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ANNUAL PROGRESS REPORT
July 1, 2009 through June 30, 2010

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

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EXECUTIVE SUMMARY: Muskellunge *Esox masquinongy* are an important and increasingly popular sportfish that are commonly stocked throughout Illinois and much of the Midwestern United States. Stocking has become the primary management tool for establishing and maintaining muskellunge populations in Illinois and across the Midwestern United States. Great demand for these fish and the high costs associated with producing them 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 data on performance of different genetic stocks of muskellunge, both within and outside their native range, 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 the muskellunge range is artificially expanded by more widespread stocking it becomes increasingly important to understand the potential impacts of muskellunge introduction on existing fisheries and aquatic communities.

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. Genetically distinct stocks are quickly becoming the new operational unit in fisheries management to optimize performance regionally. Understanding stock differentiation is especially important with a trophy species like muskellunge where 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 rest of 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 that 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 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 provides 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 eight, 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 continued. 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 2009 and spring 2010. These data were combined with modified fyke net surveys during spring 2010, including the first trap netting effort on Sam Dale Lake. Across years and lakes, the Ohio River drainage stock and the Illinois population generally appear to have similar growth rates; both consistently higher than the Upper Mississippi River drainage stock. Results thus far 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.

Muskellunge diet samples were collected from fish across 7 Illinois lakes from fall 2007 to spring 2010. These lakes included Lake Shelbyville, Lake Mingo, Ridge Lake, Pierce Lake, Lake of the Woods, Otter Lake, and Sam Dale Lake. Thus far food habits data has shown that where present, gizzard shad dominates muskellunge diet in both numbers and biomass across all size classes and seasons. Gizzard shad are not present in Ridge Lake where muskellunge diets consist primarily of bluegill, although a small percentage of the samples contained largemouth bass. 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 selecting lakes where stockings have been successful 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 the study 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. Our results suggest that across 8 lakes in a time series ranging from 3-10 years after muskellunge introduction the abundance of largemouth bass and primary prey species have not been negatively affected.

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. In particular, these long-term data will be used to examine attributes such as longevity, maximum size-at-age, and size-at-maturity. 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 stock 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, behavioral, and possibly morphological 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 greatly increasing performance (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 longer and more severe, a large body size is necessary to store sufficient energy to maintain metabolism through the 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.

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 across the latitudinal gradient of Illinois.

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). Comparison of age-1 growth 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, and begin to examine growth patterns into adulthood for fish from Sam Dale Lake. 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.

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.

To determine growth rates of juvenile fish (ages 0-2) 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, and in 2010 we began modified fyke netting surveys on Sam Dale Lake. Nets in Lake Mingo (N=17), in Pierce Lake (N=12), and in Sam Dale (N=10), 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 two week period each spring on each lake 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 55 muskellunge were captured during 7 nights of modified fyke net sampling (total of 83 net-nights) during March and April 2010. Catch rates averaged approximately 0.66 fish per net-night. Of the 55 muskellunge captured, 8 were Ohio River drainage stock, 47 were Illinois stock and none were Upper Mississippi River drainage stock. The smallest muskellunge captured was 667 mm and the largest was 1069 mm; weights ranged from 750 g to 9650 g. Twenty-eight muskellunge were age-3, 17 were age-4, 8 were age-5, 1 was age-6, and 1 was age-7. Of the 55 fish sampled 69% were male and 31% were female.

A total of 112 muskellunge were captured during the 4 nights of modified fyke net sampling (48 net-nights) in Pierce Lake during April 2010, yielding an average of 2.33 fish per net-night. Of the 112 muskellunge sampled, 33 were Ohio drainage stock, 77 were Illinois stock and 3 were Upper Mississippi River drainage stock. The smallest muskellunge captured was 605 mm and the largest was 1020 mm; weights ranged from 1230 g to 8850 g. Forty-one age-3, 33 age-4, 33 age-5, and 5 age-6 fish were sampled. Males represented 67% of the sampled muskellunge and females the other 33%.

A total of 98 muskellunge were captured during 7 nights of modified fyke net sampling (total of 70 net-nights) in Sam Dale Lake during March 2010. Catch rates averaged approximately 1.40 fish per net-night. Of the 105 muskellunge sampled 61 were Illinois stock, 30 were Ohio stock, and 3 were Upper Mississippi stock. The smallest muskellunge captured was 588 mm and the largest was 975; weights ranged from 1320 g to 7750 g. Forty-one age-2, 52 age-3, 1 age-4, and 1 age-5 fish were sampled. Males represented 52% of the sampled muskellunge and females the other 48%.

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 and Pierce Lake stratified by stocking year class. In both lakes RDGR was not significantly different between the Ohio River drainage stock and the Illinois stock for any of the year classes from 2003-2007 (Table 3). 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 in Lake Mingo, and in Pierce Lake Upper Mississippi River drainage stock showed significantly lower rates than both of these stocks for the 2003 and 2004 year classes. Overwinter growth for the Upper Mississippi River drainage fish for all other year classes were similar to the other two stocks. 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. 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 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.

In the current segment we completed analysis of juvenile growth rate in 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 prevented statistical comparisons of overwinter growth rates. Sampling during fall 2009 allowed us to assess differences in growth rates between stocks at age-1. 5 muskellunge from the Illinois stock, 5 muskellunge from the Ohio stock, and 2 muskellunge from the Upper Mississippi stock were sampled during electrofishing. The 2008 year class showed significantly higher growth for Upper Mississippi stock fish at age-1 than Ohio stock and Illinois stock fish (Table 3). In future segments we will continue to monitor the long term growth of these year classes in Sam Dale Lake using spring modified fyke net surveys. These surveys are considerably more effective than electrofishing but do not capture muskellunge effectively until age-3.

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.

Adult Size-at-Age

In Lake Mingo mean length-at-age was significantly different among stocks at age-2 (ANOVA, $P < 0.01$, Table 4). At age-2 the Illinois stock was the longest of the three stocks and the Ohio River drainage stock was longer than the Upper Mississippi River stock (Table 4). For male muskellunge there was a significant difference in mean length at age-5 with the Ohio River drainage stock being significantly longer than the Illinois stock (ANOVA, $P < 0.05$). Few older fish were sampled limiting our ability to make comparisons between stocks (Table 4). No differences were found among the stocks for female muskellunge through age-7. 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). There was a difference in weight between age-5 males with the Ohio River drainage stocking being heavier then the Illinois stock. 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 1-3 but then surpass Illinois males at ages 4-7, resulting in a higher asymptotic lengths for Ohio males than Illinois males (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 by 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 trajectories 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 $P < 0.01$, Table 6) and was still longer at age-6 but this difference was not statistically significant. Illinois females were longer than Ohio females at age-3 but among older age classes lengths were statistically similar (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. 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.

In Pierce Lake no differences were found among weights of stocks at age-2. Males at age-4 were significantly different with Upper Mississippi fish being heavier than the Illinois and Ohio River drainage stock (Table 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 females ages 4-6 (Table 6). In Pierce Lake mean weight-at-age seemed 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.

Examination of Von Bertalanffy growth functions fit to length-at-age data for male of muskellunge in Pierce show Illinois fish being longer than Ohio fish across all ages although these differences are not significant (Table 5, Figure 3). 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 between stocks (Table 5, Figure 4). Due to poor survival of the Upper Mississippi River drainage stock both sexes were pooled to obtain Von Bertalanffy parameters. The growth trajectory for Upper Mississippi muskellunge in Pierce Lake was similar to Ohio River drainage and Illinois muskellunge (Table 5, Figure 4)

In Sam Dale Lake, Upper Mississippi River drainage muskellunge were significantly longer then Ohio River drainage muskellunge at age-2 with Illinois muskellunge intermediate (ANOVA, $P < 0.01$, Table 7) Length-at-age was similar between Ohio and Upper Mississippi River drainage fishes at age-3 for both genders (Table 7). Inadequate numbers of age-4 and above fish were captured to make comparisons of growth.

At age-2, Upper Mississippi muskellunge were significantly heavier than Ohio River muskellunge with Illinois muskellunge intermediate (ANOVA, $P < 0.01$, Table 7), although these results should be treated with caution due to low sample size of Upper Mississippi fish. Weight-at-age was similar for age-3 fish across all stocks. As we collect additional samples of adult fish in future segments we will construct growth curves and compare mean length and weight at older ages for these stocks.

We are finding comparatively few differences in weight-at-age across the study lakes despite more frequent differences in length, suggesting some differences in allometric length-weight relationships between stocks. Previous studies have found morphological differences between Leech Lake Minnesota stocks when compared to other populations (Margenau and Hanson 1996). We pooled data from Sam Dale Lake, Lake Mingo, and Pierce Lake to describe the length weight relationships of Ohio River drainage, Upper Mississippi River drainage, and Illinois muskellunge. Upper Mississippi River drainage fish were consistently more lean, weighing less than Ohio or Illinois fish at similar lengths (ANCOVA, $P = 0.04$, Figure 5). In future segments, we will sample additional fish from each stock, specifically the Upper Mississippi stock, to better describe these relationship and identify any morphological differences between stocks.

RECOMMENDATIONS: In Lake Mingo, these populations/stocks generally exhibit similar growth trajectories and size-at-age. While the Illinois population seems to have a growth advantage at ages 1-2 they are surpassed by Ohio fish at older ages. Ohio males did show higher asymptotic lengths than Illinois males when comparing growth trajectories. Growth of Ohio River drainage muskellunge in Pierce Lake appeared to be slower and ultimately shorter than Illinois muskellunge based on initial data in previous reports. The inclusion of additional individuals into our long term dataset has muted any differences between growth trajectories of these stocks. We now find a pattern of very similar growth trajectories and few differences in mean length or weight at older ages between all three stocks. There is however some evidence that the Upper Mississippi River drainage stock is longer than the other stocks at age-4 in Pierce Lake. This finding, coupled with slightly slower growing Ohio fish, support the hypothesis of thermal adaptation over the countergradient variation hypothesis to explain growth patterns in muskellunge. 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. However, initial results from Sam Dale Lake, the southernmost lake included in the study, also show Upper Mississippi fish growing faster. If this pattern continues through older age classes it would provide evidence toward the countergradient variation theory which states that fish from northern latitudes should grow faster across all thermal environments.

Differences in the allometric length-weight relationship between stocks were present across lakes. Upper Mississippi River drainage muskellunge were found to be more lean than Ohio River drainage and Illinois muskellunge. This may be a result of poor condition which would explain patterns of both growth and survival. However, it is likely that the Leech Lake Minnesota stock has different morphology than other stocks and populations, (Margenau and Hanson 1996) and will need to be examined in future segments.

Continued monitoring of these stocks across all lakes, and in particular Sam Dale Lake, will help to identify the patterns of growth across 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 lakes in Illinois.

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 was concluded during this segment and comparisons based on CPUE data from nighttime pulse DC electrofishing conducted during fall 2008, spring 2009, and fall 2010 are presented here.

We continued a global analysis of adult survival rates in lakes Mingo and Pierce using data collected during the current segment. 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 during 2007-2010 (Lake Mingo) and 2008-2010 (Pierce Lake). Spring fyke net surveys in Sam Dale Lake began in 2010 and will be ongoing in an effort to describe survival for this lake. Catch rates were used to compare both survival to adulthood between stocks and annual survival of adult fish after age 3 between stocks and across years. To compare survival of each stock to adulthood in 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). The analyses do not require the assumption of constant recruitment 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 and Pierce Lake stratified by stocking year class. The analysis of juvenile survival on these lakes is complete and has been reported in previous segments. In summary, there was a pattern of similar survival between the Illinois population and the Ohio River drainage stock in Lakes Mingo and Pierce both through overwinter and to age-1 in most year classes. Upper Mississippi River drainage fish showed similar survival through overwinter but had significantly lower survival to age-1 than to the other stocks in several year classes.

Juvenile Survival Sam Dale Lake

Year classes of muskellunge were introduced into Sam Dale Lake each year from 2005-2008 (Table 2). The 2005-year class experienced significant stocking related mortality and no fish from this year class were recovered in the spring or fall of 2006. 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 (Table 8). 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. In the fall of 2009 comparison of survival to age-1 between stocks was not possible due to low numbers of recaptured muskellunge. The 2008 year class was sampled in the fall of 2009 to assess survival to age-1. Illinois muskellunge showed the highest adjusted CPUE, Ohio fish were intermediate, and Upper Mississippi muskellunge showed the lowest catch rates although the differences between stocks were not significant (Table 8). We will continue spring modified fyke net sampling on this lake to assess survival to adulthood of this year class.

Adult CPUE and Survival in Lakes Mingo and Pierce

No Upper Mississippi River drainage stock muskellunge were captured in Lake Mingo during modified fyke net sampling in the spring of 2010. 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 = 0.56 ±0.58, Table 9) compared to the Ohio River drainage stock (mean ± 95% CI = 0.13 ±0.13) but this difference was not statistically significant (ANOVA, P = 0.18). Upper Mississippi River drainage stock muskellunge were captured in low abundance in Pierce lake (mean ± 95% CI = 0.08 ±15). Illinois population and Ohio River drainage stock muskellunge were captured in higher abundance (mean ± 95% CI = 1.01 ±0.64), and 0.90(± 1.01) respectively) but the difference between all three stocks was not significant (ANOVA, P = 0.15, Table 9). A similar pattern was observed in Sam Dale Lake where Illinois population and Ohio River drainage stock muskellunge showed high survival (mean ± 95% CI = .75 ±0.50) and 0.42 ±0.24) while Upper Mississippi river drainage fish showed significantly lower survival (mean ± 95% CI = 0.06 ± 0.08), ANOVA, P = 0.02).

We compared survival to adulthood (age-3) in Lakes Mingo and Pierce among stocks across year classes. In Lake Mingo, Ohio River Drainage fish had significantly higher survival to adulthood than Upper Mississippi River drainage fish (Table 10, ANOVA, P = 0.03). Survival of the Illinois population muskellunge was intermediate. There was no significant difference in survival to adulthood in fish stocked into Pierce Lake (ANOVA, P = 0.23)

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 11-12). 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, 32% from 2008-2009, and 40% from 2009-2010 (Table 11). Averages for the Ohio River drainage stock were 43% for the period from 2007-2008, 19% from 2008-2009, and 67% from 2009-2010 (Table 11). In several instances CPUE increased within a year class from one sampling year to the next (See Table 12 as an example). This may be a result of these fish not being fully recruited to the gear at age-2 or another unknown sampling bias. In these instances survival estimates for that year class were set at 1.00. 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 = –0.06; P = 0.94) and the mean annual survival estimates for both populations were nearly identical.

Estimates of adult annual survival rates for muskellunge introduced into Pierce Lake were restricted to the period from 2008-2010 due to low numbers of muskellunge captured during spring 2007 fyke netting. The average annual survival estimate for the Illinois population from 2008-2009 was 38%, and 53% from 2009-2010. The Ohio River drainage stock had 49% annual survival from 2008-2009 and survival from 2009 to 2010 was estimated at 100% (Table 12). Adult Upper Mississippi River drainage fish were only captured in one sampling season and in low numbers, limiting our ability to describe annual mortality. Average survival of the Ohio River drainage stock was higher than the Illinois population although paired t-test analysis did not find a significant difference between the two (Paired t = -1.98; P = 0.12).

Future years of data will be required to add precision to survival comparisons in these lakes and will allow for similar comparisons to be made in Sam Dale Lake.

RECOMENDATIONS: 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, 5 adults from this stock have been sampled to date in Pierce Lake, and 3 have been sampled in Sam Dale 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 Mingo and Pierce 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. Survival of these stocks in Sam Dale Lake which is the southernmost lake in this study is of particular interest. Once compiled, results from these lakes may reveal latitudinal differences within the state among the introduced stocks. In future years we will continue 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. 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. There are strong indications in our sample lakes that summer is crucial in determining the long-term survival of stocked muskellunge. Failure to cope with adversely high summer temperatures may be an important source of mortality and could be different between stocks that have adapted to differing thermal regimes. Work remains to be done in identifying differences in thermal stress response between stocks of muskellunge.

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

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. 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 et al. 2006). Species introductions can have strong ecological effects and therefore there exists a great need for research to inform management decisions regarding introductions (Lodge et al. 1998; García-Berthou et al. 2005; Keller et al. 2007). Specific concerns regarding muskellunge introductions include the rate that these introduced populations feed on other ecologically and recreationally important fishes and the potential for negative interactions with resident fish predators (Brenden et al 2004). 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 sportfish 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 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. We also began expanding 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 muskellunge between May 2009 and May 2010 across seven Illinois lakes including Lakes Mingo, Otter, 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, 2009, and 2010) in lakes Mingo and Pierce and angled fish sampled as part of the long term creel on Ridge Lake (May – November 2007-2009). 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). In previous segments we sacrificed and later dissected muskellunge 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.

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 = 8) and reference waters (N = 8) were selected for analysis by examination of stocking records provided by the Illinois DNR and the Jake Wolfe Memorial Fish Hatchery. Data for each lake has been acquired and compiled from two sources including the Illinois Fisheries Analysis System (FAS) and data collected by INHS 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). Lakes were selected for analysis if there was an adequate time series of data from before and after muskellunge introduction and if there was evidence that significant adult populations of muskellunge had developed based on modified fyke-net catches and electrofishing (Table 13). Fyke net data were not available in Mill Creek Lake to verify adult muskellunge populations however this lake had electrofishing CPUE of stock length and greater muskellunge comparable to lakes with known established adult populations in the years following initial introduction and was therefore included in our analysis (Table 13). Each selected muskellunge lake was paired with a nearby control lake that was not stocked with muskellunge (Table 13). Control lakes were selected primarily on the basis of geographic distance and data availability however care was taken to select lakes of similar size, depth and fish communities where possible.

Muskellunge introductions and respective monitoring in individual lakes occurred over a significant time period (Table 13). Individual lakes selected for analysis varied in the timing of initial stocking from 1996-2005. In order to minimize the effects of temporal differences in data collection on our analysis each stocked and control lake combination was treated as an independent experiment and analyzed using a paired before-after control-impact design (BACIP, Underwood 1994). Paired analysis using waters from the same geographic region is a commonly utilized approach in whole lake studies as a control for local climactic variation which can mask important field patterns (Carpenter 1989). Response metrics for each lake pair included relative abundance (CPUE; number per hour) of largemouth bass, bluegills, and gizzard shad, and total fish diversity measured using Shannon's index (H'). In order to draw general conclusions concerning the effects of muskellunge introduction we utilized results from each lake pair to conduct a meta-analysis of each metric following the general approach described by Gurevitch and Hedges (2001) and the procedures for BACI designs described by Conner et al. (2007). Meta-analysis was conducted by comparing the net change in the mean difference from before and after muskellunge introduction (*d*, also known as the "effect size") across each pair of lakes before and after muskellunge introduction utilizing a paired t-test. This "Meta-BACI" technique allowed us to statistically combine the results of each of our independent paired observations with the goal of reaching general conclusions regarding the effects of muskellunge introduction.

Community Effects of Muskellunge Stocking

The study sites for evaluation of community effects of muskellunge introduction include Lake Mingo, and Ridge Lake (Coles County), with reference waters including Homer Lake (Champaign County), and Walnut Point Lake (Douglas 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 and size structure of juvenile and adult fish, larval fish density, benthic macroinvertebrate density and size structure, zooplankton density and size structure, 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).

In past reports we presented results for a number of community parameters including relative abundance of largemouth bass and bluegill, zooplankton density and size structure, algal biomass, and total phosphorous concentration utilizing data from 1998-2007 on Ridge Lake and 1998-2005 on Lake Mingo. In this segment we update the analyses of these parameters and include additional data on larval fish and benthic macroinvertebrate density incorporating data from 2008-2009. Adult fish response metrics from these lakes were also combined with those from a larger set of lakes receiving muskellunge stockings for the purpose of drawing more general conclusions and are presented in the following section (fishery effects of muskellunge stocking). Data from fall (September-November, electrofishing CPUE, seine fish density) or summer (June-August, zooplankton, chlorophyll, total phosphorous, and larval fish) sampling 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.

FINDINGS:

Muskellunge Food Habits

Stomach contents of 436 muskellunge from seven Illinois lakes were sampled between May 2009 and May 2010 yielding 168 diet items (268 fish had empty stomachs). Diet samples collected during this segment were pooled with data from previous years to describe the diet of muskellunge in each of the study lakes. Gizzard shad were the dominant diet item by frequency and wet weight in Lakes Mingo (Figure 6), Pierce (Figure 7), Shelbyville (Figure 8), and Sam Dale (Figure 9). Bluegill were the dominant diet item in Ridge Lake (Figure 10). Bluegill were the secondary prey species in Mingo, Pierce, Sam Dale, and Shelbyville while largemouth bass were the secondary prey in Ridge Lake. Low sample sizes limited our ability to describe the diets of muskellunge in Lake of the Woods and Otter Lake at this time. Other species found in low frequency included: black crappie (Pierce), brook silverside (Pierce and Sam Dale), yellow bullhead (Mingo), white bass (Shelbyville), white crappie (Sam Dale), and yellow perch (Pierce). Of all muskellunge captured, 77% had empty stomachs at the time of sampling. Gizzard shad were the most frequent prey item in lakes where they are present (Lakes Mingo, Sam Dale, Shelbyville, and Pierce). In Ridge Lake where gizzard shad are not present bluegill 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).

Fishery Effects of Muskellunge Stocking

Responses of fish community metrics to muskellunge introduction were variable among lakes (Table 14) however the results of our meta-analysis revealed some consistent patterns. Largemouth bass relative abundance measured as the number of fish collected per hour of electrofishing from standardized fall surveys showed positive effects on 6 of the 8 lakes evaluated after muskellunge introduction resulting in a statistically significant meta-analysis (paired t test on effect sizes: $t = 3.12$; $P < 0.02$; Figure 11). Across the eight lakes receiving muskellunge introductions the relative abundance of largemouth bass increased by an average of 38 (SE = 12) fish collected per hour relative to control lakes. In addition, meta-analysis indicated a marginally significant reduction in the abundance of bluegills in response to muskellunge introduction (paired $t = 1.98$; $P = 0.08$; Figure 12). The relative abundance of bluegills decreased by an average of 13 (SE = 6) fish collected per hour relative to control lakes after muskellunge introduction. Meta-analysis revealed no consistent patterns in effects of muskellunge introduction on gizzard shad relative abundance in the 5 lakes in which this species was present or total fish community diversity across all 8 lakes receiving muskellunge (Table 15).

Community Effects of Muskellunge Stocking

Introduction and establishment of significant adult populations of muskellunge in both Ridge Lake and Lake Mingo has had little effect on major components of the aquatic community (Table 16). In Ridge Lake we found no significant effects of muskellunge introduction on any of the observed parameters (Table 16). Similarly our analysis indicated few changes in Lake Mingo although there were some marginally significant changes in zooplankton metrics. Further examination of trends in average cladoceran density in Lake Mingo indicated a marginally significant decrease in abundance of these zooplankters that was not present in the control system. Marginally significant effects of muskellunge introduction on average cladoceran size structure were also evident but were driven by a slight increase in the size of zooplankters in the control system (Homer Lake) while cladoceran size remained unchanged in Lake Mingo.

RECOMENDATIONS: The third 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 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 and other soft rayed fishes when present (Wahl and Stein 1988). This suggests 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). Our meta-analysis of 8 Illinois lakes indicated a consistent pattern of increasing largemouth bass abundance (75% of cases) after muskellunge introduction. Although specific mechanisms contributing to these patterns cannot be determined it is highly unlikely that this result can be attributed to random or environmental variation. All lakes receiving muskellunge were paired with controls from the same geographic area and these control lakes showed no increase in largemouth bass catch rates. Potential mechanisms for the response of largemouth bass populations to muskellunge introduction are many however previous research on the effects of introduced predators suggests that increases in relative abundance of one or both species can often be attributed to positive indirect interactions. For example, in a recent pond experiment conducted by the INHS the presence of muskellunge indirectly increased growth of largemouth bass (Carey and Wahl 2010). This effect was presumably due to contrasting predatory styles facilitating the capture of a shared prey resource (bluegill) by the largemouth bass. Predator facilitation may occur when predator foraging behaviors are complimentary and act to increase encounter rates and vulnerability of prey thereby increasing foraging success. Predator facilitation is known to lead to increases in population growth rates of fish predators (see Eklov and VanKooten 2001) and is a potential mechanism for observed increases in relative abundance of largemouth bass after muskellunge introduction. Also consistent with the predator facilitation hypothesis is the observed reduction (although small) in bluegill density across lakes; an effect also observed in the ponds study conducted by the INHS (Carey and Wahl 2009).

Another potential explanation for increases in relative abundance of largemouth bass would be a habitat shift in response to a new predator type, which may make largemouth bass more susceptible to the electrofishing gear used to collect samples. Studies involving species introductions often document habitat shifts by native fishes in response to new competitive or predatory pressures (Eklov and VanKooten 2001; Schulze et al. 2006; Holker et al. 2007). For example, largemouth bass may spend more time in littoral areas if muskellunge increase the availability or vulnerability of prey in these habitats (for example by forcing bluegill out of vegetated refuges). Alternatively, predation risk or competition for space from adult muskellunge may cause habitat shifts in largemouth bass and the potential for such interactions should be investigated further. Currently there is no available data to support or refute the habitat shift hypothesis while available evidence does suggest a positive indirect interaction.

Thus far the available evidence suggests that muskellunge introduction has not had any major negative effects on the relative abundance of two important sport fish or fish community diversity of the littoral zone across the 8 lakes involved in our study. This analysis includes time periods ranging from 3-10 years after introduction. Over this period the data show that muskellunge have not negatively affected the abundance of largemouth bass and have had only weak (bluegill) or no (gizzard shad) effects on the abundance of primary prey fish species in these systems. Our study represents one of the first rigorous evaluations of the effects of muskellunge introduction on lake fisheries in the lower Midwest, however we caution that further research focusing on additional game and non-game species, longer time frames of observation, a larger number of case studies, and additional response metrics will be needed to thoroughly evaluate risks associated with muskellunge introduction. Future research will also be required to determine specific mechanisms by which muskellunge affect recipient aquatic communities at the whole-lake scale. In future segments we will examine additional fish and community metrics across the lakes before and after muskellunge introduction. Future metrics will include parameters related to fish growth such as condition and size structure as well as relative abundance of additional species. Further analysis of community responses in Lakes Mingo and Ridge will include abundance of juvenile littoral fishes in seine samples and a more detailed taxonomic evaluation of invertebrate communities as well as additional years of data.

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.

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

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

Table 2. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH), and North Spring Lake, IL progeny (IL) introduced in Pierce Lake, Lake Mingo and Sam Dale Lake during falls 2005-2008. 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		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: Stocked	Number of Fish: Adjusted	Number per Hectare: Stocked	Number per Hectare: Adjusted	Mean Length (mm)	Mean Weight (g)
			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 Sam Dale Lake 2005-2008. The overwinter period represents the 6 months following stocking and age-1 fall represents one year after stocking.

Stocking year class	Time period	Num *DF*	Den *DF*	F	P
2005	Overwinter	.	.	.	.
2006	Overwinter	.	.	.	.
2007	Overwinter	1	4	22.64	0.04
2008	Overwinter	.	.	.	.
2005	Age-1 Fall	.	.	.	.
2006	Age-1 Fall	.	.	.	.
2007	Age-1 Fall	.	.	.	.
2008	Age-1 Fall	2	14	13.4	0.0006

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 during 2003-2010. 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	449 (±0)^{a}	605 (±14)^{b}	628 (±11)^{b}	<0.01
Male	3	782 (±4)	757 (±11)	773 (±7)	0.06
	4	-	844 (±15)	842 (±15)	0.65
	5	-	909 (±17)^{a}	877 (±25)^{b}	0.04
	6	-	900 (±0)	976 (±25)	-
	7	-	945 (±38)	-	-
Female	3	-	790 (±19)	784 (±22)	0.77
	4	-	878 (±23)	867 (±15)	0.31
	5	909 (±0)	963 (±32)	961 (±17)	0.37
	6	-	1020 (±0)	1015 (±0)	-
	7	-	-	1068 (±0)	-
			Weight (g)		
Combined	2	480 (±0)^{a}	1519 (±105)^{b}	1740 (±98)^{b}	<0.01
Male	3	3680 (±137)	3283 (±161)	3433 (±133)	0.28
	4	-	4698 (±218)	4571 (±275)	0.32
	5	-	5927 (±414)^{a}	5229 (±484)^{b}	0.04
	6	-	6350 (±0)	6630 (±0)	-
	7	-	6165 (±225)	-	-
Female	3	-	3669 (±369)	3872 (±339)	0.47
	4	-	6038^{a} (±361)	5195 (±266)^{b}	<0.01
	5	5800 (±0)	7152 (±532)	7109 (±548)	0.51
	6	-	7950 (±0)	8003 (±0)	-
	7	-	-	9650 (±0)	-

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 2002-2010 stratified by gender. Upper Mississippi River drainage parameters estimates were calculated by combining genders.

Strain/ Sex	N	L∞ (mm)	95% C.I. Limit Upper	95% C.I. Limit Lower	K	95% C.I. Limit Upper	95% C.I. Limit Lower
Lake Mingo							
Illinois							
Male	289	922	945	899	0.66	0.71	0.59
Female	209	1087	1136	1038	0.42	0.48	0.36
Ohio							
Male	119	997	1034	960	0.50	0.56	0.44
Female	119	1109	1180	1037	0.42	0.50	0.35
Mississippi	73	1121	1367	874	0.37	0.56	0.18
Pierce Lake							
Illinois							
Male	193	1012	1055	970	0.41	0.47	0.36
Female	86	1058	1125	992	0.41	0.49	0.33
Ohio							
Male	80	941	982	900	0.51	0.59	0.43
Female	53	1082	1208	955	0.38	0.52	0.24
Mississippi	41	1011	1251	771	0.50	0.88	0.12

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 during 2003-2010. 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	-	511 (±71)	578 (±30)	0.10
Male	3	679 (±0)	711 (±17)	720 (±7)	0.36
	4	903 (±15)^{a}	806 (±18)^{b}	823 (±8)^{b}	<0.01
	5	855 (±0)^{ab}	851 (±8)^{a}	883 (±16)^{b}	0.01
	6	-	864 (±0)	919 (±41)	-
	7	-	-	-	-
Female	3	-	681 (±51)^{a}	748 (±17)^{b}	<0.01
	4	-	878 (±63)	844 (±20)	0.21
	5	-	909 (±43)	928 (±18)	0.45
	6	-	956 (±39)	966 (±34)	0.73
	7	-	-	-	-
			Weight (g)		
Combined	2	-	839 (±559)	1266 (±281)	0.26
Male	3	2030 (±0)	2576 (±225)	2615 (±102)	0.48
	4	5070 (±470)^{a}	3976 (±499)^{b}	3939 (±137)^{b}	0.04
	5	4450 (±0)	4622 (±567)	4960 (±417)	0.60
	6	-	5515 (±1695)	5540 (±186)	0.97
	7	-	-	-	-
Female	3	-	2175 (±617)^{a}	3161 (±236)^{b}	<0.01
	4	-	4630 (±343)	4923 (±267)	0.42
	5	-	5862 (±923)	6548 (±560)	0.23
	6	-	6954 (±1137)	6828 (±912)	0.87
	7	-	-	-	-

Table 7. Comparisons of mean length-at-age and weight-at-age of adult muskellunge from three stocks introduced into Sam Dale Lake stratified by gender. Means are estimated from pooled data from spring samples taken in 2010. 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	702 (±0)^{a}	622 (±15)^{b}	663 (±14)^{ab}	<0.01
Male	3	–	754 (±11)	757 (±11)	0.76
	4	–	–	–	–
	5	–	–	–	–
Female	3	817 (±52)	810 (±18)	805 (±14)	0.82
	4	–	–	847 (±0)	–
	5	–	975 (±0)	–	–
		Weight (g)			
Combined	2	2910 (±0)^{a}	1752 (±188)^{b}	2182 (±154)^{ab}	<0.01
Male	3	–	3154 (±193)	3307 (±192)	0.30
	4	–	–	–	–
	5	–	–	–	–
Female	3	3750 (±0)	3986 (±408)	4178 (±299)	0.68
	4	–	–	4410 (±0)	–
	5	–	7750 (±0)	–	–

Table 8. 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 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.

				Adjusted CPUE			
Lake	Stocking year class	Time period	Effort (hr)	Miss	OH	IL	P
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	.
Sam Dale	2008	Age-1 Fall	9.55	0.54	0.9	1.78	0.18

Table 9. Adjusted catch-per-unit effort from spring 2010 trap netting surveys and statistical comparisons (ANOVA) for the OH: Ohio River drainage stock, MISS: Upper Mississippi River drainage stock, IL: Illinois populations of muskellunge introduced into Mingo and Pierce Lakes, Illinois, during fall 2003-2007 and Sam Dale Lake 2005-2008. Lower case letters denote statistical differences following Tukey's means separation. Values in parentheses represent 95% confidence intervals.

Lake	Upper Mississippi River drainage	Ohio River drainage	Illinois	P Value
Pierce	0.08 (±0.15)	0.90 (±1.01)	1.10 (±0.64)	0.15
Mingo	0.00	0.13 (±0.13)	0.56 (±0.58)	0.18
Sam Dale	0.06 (±.08)^{b}	0.42 (±0.24)^{ab}	0.74 (±0.50)^{a}	0.02

Table 10. Adjusted catch-per-unit effort from spring trap netting surveys and statistical comparisons of survival to adulthood (Age-3) by year class of the Upper Mississippi River drainage stock, Ohio River drainage stock, and Illinois population of muskellunge sampled from Mingo and Pierce Lakes, Illinois, during spring 2005-2010. 95% confidence limits are in parenthesis and letters represent significant differences following Tukey's means separation.

Lake	Year Class	Mississippi River Drainage	Ohio River Drainage	Illinois	P Value
Mingo	2002	NA	1.34	0.76	
	2003	0.00	0.71	0.47	
	2004	0.09	2.35	1.06	
	2005	0.10	1.44	1.04	
	2006	NA	0.37	0.89	
	2007	0.00	0.09	1.07	
	Mean	0.05 (±0.05)[b]	1.05 (±0.73)[a]	0.88 (±0.21)[ab]	0.03
Pierce	2003	0.00	0.00	0.00	
	2004	0.00	0.69	1.11	
	2005	0.00	4.09	2.26	
	2006	NA	NA	1.35	
	2007	0.17	0.49	2.41	
	Mean	0.04 (±0.10)	1.32 (±2.12)	1.43 (±0.96)	0.23

Table 11. Catch-per-unit effort (number per net night) from spring fyke net surveys conducted 2007-2010 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	Survival	2010 CPUE
Illinois Population							
3	0.31		0.32		0.24		0.31
		0.97		0.61		0.59	
4	0.24		0.30		0.20		0.14
		0.47		0.35		0.41	
5	0.09		0.11		0.11		0.08
		0.22		0.00		0.19	
6+	.		0.02		0.00		0.02
		.		.		.	
Mean		0.55 (±0.40)		0.32 (±0.35)		0.40 (±0.22)	
Ohio River Drainage							
3	0.35		0.28		0.04		0.02
		0.60		0.05		1.00	
4	0.16		0.21		0.01		0.06
		0.61		0.19		1.00	
5	0.21		0.09		0.04		0.01
		0.09		0.35		0.00	
6+	.		0.02		0.04		0.00
		.		.		.	
Mean		0.43 (±0.33)		0.19 (±0.17)		0.67 (±0.65)	

Table 12. Catch-per-unit effort (number per net night) from spring fyke net surveys conducted 2007-2010 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	Survival	2010 CPUE
			Illinois Population		
3	1.23		0.34		0.72
		0.41		1.00	
4	0.36		0.50		0.65
		0.44		0.46	
5	0.59		0.16		0.23
		0.31		0.13	
6+	.		0.18		0.02
Mean		0.38 (±0.08)		0.53 (±0.50)	
			Ohio River Drainage		
3	0.36		.		0.13
		0.75		.	
4	0.23		0.27		.
		0.30		1.00	
5	0.27		0.07		0.45
		0.42		1.00	
6+	.		0.11		0.09
Mean		0.49 (±0.26)		1.00 (±0)	

Table 13. Years of available data and muskellunge stocking density, relative abundance and size structure from electrofishing (EF) and fyke net (Net Night) surveys conducted on stocked and control systems before and after muskellunge introduction in 8 Illinois lakes (column headings). Values for stocking density, catch rates, and size structure represent means from the period after initial muskellunge introduction while values in parentheses represent ranges (min-max) from the same period.

Lake	Argyle Lake	Johnson Lake	Mill Creek Lake	Lake Mingo	Ridge Lake	Sauk Trail Lake	Shovel Lake	Wheel Lake
Control Lake	Lake Jacksonville	Lake Springfield	Lincoln Trail Lake	Homer Lake	Walnut Point Lake	Lake Le-aqua-na	Lake Lou Yeager	Schuy - Rush Lake
Years Before	1988, 1991-1999	1993-2001	1988-1992,1997	1998-2002	1998-2005	1988-2000	1995-1999	1993-1995
Years After	2000, 2002 2005-2007	2002-2007	2001,2003 2005,2007	2003-2009	2006-2009	2001-2007	2000, 2002-2007	1997,1999, 2001-2003 2005,2007
Years Stocked	2000,2002-2003 2006-2007	2001-2003 2005-2007	1999-2003 2005-2007	2002-2009	2005-2008	2000-2002 2006-2007	1999,2000,200-2003 2005-2007	1999,2000,2002-2003 2005-2007
MUE Stocking Density	6.15 (2.85-9.20)	4.16 (2.47-9.05)	1.11 (1.11-1.12)	7.20 (2.47-14.06)	12.11 (7.27-14.53)	3.11 (2.47-4.94)	2.50 (2.47-2.69)	2.55 (2.47-3.18)
Mean MUE Per Net Night	1.29	1.11 (0.81-1.38)	no data	1.33 (0.75-1.77)	0.78	1.03 (0.25-2.00)	1.77 (0.5-4.25)	1.73 (0.27-4.2)
Mean MUE EF CPUE	1	1.06(0.85-1.4)	1.11(0.35-2)	2.85(2.00-4.00)	1.95(1.28-2.86)	3.03	1.63(0.74-5.2)	1.66(0.71-4.51)
Mean MUE PSD	83	39.55 (9.5-69.6)	no data	64.5 (56-77)	100	83.33 (50-100)	57.67 (35-74)	54.43 (0-80)

Table 14. Results of paired before-after control-impact analysis for 4 fish community parameters from 8 Illinois lakes in response to muskellunge introduction.

		Control	Stocked			
Lake Pair	Parameter	Before - After	Before - After	Difference(±SE)	F	*P*
Argyle - Jacksonville	LMB CPUE	-7.72	15.00	22.72(32.21)	0.62	0.45
	BLG CPUE	5.44	25.47	20.03(17.78)	1.50	0.26
	GZS CPUE	0.06	33.61	33.55(24.99)	1.80	0.21
	H'	0.26	-0.29	-0.55(0.14)	14.47	<0.01
Johnson - Springfield	LMB CPUE	7.48	-47.19	-54.67(14.7)	27.43	<0.01
	BLG CPUE	2.43	13.72	11.29(13.16)	0.74	0.41
	GZS CPUE	2.61	9.31	6.7(6.94)	0.93	0.36
	H'	0.11	0.72	0.61(0.13)	21.14	<0.01
Mill Creek - Lincoln Trail	LMB CPUE	51.86	-36.76	-88.62(74.68)	1.41	0.27
	BLG CPUE	363.07	-141.41	-504.48(190.59)	7.01	0.03
	GZS CPUE	.	.	.	.	.
	H'	0.19	-0.07	-0.26(0.13)	4.25	0.08
Mingo - Homer	LMB CPUE	-5.60	1.14	6.74(15.26)	0.20	0.67
	BLG CPUE	89.22	143.78	54.56(193.20)	0.57	0.48
	GZS CPUE	-18.26	-26.12	-7.86(20.68)	0.20	0.68
	H'	0.06	0.18	0.12(0.12)	1.43	0.35
Ridge - Walnut Point	LMB CPUE	43.45	-27.87	-71.32(56.77)	1.64	0.23
	BLG CPUE	71.76	141.15	69.39(137.14)	0.26	0.63
	GZS CPUE	.	.	.	.	.
	H'	-0.07	-0.14	-0.07(0.25)	0.07	0.81
Suak Trail - Leaquana	LMB CPUE	-13.17	-75.22	-62.05(31.13)	4.07	0.06
	BLG CPUE	-5.82	21.57	27.39(104.61)	0.07	0.79
	GZS CPUE	.	.	.	.	.
	H'	0.07	-0.25	-0.32(0.18)	4.83	<0.05
Shovel - Lou Yeager	LMB CPUE	4.35	-33.56	-37.91(29.01)	2.07	0.20
	BLG CPUE	-1.50	-2.45	-0.95(29.17)	0.00	0.98
	GZS CPUE	5.79	2.39	-3.4(9.28)	0.13	0.75
	H'	0.24	0.87	0.63(0.33)	7.77	0.03
Wheel - Schuy Rush	LMB CPUE	24.92	-40.39	-65.31(14.14)	23.79	<0.01
	BLG CPUE	8.2	22.01	13.81(7.84)	3.12	0.15
	GZS CPUE	3.47	4.67	1.20(12.31)	0..01	0.92
	H'	-0.30	0.15	0.45(0.34)	1.76	0.23

Table 15. Results of meta-analysis for 4 fish community parameters from 8 Illinois Lakes examined for effects of muskellunge introduction. Effect size is calculated as the average of [Stocked After – Stocked Before] - [Control After – Control Before]. Standard errors are calculated using pooled variance from each time period on stocked and control systems.

Parameter	Mean Effect Size(±SE)	df	t-ratio	*P*
LMB CPUE	38.41(12.28)	7	3.12	<0.02
BLG CPUE	-13.01(6.56)	7	-1.98	0.08
GZS CPUE	3.33(3.85)	4	0.86	0.44
H'	0.00(0.16)	7	0.01	0.99

Table 16. Results of paired before-after control-impact analysis for 6 community parameters in response to muskellunge introduction in Ridge Lake and Lake Mingo.

Parameter	Stocked Before - After	Control Before - After	Difference(±SE)	*P*
		Ridge Lake		
Cladoceran Density (#/L)	-224.49	-22.93	-201.56(190.35)	0.31
Cladoceran Length (mm)	0.03	0.10	-0.07(0.15)	0.76
Chlorophyll a (ug/L)	-3.47	-6.5	3.03(10.22)	0.78
Total P (ug/L)	-4.10	-13.48	9.48(35.11)	0.80
Larval Fish Density (# /m^3)	7.24	27.19	-19.95(28.85)	0.51
Benthos Density (#/m^2)	2977.70	569.34	2408.36(1948.51)	0.24
		Lake Mingo		
Cladoceran Density (#/L)	133.13	17.16	115.97(52.59)	0.08
Cladoceran Length (mm)	0.00	-0.19	-0.19(0.08)	0.07
Chlorophyll a (ug/L)	-2.07	-0.18	-1.89(5.77)	0.76
Total P (ug/L)	-45.83	-20.09	-25.74(50.47)	0.64
Larval Fish Density (# /m^3)	-1.82	28.31	30.13(39.41)	0.46
Benthos Density (#/m^2)	2656.17	1734.09	922.08(3013.99)	0.78

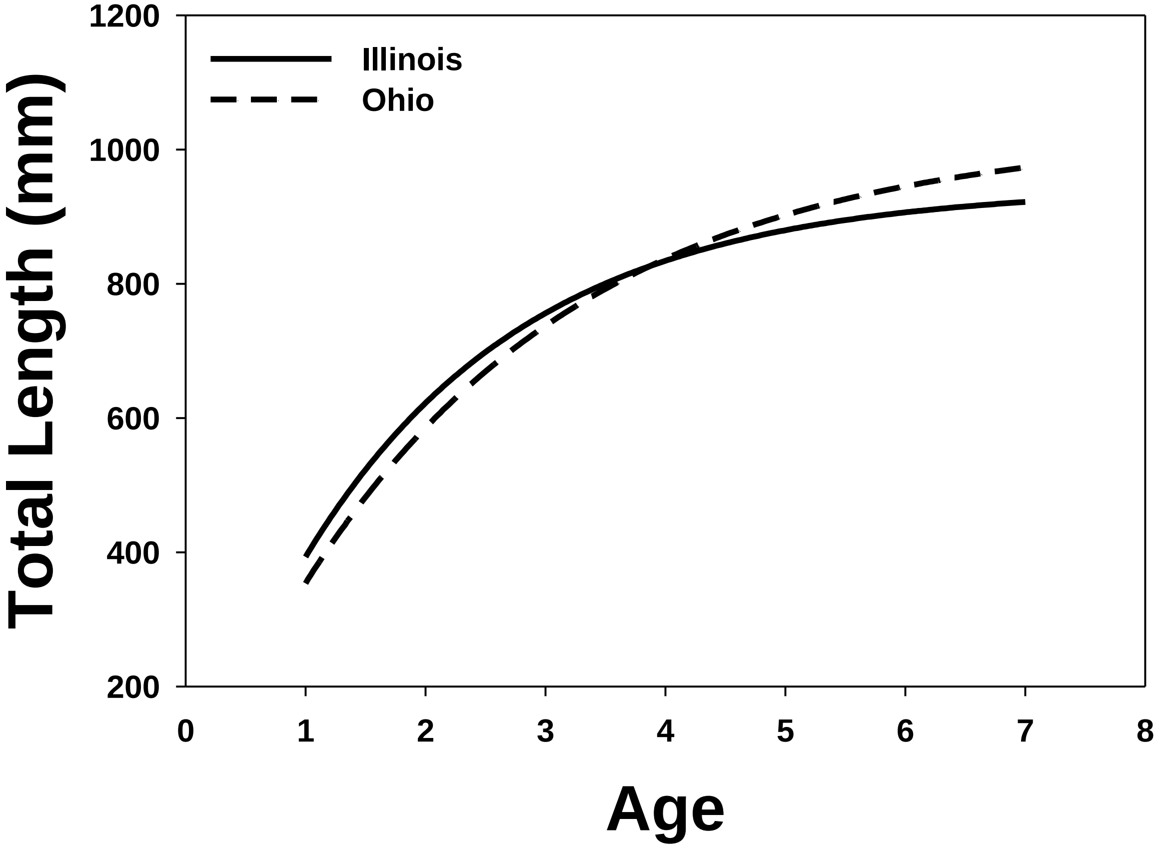

Figure 1. Fitted von Bertalanffy growth functions for male muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) sampled in Lake Mingo from fall 2003 through spring 2010.

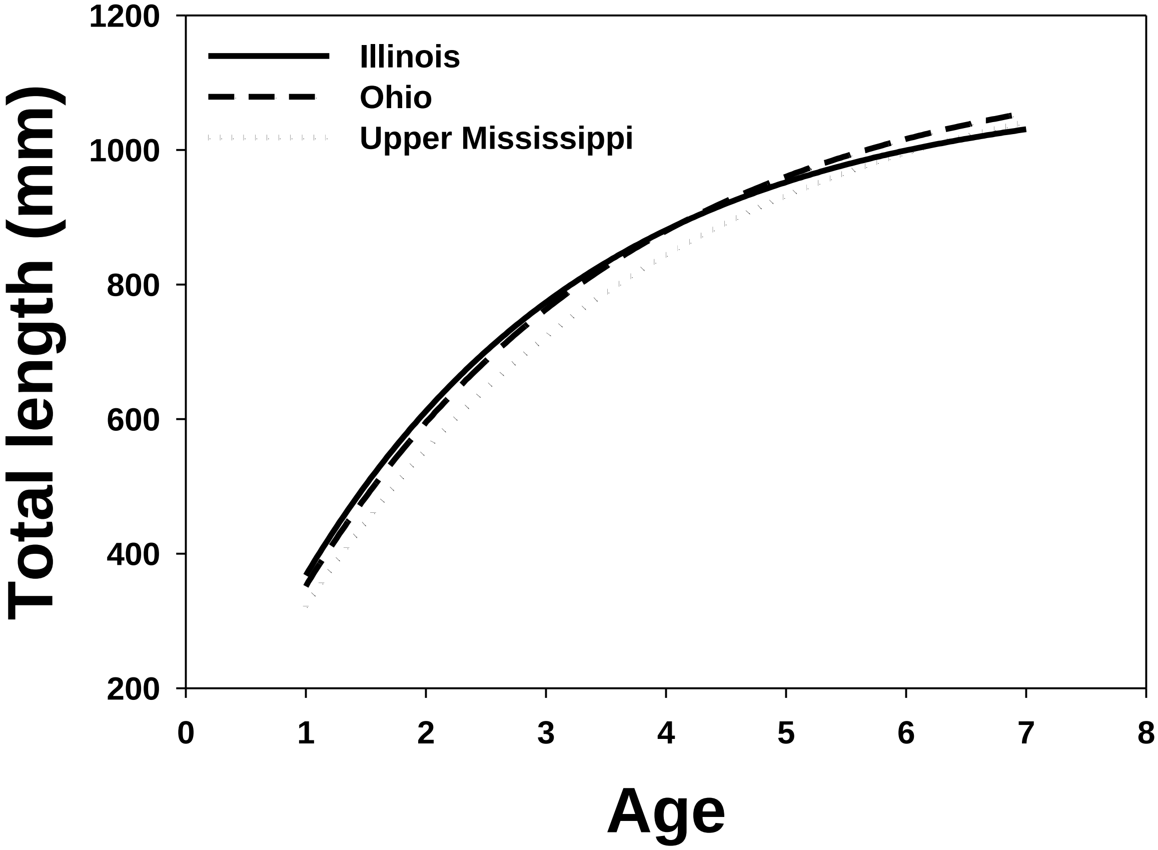

Figure 2. Fitted von Bertalanffy growth functions for female muskellunge from the Illinois population (solid line) the Ohio River drainage stock (long dashed line) and the Upper Mississippi River drainage stock sampled in Lake Mingo from fall 2003 through spring 2010. The growth function for the Upper Mississippi River drainage stock (short dashed line) was fit by pooling both genders due to low survival of this stock.

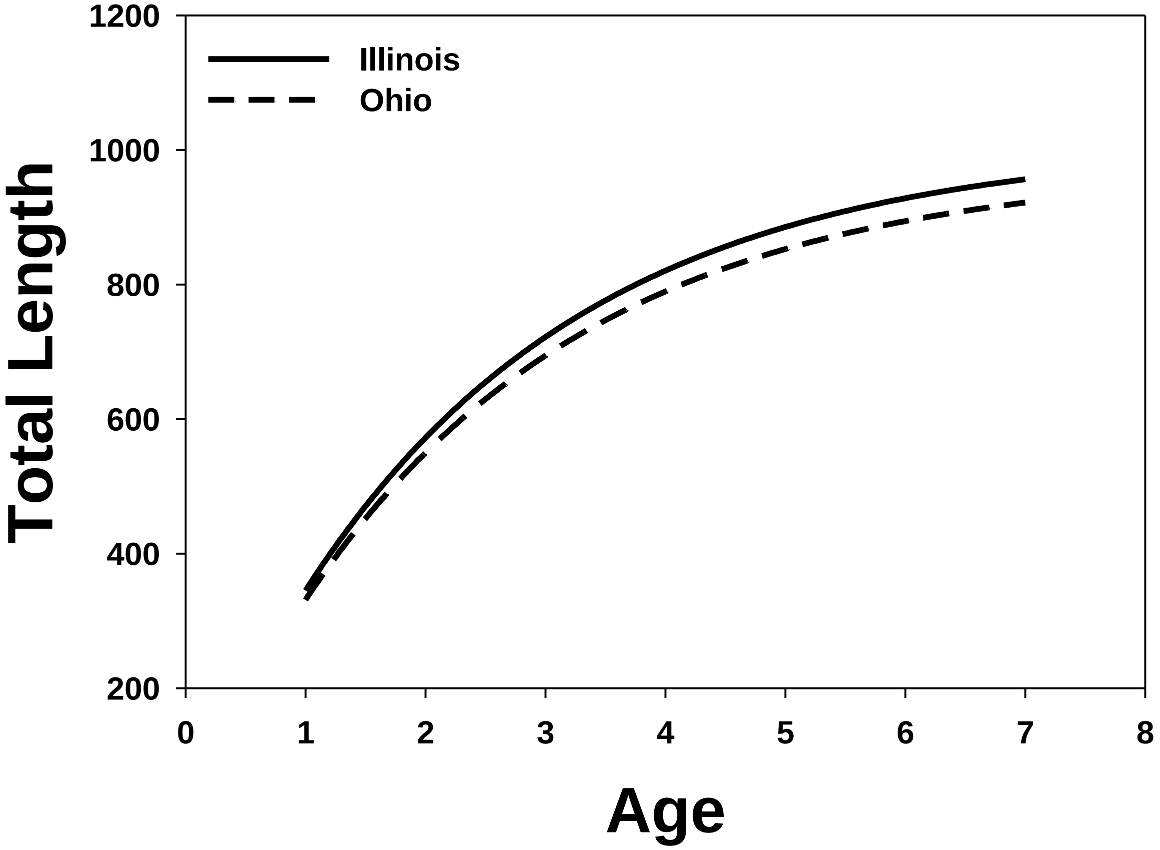

Figure 3. Fitted von Bertalanffy growth functions for male muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) sampled in Pierce Lake from fall 2004 through spring 2010.

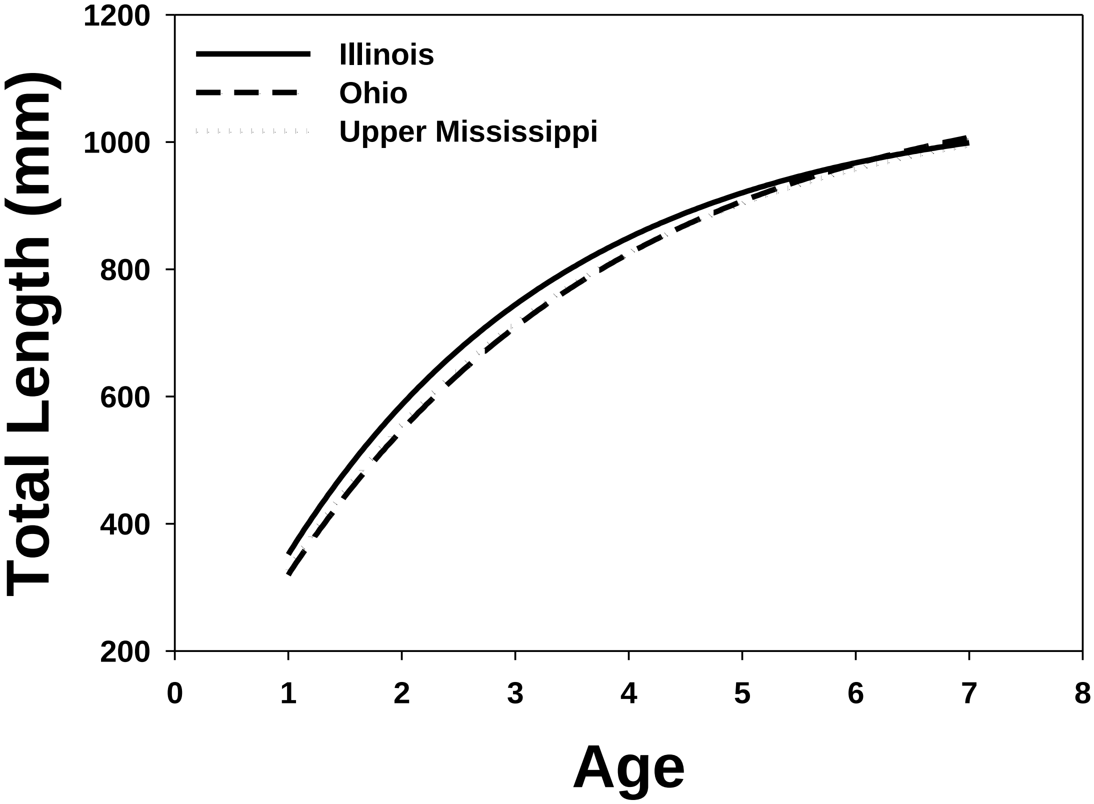

Figure 4. Fitted von Bertalanffy growth functions for female muskellunge from the Illinois population (solid line), the Ohio River drainage stock (long dashed line), and the Upper Mississippi river Drainage stock sampled in Pierce Lake from fall 2004 through spring 2010. The growth function for the Upper Mississippi River drainage stock (short dashed line) was fit by pooling both genders due to low survival of this stock.

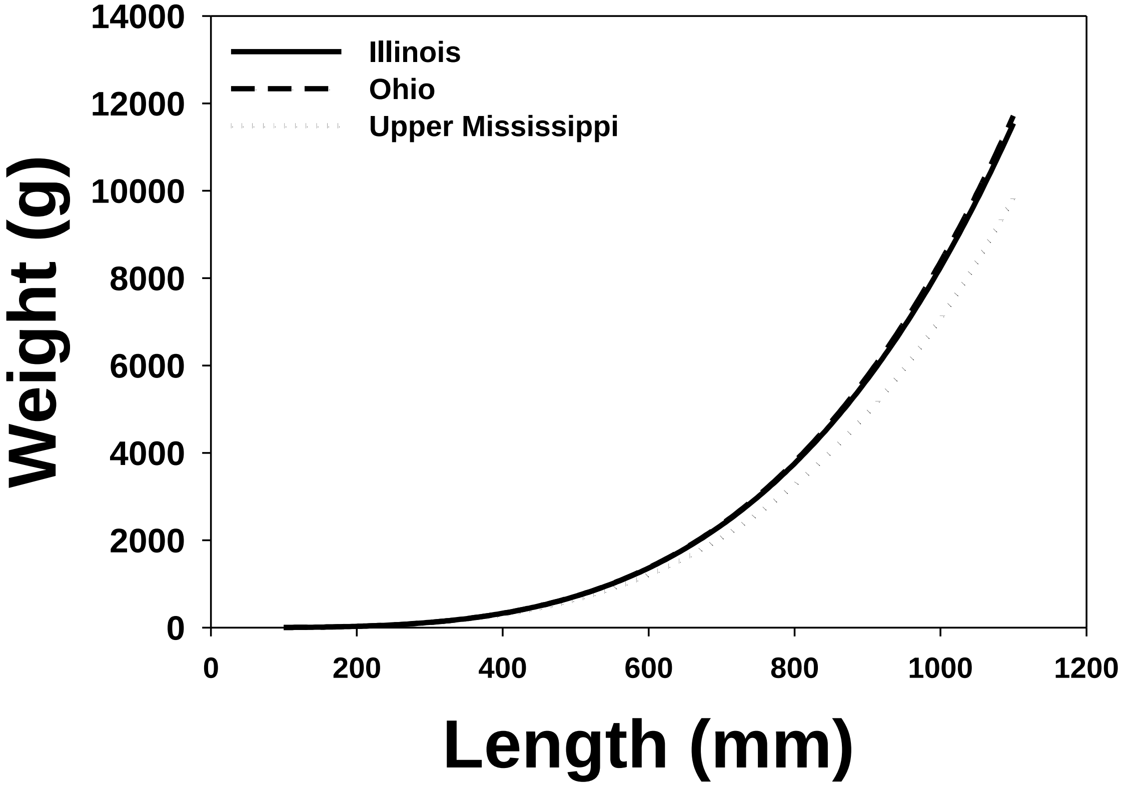

Figure 5. Length-weight relationships for muskellunge of the Illinois population (solid line), Ohio river drainage (long dashed line), and the Upper Mississippi River drainage (short dashed line) in three lakes (Lakes Mingo, Pierce, and Sam Dale) in Illinois.

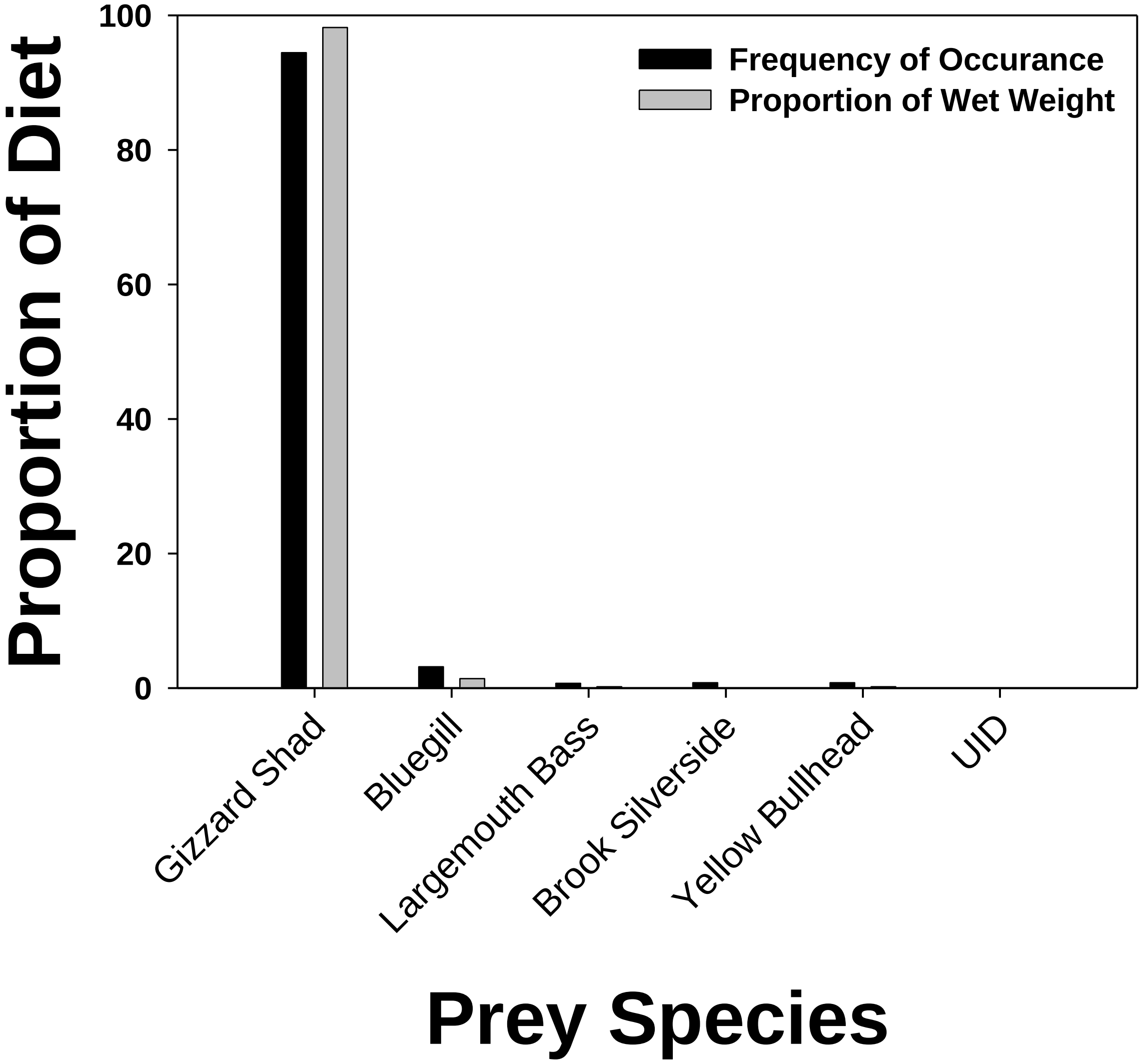

Figure 6. Diet composition of muskellunge sampled in Lake Mingo via shoreline electrofishing and modified fyke nets, May 2007 – April 2010. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

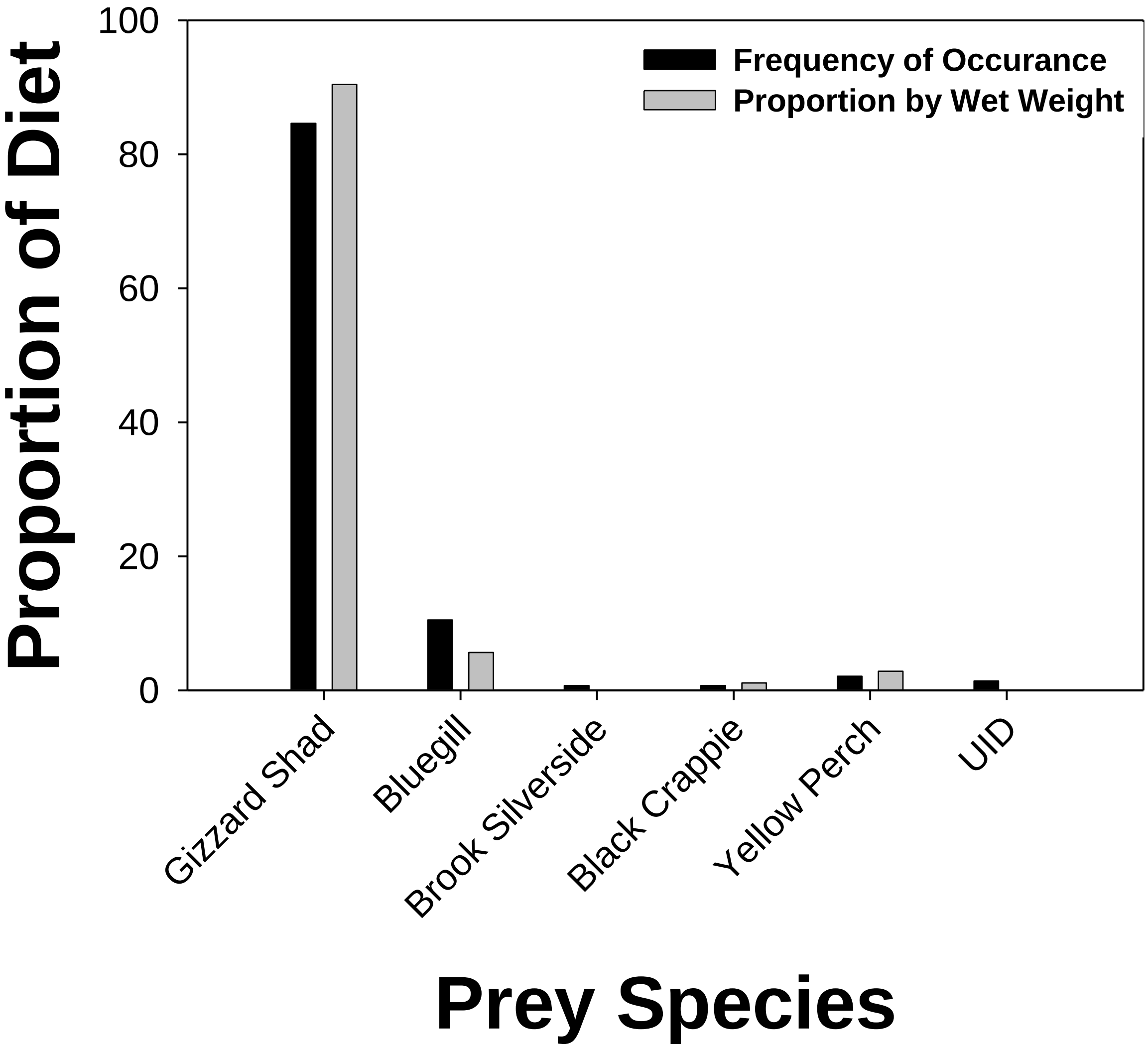

Figure 7. Diet composition of muskellunge sampled in Pierce Lake via shoreline electrofishing and modified fyke nets, May 2007 – April 2010. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

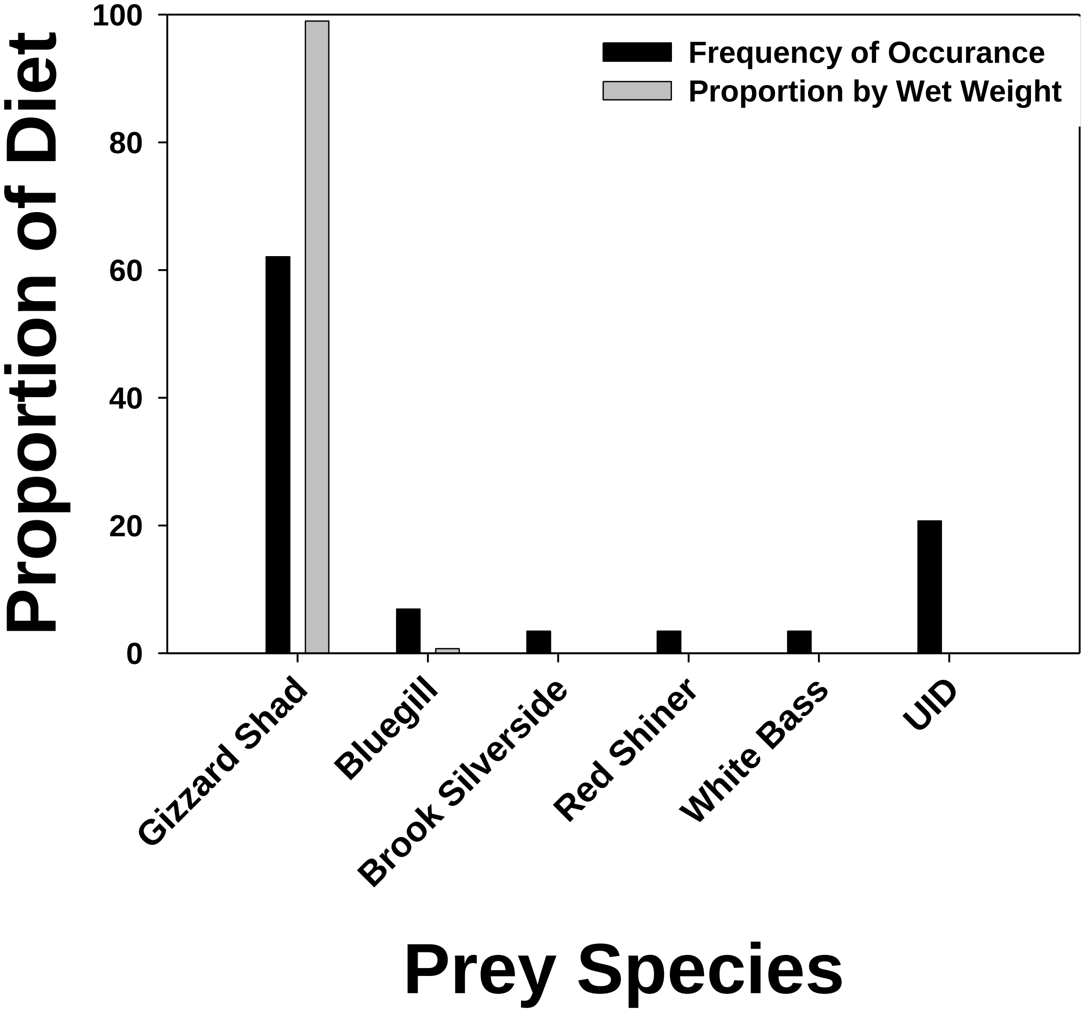

Figure 8. Diet composition of muskellunge sampled in Lake Shelbyville via shoreline electrofishing, May 2007 – April 2010. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

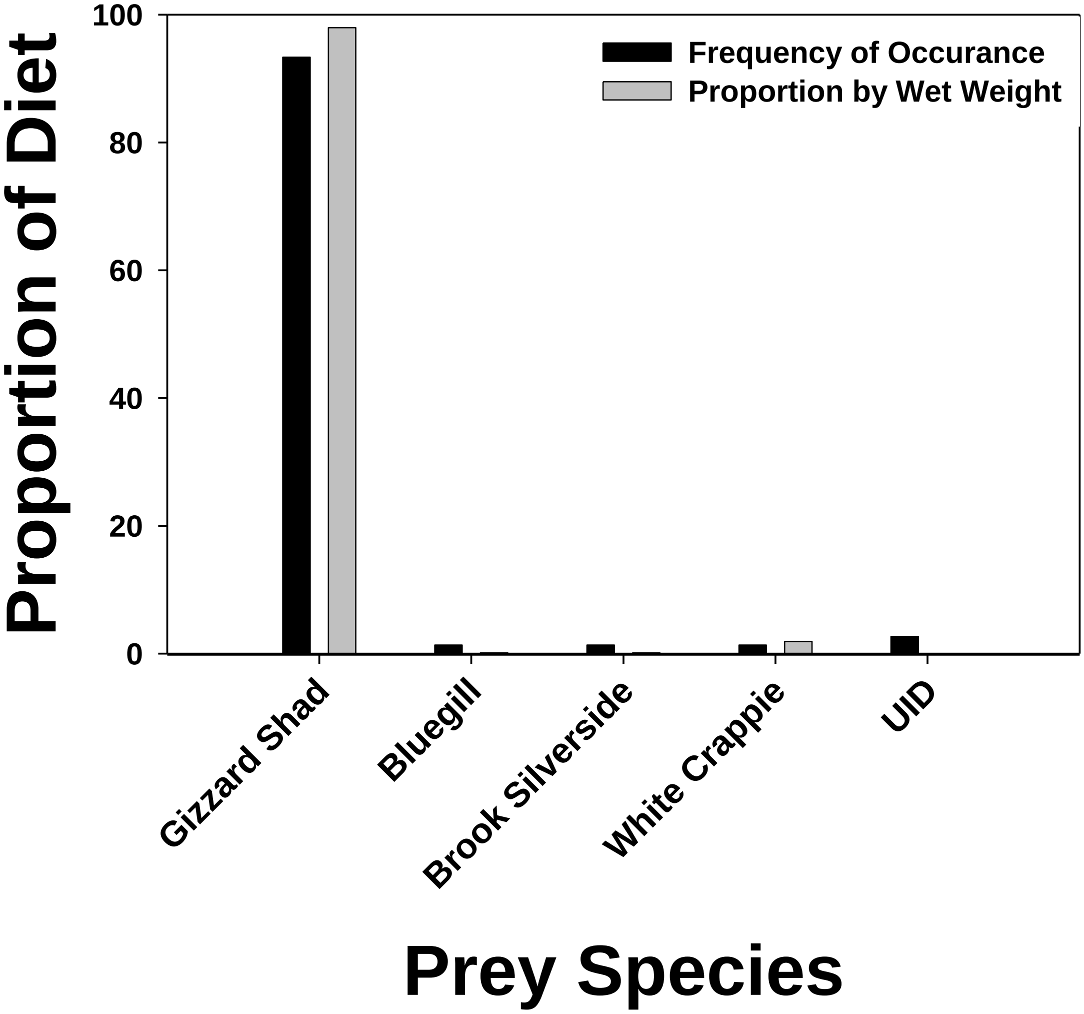

Figure 9. Diet composition of muskellunge sampled in Sam Dale Lake via trap netting and shoreline electrofishing, May 2007 – April 2010. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

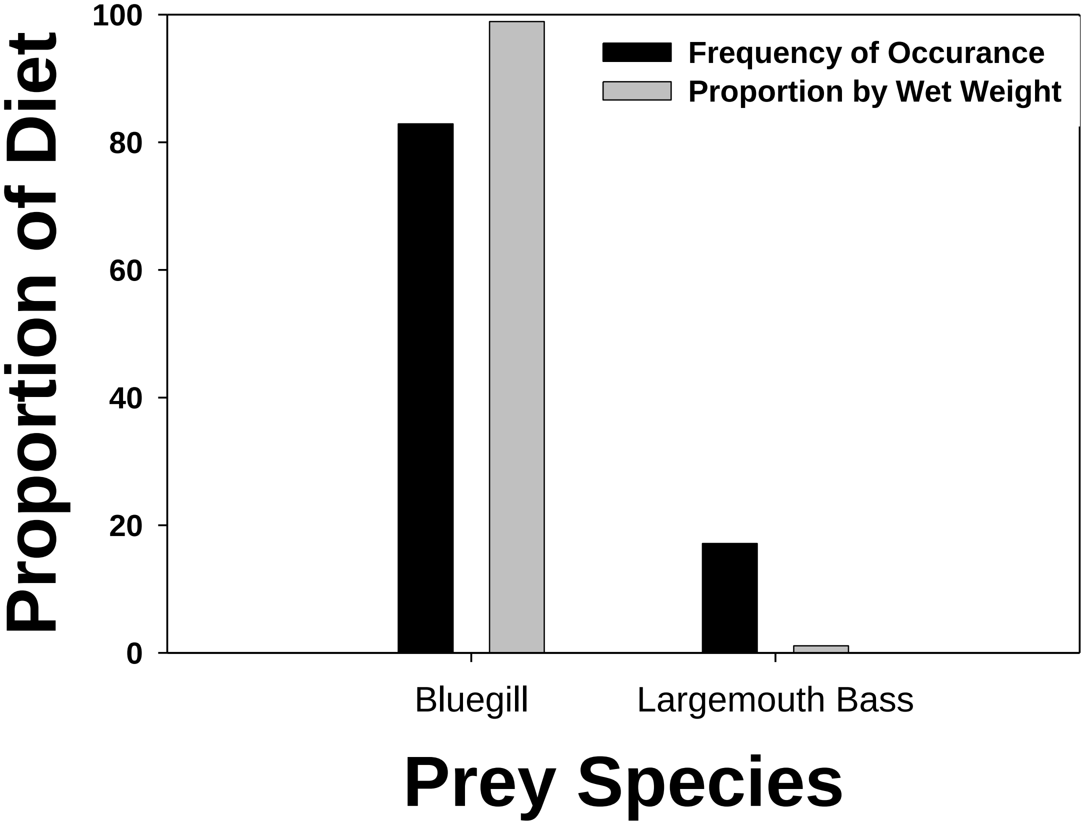

Figure 10. Diet composition of muskellunge sampled in Ridge Lake via shoreline electrofishing, modified fyke netting, and angler creel, May 2007 – April 2010. Data are pooled across samples from each season (Spring-Fall) and year. Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

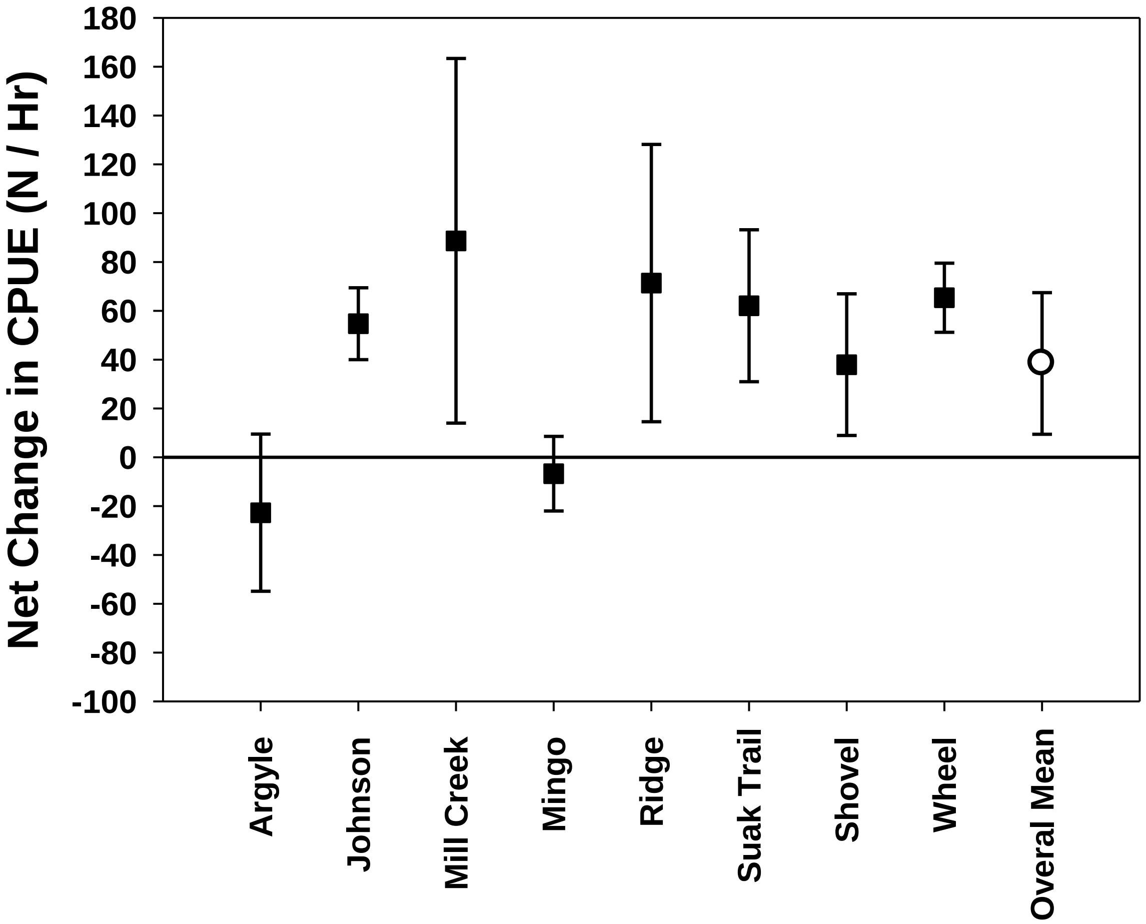

Figure 11. Net change ([After – Before Stocked] – [After –Before Control]) in number of largemouth bass collected per hour during standardized fall electrofishing surveys in Illinois lakes (N = 8) receiving muskellunge introductions relative to their respective control lakes (N = 8) from the same geographic area. Error bars represent standard errors of effect sizes for each lake pair (solid squares) whereas overall effect size (open circle) is indicated and its mean and 95% confidence interval.

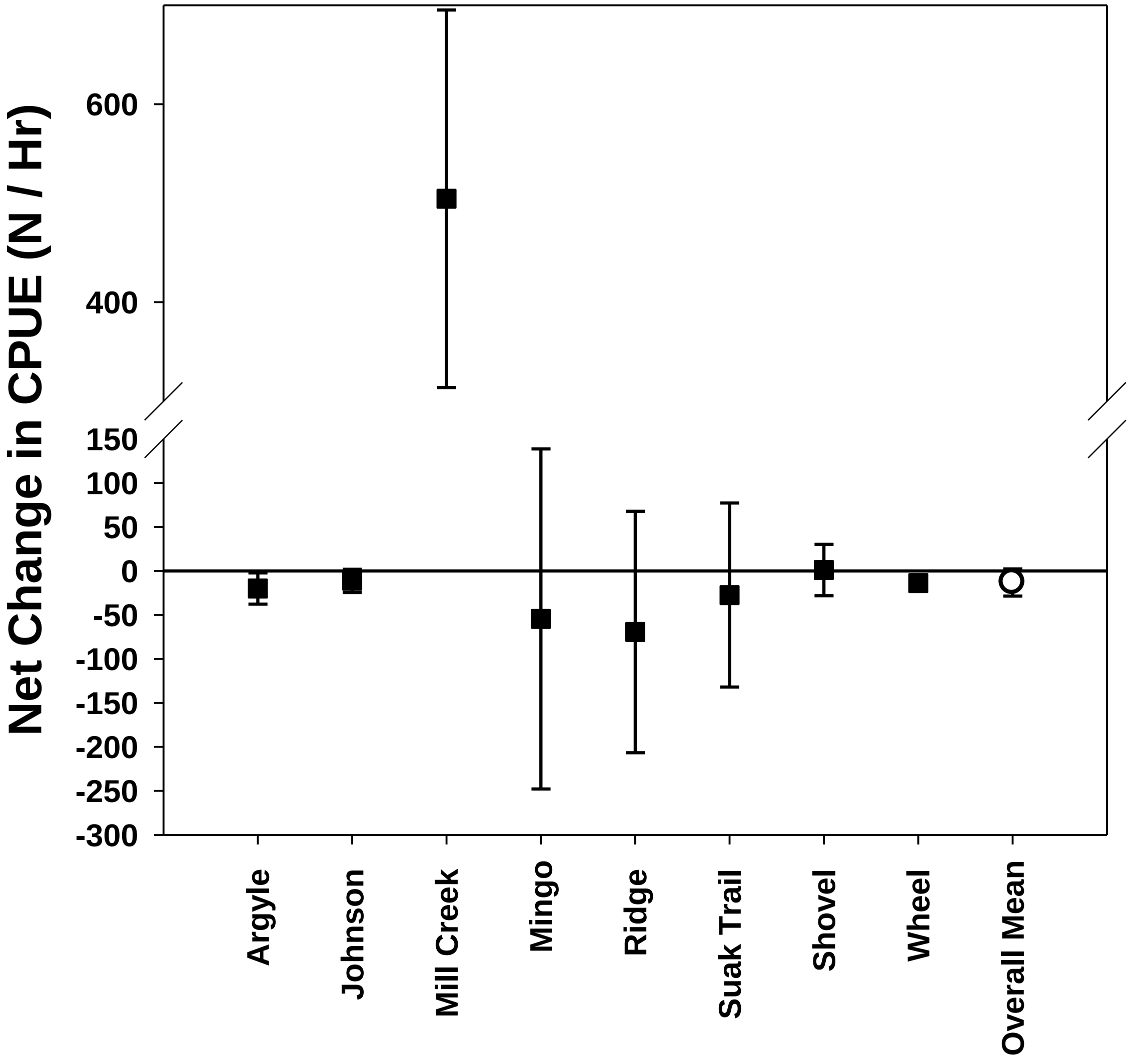

Figure 12. Net change ({[After – Before Stocked] – [After –Before Control]) in number of bluegills collected per hour during standardized fall electrofishing surveys in Illinois lakes (N = 8) receiving muskellunge introductions relative to their respective control lakes (N = 8) from the same geographic area. Error bars represent standard errors of effect sizes for each lake pair (solid squares) whereas overall effect size (open circle) is indicated and its mean and 95% confidence interval.