±5.3)

Table 2. Continued.

Lake	Stock	Population	Stocking Date	Number of Fish		Number per Hectare		Mean Length (mm)	Mean Weight (g)
				Stocked	Adjusted	Stocked	Adjusted		
			2005						
Pierce	MISS	Leech Lake, MN	October 10, 2005	166	154	2.7	2.5	235 (±5.1)	50 (±3.7)
	OH	Clear Fork Lake, OH	September 24, 2005	302	161	4.9	2.6	261 (±4.1)	75 (±3.8)
	IL	North Spring Lake, IL	August 31, 2005	300	300†	4.9	4.9	270 (±4.6)	87 (±5.1)
Mingo	MISS	Leech Lake, MN	October 11, 2005	193	186	2.7	2.6	233 (±5.5)	48 (±3.8)
	OH	Chautauqua Lake, NY	September 28, 2005	196	196	2.7	2.7	234 (±3.7)	45 (±2.3)
	IL	North Spring Lake, IL	August 30, 2005	325	325	4.5	4.5	267 (±4.8)	79 (±5.8)
Sam Dale	MISS	Leech Lake, MN	November 16, 2005	192	185	2.4	2.4	255 (±5.9)	57 (±4.9)
	OH	Cave Run Lake, KY	August 19, 2005	306	10‡	3.9	0.1	232 (±5.0)	56 (±3.5)
	OH	Clear Fork Lake, OH	September 23, 2005	306	115‡	3.9	1.5	261 (±4.1)	75 (±3.8)
	IL	North Spring Lake, IL	August 31, 2005	300	186	3.8	2.4	273 (±4.1)	88 (±5.2)

Table 2. Continued.

Lake	Stock	Population	Stocking Date	Number of Fish		Number per Hectare		Mean Length (mm)	Mean Weight (g)
				Stocked	Adjusted	Stocked	Adjusted		
			2006						
Pierce	IL	North Spring Lake, IL	August 23, 2006	303	303†	5.0	5.0	286 (±6.3)	116 (±8.8)
Mingo	OH	Cave Run Lake, KY	August 16, 2006	332	192	4.6	2.7	244 (±5.3)	66 (±5.9)
	IL	North Spring Lake, IL	August 23, 2006	302	282	4.2	3.9	281 (±7.6)	112 (±10.1)
Sam Dale	IL	North Spring Lake, IL	August 23, 2006	303	20	3.9	0.3	278 (±7.2)	106 (±10.0)

Table 2. Continued.

Lake	Stock	Population	Stocking Date	Number of Fish		Number per Hectare		Mean Length (mm)	Mean Weight (g)
				Stocked	Adjusted	Stocked	Adjusted		
			2007						
Pierce	MISS	Leech Lake, MN	November 29, 2007	250	250	4.1	4.1	325 (±7.2)	153 (±10.9)
	OH	Clear Fork Lake, OH	September 27, 2007	263	263	4.3	4.3	234 (±5.4)	55 (±4.3)
	IL	Spirit Lake, IA*	September 13, 2007	300	300	4.9	4.9	285 (±4.2)	125 (±6.0)
Mingo	MISS	Leech Lake, MN	November 30, 2007	270	270	3.8	3.8	326 (±7.6)	155 (±11.5)
	OH	Cave Run Lake, KY	August 2, 2007	397	267	5.5	3.7	231 (±4.0)	54 (±2.8)
	IL	Spirit Lake, IA*	September 13, 2007	300	293	4.2	4.1	286 (±3.7)	126 (±5.5)
Sam Dale	MISS	Leech Lake, MN	November 30, 2007	260	260	3.3	3.3	325 (±7.6)	156 (±11.5)
	OH	Clear Fork Lake, OH	September 27, 2007	318	312	4.1	4.0	232 (±5.2)	54 (±4.1)
	IL	Spirit Lake, IA*	September 13, 2007	300	300†	3.8	3.8	284 (±4.0)	124 (±5.7)

Table 2. Continued.

Lake	Stock	Population	Stocking Date	Number of Fish		Number per Hectare		Mean Length (mm)	Mean Weight (g)
				Stocked	Adjusted	Stocked	Adjusted		
			2008						
Sam Dale	MISS	Leech Lake, MN	November 19, 2008	257	257	3.3	3.3	217 (±5.4)	40 (±3.2)
	OH	Cave Run Lake, KY	November 18, 2008	193	193	2.5	2.5	338 (±7.3)	174 (±14.2)
	IL	North Spring Lake, IL	August 24, 2008	300	300	3.8	3.8	290 (±5.8)	119 (±7.9)

†Mortality cages not utilized due to logistical constraints

*Eggs obtained from Iowa Department of Natural Resources and reared at the Jake Wolf Fish Hatchery, Illinois Department of Natural Resources

Table 3. Analysis-of-variance type III tests of the fixed main effect of stock on relative daily growth rates of three stocks (OH: Ohio River drainage stock, MISS: Upper Mississippi River drainage stock, IL: Illinois population) of age-0 muskellunge introduced into Mingo and Pierce Lakes, Illinois, during fall 2003-2007 and Sam Dale Lake 2005-2008. The overwinter period represents the 6 months following stocking and age-1 fall represents one year after stocking.

Lake	Stocking year class	Time period	Num *DF*	Den *DF*	F	P
Mingo	2003	Overwinter	2	61	1.07	0.35
Mingo	2004	Overwinter	2	60	57.77	<0.0001
Mingo	2005	Overwinter	2	11	5.94	0.018
Mingo	2006	Overwinter	.	.	.	.
Mingo	2007	Overwinter	2	26	0.21	0.81
Mingo	2003	Age-1 Fall	1	16	1.05	0.32
Mingo	2004	Age-1 Fall	.	.	.	.
Mingo	2005	Age-1 Fall	.	.	.	.
Mingo	2006	Age-1 Fall	.	.	.	.
Mingo	2007	Age-1 Fall	.	.	.	.
Pierce	2003	Overwinter	2	19	13.21	0.0003
Pierce	2004	Overwinter	2	23	13.93	0.0001
Pierce	2005	Overwinter	2	31	5.01	0.013
Pierce	2006	Overwinter	.	.	.	.
Pierce	2007	Overwinter	2	7	1.30	0.33
Pierce	2003	Age-1 Fall	1	7	0.07	0.80
Pierce	2004	Age-1 Fall	1	5	0.39	0.56
Pierce	2005	Age-1 Fall	2	7	0.05	0.95
Pierce	2006	Age-1 Fall	.	.	.	.
Pierce	2007	Age-1 Fall	.	.	.	.
Sam Dale	2005	Overwinter	.	.	.	.
Sam Dale	2006	Overwinter	.	.	.	.
Sam Dale	2007	Overwinter	1	4	22.64	0.04
Sam Dale	2008	Overwinter	.	.	.	.
Sam Dale	2005	Age-1 Fall	.	.	.	.
Sam Dale	2006	Age-1 Fall	.	.	.	.
Sam Dale	2007	Age-1 Fall	.	.	.	.

Table 4. Comparisons of mean length-at-age and weight-at-age of adult muskellunge from three stocks introduced into Lake Mingo stratified by gender. Means are estimated from pooled data from spring samples taken 2003-2009. Lower case letters denote statistical differences following Tukey's means separation. Values in parentheses represent 95% confidence intervals.

Sex	Age	Mississippi River Drainage	Ohio River Drainage	Illinois	P Value
			Length (mm)		
Combined	2	472 (±0)[a]	582 (±14)[b]	628 (±11)[c]	<0.01
Male	3	792 (±25)	763 (±12)	778 (±9)	0.06
	4	-	837 (±16)[a]	857 (±16)[b]	< 0.05
	5	-	906 (±17)	895 (±39)	0.56
	6	-	900 (±0)	-	-
	7	-	944.5 (±248)	-	-
Female	3	-	784 (±108.4)	791(±31)	0.69
	4	-	882 (±20)	867 (±13)	0.19
	5	920 (±0)	957 (±66)	962 (±21)	0.62
	6	-	1020 (±0)	1015 (±0)	-
	7	-	-	-	-
			Weight (g)		
Combined	2	731(±0)[a]	1387(±108)[a]	1748 (±100)[b]	<0.01
Male	3	3795(±890)	3377(±166)	3392(±134)	0.48
	4	-	4540 (±226)	4699 (±314)	0.45
	5	-	5885 (±456)	5274 (±934)	0.22
	6	-	6350 (±0)	-	-
	7	-	6165 (±1462)	-	-
Female	3	-	3459 (±439)	3869 (±429)	0.16
	4	-	6038[a] (±361)	5176[b] (±301)	<0.01
	5	5971 (±0)	7137 (±1027)	7117 (±690)	0.68
	6	-	7950 (±0)	8003 (±0)	-
	7	-	-	-	-

Table 5. Parameter estimates and 95% confidence intervals of Von Bertalanffy growth functions fitted to pooled length-at-age data from three stocks of muskellunge introduced into Lake Mingo and Pierce Lake 2002-2007 stratified by gender. Upper Mississippi River drainage parameters estimated from Lake Mingo were calculated by combining genders.

		L∞	95% C.I. Limit			95% C.I. Limit	
Strain/ Sex	N	(mm)	Upper	Lower	K	Upper	Lower
Lake Mingo							
Illinois							
Male	125	928	963	893	0.64	0.74	0.53
Female	67	1132	1264	1000	0.35	0.49	0.21
Ohio							
Male	103	949	985	913	0.70	0.85	0.54
Female	32	1119	1197	1041	0.41	0.50	0.33
Mississippi	73	1121	1367	874	0.37	0.56	0.18
Pierce Lake							
Illinois							
Male	107	1000	1047	954	0.43	0.51	0.36
Female	32	1037	1119	955	0.43	0.57	0.28
Ohio							
Male	37	877	929	824	0.83	1.16	0.49
Female	32	1009	1124	895	0.43	0.61	0.24

Table 6. Comparisons of mean length-at-age and weight-at-age of adult muskellunge from three stocks introduced into Pierce Lake stratified by gender. Means are estimated from pooled data from spring samples taken 2003-2009. Lower case letters denote statistical differences following Tukey's means separation. Values in parentheses represent 95% confidence intervals.

Sex	Age	Mississippi River Drainage	Ohio River Drainage	Illinois	P Value
			Length (mm)		
Combined	2	-	506 (±457)	575 (±37)	0.19
Male	3	-	723 (±25)	733 (±9)	0.35
	4	887^{a} (±96)	815^{b} (±21)	826^{b} (±10)	0.01
	5	-	833^{a} (±20)	885^{b} (±20)	<0.01
	6	-	864 (±0)	919 (±41)	-
	7	-	-	-	-
Female	3	-	784 (±44)	791 (±83)	0.69
	4	-	835 (±30)	862 (±27)	0.51
	5	-	869 (±171)	929 (±25)	0.20
	6	-	926 (±75)	954 (±43)	0.33
	7	-	-	-	-
			Weight (g)		
Combined	2	-	787 (±3621)	1266 (±339)	0.30
Male	3	-	2728 (±321)	2747 (±116)	0.89
	4	4860 (±3050)	4229 (±559)	4061 (±194)	0.31
	5	-	4508 (±1332)	4965 (±668)	0.47
	6	-	4650 (±0)	5540 (±409)	-
	7	-	-	-	-
Female	3	-	2490 (±25)	3203 (±343)	<0.01
	4	-	4700 (±754)	5010 (±424)	0.65
	5	-	6027 (±1563)	6628 (±767)	0.36
	6	-	6782 (±2616)	6516 (±1174)	0.77
	7	-	-	-	-

Table 7. Adjusted catch-per-unit effort from spring and fall electrofishing surveys and statistical comparisons for the OH: Ohio River drainage stock, MISS: Upper Mississippi River drainage stock, IL: Illinois population of age-0 muskellunge introduced into Mingo and Pierce Lakes, Illinois, during fall 2003-2007 and Sam Dale Lake 2005-2008. The overwinter period represents the 6 months following stocking and age-1 fall represents one year after stocking. Letters represent significant differences following Tukey's means separation.

Lake	Stocking year class	Time period	Effort (hr)	Adjusted CPUE Miss	Adjusted CPUE OH	Adjusted CPUE IL	P
Mingo	2003	Overwinter	21.0	2.28	3.83	3.53	0.47
Mingo	2004	Overwinter	28.4	6.30[a]	3.11[ab]	2.43[b]	0.031
Mingo	2005	Overwinter	11.1	2.45	1.35	1.43	0.99
Mingo	2006	Overwinter	15.8	0	0.79[a]	4.67[b]	0.01
Mingo	2007	Overwinter	6.5	24.99[a]	3.81[b]	8.02[b]	0.01
Mingo	2003	Age-1 Fall	22.6	0	1.26[a]	0.74[b]	0.014
Mingo	2004	Age-1 Fall	17.7	0.46	0	0.34	0.49
Mingo	2005	Age-1 Fall	15.7	0	0	0.75	.
Mingo	2006	Age-1 Fall	10.8	NA	0	0.67	.
Mingo	2007	Age-1 Fall	7.7	0	0	0.78	.
Pierce	2003	Overwinter	16.5	2.92	3.33	0.74	0.22
Pierce	2004	Overwinter	26.0	1.77	1.08	1.10	0.79
Pierce	2005	Overwinter	15.6	8.53	1.55	1.86	0.078
Pierce	2006	Overwinter	11.3	0	0	1.94	.
Pierce	2007	Overwinter	8.7	4.5	1.96	0.67	0.18
Pierce	2003	Age-1 Fall	17.6	0	0.55[a]	0.98[b]	0.05
Pierce	2004	Age-1 Fall	18.1	0	1.20[a]	0.37[b]	0.05
Pierce	2005	Age-1 Fall	13.8	0.39	0.94	1.72	0.41
Pierce	2006	Age-1 Fall	10.1	NA	NA	3.04	.
Pierce	2007	Age-1 Fall	6.6	0	0	0.76	.
Sam Dale	2005	Overwinter	12.5	0	0	0	.
Sam Dale	2006	Overwinter	2.33	0	0	0	.
Sam Dale	2007	Overwinter	6.2	2.50	0	2.17	0.62
Sam Dale	2008	Overwinter	8.2	0	0.24	0.12	0.51
Sam Dale	2005	Age-1 Fall	0	0	0	0	.
Sam Dale	2006	Age-1 Fall	0	NA	NA	0	.
Sam Dale	2007	Age-1 Fall	10.56	0	0	0.56	.

Table 8. Catch-per-unit effort (number per net night) from spring fyke net surveys conducted 2007-2009 and annual survival estimates for adult muskellunge introduced into Lake Mingo by age class. Estimates of annual survival are for the time period between successive spring fyke net surveys. Numbers in parentheses represent 95% confidence intervals.

Age	2007 CPUE	Survival	2008 CPUE	Survival	2009 CPUE
			Illinois Population		
3	0.31		0.32		0.24
		0.97		0.61	
4	0.24		0.30		0.20
		0.47		0.35	
5	0.09		0.11		0.11
		0.22		0.00	
6+	.		0.02		0.00
		.		.	
Mean		0.55(±0.40)		0.32(±0.35)	
			Ohio River Drainage		
3	0.35		0.28		0.04
		0.60		0.05	
4	0.16		0.21		0.01
		0.61		0.19	
5	0.21		0.09		0.04
		0.09		0.35	
6+	.		0.02		0.04
		.		.	
Mean		0.43(±0.33)		0.19(±0.17)	

Table 9. Catch-per-unit effort (number per net night) from spring fyke net surveys conducted 2009-2009 and annual survival estimates for adult muskellunge introduced into Pierce Lake by age class. Estimates of annual survival are for the time period between successive spring fyke net surveys. Numbers in parentheses represent 95% confidence intervals.

Age	2008 CPUE	Survival	2009 CPUE
	Illinois Population		
3	1.23		0.34
		0.41	
4	0.36		0.50
		0.44	
5	0.59		0.16
		0.31	
6	.		0.18
Mean		0.38(±0.08)	
	Ohio River Drainage		
3	0.36		.
		0.75	
4	0.23		0.27
		0.30	
5	0.27		0.07
		0.42	
6+	.		0.11
Mean		0.49(±0.26)	

Table 10. Paired Before-After, Control-Impact (BACIP) analysis to test for changes in food web components through time following supplemental stocking of muskellunge into Lake Mingo and Ridge Lake. Mean difference for each parameter between stocked and unstocked (reference) lakes are shown before and after stocking. P-values indicate significance of the change in mean differences between stocked and reference lakes after muskellunge introduction. Values in parentheses represent 95% confidence intervals.

Parameter	Stocked - Reference Difference Before	Stocked - Reference Difference After	t	*P*
		Lake Mingo		
Largemouth Bass CPUE (#/Hr)	3.03(±34.12)	-2.58(±28.23)	0.38	0.71
Bluegill CPUE (#/Hr)	-21.77(±38.63)	-23.56(±48.86)	0.11	0.92
Cladoceran Density (#/L)	0.35(±1.96)	-1.72(±3.31)	2.09	0.10
Cladoceran Size (mm)	0.07(±1.00)	-0.16(±0.65)	2.43	0.16
Chlorophyll a (ug/L)	-9.51(±24.30)	-13.82(±39.70)	0.67	0.55
Total Phosphorous (ug/L)	-21.34(±29.36)	4.38(±262.28)	-0.42	0.72
		Ridge Lake		
Largemouth Bass CPUE (#/Hr)	-11.85(±31.15)	43.90(±170.01)	-1.34	0.29
Bluegill CPUE (#/Hr)	-59.09(±90.12)	8.51(±89.59)	-1.8	0.12
Cladoceran Density (#/L)	3.50(±5.35)	3.05(±4.84)	0.18	0.86
Cladoceran Size (mm)	-0.25(±0.24)	-0.48(±9.04)	2.33	0.05
Chlorophyll a (ug/L)	1.71(±15.58)	5.09(±53.94)	-0.52	0.63
Total Phosphorous (ug/L)	0.04(±54.87)	-10.91(±310.63)	0.35	0.76

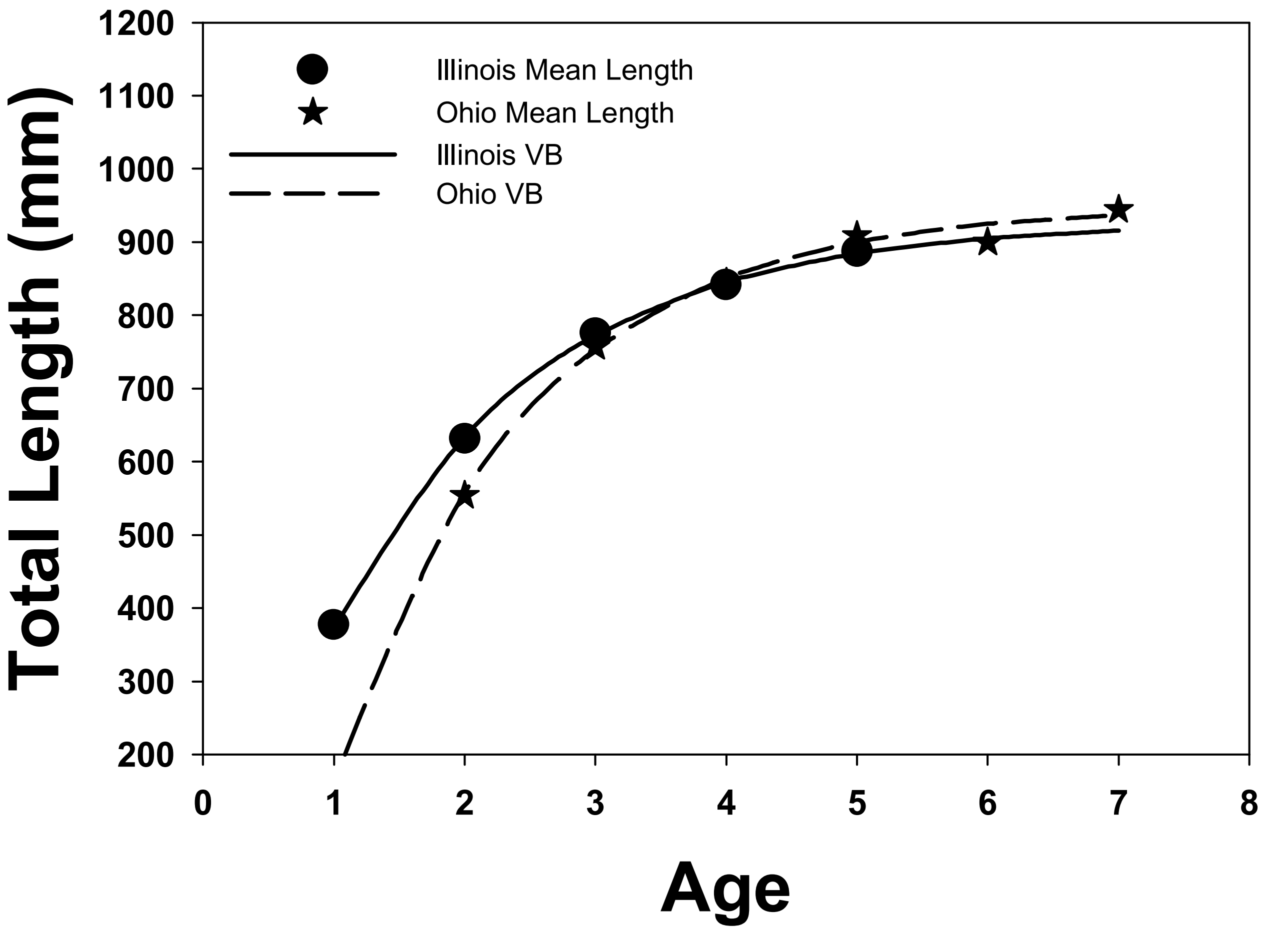

Figure 1. Mean total length (mm) at age (symbols) and fitted von Bertalanffy growth functions (lines) for male muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Lake Mingo from fall 2002 through fall 2007.

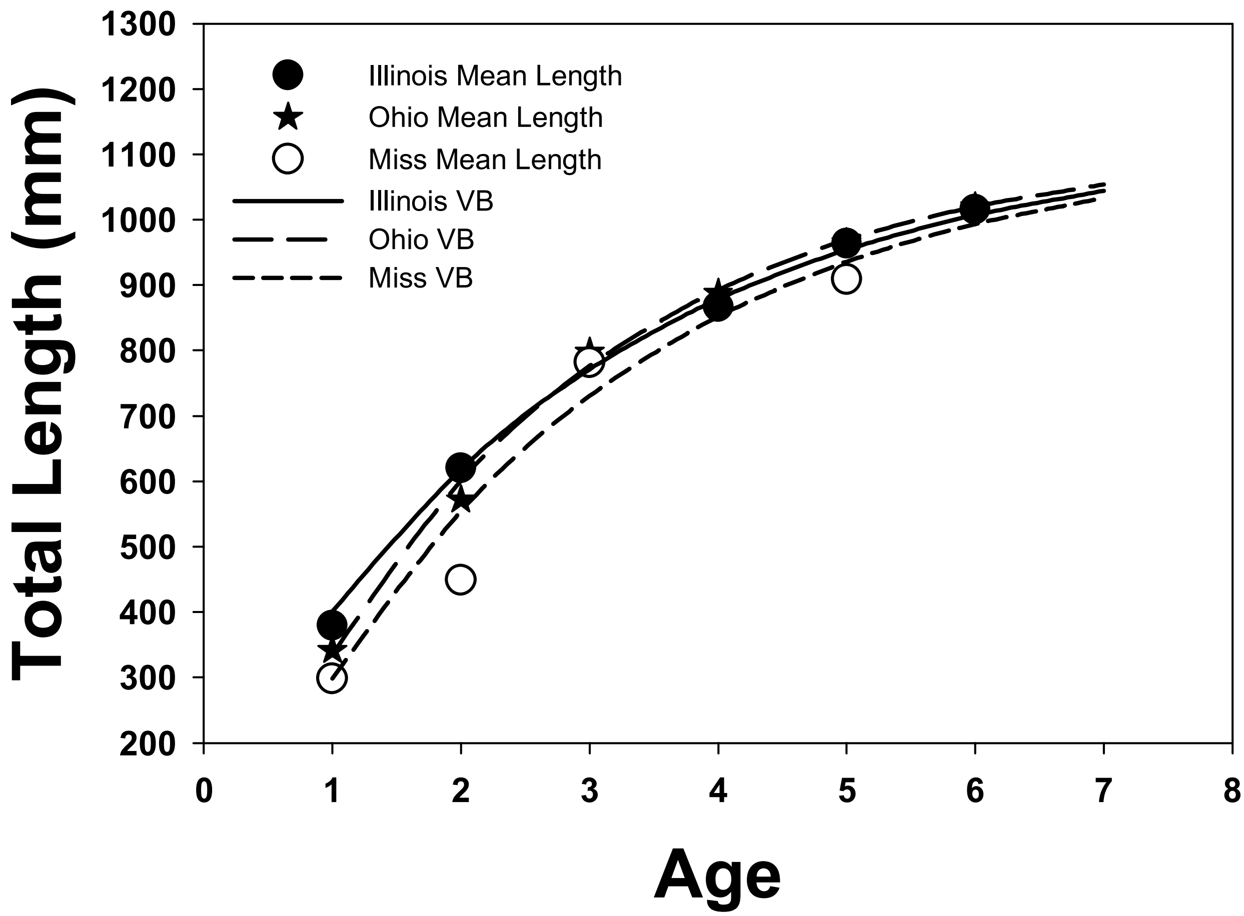

Figure 2. Mean total length (mm) at age and fitted von Bertalanffy growth functions for female muskellunge from the Illinois population (solid line) the Ohio River drainage stock (long dashed line) and the Upper Mississippi River drainage stock introduced into Lake Mingo from fall 2002 through fall 2007. The growth function for the Upper Mississippi River drainage stock (short dashed line) was fit by pooling both genders due to low survival of this stock.

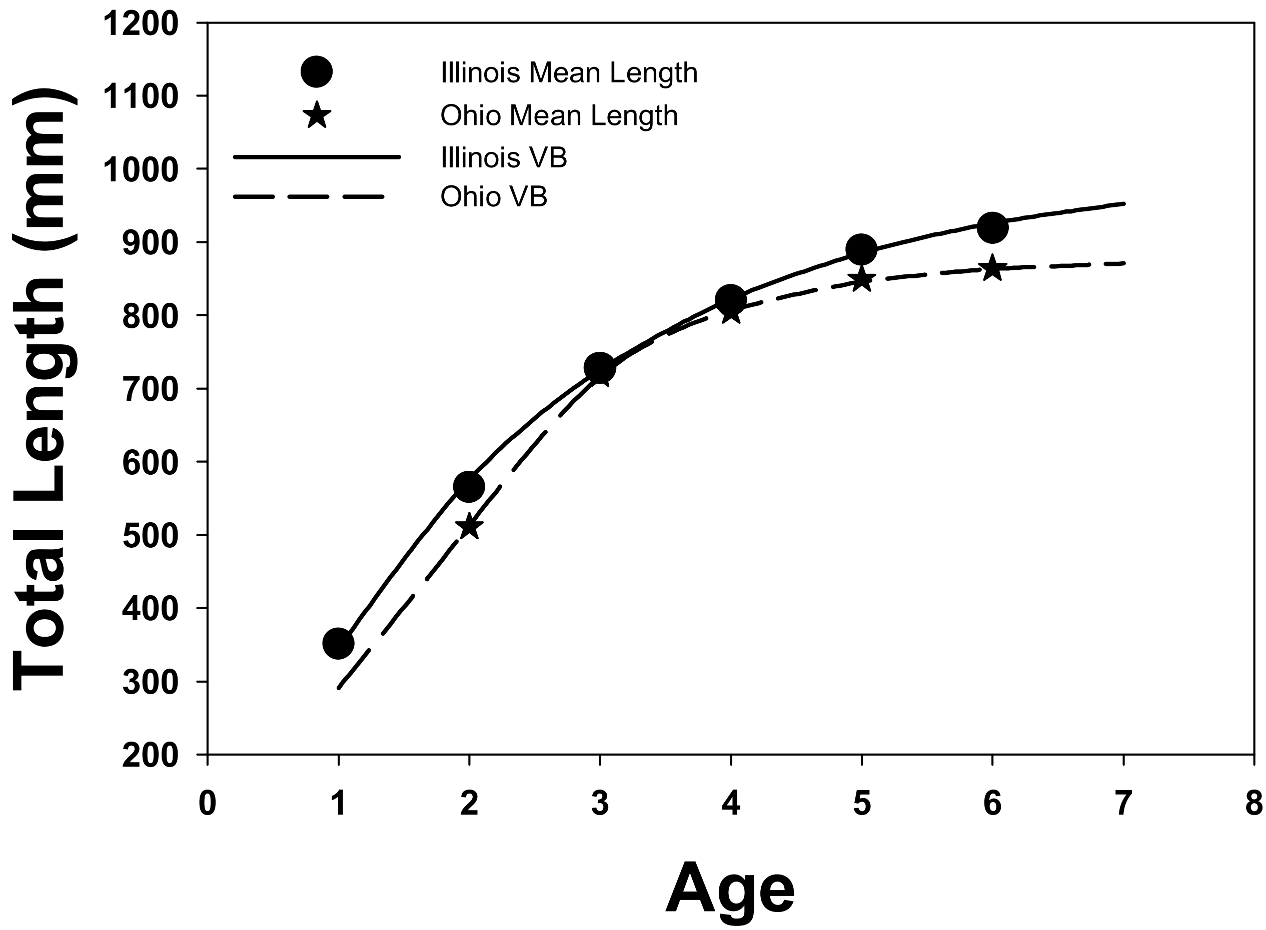

Figure 3. Mean total length (mm) at age and fitted von Bertalanffy growth functions for male muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Pierce Lake from fall 2003 through fall 2007.

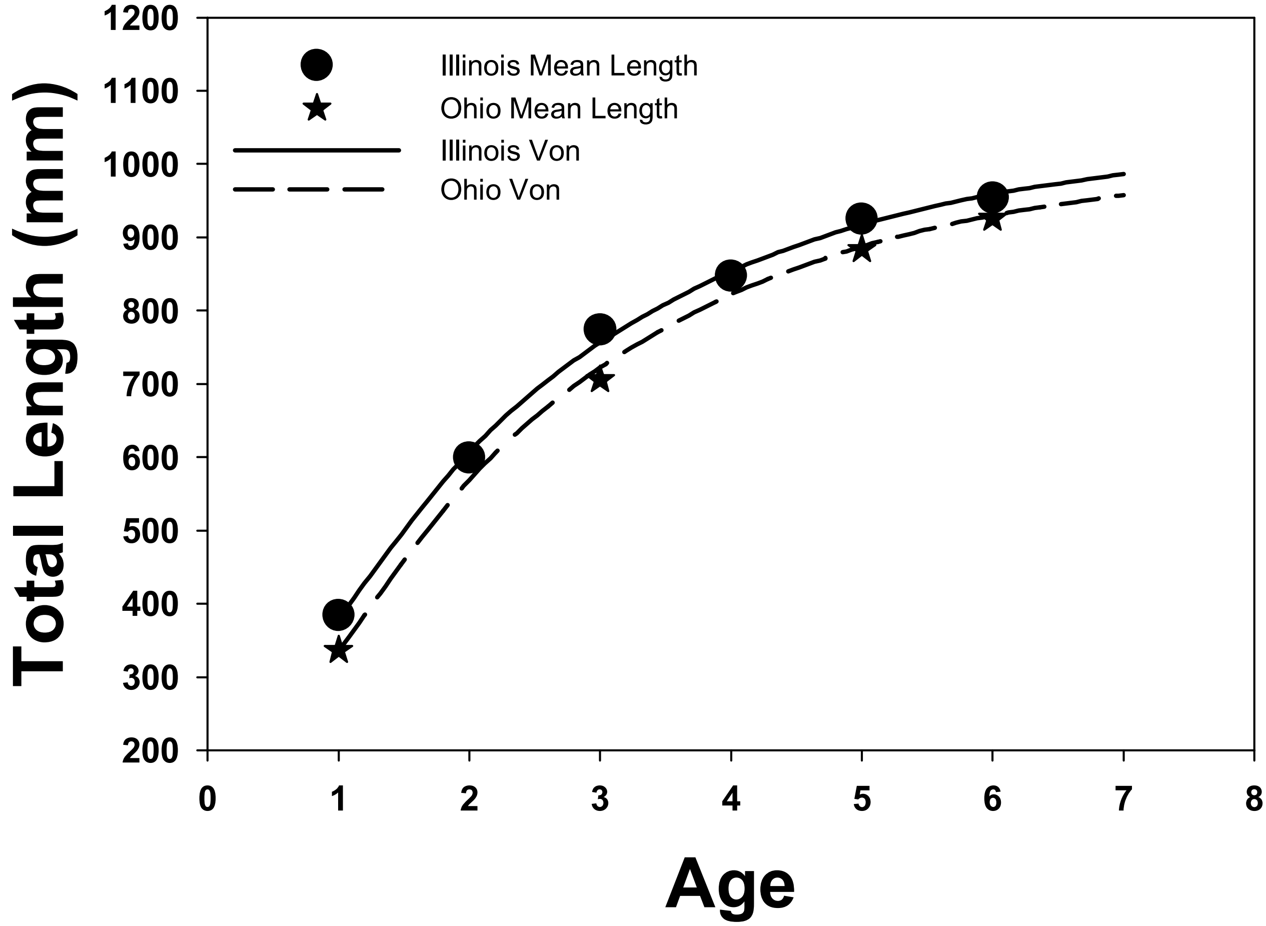

Figure 4. Mean total length (mm) at age and fitted von Bertalanffy growth functions for female muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Pierce Lake from fall 2003 through fall 2007.

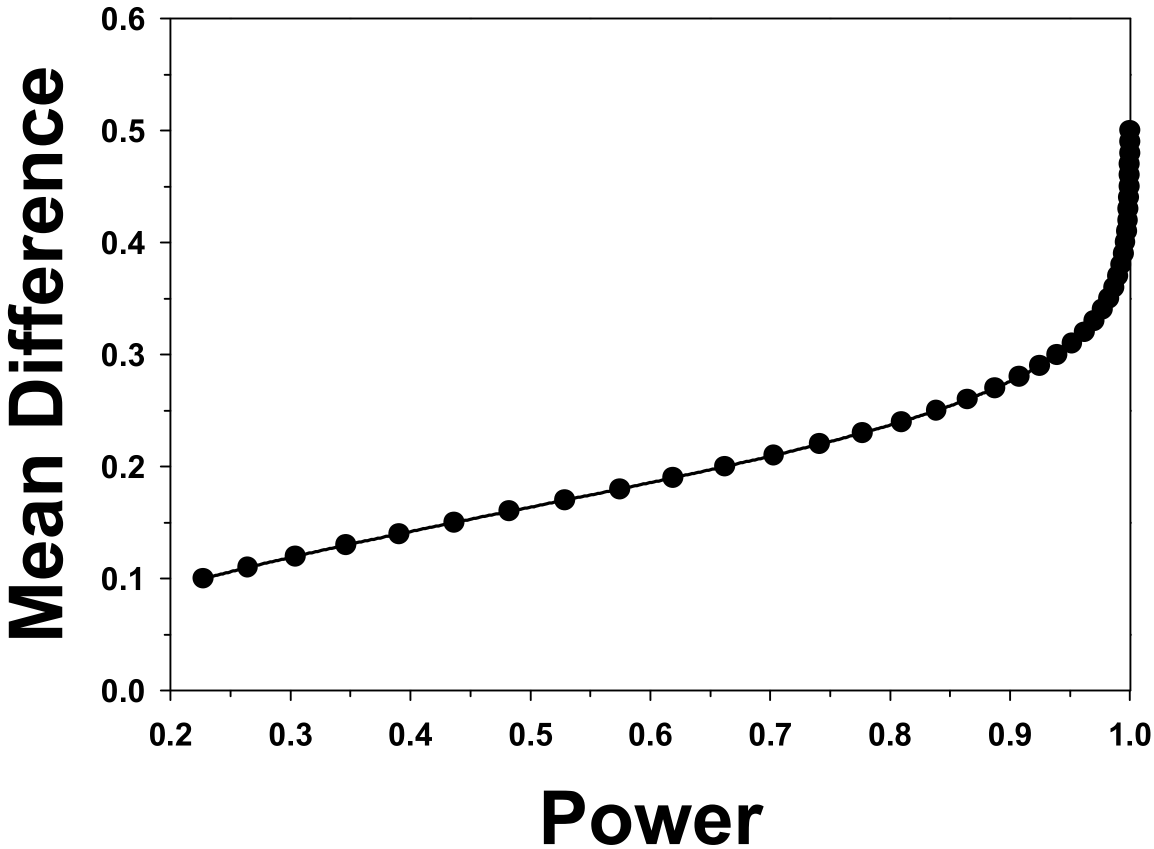

Figure 5. Power curve for the paired comparison of annual survival of adult muskellunge from the Illinois population and Ohio River drainage stock in Lake Mingo. Mean is the difference in survival rate between stocks (effect size) and power represents the probability of detecting such a difference given the current estimated variance and sample size at an alpha of 0.05.

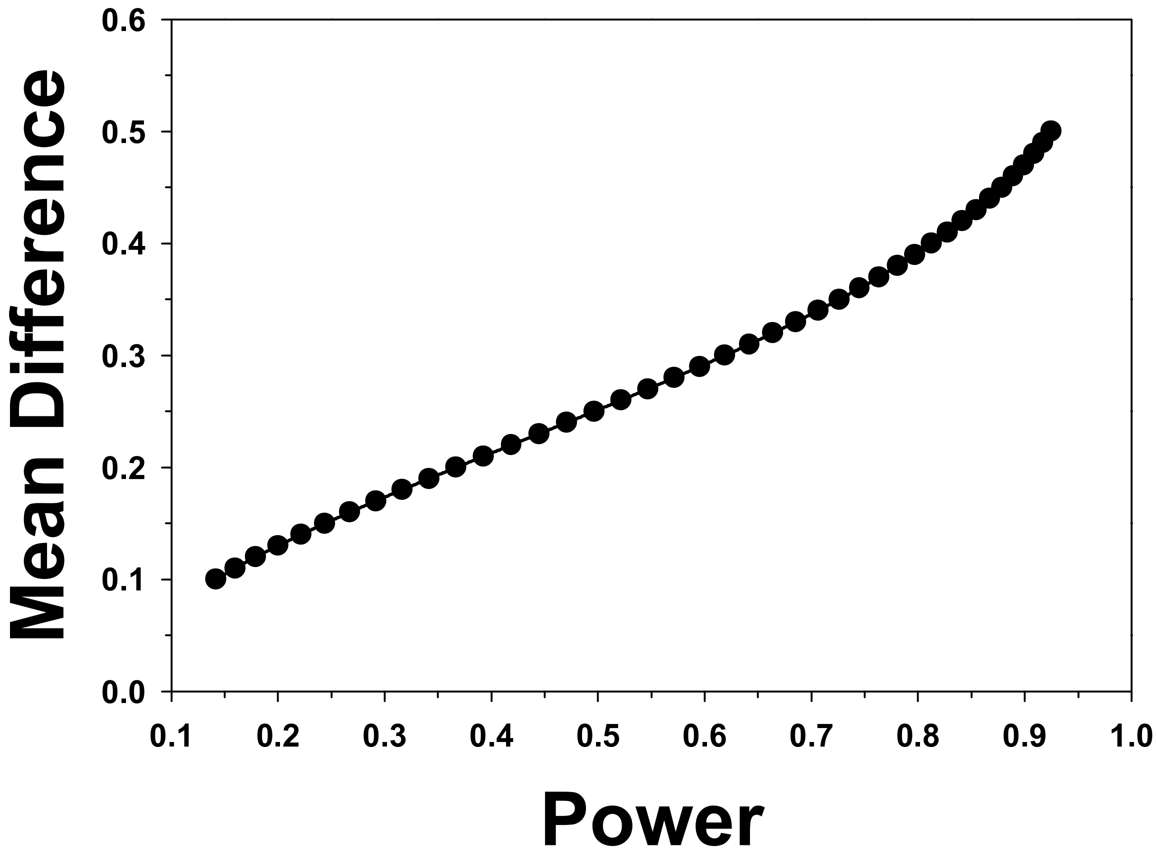

Figure 6. Power curve for the paired comparison of annual survival of adult muskellunge from the Illinois population and Ohio River drainage stock in Pierce Lake. Mean is the difference in survival rate between stocks (effect size) and power represents the probability of detecting such a difference given the current estimated variance and sample size at an alpha of 0.05.

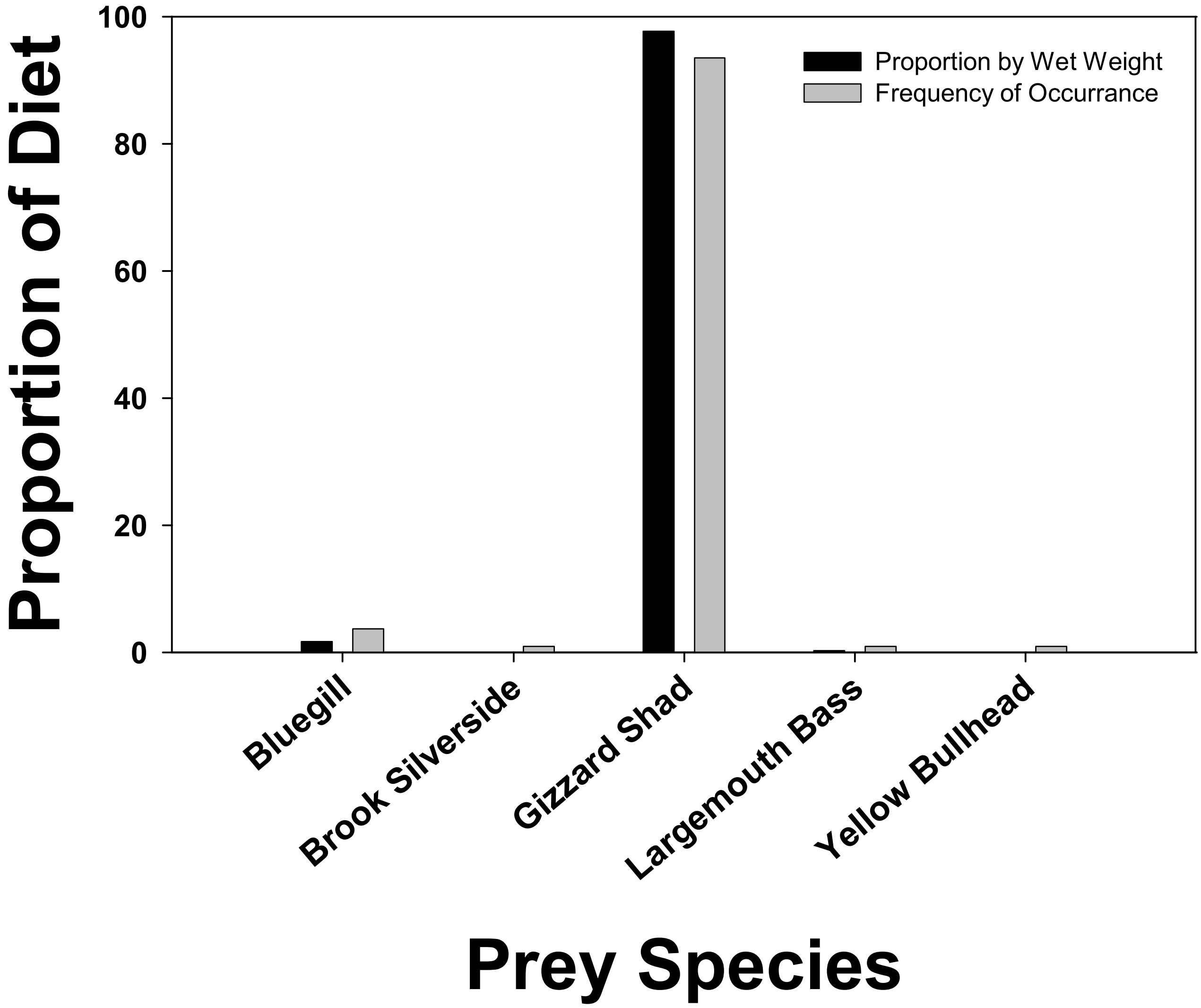

Figure 7. Diet composition of muskellunge sampled in Lake Mingo via shoreline electrofishing and modified fyke nets, June 2007 – April 2009. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

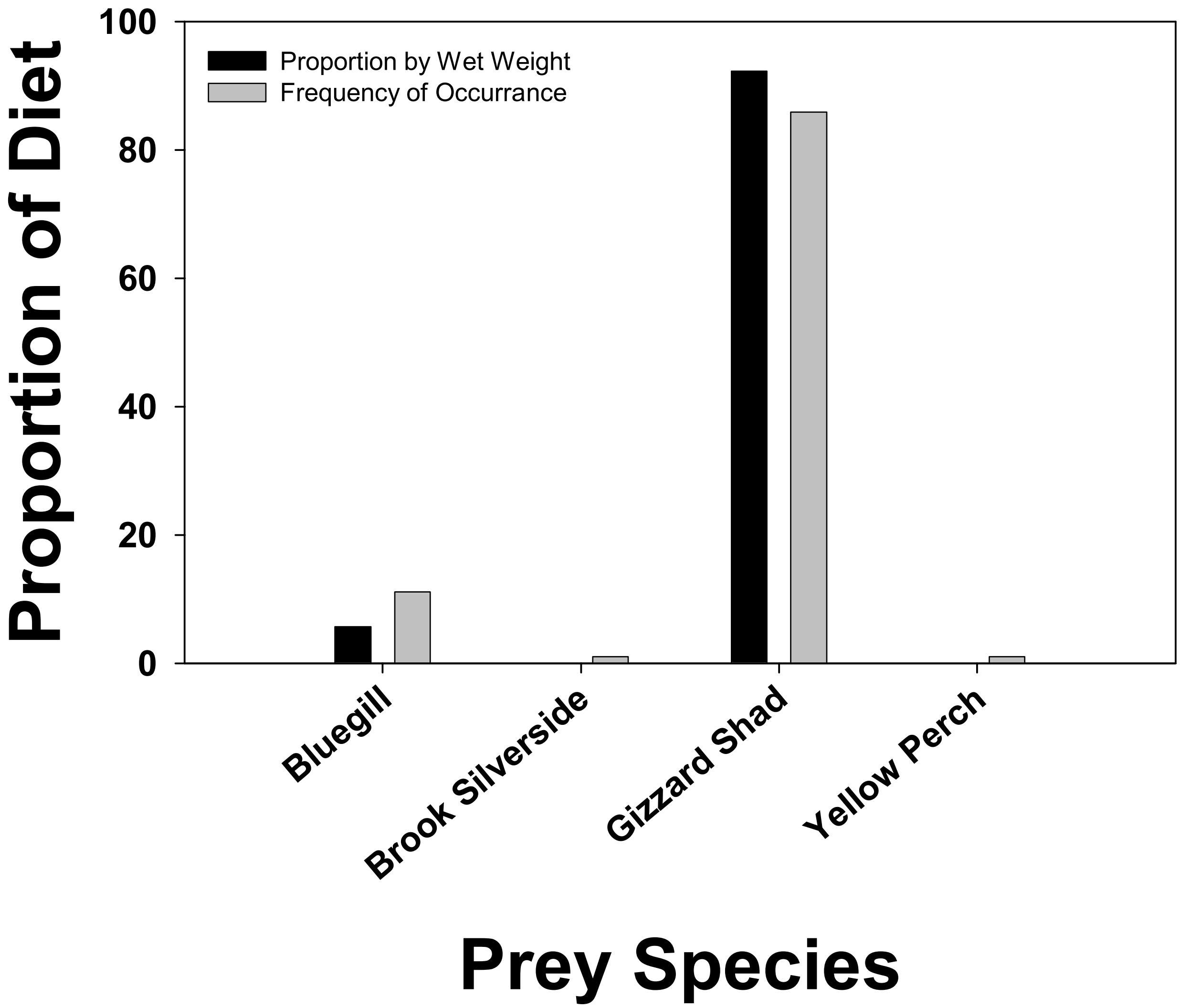

Figure 8. Diet composition of muskellunge sampled in Pierce Lake via shoreline electrofishing and modified fyke nets, June 2007 – April 2009. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

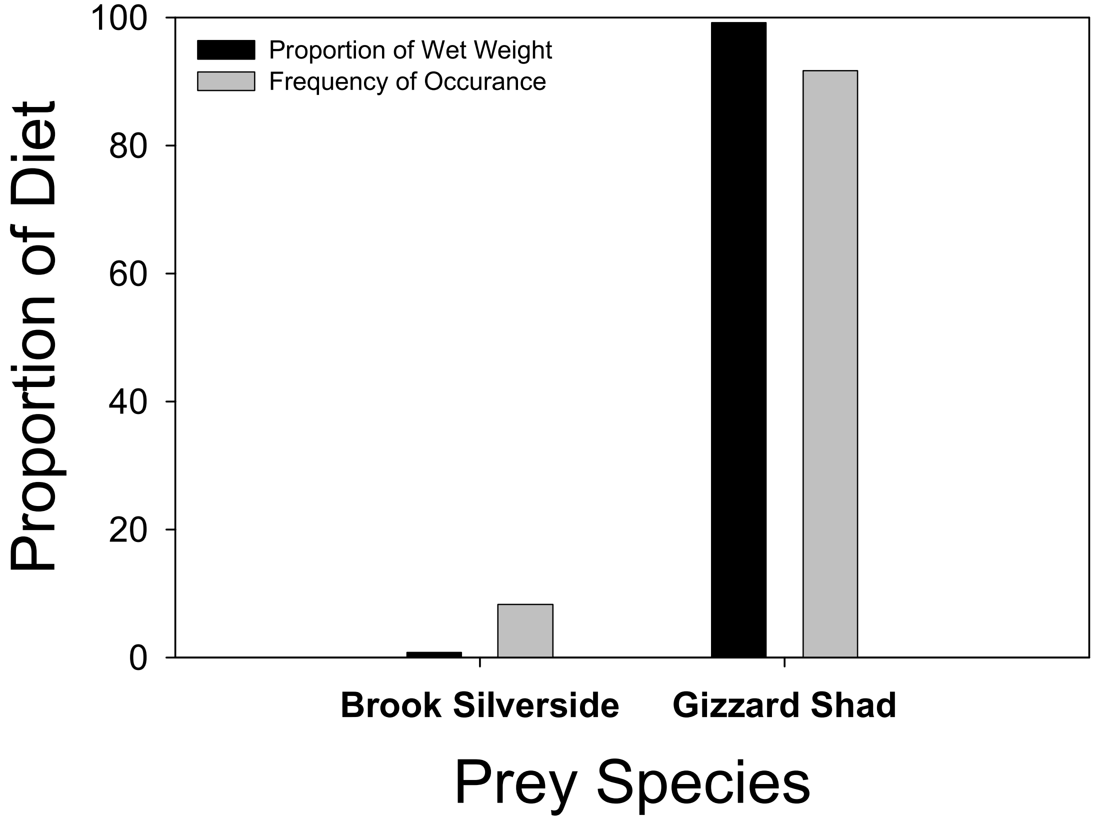

Figure 9. Diet composition of muskellunge sampled in Sam Dale Lake via shoreline electrofishing, June 2007 – April 2009. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

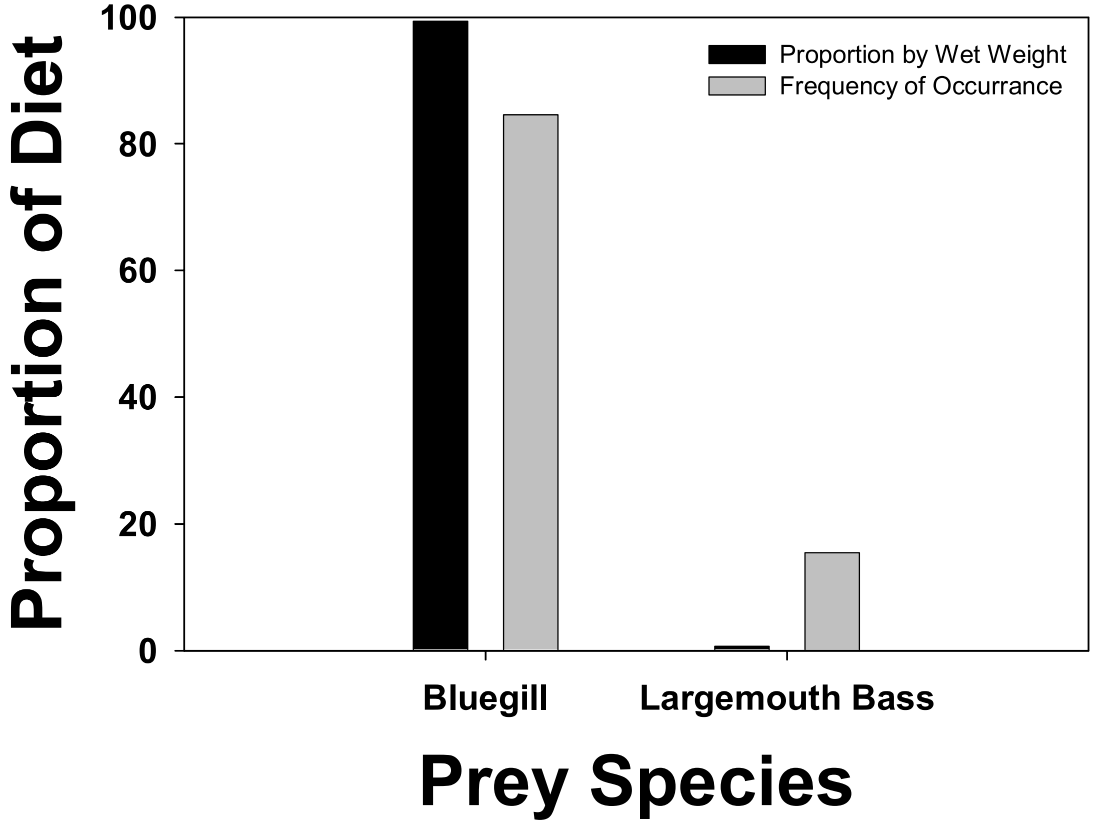

Figure 10. Diet composition of muskellunge sampled in Ridge Lake via shoreline electrofishing, and angler creel, June 2007 – April 2009. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

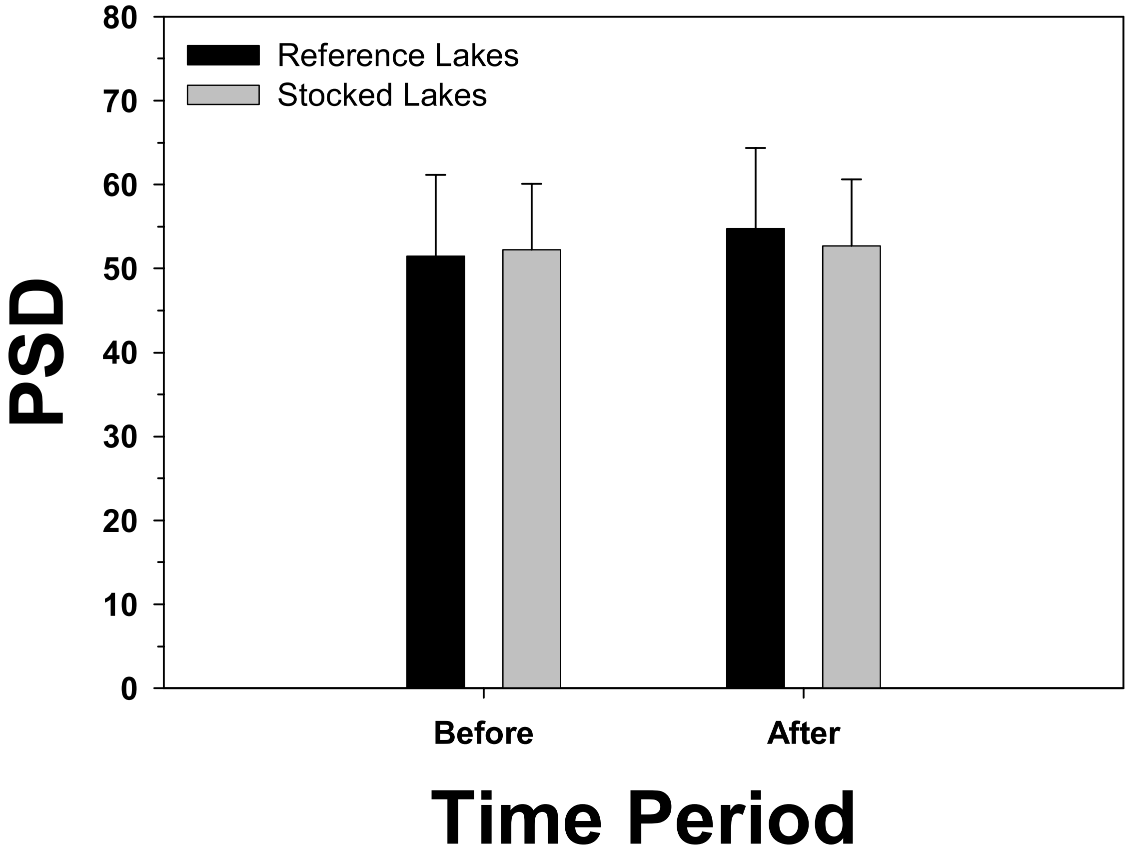

Figure 11. Mean proportional stock density of largemouth bass sampled in fall electrofishing surveys before and after muskellunge introduction for stocked and unstocked lakes. Data represent averages from four years before and four years after muskellunge introduction from three stocked lakes (Mill Creek, Shovel, and Staunton City) and two reference lakes (Bloomington and Leaquana).

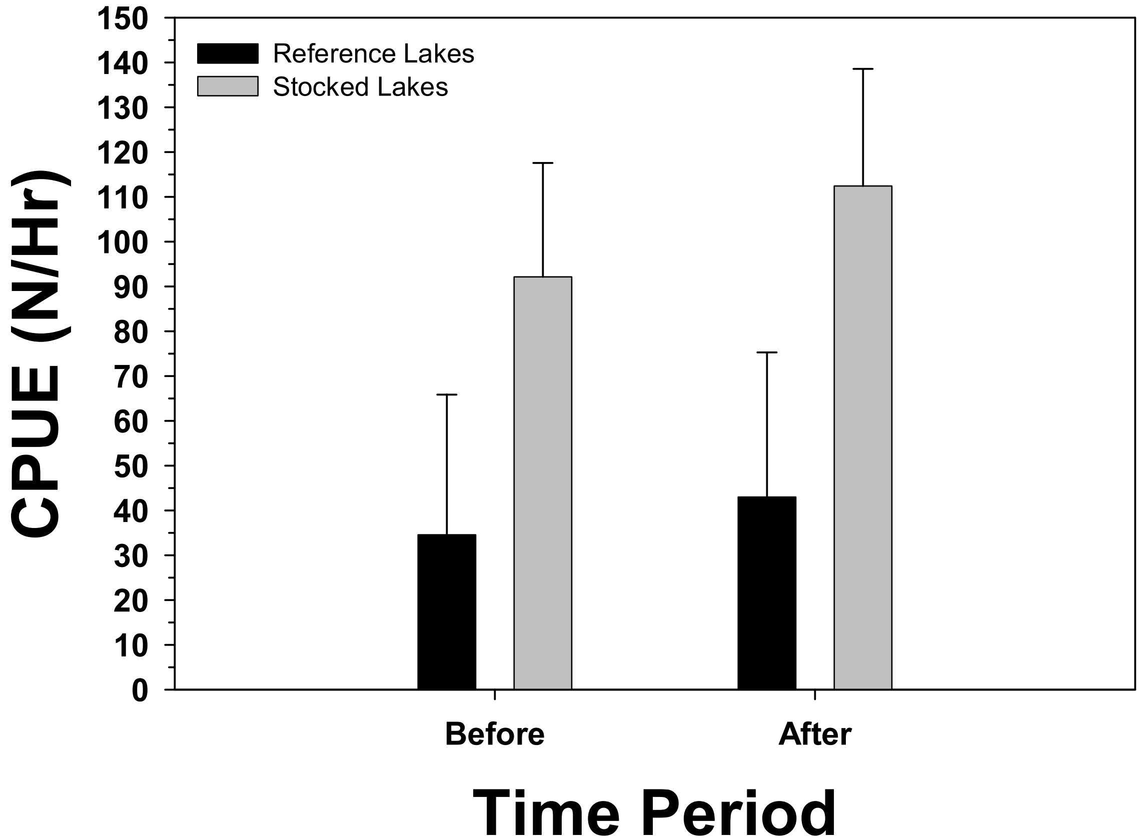

Figure 12. Mean catch-per-unit-effort of largemouth bass sampled in fall electrofishing surveys before and after muskellunge introduction for stocked and unstocked lakes. Data represent averages from four years before and four years after muskellunge introduction from three stocked lakes (Mill Creek, Shovel, and Staunton City) and two reference lakes (Bloomington and Leaquana).