ILLINOIS
NATURAL HISTORY
SURVEY

ANNUAL PROGRESS REPORT
July 1, 2007 through June 30, 2008

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

C.S. DeBoom, C.P. Wagner, M.J. Diana, and D.H. Wahl
Division of Ecology and Conservation Sciences, Illinois Natural History Survey

Submitted to
Division of Fisheries
Illinois Department of Natural Resources
Federal Aid Project F – 151 – R

August 2008

INHS Technical Report 2008/28

ANNUAL PROGRESS REPORT

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

C.S. DeBoom, C.P. Wagner, M.J. Diana, and D.H. Wahl
Division of Ecology and Conservation Sciences, Illinois Natural History Survey

Submitted to
Division of Fisheries
Illinois Department of Natural Resources
Federal Aid Project F – 151 – R
July 1, 2007 – June 30, 2008

August 2008

David H. Wahl Principal Investigator	Michael Douglas, Director Division of Ecology and Conservation Sciences

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, a division of the Illinois Department of Natural Resources. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources.

Acknowledgements:

The authors wish to thank the Illinois Department of Natural Resources (IDNR), Division of Fisheries and the staff of the Jake Wolf Memorial Fish Hatchery, IDNR, for production of muskellunge and assistance with numerous tasks. In particular, S. Pallo J., Ferencak and S. Krueger helped coordinate activities with the Division of Fisheries, IDNR. We would especially like to thank the Illini Muskies Alliance, the Central Illinois Muskie Hunters and the other Illinois muskie clubs for their generous donations to purchase fish this past year and for their continued support of the project. In addition, IDNR, and specifically M. Garthaus and D. Sallee, provided nets and assistance for the Lake Mingo and Pierce Lake trap net surveys. We thank M. Hern and the Kentucky Department of Fish and Wildlife, D. Waller and the Missouri Department of Conservation, J. Navarro and the Ohio Department of Natural Resources, L. Hines and M. Marcinko and the Pennsylvania Fish and Boat Commission, P. Hulbert and the New York State Department of Environmental Conservation, R. Johannes and the Minnesota Department of Natural Resources, A. Kaas and the Wisconsin Department of Natural Resources, J. Rush and the Lake Carroll Hatchery, and J. Farrell and the Thousand Islands Biological Station for contributions of muskellunge for the study. In addition, the authors would like to thank the staff at the Kaskaskia and Sam Parr Biological Stations as well as student volunteers for laboratory and field help, especially L. Einfalt, J. Clark, B. Bushman, Eric Geibelstein, Matt VanLandeghem, Mike Carey, Joe Parkos, B. Ruebush, N. Dubravec, M. Nannini, E. Smolik, R. Wagner, and J. Wisher.

TABLE OF CONTENTS

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

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

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

During segment six, all activities outlined in the annual work plan were accomplished and were completed within the specified budget. During this segment, two jobs related to

muskellunge stock evaluation and one job related to food habits and effects of muskellunge introduction were completed. In previous segments of the study, we compared initial growth and survival of muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois North Spring Lake progeny in two Illinois lakes. During this segment muskellunge fingerlings from four sources were introduced into Pierce Lake, Lake Mingo, and Sam Dale Lake at rates ranging from 3.3 – 4.9 fish per hectare during fall 2007. Electrofishing was conducted during fall 2007 and spring 2008, and combined with modified fyke net surveys during spring 2008 in all lakes. Across years and lakes, the Ohio River drainage stock and the Illinois population appear to have similar growth rates; both consistently higher than the Upper Mississippi River drainage stock. Results from lake introductions suggest that after the first summer, the Ohio River drainage stock and Illinois population typically have similar survival and both are higher than the Upper Mississippi River drainage stock. These, and future 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 280 fish across 4 Illinois lakes. These lakes included Lake Shelbyville, Lake Mingo, Ridge Lake, and Pierce Lake. Diet analysis showed that where present, gizzard shad dominated muskellunge diet in both numbers and biomass across all size classes and seasons. Diet of muskellunge in Ridge Lake consisted primarily of bluegill although a small percentage of the samples contained largemouth bass. Diet in this lake is limited by low species diversity and the lack of preferred prey such as gizzard shad. Diet breadth was highest in Lake Shelbyville likely due to its large size and diverse fish community. Preliminary results 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 over the past year, 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 trends are present.

In the current segment we began examining two sets of analyses 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 a series of control 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 will be compared to control 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 largemouth bass and bluegill abundance have not been negatively affected by muskellunge stocking in Lake Mingo. In addition gizzard shad abundance has remained relatively constant although the average size of gizzard shad sampled in Lake Mingo has increased relative to controls. The increase in size structure of gizzard shad in Lake Mingo may be due to increased predation pressure on smaller size classes by juvenile muskellunge.

The second set of analyses on effects of muskellunge stocking involves a larger sample of lakes taken from the state FAS database. Examination of muskellunge stocking records has identified several lakes that received concurrent initial stockings of muskellunge. This analysis will focus specifically on fish communities and creel data comparing trends before and after muskellunge introduction with a series of control lakes. Controls will be selected by choosing lakes which have similar geographic, physiochemical, morphometric and fishery characteristics to lakes receiving muskellunge stockings. This analysis will provide a more rigorous examination of muskellunge effects on existing fisheries due to a larger number of replicate lakes.

In future years we will continue to monitor populations of muskellunge in lakes Mingo, Pierce and Sam Dale to evaluate long term growth and survival differences between stocks and populations. The results obtained from initial years will be combined with those from future years to identify the long-term growth and survival differences among genetic stocks of muskellunge. Results will be used to develop guidelines for future muskellunge stockings that maximize growth, survival, and angler satisfaction in lakes throughout Illinois. As the management of muskellunge fisheries improves due to increased understanding of intraspecific variation, the effects of these highly predacious fishes on the existing aquatic community also needs to be considered. In future segments we will continue to examine the food habits and effects of muskellunge on existing and native communities. 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 substantial revision over the last century (Crossman 1978; Crossman 1986). During the late 1800's and early 1900's, apparent correlations between markings and location led to the establishment of three separate species for a short time (Crossman 1978). As interpretation of the color and marking distinctions progressed, the idea of subspecies was introduced (Hubbs and Lagler 1958; McClane 1974; Smith 1979). By the late 1970's the idea that all variations were indeed one single species, without enough evidence to warrant subspecies classifications, had been established (Crossman 1978). More recent genetic analysis of various populations revealed three distinct clusters that were found to be related to major river drainage origins, suggesting the existence of divergent stocks (Koppelman and Philipp 1986). Existing information indicates muskellunge persisted through the Wisconsin glacier period in the Mississippi refugium and upon glacial recession, moved north up the Mississippi valley and established its current range via the Mississippi and Ohio River systems, as well as precursors to tributaries of the Great Lakes (Crossman 1978; Crossman 1986). Muskellunge were isolated by major river drainages and experienced different environmental conditions and thermal histories. As these isolated groups diverged through recolonization, genetic processes, such as natural selection, resulted in stocks of muskellunge that are genetically dissimilar, and likely physiologically and behaviorally different from one another (Altukhov 1981; MacLean and Evans 1981; Ihssen et al. 1981; Clapp and Wahl 1996; Begg et al. 1999). The currently identified genetically distinct muskellunge stocks are the Upper Mississippi River drainage stock, the Great Lakes/St. Lawrence River drainage stock, and the Ohio River drainage stock (Koppelman and Philipp 1986; Clapp and Wahl 1996).

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

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

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

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

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

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

PROCEDURES: As described in previous annual reports, we began by comparing growth between different stocks and populations of muskellunge in Lake Mingo, Vermillion County, Illinois, as well as in Pierce Lake, Winnebago County, and Sam Dale Lake, Wayne County (Figure 1, Table 2). These lakes represent the climatic variation associated with latitude that exists throughout Illinois. Introductions were again made into study lakes in fall 2007 (Table 3); successful stockings of each muskellunge stock were completed in each study lake including Lake Mingo, Sam Dale Lake and Pierce Lake.

The Cave Run Lake population obtained from the Kentucky Department of Fish and Wildlife represented muskellunge from the Ohio River drainage stock introduced into Lake Mingo in fall 2007 while the Clear Fork Lake population obtained from the Ohio Division of Wildlife represented muskellunge from the Ohio River drainage stock introduced into Lakes Sam Dale and Pierce. The Upper Mississippi River drainage stock introduced into all three study lakes in fall 2007 were represented by the Leech Lake Minnesota population. The Leech Lake fish were purchased from a private hatchery with funds donated by the Illini Muskies Alliance. The Illinois population, which was raised from eggs brought from Spirit Lake Iowa due to complications in the culture of North Spring Lake fish, was obtained from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Natural Resources in 2007 and introduced into the three study lakes (Table 3). Attempts were made to stock as similar of sizes and condition of fish as possible in each lake. Subsamples of each stock were held in three 3-m deep predator-free cages (N=15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress (Clapp et al. 1997; Hoxmeier et al. 1999). 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 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination, Table 4) and freeze cauterization of the wound for later identification of the stock (Boxrucker 1982). Beginning in fall 2004, we also freeze branded all stocked fish in an effort to better enable age determination (in combination with scale aging) in future years. The 2007 brand was a left-posterior vertical brand. The brand will be applied differentially by year, with 2008 fish receiving a right-middle horizontal brand, and so forth (Table 4).

To determine growth rates, nighttime pulse DC boat-electrofishing sampling was performed from October through November 2007 and from March through April 2008 on all study lakes. Length (nearest mm) and weight (nearest g) measurements were taken on sampled muskellunge. The pelvic fin clip was used to identify the stock and population and a caudal fin clip was used to conduct a Schnabel population estimate within each sampling season (Ricker 1975). Scales were taken from all sampled muskellunge older than YOY in order to determine age class (herein described as 2002 – 2006 year classes). Upon capture, muskellunge from the 2002 – 2006 year classes in Lake Mingo and the 2003 – 2006 year classes in Pierce Lake were implanted with a Passive Integrated Transponder (PIT) tag prior to release to aid in future identification (Wagner et al. 2007). Daily temperatures were recorded using a thermograph placed at 1-m depth to assess the role of temperature in influencing growth rates of different stocks and populations. Data were used to determine mean daily growth rates (g/d) and mean relative growth rates (standardizing by initial weight, g/g/d) among the stocks of muskellunge in the study lakes through age-1. Growth rates were analyzed using analysis of variance (ANOVA) models and, as sample sizes allowed, size-at-age data were used to estimate von Bertalanffy growth functions in SAS Version 8.2 (Proc NLin) (Beverton 1954; Beverton and Holt 1957, Isely and Grabowski 2007). General patterns in size-at-age (length and weight) between stocks were also examined using analysis of covariance models (ANCOVA) with age and size as main effects and mean length or weight at stocking as the covariate (Isely and Grabowski 2007). All analyses were performed with the SAS® System and P-values less than 0.05 were considered significant.

Data from electrofishing were combined with modified fyke net surveys conducted March 30 – April 3, 2008 on Mingo Lake and April 14 – April 16, 2007 on Pierce Lake. Modified fyke nets (N = 14) were set in Lake Mingo and run for 4 nights, resulting in 53 net-nights of effort (three net nights were discarded due to poor sets). Eleven modified fyke nets were set in Pierce Lake for 2 nights yielding 22 net-nights of effort (Figure 3). Nets were 3.8 cm bar mesh (1.5 in) and frames were 1.2 X 1.8 m with six 0.75 m hoops. Nets were checked between 0800 and 1200 hr each day. Surface water temperatures were 7.0 – 11.0 °C during the sampling weeks.

FINDINGS:

Modified Fyke Net Surveys – Lake Mingo and Pierce Lake

A total of 69 muskellunge were captured during the 2 nights of modified fyke net sampling in Pierce Lake during April 2008, yielding an average of 3.14 fish per net-night. Nightly average capture rates ranged from 0.63 to 2.50 fish per net-night. Of the 69 muskellunge sampled, 19 were Ohio River drainage stock, 50 were Illinois population, and 0 were Upper Mississippi River drainage stock (Table 6). The smallest muskellunge captured was 542 mm and the largest was 960 mm; weights ranged from 910 g to 7560 g. No age-1 muskellunge were captured; however, two age-2, thirty-five age-3, twelve age-4, and 20 age-5 fish were sampled. (Table 5). Males represented 82% of the sampled muskellunge and females the other 18%. Data obtained from the modified fyke net surveys was integrated with electrofishing data for calculations of growth and survival.

In Lake Mingo, a total of 99 muskellunge were netted during the 4 nights in March-April 2008 resulting in an average of 1.87 fish per net-night. Nightly average capture rates (catch-per-unit-effort, CPUE) ranged from 1.00 to 2.41 fish per net-night. Of the 99 muskellunge captured, 35 were Ohio River drainage stock, 61 were Illinois population, two were Upper Mississippi River drainage stock and one was unidentifiable. (Table 5). The smallest muskellunge captured was 550 mm and the largest was 1020 mm; weights ranged from 1001 g to 8160 g. Twenty-four muskellunge were age-2, thirty-three were age-3, twenty-seven were age-4, twelve were age-5, and two were age-6 (Table 6). Sex was not able to be determined for all muskellunge; however, of those identifiable, 31% were female and 69% were male. This ratio is not surprising because spring muskellunge fyke netting CPUE is typically higher for male fish by a ratio of 2-3:1 (IDNR personal communication).

2002 Year Class

Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois, stocked into Lake Mingo during fall 2002 (Table 2) were monitored through fall 2007 and spring 2008 (Table 7). Unequal numbers were stocked due to limited availability of Cave Run Lake muskellunge. Mean initial lengths of the two populations were similar, but mean initial weights were higher for the Illinois population than the Cave Run Lake population (Table 2). Five and a half years following stocking (spring 2008), the Illinois population and Ohio River drainage appear to be of almost identical length (1015-1020 mm) and weight (7950-8003 g) although no statistical comparisons could be made due to low sample sizes (1 fish of each stock).

2003 Year Class

In fall 2003, three populations were introduced in Pierce Lake (Table 2) and were sampled during fall 2007 and spring 2008 (Table 8). Some differences in stocking sizes existed with the Upper Mississippi River drainage stock having the lowest mean initial lengths and weights and the Illinois population having the highest mean initial lengths and weights (Table 2). Previous sampling showed no differences in mean daily growth and mean relative daily growth rates between the Illinois population and the Ohio River drainage stock (Figure 5, Table 8) one year after stocking. No Upper Mississippi River drainage stock fish were collected during spring 2008 sampling. Three and a half years following stocking (spring 2008), the Illinois population muskellunge were longer ($P = 0.015$) than the Ohio River drainage stock fish (Table 9). Weights were not different among stocks during spring 2008 sampling ($P > 0.5$, Table 8).

Three populations of muskellunge were introduced in Lake Mingo in fall 2003 (Table 2) and were sampled during fall 2007 and spring 2008 (Table 9). Stocking sizes were similar, with the Illinois population having only slightly higher mean initial lengths and weights (Table 2). Previous sampling revealed no differences in mean daily growth rates or mean relative daily growth rates between the Ohio River drainage stock and the Illinois population one year after stocking. Four and a half years following stocking (spring 2008), all three stocks are of similar length ($P > 0.29$) and weight ($P > 0.59$, Table 9).

2004 Year Class

Three populations were introduced in Pierce Lake during fall 2004 (Table 2) and were sampled in fall 2007 and spring 2008 (Table 10). Only slight differences in stocking size existed with the Upper Mississippi River drainage stock marginally longer and heavier than the Illinois population. In turn, the Illinois population was only slightly larger, an average of 11 mm and 12 g, than the Ohio River drainage stock muskellunge (Table 2). One year after stocking, only two Illinois population and five Ohio River drainage stock muskellunge were sampled during fall 2005. The Illinois muskellunge were larger than the Ohio River drainage stock, suggesting higher growth rates one year following stocking. No muskellunge from the Upper Mississippi River drainage stock were sampled after spring 2005 (Table 10). Three and a half years following stocking (spring 2008), the Illinois population and Ohio River drainage stock are of similar length ($P = 0.14$) and weight ($P = 0.18$).

In fall 2004, three populations of muskellunge were introduced in Lake Mingo (Table 2) and sampled in fall 2007 and spring 2008 (Table 11). Negligible differences in stocking size existed among populations, with the Leech Lake and Illinois populations not differing in mean initial length or weight and the Leech Lake and Clear Fork Lake populations having similar mean initial weight. The Illinois population had a slightly higher mean initial length and weight than the Clear Fork Lake population that, in turn, had a modestly higher mean initial length than the Leech Lake population (Table 2). Three and a half years following stocking (spring 2008), the Illinois population and Ohio River drainage stocks are of similar length ($P = 0.32$) and weight ($P = 0.13$). No Upper Mississippi River drainage fish were sampled in fall 2007 or spring 2008.

2005 Year Class

Three populations were introduced in Pierce Lake during fall 2005 (Table 2) and sampled in fall 2007 and spring 2008 (Table 12). Minimal differences in stocking size existed between the Ohio River drainage stock and Illinois population muskellunge. The Upper Mississippi River drainage stock was slightly smaller than the other two populations at stocking (Table 2). One year after stocking, only one Upper Mississippi River drainage stock muskellunge and two Ohio River drainage fish were collected (Table 12), limiting the ability to make statistical comparisons. Two and a half years following stocking (spring 2008), the Illinois population appear marginally longer than the Ohio River drainage stock ($P = 0.052$) but of equal weight ($P > 0.22$).

Three populations of muskellunge were introduced in Lake Mingo in fall 2005 (Table 2) and sampled during fall 2007 and spring 2008 (Table 13). Negligible differences in stocking size existed between the Upper Mississippi River drainage stock and the Ohio River drainage stock, and the Illinois population was about 30 mm longer and 30-35 g heavier than the other two populations at stocking (Table 2). Only Illinois population muskellunge were collected during fall 2006 sampling (Table 13). Consequently, no statistical comparisons are possible for growth rates one year after stocking. No Upper Mississippi River drainage stock fish were collected after spring 2006 (Table 13). Two and a half years after stocking (spring 2008), the Illinois population is significantly longer ($P = 0.0492$) but not heavier ($P > 0.27$) than the Ohio River drainage stock (Table 13).

Four populations (three stocks) were introduced in Sam Dale Lake in fall 2005 (Table 2) and attempts were made to sample these fish in spring 2007. Stocking sizes were fairly similar with the largest difference existing between the Kentucky Cave Run Lake population and the Illinois population (Table 2). As discussed in previous annual reports several of these stockings experienced high initial mortality (38-97%). No surviving muskellunge have been sampled from this stocking through spring 2008, likely because of high initial stocking mortality.

2006 Year Class

Only one population of muskellunge, the Illinois North Spring Lake progeny, was introduced into Pierce Lake during fall 2006 (Table 2) due to limited availability of additional populations and in- and out-of-state concerns regarding Viral Hemorrhagic Septicemia Virus (VHSV). Four muskellunge from this stocking were sampled in spring 2008.

Two populations of muskellunge were introduced in Lake Mingo in fall 2006 (Table 2) and sampled in fall 2007 and spring 2008 (Table 14). Unequal numbers were stocked (Cave Run Lake N = 332 and Illinois N = 302) due to limited availability of the populations. Fish from the Upper Mississippi River drainage stock were not obtained due to concerns regarding VHSV. Muskellunge from the Illinois population were about 15% longer than fish from the Ohio River drainage stock (Table 3). Ten muskellunge were sampled one year after stocking (Table 14); however, only one fish was captured from the Ohio River drainage stock, limiting the validity of statistical analyses of growth rates. One and a half years after stocking (spring 2008) the Illinois population muskellunge are significantly longer ($P = 0.0094$) and heavier ($P = 0.0061$).

Only one population of muskellunge, the Illinois North Spring Lake progeny, was introduced into Sam Dale Lake during fall 2006 (Table 3) due to limited availability of additional populations and in- and out-of-state concerns regarding VHSV. No muskellunge from this stocking were sampled in fall 2007 or spring 2008. This lake will be stocked in future segments to establish additional year classes of multiple populations and stocks. Sampling will continue on this lake in future segments.

2007 Year Class

Three populations were introduced into Pierce Lake during fall 2007 (Table 3). Unequal numbers were stocked (Leech Lake N = 250, Clear Fork Lake N = 263, and Illinois - Spirit Lake, Iowa N = 300) due to limited availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for all three populations. Excellent survival of each population was likely due to late stockings and cooler water temperatures. Some differences in stocking sizes existed with the Upper Mississippi River drainage stock having the highest mean initial lengths and weights and the Ohio River drainage stock having the lowest mean initial lengths and weights. The Illinois population had mean initial lengths and weights intermediate between the other two stocks (Table 3). Spring 2007 sampling (Table 15) revealed no significant overwinter differences in mean daily growth rates (Figure 4, Table 16, ANOVA, $P > 0.34$) or mean relative growth rates (Figure 4, Table 16, ANOVA, $P > 0.33$) among populations.

In fall 2007, three populations were introduced in Lake Mingo (Table 3). Unequal numbers were stocked (Leech Lake N = 270, Cave Run Lake N = 397, and Illinois – Spirit Lake, Iowa N = 300) due to limited availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for the Upper Mississippi River drainage stock, 33% for the Ohio River drainage stock, and 3% for the Illinois – Spirit Lake, Iowa population. The mortality experienced by the Ohio River drainage stock was attributable to the earlier stocking date which resulted in warmer water temperatures (30.7 °C). Subsequent analysis of survival will be adjusted to account for this initial mortality. Spring 2007 sampling (Table 17) showed that the Ohio River drainage and Illinois population muskellunge had higher overwinter daily and relative daily growth rates than the Upper Mississippi River drainage fish, (Figure 5, Table 18) although these differences were not statistically different due to low sample sizes.

Three populations were introduced in Sam Dale Lake in fall 2007 (Table 3). Unequal numbers were stocked (Leech Lake N = 260, Clear Fork Lake 318, and Illinois – Spirit Lake, Iowa N = 300) due to limited availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hours post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for the Upper Mississippi River drainage stock and 2% for the Ohio River drainage stock. Due to logistical constraints, mortality cages were not used when stocking the Illinois-Spirit Lake, Iowa population; however stocking events in lakes Pierce and Mingo the same day had initial mortalities of 0% and 3% respectively. We assume mortality for the Illinois-Spirit Lake Iowa population to be minimal. Subsequent analysis of survival will be adjusted to account for these initial mortality calculations. No Ohio River drainage muskellunge were sampled in Spring 2008 which limited our overwinter growth comparisons to the Upper Mississippi River drainage stock and the Illinois Spirit Lake Iowa population. Spring 2008 sampling (Table 19) showed significant differences in overwinter mean daily growth rates between the two populations (Figure 6, Table 20, ANOVA, $P < 0.009$). After adjusting for differences in initial stocking weight, a significant difference was found between stocks (Figure 6, Table 20, ANOVA, $P = 0.04$). The Illinois-Spirit Lake Iowa population exhibited higher mean relative daily growth rates than the Upper Mississippi River drainage stock.

Pooled Year Classes

To compare growth of stocks across year classes, data from spring sampling periods in Lake Mingo were pooled and used to construct size-at-age von Bertalanffy growth functions. Total length and age data from each stock were used to estimate model parameters using the nonlinear fit procedure (PROC NLIN) in SAS Version 8.2 (Isely and Grabowski 2007). Models were fit to samples of each stock stratified by lake and gender. Overall, the growth trajectories of the Illinois population and the Ohio River drainage stock are similar (Figure 7); with asymptotic length (L Inf) being higher on average for females than males across stocks (Table 21). The Ohio River drainage stock appears to have a lower mean length-at-age during ages 1 and 2 but then matches and slightly overtakes the Illinois population at later ages. Between these two stocks no significant differences were found in asymptotic length, or growth coefficients with all 95% confidence intervals showing overlap (Table 21). Differences in asymptotic length between male and female fish were only outside of the 95% confidence intervals for Ohio River drainage fish in Lake Mingo suggesting the Ohio stock may be displaying more sexual dimorphism in this lake. Male fish also had higher growth coefficients (k parameters) indicating the asymptotic length is reached more quickly in male fish across stocks and lakes (Ricker 1975, Table 21). Growth of the Upper Mississippi River drainage muskellunge appears slower at early ages while inferences on adult size and growth have been limited by poor survival of this strain. Future analyses will incorporate this stock as sample sizes allow.

Growth functions were also fit to mean length-at-age data from Pierce Lake. Data from spring sampling periods 2003-2008 were pooled and used to construct size-at-age von Bertalanffy growth functions. Data were not stratified by sex for this lake due to lower sample sizes. Overall, the growth trajectories of the Illinois population and the Ohio drainage stock are nearly identical with the Ohio drainage stock showing a slightly smaller size at earlier ages (Figure 8). The length-at-age of the two populations appears to become more similar through time. No significant differences were found between these two stocks in asymptotic length or growth coefficients (Table 22). Growth functions fit to the Upper Mississippi River drainage muskellunge indicated a lower growth trajectory at younger ages. These growth differences appear to disappear at larger sizes although this conclusion is based on very few adult fish due to poor survival of Upper Mississippi River strain muskellunge. Future analyses will incorporate this stock as sample sizes allow. In addition, dependent on sample sizes, future analyses will be stratified by sex to examine gender differences within and between stocks.

Mean length at age data were also examined for differences between stocks in each lake using an analysis of covariance (ANCOVA) with initial length (mean length at stocking) as the covariate (Table 23). This analysis allowed comparisons of mean length at age across year classes and among stocks of muskellunge by examination of the stock*age interaction term. Both genders were pooled in these analyses to increase sample sizes and to allow for examination of general trends between stocks. When a significant stock*age interaction was found differences between stocks at each age were separated and tested using slice statements and a tukey adjustment (Isely and Grabowski 2007). In Lake Mingo mean length-at-age was marginally different between the Illinois and Upper Mississippi River drainage stocks (Table 24, ANCOVA, Stock*Age $P = 0.07$) at age-1 (Tukey, $P < 0.001$) and age-2 (Tukey, $P = 0.017$) but was similar across all other age classes. Mean weight-at-age was marginally different between the Illinois and Upper Mississippi River drainage stocks (ANCOVA, Stock*Age $P = 0.08$) for ages 1 (Tukey, $P < 0.0001$) and 2 (Tukey, $P = .05$) but not at older ages. Examination of slice statements indicated that where significant differences were found, the Illinois stock was significantly heavier and longer than the Upper Mississippi River drainage stock but similar to the Ohio River drainage stock for age-1 and 2 fish. These differences however, were not evident in older age classes (Table 23).

In Pierce Lake mean length-at-age (Table 23) was examined for the Ohio River drainage stock and the Illinois populations. Low survival of Upper Mississippi River drainage muskellunge precluded analysis of these fish at this time. Mean length-at-age was significantly different at age-1 (Table 25, ANCOVA, Stock*Age $P = 0.004$, Tukey, $P = 0.0004$) with the Illinois stock muskellunge being longer. Mean weight-at-age was significantly different at ages 4 and 5 but not earlier ages (ANCOVA, Stock*Age $P = .002$, age-4 Tukey, $P = 0.02$, age-5 Tukey = 0.006). Examination of slice statements revealed that the Ohio River drainage stock was marginally heavier than the Illinois population at age-4, but the Illinois population muskellunge were heavier at age-5. Future analyses of mean size-at-age will be stratified by gender as sample sizes allow.

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

In the lake experiment, the Illinois population and Ohio River drainage stock generally exhibit similar growth rates and trajectories. While the Illinois population seems to have a size advantage at earlier ages, these differences disappear after age-2. The Upper Mississippi River drainage stock has typically grown slower although low survival of this stock has limited inferences on growth. In the pond experiment, the Ohio River drainage stock had significantly higher growth rates than both the Illinois population and the Upper Mississippi River drainage stock, while the Illinois population and the Upper Mississippi River drainage stock exhibited similar growth rates. Thus far in this study, the thermal adaptation concept appears to explain growth of muskellunge stocks more closely than the countergradient variation theory. The climate of the Ohio River drainage is generally more similar to Illinois than is the climate of the Upper Mississippi River drainage. Under the assumptions of the thermal adaptation concept, it would be predicted that the Ohio River drainage stock would exhibit higher growth rates in Illinois than the Upper Mississippi River drainage stock. The North Spring Lake population used for broodstock in Illinois was first established in the early 1980's and has subsequently been stocked yearly with muskellunge from throughout the native range of the species. The actual progeny of broodstock from any particular year results in an unknown-origin population, or possibly, a mixed-origin population. Future years of data are needed, with as similar of initial lengths and weights as possible among stocks and populations, to be able to determine if the current trend of faster growth of the Ohio River drainage stock, as compared to the Upper Mississippi River drainage stock, is consistent.

Further fall and spring monitoring of the study lakes will be conducted, as well as additional introductions of the various stocks into the lakes for the purpose of growth evaluations. Modified fyke netting will be continued in Pierce and Mingo Lakes in future segments and incorporated into the protocol of Sam Dale Lake as year classes mature. The pond experiment is complete and findings will continue to be compared to lake samples in future segments of the study. The results contained in this report will be combined with data from future segments to identify differences among genetic stocks of juvenile and adult muskellunge and to develop guidelines for future stockings that maximize growth in impoundments throughout Illinois.

Job 101.2 Evaluating survival of different stocks of muskellunge

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

INTRODUCTION: In addition to growth, survival differences among genetically distinct muskellunge stocks and populations may be important in determining the most appropriate populations for use in management applications. Survival is a consequence of life history modes to which stocks have evolved (Begg et al. 1999) and is an important determinant of a species' productivity and evolutionary potential (Shaklee and Currens 2003). Physiological differences among stocks could affect survival rates at various temperatures and will affect the value of a population for stocking in various waters throughout Illinois.

Numerous studies have investigated differences in survival among stocks. Most recently differences in survival have been documented between two endemic stocks of largemouth bass from South Carolina. These differences were attributed to a gradient of selection acting across the hybrid zone of northern *Micropterus salmoides salmoides* and Florida largemouth bass *Micropterus salmoides salmoides* (Leitner and Bulak 2008). In comparisons of survival of northern largemouth bass, Florida largemouth bass, and their F1 hybrids in central Illinois, the native northern largemouth bass was shown to have the highest survival rates (Philipp and Whitt 1991). Further work suggested significant survival differences between stocks of northern largemouth bass from two different river drainages within Illinois when both were stocked in northern and southern Illinois (Philipp and Claussen 1995). Significant differences in survival were also found between hatchery reared and wild steelhead trout *Salmo gairdneri* in stream and pond evaluations; however outcomes varied between systems (Reisenbichler and McIntyre 1977). Genetic origin has been shown to influence survival among stockings of lake trout *Salvelinus namaycush* in two lakes in Ontario (MacLean et al. 1981). These studies suggest that geographic origin (stock) can have a substantial influence on survival across a given region.

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

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

PROCEDURES: As described in Job 101.1, we stocked muskellunge from the Illinois population, Upper Mississippi River drainage stock and the Ohio River drainage stock into three study reservoirs in fall 2007 (Table 3). Muskellunge were stocked at a large fingerling size to increase initial survival across all populations as determined in previous studies (Carline et al. 1986; Szendrey and Wahl 1996; McKeown et al. 1999). Size-specific effects from predation (Wahl and Stein 1989), prey availability (Szendrey and Wahl 1996), and thermal stress (Wahl 1999) have been shown to be negligible with muskellunge ≥ 200 mm total length. Stocked fish were also reared under as similar conditions and feeding regimes as possible so as to eliminate any indirect biases on either survival or vulnerability to predation (Szendrey and Wahl 1995). Subsamples of each stock were held in three 3-m deep predator-free cages (N = 15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress (Clapp et al. 1997; Hoxmeier et al. 1999). Muskellunge from each population were stocked at rates between 3.3 – 4.9 fish per hectare (Table 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination) and freeze cauterization of the wound for later identification of the stock (Table 4). Previous work has suggested that removal of any single paired fin is equally detrimental to short-term survival (3-mos) and the loss of a pelvic fin is less detrimental than loss of a pectoral fin over the long term (McNeil and Crossman 1979). Additionally, foraging behaviors and growth of age-0 muskellunge were not affected by fin-clipping any of the paired fins (individual or in combination) in controlled trials (Scimone et al., in review). Beginning in fall 2004, we freeze branded all stocked fish to be used in combination with scale aging to better determine age in future years. The 2007 brand was a left-posterior vertical brand. The brand will be applied differentially by year, such that each stocking year will have a different freeze brand location (Table 4). The freeze brand, in conjunction with the pelvic fin clip, will allow accurate identification of both the major river drainage stock as well as the specific population under examination. To determine survival, nighttime pulse DC boat-electrofishing sampling was conducted from October through November 2007 and from March through April 2008 on all study reservoirs. Data from electrofishing were combined with modified fyke net surveys conducted March 30 – April 3, 2008 on Mingo Lake and April 14 – April 16, 2008 on Pierce Lake. As appropriate, electrofishing and modified fyke net catch-per-unit-effort (CPUE, fish per hour or fish per net-night) and Schnabel population estimates (Ricker 1975) were used to assess survival differences among stocks. In addition, estimates of annual survival were calculated for each stock and year class in Lakes Mingo and Pierce using cohort catch curves (Miranda and Bettoli 2007). Catch curves were calculated using annual catch data from each year class and each stock in spring electrofishing samples from 2003-2008. Annual survival and associated standard errors were then calculated using Robson and Chapman's maximum likelihood technique (Robson and Chapman 1961). Differences between stocks were tested using t-tests and adjusted using Bonferroni corrections in the case of multiple comparisons (Zar 1999).

FINDINGS:

2002 Year Class

Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois (Table 1), stocked into Lake Mingo during fall 2002 (Table 2) were monitored during fall 2007 and spring 2008. As reported in previous annual reports, survival one year after stocking was similar for the Ohio River drainage muskellunge (28%) and the Illinois population (24%) as determined from Schnabel population estimates. Adjusted CPUE was calculated to account for unequal stocking numbers between stocks and populations and again showed no differences between populations one year after stocking (Table 26). Adjusted CPUE was similar ($P = 0.65$) between the Ohio River drainage stock and the Illinois population during the spring 2008 modified fyke net survey, suggesting similar survival of the two populations five and a half years after stocking. Annual survival of the two populations estimated using cohort catch-curves were slightly higher for the Ohio River drainage stock than the Illinois population (Table 32) but this difference was not statistically significant ($P = 0.08$). Schnabel population estimates were not computed due to inadequate within-season recapture numbers during spring 2008.

2003 Year Class

In fall 2003, three populations were introduced in Pierce Lake (Table 2). Adjusted CPUE indicates no differences between the Ohio River drainage stock and the Illinois population (Tukey, $P = 0.45$). No Upper Mississippi River drainage stock fish were captured during fall 2004, one year following stocking. Four and a half years following stocking, the Ohio River drainage stock and the Illinois population exhibited similar adjusted CPUE (Tukey, $P = 0.95$) during the spring 2008 modified fyke net survey, indicating similar survival. No Upper Mississippi River drainage stock muskellunge from the 2003 year class were sampled in the spring 2008 modified fyke nets (Table 5). Survival estimates using cohort catch-curves were higher for the Illinois population than the Ohio River drainage stock ($P = <0.01$, Table 32). Low annual survival occurred for the Upper Mississippi River drainage stock.

Three populations of muskellunge were introduced in Lake Mingo in fall 2003 (Table 2). As presented in earlier annual reports, no difference in adjusted CPUE was observed between the Ohio River drainage muskellunge and the Illinois fish during the fall 2004 sampling season (Table 27), indicating no survival differences one year after stocking. No Upper Mississippi River drainage stock muskellunge were sampled after spring 2004. Four and a half years following stocking, the Ohio River drainage stock and the Illinois population exhibited similar adjusted CPUE (Tukey, $P = 0.91$) during the spring 2008 modified fyke net survey, indicating similar survival. Only one Upper Mississippi River drainage stock muskellunge from the 2003 year class was sampled in the spring 2008 modified fyke nets (Table 6). Annual survival estimated using cohort catch-curves were marginally different ($P = 0.08$) with the Illinois population surviving slightly better than the Ohio River drainage stock (Table 32). For both Pierce and Mingo Lakes, Schnabel population estimates could not be obtained for the spring 2008 sampling period due to low or no within-season recaptures.

2004 Year Class

In fall 2004, three populations of muskellunge were introduced in Pierce Lake (Table 2). One year following stocking, no differences in adjusted CPUE were detected between the Ohio River drainage stock and the Illinois population (Tukey, P = 0.24). No fish from the Upper Mississippi River drainage were sampled during fall 2005 (Table 28). Further, no muskellunge from the Upper Mississippi River drainage stock or Illinois population were sampled during electrofishing sampling from spring 2006 – spring 2008 (Table 28). Three and a half years following stocking (spring 2008), no differences in modified fyke net CPUE existed between the Ohio River drainage stock and the Illinois population (Tukey, P = 0.76). Sample sizes of Illinois population and Upper Mississippi River drainage muskellunge are too low at this time to allow estimation of annual survival using cohort catch-curves or Schnabel population estimates.

Three populations were introduced in Lake Mingo in fall 2004 (Table 2). Although survival during the first winter was high for the Upper Mississippi River drainage stock, catch rates have declined and were lowest for this stock at older ages. No differences (Tukey, P = 0.99) in adjusted CPUE were observed one year following stocking between the Upper Mississippi River drainage stock and the Illinois population (Table 28). No fish from the Ohio River drainage stock 2004 year class were collected during fall 2005 sampling (Table 28). Three and a half years after stocking, no differences in modified fyke net CPUE were observed between the Illinois population and Ohio River drainage stock (P = 0.50, Table 6) during the spring 2008 survey. Cohort catch-curve estimates of annual survival were similar between the Illinois population and Ohio River Drainage stock (P = 0.48) however, survival was lower for the Upper Mississippi River drainage stock compared to both the Illinois population (P < 0.0001) and the Ohio River drainage stock (P = 0.004, Table 32). Lack of sufficient within-season recaptures in spring 2008 prohibited the computation of Schnabel population estimates.

2005 Year Class

Three populations of muskellunge were introduced in Pierce Lake in fall 2005 (Table 2). No differences in adjusted CPUE were detected among stocks one year after stocking (Table 29). No Upper Mississippi River drainage fish from the 2005 year class were captured in spring 2008 nets. Two and a half years following stocking (spring 2008), no differences in modified fyke net CPUE existed between the Ohio River drainage stock and the Illinois population (P = 0.64). Sample sizes of Illinois population and Upper Mississippi River drainage muskellunge are too low at this time to allow estimation of annual survival using cohort catch-curves.

In fall 2005, three populations of muskellunge were introduced in Lake Mingo (Table 2). Fish from the Illinois population were captured during fall 2006 sampling; however, no muskellunge from the Upper Mississippi River drainage and Ohio River drainage stock were captured one year after stocking (Table 29). Two and a half years after stocking no differences in modified fyke net CPUE existed between the Ohio River drainage stock and the Illinois population (Tukey, P = 0.49) while the Upper Mississipi River drainage muskellunge were collected at a lower rate than both the Ohio River drainage stock (Tukey, P = 0.009) and the Illinois population (Tukey, P = 0.05).

Three populations of muskellunge were introduced into Sam Dale Lake in fall 2005 (Table 2). No muskellunge were captured fall 2006-spring 2008 sampling seasons, despite adequate effort. Sampling of Sam Dale Lake will continue and any captures of this year class will be reported in subsequent segments.

2006 Year Class

During fall 2006, only Illinois population muskellunge were introduced into Pierce Lake (Table 2) due to limited availability and concerns regarding VHSV. Because of a lack of conspecific comparisons, survival within this year class will not be compared during this or future segments.

In fall 2006, two populations of muskellunge were introduced in Lake Mingo (Table 2). Unequal numbers were stocked (Cave Run Lake N = 332 and Illinois population N = 302) due to limited availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. The Ohio River drainage stock exhibited a 42% initial mortality rate and the Illinois population had a 7% initial mortality rate (Table 2). Subsequent analyses of survival will be adjusted to account for the initial mortality experienced by both populations. One and a half years after stocking the Illinois and Ohio River drainage muskellunge have similar electrofishing catch rates (P = 0.59, Table 30). Lack of within-season recaptures prohibited the calculation of Schnabel population estimates for the 2006 year class muskellunge during spring 2008 sampling. Cohort catch-curves will be developed for these two stockings as future years of data allow to compare annual mortality estimates between the two stocks.

Only the Illinois population was introduced into Sam Dale Lake (Table 2) during fall 2006 due to limited availability of other stocks and VHSV concerns. Despite adequate effort, no muskellunge were collected during spring 2008 sampling. As a result, survival will not be compared during this or future segments for the 2006 year class in Sam Dale Lake.

2007 Year Class

Three populations were introduced into Pierce Lake during fall 2007 (Table 3). Unequal numbers were stocked (Leech Lake N = 250, Clear Fork Lake N = 263, and Illinois - Spirit Lake, Iowa N = 300) based on availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for all three populations. Spring 2008 electrofishing catch rates (Table 31) were not significantly different among stocks (ANOVA, P = 0.18) suggesting similar overwinter survival.

In fall 2007, three populations were introduced in Lake Mingo (Table 3). Unequal numbers were stocked (Leech Lake N = 270, Cave Run Lake N = 397, and Illinois – Spirit Lake, Iowa N = 300) based on availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hrs post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for the Upper Mississippi River drainage stock, 33% for the Ohio River drainage stock, and 3% for the Illinois – Spirit Lake, Iowa population. Spring 2008 electrofishing catch rates (Table 31) were significantly higher for the Upper Mississippi River drainage stock compared to the Ohio River drainage stock (Tukey, P = 0.02) and the Illinois population (Tukey, P = 0.03). There were no differences in catch rates between the Illinois population and the Ohio River drainage stock (Tukey, P = 0.52). Overwinter survival appears to be higher for the Upper Mississippi River drainage stock in the 2007 year classes.

Three populations were introduced in Sam Dale Lake in fall 2007 (Table 3). Unequal numbers were stocked (Leech Lake N = 260, Clear Fork Lake 318, and Illinois – Spirit Lake, Iowa N = 300) based on availability of the populations. Three 3-m deep predator-free mortality cages were monitored for 48-hours post-stocking to evaluate stocking mortality of each population. Initial mortality rates were 0% for the Upper Mississippi River drainage stock and 2% for the Ohio River drainage stock. Due to logistical constraints, mortality cages were not used when stocking the Illinois-Spirit Lake, Iowa population; however stocking events in lakes Pierce and Mingo the same day had low initial mortalities. We assume mortality for the Illinois-Spirit Lake Iowa population to be minimal. No Ohio River drainage muskellunge were sampled in Spring 2007 suggesting low overwinter survival. Spring 2008 electrofishing catch rates (Table 31) were not different between the Upper Mississippi River drainage stock and the Illinois Spirit Lake Iowa population (ANOVA, P = 0.62) suggesting similar overwinter survival.

RECOMMENDATIONS: Any long-term differences in survival among muskellunge populations will have important implications for conservation and stocking of muskellunge. Survival differences we observed among muskellunge during the initial segments of this study can influence the success and cost-effectiveness of a muskellunge stocking program (Margenau 1992). We have found initial survival differences among populations of muskellunge that will need to continue to be monitored as additional year classes of fish mature.

These results suggest that the prevailing trend in survival one year after stocking is equal survival between the Ohio River drainage stock and Illinois population, with the Upper Mississippi River drainage typically exhibiting poor survival. The first summer at Illinois latitudes appears to negatively affect the survival of these fish.During spring netting surveys of older muskellunge, the Ohio River drainage stock and Illinois population consistently were represented similarly in catches. The Upper Mississippi River drainage stock is typically captured at lower rates than conspecifics, suggesting that the trends observed in survival one year after stocking remain through adulthood. Current estimates of annual survival among stocks using cohort catch curves supports these general conclusions. Repeated year classes reaching adulthood will provide multiple estimates of annual survival for each stock and will aid in assessing the consistency of these trends. The pooled analysis of the three pond trials support these conclusions, with the Ohio River drainage stock and Illinois population having similar survival one year after stocking, and collectively these muskellunge have significantly higher survival than fish from the Upper Mississippi River drainage.

Further fall and spring monitoring of the study lakes will be conducted, as well as additional introductions of the various stocks into the three lakes for the purpose of evaluating survival differences among stocks. In particular, additional stockings in Sam Dale Lake are needed given the apparent low survival of the initial stockings. In future segments, sampling effort will be shifted to include less fall electrofishing sampling and will include greater effort during spring modified fyke net surveys. Capturing more muskellunge during these net surveys will provide greater precision for von Bertalanffy growth functions as well as annual survival estimates. The results obtained from these past and future years will be used to identify long-term differences in survival and longevity among genetic stocks of muskellunge. This long-term data will be particularly valuable to determine if any differences exist between stocks in maximum size or trophy potential as development of a trophy fishery has been shown to be a primary muskellunge management goal among resource agencies (Margenau and Petchenik 2004).

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

Studies of interactions concerning muskellunge and other fish species have examined predatory effects and diet contents in river systems (Brenden et al 2004, Curry et al 2007) northern lakes, (Bozek et al 1999) or waters on the fringe of the native muskellunge range (Krska and Applegate 1982). A few studies exist in the literature which report competitive or predatory effects in one or two lake systems. For example Becker (1983) attributed muskellunge with the decline of largemouth bass populations in two Wisconsin lakes. Another study documented a decline in black crappie and white sucker populations in Iron Lake, Michigan as a result of muskellunge introduction (Siler and Bayerle 1986). In northern Wisconsin lakes, yellow perch (*Perca flavescens),* catastomids (*Catastomus spp.*), sunfish (*Lepomis spp),* and crappie (*Pomoxis spp.)* dominated muskellunge diets across 34 waterbodies. Catastomid species also dominated the diets of large muskellunge from the New River, Virginia. An ontogenetic diet shift was noted in muskellunge from both the New River where fish switched from smaller prey fish to larger catastomids at around 800 mm (Brenden 2004). While these studies are useful to understanding muskellunge interactions in these respective regions they are of limited value to Illinois and other lower Midwestern fisheries managers working on systems with differing predator and prey assemblages. Published information on muskellunge diet in southerly and lower Midwestern reservoirs has 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 available, 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 and community effects of muskellunge introduction on a number of Illinois lakes with differing morphological and biotic characteristics. Knowledge of the 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 begin investigation of the dietary habits and ecological consequences of muskellunge stocking in six lakes. Future work will involve an expanded data set focused on lakes with muskellunge introductions utilizing data from the Illinois Fishery Analysis System (FAS) database and continued diet sampling.

PROCEDURES:

Muskellunge Food Habits

Diet samples were collected from muskellunge sampled on Lakes Mingo, Pierce, and Sam Dale as well as Ridge Lake, Otter Lake and Lake Shelbyville, in each season from summer 2007 through spring 2008. 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) in lakes Mingo and Pierce and angled fish sampled as part of the long term creel on Ridge Lake (May 2007- November 2008). Diet contents were removed from all sizes of muskellunge sampled via pulsed gastric lavage (Foster 1977). Diet samples were labeled with the date, location, length and weight of muskellunge, stored in plastic bags and immediately frozen upon return from the field. Diet samples were later thawed, measured for total, fork, or backbone length, weighed and identified to species using scales and muscle tissue (Oates et al. 1993). Three muskellunge were sacrificed and later dissected to verify that lavage completely sampled all gut contents. Measurements of prey length were used to back-calculate wet weight of each item using regression equations from Wahl and Stein (1988) and Anderson and Neumann (1996). Data were then used to calculate frequency of occurrence and proportion by weight of prey species found in muskellunge diets (Bowen 1996).

Community Effects of Muskellunge Stocking

The study sites for evaluation of community effects of muskellunge introduction include Lake Mingo, and Ridge Lake (Coles County), while reference waters include Homer Lake (Champaign County), Wood Lake (Moultrie County), Charleston Lake (Coles County) Walnut Point Lake (Douglas County) and Lincoln Trail Lake (Clark County). All of these lakes have been monitored since fall of 1998 as part of ongoing or previous Federal Aid in Sport Fish Restoration Projects (F-135-R, Factors influencing largemouth bass recruitment and stocking and F-128-R, Quality management of bluegill populations). Data have been collected on relative abundance of fish species, larval fish density, benthic macroinvertebrate density, zooplankton density, chlorophyll a concentration, water clarity, total phosphorous, temperature and dissolved oxygen using standard methodologies (for specific sampling details see Diana et al 2008). In addition to lakes monitored for community analyses, nine lakes receiving consistent muskellunge introductions beginning in fall of 1999 and fall 2000 have been identified using stocking records obtained from the Jake Wolf Memorial fish hatchery (Table 35). Analysis of these data sets will consist of comparisons of fish community and creel data between stocked (I, Impact) and reference (C, Control) lakes before (B) and after (A) stocking using a replicated BACI (MBACI) design (Underwood 1994, Keough and Mapstone 1995). Changes to community parameters in Lakes Mingo and Ridge will be analyzed using a paired BACI (BACIP, Underwood 1994) design due to a lack of replicates for some parameters. Paired analysis using waters from the same geographic area has been suggested as a better approach to whole lake studies when replicates of impacted locations are limited (Carpenter 1989).

In this segment we present initial analysis of the effects of muskellunge introduction on the relative abundance of largemouth bass (a potential competitor) and size structure of gizzard shad (the primary prey species) in Lake Mingo; utilizing Homer Lake as a reference. Homer Lake was selected as a reference due to its similar morphological characteristics, fish community and close geographic proximity to Lake Mingo. Both lakes have been sampled for these parameters for four years prior to muskellunge introduction into Lake Mingo in fall of 2002. Data collection is ongoing and will continue to be collected in subsequent years. In this segment we present data through 2005 as data from 2006-2007 has not yet been processed. Largemouth bass and gizzard shad from each lake were sampled using 3-phase AC electrofishing on a minimum of two dates each spring (April-May) and fall (September-October) in each year from 1998 to 2005. Three transects were sampled for 0.5 hour each on each sampling date (Diana et al 2008). All largemouth bass and gizzard shad collected were measured for total length and largemouth bass were assigned to age classes using scale samples. Catch per unit effort (CPUE, # of fish collected per hour) of largemouth bass and mean length of collected gizzard shad were calculated for each sample date and then averaged across sampling dates to produce a single measurement for each year. Only fall samples were used in final analyses to standardize for any seasonal biases. Data were analyzed using a paired BACI design suited to a repeated measures analysis of variance (Keough and Mapstone 1995) to test for differences in largemouth bass CPUE and mean length of gizzard shad, in two separate analyses.

FINDINGS:

Muskellunge Food Habits

From June of 2007 to April of 2008 we sampled diet contents of 280 muskellunge across four Illinois Lakes. Muskellunge ranged in size from 259-1095 mm and were sampled in each season from spring through fall. Sampling revealed that gizzard shad dominated muskellunge diet by number and weight in Lakes Mingo (Figure 10), Pierce (Figure 11) and Shelbyville (Figure 12), while diets in Ridge Lake were dominated by bluegill (Figure 13). Low sample sizes and a high percentage of empty stomachs limited our ability to describe diets of muskellunge in Otter Lake in this segment. Bluegills were a significant secondary prey species in Lakes Mingo, Pierce and Shelbyville while largemouth bass comprised a secondary prey species in Ridge Lake. Other prey species consumed were yellow perch in Pierce Lake, and cyprinids including red shiners and brook silversides in Lakes Mingo and Shelbyville. Diet composition in

Illinois lakes appears similar to findings in Ohio impoundments where gizzard shad were the primary muskellunge prey. The diet of muskellunge in Ridge Lake reflects the lack of alternative prey species in this simple largemouth bass-bluegill system. The finding that around 15% of diets in Ridge Lake were found to contain largemouth bass suggests that predation on bass by muskellunge increases in the absence of alternative soft-rayed prey (Figure 13).

Community Effects of Muskellunge Stocking

We found no evidence for a decline in largemouth bass CPUE after muskellunge introduction into Lake Mingo based on data from four years of pre (1998-2001) and four years of post (2002-2005) stocking. In fact, there was a marginally significant increase in largemouth bass CPUE (BACI, P = 0.08, Table 33). The mean number of largemouth bass collected per hour of electrofishing increased in Lake Mingo from before to after muskellunge stocking from 43 to 61 fish per hour (Figure 14). This change was not seen in Homer Lake (the reference system) which showed almost no change between the two time periods from 60 largemouth bass per hour (1998-2001) to 59 bass per hour (2002-2005, Table 33, Figure 14). While the mechanism for the increase in largemouth bass collected in Lake Mingo from 1998 to 2005 is unclear, we can conclude that the stocking of muskellunge beginning in the fall of 2002 has not had a negative influence on the relative abundance of largemouth bass in the system. The largemouth bass population will continue to be monitored in subsequent years and any future changes will be reported.

A significant change in the average size of gizzard shad collected via shoreline electrofishing was found after muskellunge introduction into Lake Mingo (BACI, P = 0.007, Table 34). Mean length of gizzard shad in electrofishing samples from Lake Mingo increased from 209 mm before muskellunge stocking to 242 mm after muskellunge were introduced, while the mean length of gizzard shad decreased slightly in the reference system (207mm before to 183mm after, Table 34, Figure 15). Increased predation pressure from introduced muskellunge and a concurrent increase in the largemouth bass population are likely causes for this shift in size structure. Largemouth bass and a number of introduced predators including saugeye, hybrid striped bass, and muskellunge are known to prey heavily on smaller size classes of gizzard shad (Cyterski and Ney 2005, Wahl and Stein 1988, Wahl and Stein 1991). In future segments we will examine the potential for resource limitation as a result of the increased predation pressure on the forage base of Lake Mingo by comparing size specific growth rates of largemouth bass before and after muskellunge introduction using methods from Schindler (2000). Analysis of largemouth bass growth will provide a test of potential resource competition among predators occurring due to muskellunge introduction.

RECOMMENDATIONS: The first year of muskellunge diet information has shown little predation on largemouth bass or other game species. Diet information from Lakes Mingo, Pierce and Shelbyville indicates that gizzard shad make up the bulk of muskellunge diet wherever they are available. These findings provide Illinois lake managers with evidence that muskellunge are not responsible for direct predation on most popular game species. In this segment we present diet data as the frequency of occurrence and proportion by weight of each prey species in each of the studied lakes across seasons. As sample sizes increase in future years we will begin to examine seasonal trends in muskellunge diet both within and across lakes. Of particular interest to management is the potential for seasonal or annual declines in the abundance of preferred prey, which may increase predation pressure on game species and/or increase competition with other top predators such as largemouth bass due to increased niche compression (Hutchinson 1958). Past diet information on muskellunge in Ohio reservoirs found that low abundance of gizzard shad in spring resulted in diversification of prey and may lead to seasonal increases in predation on game species like bluegill and largemouth bass (Wahl and Stein 1988). In addition, future analyses will examine diet data by size class of muskellunge to allow for detection of any ontogonetic changes in diet composition. Examination of multiple years and seasons of muskellunge diet will enhance our ability to detect possible changes in diet composition in response to fluctuations in abundances of preferred prey species such as gizzard shad. Knowledge of seasonal and annual patterns in muskellunge diet will provide insight into responses to fluctuations in primary prey species which may alter both direct (predation) and indirect (competition) interactions with established recreational species. This information will provide evidence of the potential for muskellunge to impact established fisheries through predation which will enable managers to better respond to angler concerns about muskellunge introductions into their local waters.

Initial assessment of the fish community of Lake Mingo before and after stocking suggests that muskellunge introduction has had a significant effect on the size structure of gizzard shad while not affecting the abundance of largemouth bass. These results provide a first step in the examination of the effects of muskellunge introduction on lake communities; however extrapolation of these findings to other systems should be done with caution. Lakes with different predator and prey communities, depth, productivity or habitat may respond differently to the effects of muskellunge introduction. In addition it is still unclear what effect (if any) muskellunge introduction has had on the growth rate or body condition of largemouth bass. In future segments we will examine the response of the fish community and angler creel to muskellunge introduction across nine Illinois impoundments using data from the state FAS database. We will also begin to examine the responses of a wider array of community parameters to muskellunge introduction in lakes Mingo and Ridge. These analyses will address possible cascading effects of increased predation on planktivores such as gizzard shad and bluegill. This will also allow a test of the generality of the effects observed in Lake Mingo and enable us to make wider inference concerning the effects of muskellunge stocking on fisheries in Illinois and the lower Midwest. In future segments we will present analysis of additional community parameters in lakes Mingo and Ridge as well as a more rigorous analysis of muskellunge effects on fish community and angler catch utilizing data from the Illinois FAS database. These findings will provide fisheries managers with valuable information about the potential effects of muskellunge introduction and allow for more informed decisions concerning the potential costs and benefits of developing muskellunge fisheries in the Midwest.

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.

BUDGET TABLE:

Project Segment 6

Job	Proposed Cost	Actual Cost
Job 101.1	$34,307	$34,307
Job 101.2	$34,307	$34,307
Job 101.3	$25,454	$25,454
Job 101.4	$16,600	$16,600

LITERATURE CITED

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

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

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

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

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

Beverton, R.J.H. 1954. Notes on the use of theoretical models in the study of the dynamics of exploited fish populations. U.S. Fish. Lab. Beaufort. North Carolina. Misc. contrib. 2: 159 pp.

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

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

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

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

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

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

Carline, R.F., R.A. Stein, and L.M. Riley. 1986. Effects of size at stocking, season, largemouth bass predation, and forage abundance on survival of tiger muskellunge, Pages 151-167 *in* G. E. Hall, editor. Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland, USA.

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

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

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

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

Conover, D.O., and E.T. Schultz. 1995. Phenotypic similarity and the evolutionary significance of countergradient variation. Trends in Ecology & Evolution 10: 248-252.

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

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

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

Cyterski, M.J., and J.J. Ney. 2005. Availability of clupeid prey to primary piscivores in Smith Mountain Lake, Virginia. Transactions of the American Fisheries Society 134:1410-1421.

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

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

Elsayed, E., M. Faisal, M. Thomas, G. Whelan, W. Batts, and J. Winton. 2006. Isolation of viral hemorrhagic septicaemia virus from muskellunge, *Esox masquinongy* (Mitchill), in Lake St. Clair, Michigan, USA reveals a new sublineage of the North American genotype. Journal of Fish Diseases 29: 611-619.

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

Gagne, N., A.M. MacKinnon, L. Boston, B. Souter, M. Cook-Versloot, S. Griffiths, and G. Oliver. 2007. Isolation of viral haemorrhagic septicaemia virus from mummichog, stickleback, striped bass, and brown trout in eastern Canada. Journal of Fish Diseases 30: 213-223.

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

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

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

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

Isely, J.J., R.L. Noble, J.B. Koppelman, and D.P. Philipp. 1987. Spawning period and first-year growth of northern, Florida, and intergrade stocks of largemouth bass. Transactions of the American Fisheries Society 116: 757-762.

Isely, J.J., and T.B. Grabowski. 2007. Age and growth. Pages 187-228 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

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

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

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

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

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

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

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

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

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

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

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

Margenau, T.L. 1992. Survival and cost-effectiveness of stocked fall fingerling and spring yearling muskellunge in Wisconsin. North American Journal of Fisheries Management 12: 484-493.

Margenau, T.L. and D.A. Hanson. 1997. Performance of Leech Lake, Minnesota, muskellunge in a Wisconsin Lake. Wisconsin Department of Natural Resources Research Report 175 175: 1-11.

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

Margenau, T.L. and J.B. Petchenik. 2004. Social aspects of muskellunge management in Wisconsin. North American Journal of Fisheries Management 24: 82-93.

Mather, M.E., and D.H. Wahl. 1989. Comparative mortality of three esocids due to stocking stressors. Canadian Journal of Fisheries and Aquatic Sciences 46: 214-217.

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

McKeown, P.E., J.L. Forney, and S.R. Mooradian. 1999. Effects of stocking size and rearing method on muskellunge survival in Chautauqua Lake, New York. North American Journal of Fisheries Management 19: 249-257.

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

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

Miranda, L.E, and P.W. Bettoli, 2007. Mortality. Pages 229-277 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

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

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

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

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

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

Philipp, D.P. and G.S. Whitt. 1991. Survival and growth of northern, Florida, and reciprocal F1 hybrid largemouth bass in Central Illinois. Transaction of the American Fisheries Society 120: 58-64.

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

Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout *Salmo gairdneri*. Journal of the Fisheries Research Board of Canada 34: 123-128.

Robson, D.S., and D.G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181-189.

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

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

Schindler D.E., S. I. Geib, and M. R. Williams. 2000. Patterns of fish growth along a residential development gradient in north temperate lakes. Ecosystems 3:229-237.

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

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

Scimone, A., C.P. Wagner, L.M. Einfalt, and D.H. Wahl. In review. Effects of fin-clipping on the foraging behavior and growth of age-0 muskellunge.

Scott, W.B. and E.J. Crossman. 1998. Freshwater fishes of Canada, 2nd Edition. Oakville, Ontario, Canada.

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

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

Szendrey, T.A. and D.H. Wahl. 1995. Effect of feeding experience on growth, vulnerability to predation, and survival of esocids. North American Journal of Fisheries Management 15: 610-620.

Szendrey, T.A. and D.H. Wahl. 1996. Size-specific survival and growth of stocked muskellunge: effects of predation and prey availability. North American Journal of Fisheries Management 16: 395-402.

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

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

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

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

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

Wahl, D.H. 1999. An ecological context for evaluating the factors influencing muskellunge stocking success. North American Journal of Fisheries Management 19: 238-248.

Weatherbase. 2004. http://www.weatherbase.com/

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

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

Zar, J.H. 1999. Biostatistical Analysis 4th Edition. Prentice Hall. Englewood Cliffs, NJ.

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

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

Table 2. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH) and North Spring Lake, IL progeny (IL) introduced in Pierce Lake, Lake Mingo and Sam Dale Lake during falls 2002 - 2006. Ajusted 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		
			2002						
Mingo	OH	Cave Run Lake, KY	October 30, 2002	171	171	2.4	2.4	315 (±7.5)	155 (±8.2)
	IL	North Spring Lake, IL	October 24, 2002	400	400	5.6	5.6	336 (±5.6)	200 (±11.7)
			2003						
Pierce	MISS	Leech Lake, MN	November 7, 2003	100	100†	1.6	1.6	197 (±5.0)	28 (±2.5)
	OH	Lake Chautauqua, NY	September 19, 2003	234	234†	3.8	3.8	225 (±2.6)	44 (±1.7)
	IL	North Spring Lake, IL	August 29, 2003	500	500†	8.2	8.2	258 (±3.3)	77 (±2.9)
Mingo	MISS	Leech Lake, MN	October 31, 2003	285	285	4.0	4.0	237 (±9.0)	60 (±7.7)
	OH	Clear Fork Lake, OH	September 4, 2003	288	288	4.0	4.0	227 (±2.5)	56 (±2.2)
	IL	North Spring Lake, IL	August 29, 2003	500	433	7.0	6.0	258 (±3.3)	77 (±2.9)

Table 2. Continued.

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

Table 2. Continued.

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

†Mortality cages not utilized due to logistical constraints

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

‡Stocking events combined for subsequent analyses due low initial survival

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)

[†]Mortality cages not utilized due to logistical constraints

Table 3. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH) and Spirit Lake, IA progeny (IL) introduced in Pierce Lake, Lake Mingo, and Sam Dale Lake during fall 2007. 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		
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)

*Eggs obtained from Iowa Department of Natural Resources and reared at the Jake Wolf Fish Hatchery, Illinois Department of Natural Resources
†Mortality cages not utilized due to logistical constraints

Table 4. Summary of age-identifying freeze brands given to all stocked muskellunge by year. Freeze brands, in conjunction with scale samples, will allow for greater aging accuracy. Prior to introduction, muskellunge from the Upper Mississippi River drainage (MISS), the Ohio River drainage (OH), and the North Spring Lake, IL progeny (IL) are given a unique and consistent complete pelvic fin clip followed by cauterization of the wound.

Stocking Year	Age-Identifying Freeze Brand
Fall 2004	Right-Posterior Vertical
Fall 2005	Left-Anterior Vertical
Fall 2006	Right-Anterior Vertical
Fall 2007	Left-Posterior Vertical
Fall 2008	Right-Middle-Horizontal

Stock	Stock-Identifying Complete Fin Clip
MISS	Both pelvic
OH	Left pelvic
IL	Right pelvic

Table 5. Summary of muskellunge captured in modified fyke nets April 16-19, 2007 in Pierce Lake. Catch-per-unit-effort (CPUE) is expressed as muskellunge per net-night adjusted to account for different initial stocking numbers. Age classes correspond to year of stocking: IV = 2003, III = 2004, II = 2005, and I = 2006. NA indicates ages and populations not stocked.

	Ohio River Drainage		Mississippi River Draiange		Illinois	
Age	N	CPUE	N	CPUE	N	CPUE
I	0	0.00	0	0.00	0	0.00
II	NA	NA	NA	NA	2	0.30
III	8	2.26	0	0.00	27	4.09
IV	5	0.94	0	0.00	8	1.21
V	6	1.17	0	0.00	13	1.18

Table 6. Summary of muskellunge captured in modified fyke nets March 31-April 3, 2008 in Lake Mingo. Catch-per-unit-effort (CPUE) is expressed as muskellunge per net-night adjusted to account for different initial stocking numbers. Age classes correspond to year of stocking: VI = 2002, V = 2003, IV = 2004, III = 2005, II = 2006, and I = 2007. NA indicates populations and ages not stocked.

	Ohio River Drainage		Mississippi River Draiange		Illinois	
Age	N	CPUE	N	CPUE	N	CPUE
I	0	0.00	0	0.00	0	0.00
II	3	0.29	0	0.00	21	1.41
III	15	1.44	1	0.10	18	1.04
IV	11	1.41	0	0.00	15	0.97
V	5	0.33	1	0.07	6	0.26
VI	1	0.11	NA	NA	1	0.05

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

Season	Ohio River Drainage	Illinois
	Length (mm)	
Fall 2002	315 (±7.5)	336 (±5.6)
Fall 2003	623 (±16.3)	650 (±11.6)
Fall 2004	818 (±35.4)	843 (±0.0)
Fall 2005	897 (±41.6)	849 (±78.2)
Spring 2006	874 (±24.1)	877 (±438.4)
Fall 2006	935 (±0.0)	-
Spring 2007	944 (±30.2)	967 (±49.5)
Fall 2007	-	-
Spring 2008	1020 (±0.0)	1015 (±0.0)
	Weight (g)	
Fall 2002	155 (±8.2)	200 (±11.7)
Fall 2003	1457 (±106.4)	1735 (±118.3)
Fall 2004	3983 (±592.2)	4639 (±0.0)
Fall 2005	5355 (±1141.9)	4233 (±1839.2)
Spring 2006	5220 (±387.7)	5050 (±15501.6)
Fall 2006	5920 (±0.0)	-
Spring 2007	6627 (±705.5)	6823 (±1705.7)
Fall 2007	-	-
Spring 2008	7950 (±0.0)	8003 (±0.0)

Table 8. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the New York Lake Chautauqua population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	197 (±5.0)	225 (±2.6)	258 (±3.3)
Spring 2004	202 (±46.2)	284 (±9.4)	347 (±11.4)
Fall 2004	-	471 (±324.0)	552 (±34.0)
Spring 2005	-	511 (±457.4)	580 (±163.2)
Fall 2005	-	-	666 (±870.4)
Spring 2006	-	-	892 (±0.0)
Fall 2006	-	-	-
Spring 2007	903 (±95.3)	819 (±73.5)	843 (±21.6)
Fall 2007	-	-	-
Spring 2008	-	867 (±31.6)	907 (±18.2)
		Weight (g)	
Fall 2003	28 (±2.5)	44 (±1.7)	77 (±2.9)
Spring 2004	28 (±21.7)	102 (±11.6)	191 (±30.8)
Fall 2004	-	532 (±813.2)	931 (±251.4)
Spring 2005	-	839 (±3621.3)	1319 (±1572.3)
Fall 2005	-	-	1460 (±6099.0)
Spring 2006	-	-	6096 (±0.0)
Fall 2006	-	-	-
Spring 2007	5070 (±3049.5)	3980 (±1775.3)	4318 (±555.5)
Fall 2007	-	-	-
Spring 2008	-	5426 (±1247.2)	5800 (±639.5)

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

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	237 (±9.0)	227 (±2.5)	258 (±3.3)
Spring 2004	301 (±18.0)	306 (±9.7)	352 (±11.7)
Fall 2004	-	541 (±34.1)	562 (±44.6)
Spring 2005	-	578 (±58.6)	611 (±972.0)
Fall 2005	-	811 (±0.0)	747 (±26.8)
Spring 2006	-	744 (±22.5)	745 (±34.6)
Fall 2006	-	-	835 (±0.0)
Spring 2007	-	856 (±22.3)	885 (±15.0)
Fall 2007	-	-	902 (±0)
Spring 2008	909 (±0)	911.6 (±11.7)	943 (±45.6)
		Weight (g)	
Fall 2003	60 (±7.7)	56 (±2.2)	77 (±2.9)
Spring 2004	105 (±22.2)	128 (±17.1)	202 (±29.0)
Fall 2004	-	1011 (±287.5)	1112 (±358.3)
Spring 2005	-	1461 (±605.3)	1836 (±11486.4)
Fall 2005	-	3830 (±0.0)	2625 (±417.3)
Spring 2006	-	3133 (±388.8)	2867 (±378.0)
Fall 2006	-	-	4750 (±0.0)
Spring 2007	-	5226 (±613.6)	5500 (±308.7)
Fall 2007	-	-	5170 (±0)
Spring 2008	5880 (±0)	6150 (±377.2)	6633 (±1240.7)

Table 10. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2004. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. No fish from the 2004 Year Class were captured in the spring 2006 sampling. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2004	287 (±7.9)	261 (±5.0)	272 (±4.7)
Spring 2005	292 (±14.4)	331 (±19.5)	360 (±18.5)
Fall 2005	-	518 (±47.4)	551 (±393.9)
Spring 2006	-	-	-
Fall 2006	-	775 (±0.0)	-
Spring 2007	-	741 (±77.5)	749 (±51.3)
Fall 2007	-	863 (±0)	804 (±0)
Spring 2008	-	851 (±13.4)	829 (±24.3)
		Weight (g)	
Fall 2004	96 (±9.7)	76 (±5.1)	88 (±5.1)
Spring 2005	98 (±21.0)	188 (±63.9)	236 (±48.4)
Fall 2005	-	721 (±207.6)	992 (±3195.6)
Spring 2006	-	-	-
Fall 2006	-	3250 (±0.0)	-
Spring 2007	-	3090 (±996.4)	2822 (±392.5)
Fall 2007	-	4800 (±0)	4190 (±0)
Spring 2008	-	4678 (±339.1)	4277 (±481.9)

Table 11. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2004. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2004	280 (±8.2)	261 (±5.6)	273 (±4.6)
Spring 2005	297 (±9.2)	334 (±8.4)	371 (±9.9)
Fall 2005	540 (±914.8)	-	573 (±285.9)
Spring 2006	449 (±0.0)	563 (±33.8)	602 (±21.9)
Fall 2006	740 (±0.0)	-	753 (±38.8)
Spring 2007	780 (±0.0)	772 (±17.1)	771 (±18.0)
Fall 2007	-	-	-
Spring 2008	-	839.33 (±16.1)	829 (±14.22)
		Weight (g)	
Fall 2004	85 (±9.1)	74 (±5.3)	88 (±5.3)
Spring 2005	104 (±10.6)	179 (±16.7)	250 (±25.6)
Fall 2005	966 (±6321.3)	-	1125 (±2477.7)
Spring 2006	480 (±0.0)	1216 (±258.9)	1440 (±204.4)
Fall 2006	2080 (±0.0)	-	2973 (±518.5)
Spring 2007	3610 (±0.0)	3421 (±237.6)	3388 (±282.6)
Fall 2007	-	-	-
Spring 2008	-	4812 (±466.6)	4412 (±312.8)

Table 12. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2005. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2005	235 (±5.1)	261 (±4.1)	270 (±4.6)
Spring 2006	255 (±7.4)	317 (±34.0)	307 (±35.1)
Fall 2006	443 (±0.0)	430 (±1124.5)	503 (±51.0)
Spring 2007	-	-	-
Fall 2007	-	696 (±0)	633 (±660.7)
Spring 2008	-	701 (±13.4)	718 (±9.5)
		Weight (g)	
Fall 2005	50 (±3.7)	75 (±3.8)	87 (±5.1)
Spring 2006	63 (±6.3)	142 (±59.3)	140 (±39.5)
Fall 2006	362 (±0.0)	498 (±2515.0)	693 (±316.7)
Spring 2007	-	-	-
Fall 2007	-	2260 (±0)	1650 (±6098.9)
Spring 2008	-	2460 (±94.3)	2612 (±142.4)

Table 13. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2005. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the New York Chautauqua Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2005	233 (±5.5)	234 (±3.7)	267 (±4.8)
Spring 2006	250 (±38.3)	283 (±81.0)	366 (±38.4)
Fall 2006	-	-	594 (±67.0)
Spring 2007	-	562 (±29.0)	638 (±29.9)
Fall 2007	-	-	717 (±0)
Spring 2008	784 (±0)	748 (±23.9)	779 (13.93)
		Weight (g)	
Fall 2005	48 (±3.8)	45 (±2.3)	79 (±5.8)
Spring 2006	61 (±32.7)	98 (±88.5)	247 (±82.1)
Fall 2006	-	-	1346 (±869.2)
Spring 2007	-	1225 (±236.9)	1712 (±169.7)
Fall 2007	-	-	1980 (±0)
Spring 2008	3750 (±0)	3230 (±337.5)	3511 (±228.2)

Table 14. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2006. Spring sampling was conducted from March 15 through May 4, 2007. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. No Upper Mississippi River Drainage muskellunge were introduced. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Illinois
	Length (mm)	
Fall 2006	244 (±5.3)	281 (±7.6)
Spring 2007	359 (±343.1)	375 (±13.1)
Fall 2007	-	522 (±978.3)
Spring 2008	578 (±21.4)	631 (±49.9)
	Weight (g)	
Fall 2006	66 (±5.9)	112 (±10.1)
Spring 2007	223 (±711.5)	270 (±37.2)
Fall 2007	-	830 (±5082)
Spring 2008	1270 (±137.9)	1795 (±170.5)

Table 15. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2007. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are Spirit Lake Iowa progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2007	325 (±7.2)	234 (±5.4)	285 (±4.2)
Spring 2008	326 (±11.6)	301 (±15.9)	344 (±0)
		Weight (g)	
Fall 2007	153 (±10.9)	55 (±4.3)	125 (±6.0)
Spring 2008	146 (±22.9)	153 (±52.7)	223 (±0)

Table 16. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative daily growth rates (g/g/d) of muskellunge populations from the Ohio River drainage, Upper Mississippi River drainage and Spirit Lake, Iowa population introduced in Pierce Lake during fall 2007. Growth is for the 6-month interval from stocking through the following Spring (October 2007 through March 2008). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	2	6817.5	1.3	0.34
Error	7	19149.0		
		Mean relative daily growth rate (g/g/d)		
Stock	2	3182.6	1.3	0.33
Error	7	8672.2		

Table 17. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2007. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are Spirtit Lake Iowa progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2007	326 (±7.6)	231 (±4.0)	286 (±3.7)
Spring 2008	313 (±9.6)	309 (±88.6)	347 (±16.1)
		Weight (g)	
Fall 2007	155 (±11.5)	54 (±2.8)	210 (±35.2)
Spring 2008	132 (±14.9)	153 (±146.8)	202 (±29.0)

Table 18. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative daily growth rates (g/g/d) of muskellunge populations from the Ohio River drainage, Upper Mississippi River drainage and Spirit Lake, Iowa population introduced in Lake Mingo during fall 2007. Growth is for the 6-month interval from stocking through the following Spring (October 2007 through March 2008). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	2	1461.4	0.23	0.80
Error	26	82530.0		
		Mean relative daily growth rate (g/g/d)		
Stock	2	375.9	0.21	0.81
Error	26	22790.0		

Table 19. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of threee stocks of muskellunge introduced in Sam Dale Lake during fall 2007. Spring and fall sampling seasons were comprised of multiple sampling events per season. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are Spirit Lake, Iowa progeny. No Ohio drainage fish from the 2007 year class were captured in the spring 2008 sampling. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2007	325 (±7.6)	232 (±5.2)	284 (±4.0)
Spring 2008	326 (±43.5)	-	378 (±5.1)
		Weight (g)	
Fall 2007	156 (±11.5)	54 (±4.1)	124 (±5.7)
Spring 2008	137 (±21.0)	-	319 (±14.49)

Table 20. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative daily growth rates (g/g/d) of muskellunge populations from the Upper Mississippi River drainage, and the Spirit Lake, Iowa population introduced in Sam Dale Lake during fall 2007. Growth is for the 6-month interval from stocking through the following Spring (October 2007 through March 2008). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	1	2.21	22.64	0.009
Error	4	0.09		
		Mean relative daily growth rate (g/g/d)		
Stock	1	0.49	7.8	0.049
Error	4	0.25		

Table 21. Parameter estimates and 95% confidence intervals of Von Bertalanffy growth functions fitted to pooled length-at-age data from Lake Mingo muskellunge sampled spring 2004-2008 and stratified by sex.

Stock	Gender	N	Parameter	Estimate	Lower 95%	Upper 95%
Illinois	Male	94	L Inf	932.00	883.60	980.50
			T0	0.17	-0.04	0.37
			K	0.62	0.49	0.76
Ohio	Male	93	L Inf	968.80	914.10	1023.50
			T0	0.62	0.27	0.97
			K	0.63	0.45	0.81
Illinois	Female	46	L Inf	1155.60	963.40	1347.70
			T0	-0.25	-0.93	0.43
			K	0.34	0.16	0.51
Ohio	Female	31	L Inf	1123.20	1042.40	1204.10
			T0	0.13	-0.03	0.29
			K	0.41	0.32	0.49

Table 22. Parameter estimates and 95% confidence intervals of Von Bertalanffy growth functions fitted to pooled length-at-age data from Pierce Lake muskellunge sampled spring 2004-2008.

Stock	N	Parameter	Estimate	Lower 95%	Upper 95%
Illinois	94	L Inf	966.40	918.10	1014.70
		T0	0.12	0.00	0.24
		K	0.50	0.42	0.59
Ohio	93	L Inf	998.60	917.40	1079.80
		T0	0.20	0.08	0.33
		K	0.45	0.34	0.56

Table 23. Estimated mean length-at–age and weight-at-age of three stocks of muskellunge stocked into lakes Mingo and Pierce. Means are estimated from spring samples taken 2003-2008.

Lake	Age	Mississippi River Drainage	Ohio River Drainage	Illinois
			Length (mm)	
Mingo	1	298 (±7.5)	328 (±6.2)	363 (±4.8)
	2	449 (±0)	606 (±13.4)	630 (±12.8)
	3	782 (±0)	762 (±11.5)	773 (±10.6)
	4	-	860 (±13.2)	859 (±11.5)
	5	909 (±0)	934 (±20.6)	954 (±26.0)
	6	-	1020 (±0)	1015 (±0)
Pierce	1	270 (±11.2)	303 (±9.2)	347 (±15.2)
	2	.	511 (±72.0)	578 (±30.8)
	3	.	713 (±18.8)	728 (±14.3)
	4	902 (±0)	847 (±11.0)	837 (±14.2)
	5	.	860 (±24.8)	907 (±16.8)
			Weight (g)	
Mingo	1	108 (±8.2)	165 (±10.2)	242 (±12.9)
	2	480 (±140.0)	1538 (±102.8)	1744 (±114.2)
	3	3680 (±0)	3338 (±158.2)	3421 (±166.9)
	4	-	5104 (±250.1)	4963 (±280.8)
	5	5880 (±0)	6486 (±465.3)	6728 (±798.6)
	6	-	7950 (±0)	8003 (±0)
Pierce	1	81 (±12.2)	135 (±20.4)	217 (±33.1)
	2	.	839 (±570.0)	1264 (±286.4)
	3	.	2653 (±126.2)	2751 (±237.2)
	4	5070 (±480)	4758 (±770.5)	4302 (±336.2)
	5	.	5081 (±886.5)	5800 (±591.42)

Table 24. Analysis of covariance tests of the effects of stock, initial length and age on length and at- weight of sampled Ohio River drainage and Illinois Stock muskellunge introduced into Lake Mingo 2002-2007. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Length (mm)		
Stock	1	1666.2	1.3	0.25
Age	5	24327858.0	6.6	<0.0001
Stock*Age	5	12859.0	2.1	0.07
Initial Length	1	71254.0	56.8	<0.0001
Error	492	617474.0		
		Weight (g)		
Stock	2	2856141.0	4.3	0.01
Age	6	683845758.0	4.1	<.0001
Stock*Age	11	6111255.0	1.7	0.08
Initial Weight	1	2703025.0	8.1	0.005
Error	890	297119535.0		

Table 25. Analysis of covariance tests of the effects of stock, initial length and age on length of length and weight of sampled Ohio River drainage and Illinois Stock muskellunge introduced into Pierce Lake 2003-2007. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Length (mm)		
Stock	1	1.0	0.0	0.99
Age	5	12601148.0	745.6	<0.0001
Stock*Age	5	60153.0	3.6	0.004
Initial Length	1	47711.0	14.1	0.0002
Error	329	1112012.0		
		Weight (g)		
Stock	1	922.8	0.0	0.95
Age	5	808603807.0	634.9	<.0001
Stock*Age	5	4867201.0	3.8	0.0022
Initial Weight	1	62584.0	0.3	0.62
Error	329	83797086.0		

Table 26: Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of two stocks of muskellunge introduced into Lake Mingo in fall 2002. Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance.

Sampling Season	Effort (hr)	Adjusted CPUE OH	Adjusted CPUE IL	P
Spring 2003	26.4	8.97	5.30	0.14
Fall 2003	16.0	6.40	4.40	0.36
Spring 2004	21.0	7.57	0.97	0.031
Fall 2004	22.6	1.16	0.10	0.051
Spring 2005	28.4	1.34	0.76	0.53
Fall 2005	17.7	1.86	0.34	0.034
Spring 2006	11.1	0.00	0.23	0.36
Fall 2006	15.7	0.40	0.00	0.35
Spring 2007	15.8	0.00	0.14	0.34
Fall 2007	10.8	0.00	0.00	-
Spring 2008	6.5	0.00	0.00	-

Table 27. Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of three stocks of muskellunge introduced into Pierce and Mingo Lakes in fall 2003. Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance. Lower case letters denote statistical differences following Tukey's means separation.

Sampling Season	Effort (hr)	Adjusted CPUE			P
		MISS	OH	IL	
		Pierce Lake			
Spring 2004	16.5	2.92	3.33	0.74	0.22
Fall 2004	17.6	0.00	0.55	0.98	0.053
Spring 2005	26.0	0.00	0.31	0.23	0.43
Fall 2005	18.1	0.00	0.00	0.24	0.12
Spring 2006	15.6	0.00	0.00	0.00	-
Fall 2006	13.8	0.00	0.00	0.00	-
Spring 2007	11.3	1.54	0.00	0.31	0.52
Fall 2007	10.1	0.00	0.00	0.00	-
Spring 2008	8.7	0.00	0.00	0.40	0.46
		Lake Mingo			
Spring 2004	21.0	2.28	3.83	3.53	0.47
Fall 2004	22.6	0.00^{b}	1.26^{a}	0.74^{ab}	0.014
Spring 2005	28.4	0.00^{b}	0.73^{a}	0.15^{ab}	0.049
Fall 2005	17.7	0.00	0.17	0.51	0.17
Spring 2006	11.1	0.00	0.00	0.21	0.41
Fall 2006	15.7	0.00	0.00	0.15	0.40
Spring 2007	15.8	0.00	0.00	0.50	0.16
Fall 2007	10.8	0.54	0.00	0.76	0.81
Spring 2008	6.5	0.00	0.00	0.00	-

Table 28. Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of three stocks of muskellunge introduced into Pierce and Mingo Lakes in fall 2004. Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance. Lower case letters denote statistical differences following Tukey's means separation.

Sampling Season	Effort (hr)	Adjusted CPUE			P
		MISS	OH	IL	
		Pierce Lake			
Spring 2005	26.0	1.77	1.08	1.10	0.79
Fall 2005	18.1	0.00^{b}	1.20^{a}	0.37^{ab}	0.046
Spring 2006	15.6	0.00	0.00	0.00	-
Fall 2006	13.8	0.00	0.26	0.00	0.39
Spring 2007	11.3	0.00	0.32	0.00	0.41
Fall 2007	10.1	0.00	0.54	0.53	0.62
Spring 2008	8.7	0.00	0.83	0.00	0.46
		Lake Mingo			
Spring 2005	28.4	6.30^{a}	3.11^{ab}	2.43^{b}	0.031
Fall 2005	17.7	0.46	0.00	0.34	0.49
Spring 2006	11.1	0.48	0.63	0.00	0.62
Fall 2006	15.7	0.29^{a}	0.00^{a}	1.29^{b}	<0.01
Spring 2007	15.8	0.00	0.35	0.52	0.24
Fall 2007	10.8	0.00	0.00	0.00	-
Spring 2008	6.5	0.00	1.13	1.73	0.30

Table 29. Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of three stocks of muskellunge introduced into Pierce and Mingo Lakes in fall 2005.Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance.

Sampling Season	Effort (hr)	Adjusted CPUE			P
		MISS	OH	IL	
			Pierce Lake		
Spring 2006	15.6	8.53	1.55	1.86	0.078
Fall 2006	13.8	0.39	0.94	1.72	0.41
Spring 2007	11.3	0.00	0.00	0.00	-
Fall 2007	10.1	0.00	0.43	0.87	0.29
Spring 2008	8.7	0.00	0.00	0.67	0.46
			Lake Mingo		
Spring 2006	11.1	2.45	1.35	1.43	0.99
Fall 2006	15.7	0.00	0.00	0.75	0.16
Spring 2007	15.8	0.00	0.00	0.18	0.39
Fall 2007	10.8	0.00	0.00	1.02	0.39
Spring 2008	6.5	0.00	0.00	2.42	0.46

Table 30. Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of three stocks of muskellunge introduced into Pierce and Mingo Lakes in fall 2006. Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance. NA indicates populations not stocked.

Sampling Season	Effort (hr)	Adjusted CPUE			P
		MISS	OH	IL	
			Pierce Lake		
Spring 2007	11.3	NA	NA	1.94	-
Fall 2007	10.1	NA	NA	3.04	-
Spring 2008	8.7	NA	NA	1.85	-
			Lake Mingo		
Spring 2007	15.8	NA	0.79	4.67	0.01
Fall 2007	10.8	NA	0.00	0.67	0.42
Spring 2008	6.5	NA	3.56	1.21	0.59

Table 31. Adjusted catch-per-unit-effort (CPUE) of electrofishing (fish/hr) through time of three stocks of muskellunge introduced into Pierce, Mingo, and Sam Dale Lakes in fall 2007. Adjusted CPUE is subject to a natural logarithmic transformation and analyzed using an analysis of variance. Lower case letters denote statistical differences following Tukey's means separation.

Sampling Season	Effort (hr)	Adjusted CPUE			P
		MISS	OH	IL	
			Pierce Lake		
Spring 2008	8.7	4.50	1.96	0.67	0.18
			Lake Mingo		
Spring 2008	6.5	24.99[a]	3.81[b]	8.02[b]	0.01
			Sam Dale Lake		
Spring 2008	6.2	2.50	0.00	2.17	0.62

Table 32. Annual survival estimates of individual year classes of three stocks of muskellunge from cohort catch-curves in Lakes Mingo and Pierce 2002-2007. Lower case letters denote statistical differences following means separation using a Bonferroni correction.

Stocking Year Class	Ohio River Drainage	Mississippi River Drainage	Illinois	P
		Lake Mingo		
2002	0.40 (±0.09)	-	0.31 (±0.10)	0.08
2003	0.13 (±0.13)	-	0.30 (±0.12)	0.08
2004	0.27 (±0.19)[a]	0.03 (±0.06)[b]	0.36 (±0.17)[a]	<0.01
2005	-	-	-	-
2006	0.4 (±0.48)[b]	-	0.04 (±0.08)[a]	0.01
2007	-	-	-	-
		Pierce Lake		
2003	0.12 (±0.17)[b]	0.60 (±0.32)[ab]	0.54(±0.20)[a]	<0.01
2004	0.38 (±0.27)	-	-	-
2005	0.33 (±0.41)	-	-	-
2006	-	-	0.25 (±0.25)	-
2007	-	-	-	-

Table 33. Repeated measures analysis of variance tests of the effects of treatment (stocked vs. control lake), time period (before vs. after muskellunge stocking) , transect and year on the mean number of largemouth bass collected per hour of electrofishing in lakes Homer and Mingo fall 1998-2005 (SAS Institute V8). Tests of stocking effects for the BACIP design are presented in bold.

Source of Variation	Degrees of Freedom	F	Pr > F
Control Vs. Stocked	1	2.76	0.13
Period Before Vs. After Stocking	1	0.28	0.13
Before Vs. After * Control Vs. Stocked	**1**	**10.57**	**0.08**
Control Vs. Stocked* Time (Before Vs. After)	12	2.20	0.03
Transect (Control Vs. Stocked)	4	0.45	0.02

Table 34. Repeated measures analysis of variance tests of the effects of treatment (impact vs. control lake) , time period (before vs. after muskellunge stocking) , transect and year on the mean length of gizzard shad sampled in lakes Homer and Mingo fall 2001-2005 (SAS Institute V8). Tests of stocking effects for the BACIP design are presented in bold.

Source of Variation	Degrees of Freedom	F	Pr > F
Control Vs. Stocked	1	9.03	0.011
Period Before Vs. After Stocking	1	0.28	0.61
Before Vs. After * Control Vs. Stocked	**1**	**10.57**	**<0.01**
Control Vs. Stocked* Time (Before Vs. After)	9	2.20	0.08
Transect (Control Vs. Stocked)	6	0.45	0.83

Table 35. Illinois lakes identified for examination of the effects of muskellunge stocking as part of Job 101.3. All lakes excluding Lake Mingo, and Ridge Lake, were identified using stocking records from the Jake Wolf Memorial Fish Hatchery 1988-2007.

Lake	County	Year of Initial Stocking	Data Source
Argyle Lake	McDonough	2000	Illinois FAS
Shovel Lake	Peoria	1999	Illinois FAS
Forbes Lake	Marion	1999	Illinois FAS
Mill Creek Lake	Clark	1999	Illinois FAS
Pana Lake	Shelby	2000	Illinois FAS
Prairie Lake	Sangamon	1999	Illinois FAS
Spring Lake	McDonough	2000	Illinois FAS
Staunton City Lake	Macoupin	1999	Illinois FAS
Lake Mingo	Vermillion	2002	INHS
Ridge Lake	Coles	2006	INHS

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

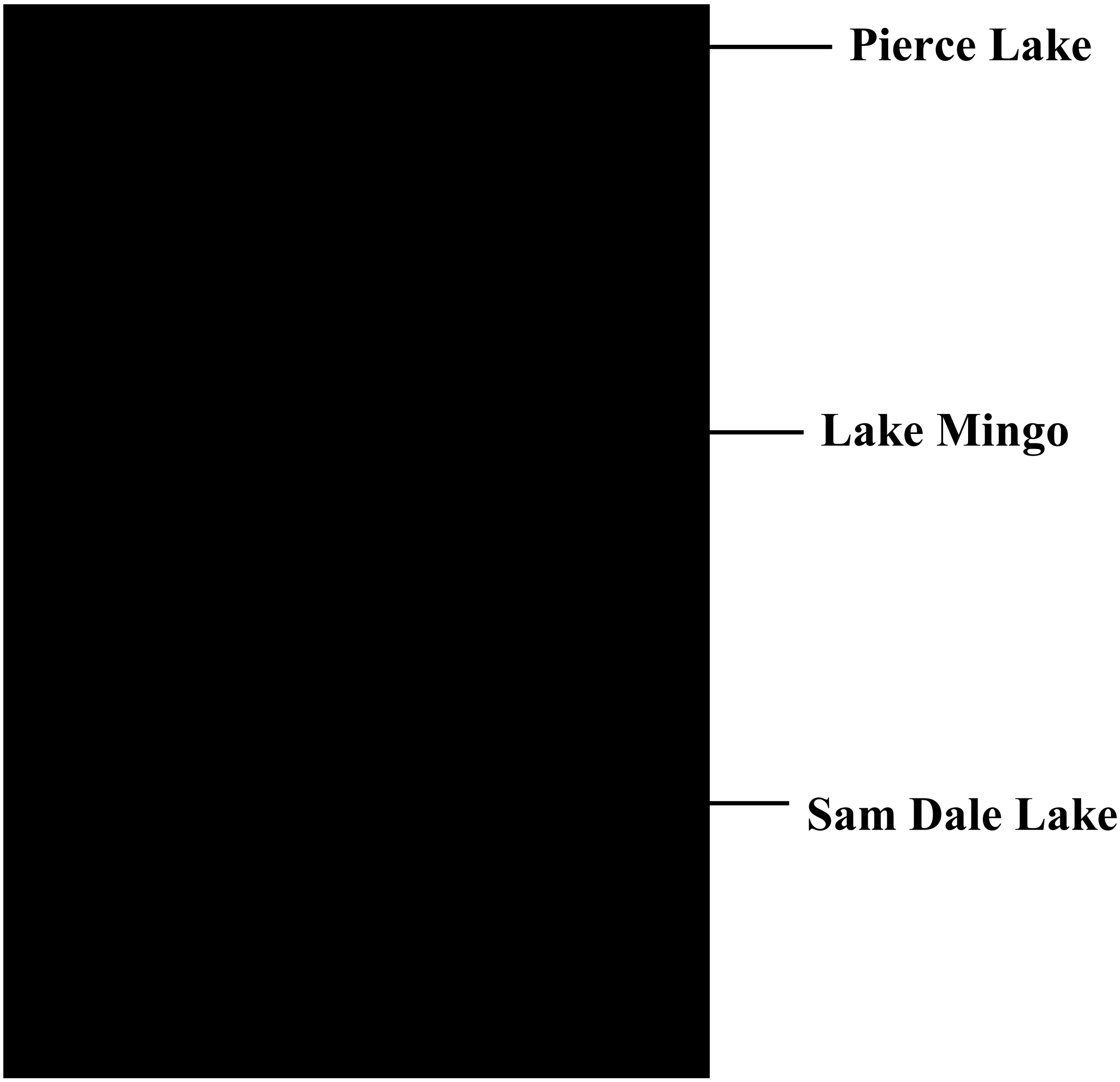

Figure 2. Locations of the 14 modified fyke nets set in Lake Mingo on March 30th and removed on April 3, 2008. Total effort was 53 net-nights.

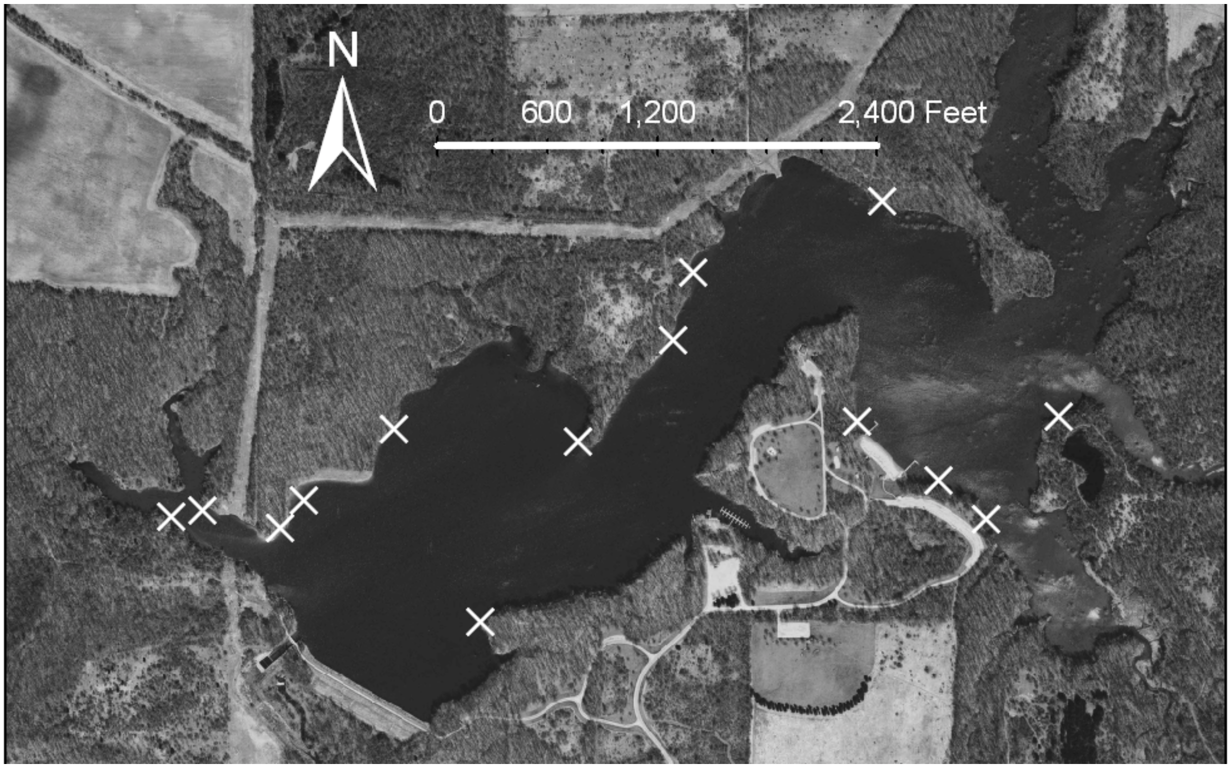

Figure 3. Locations of the 11 modified fyke nets set in Pierce Lake on April 16th and removed on April 17th, 2008. Total effort was 22 net-nights.

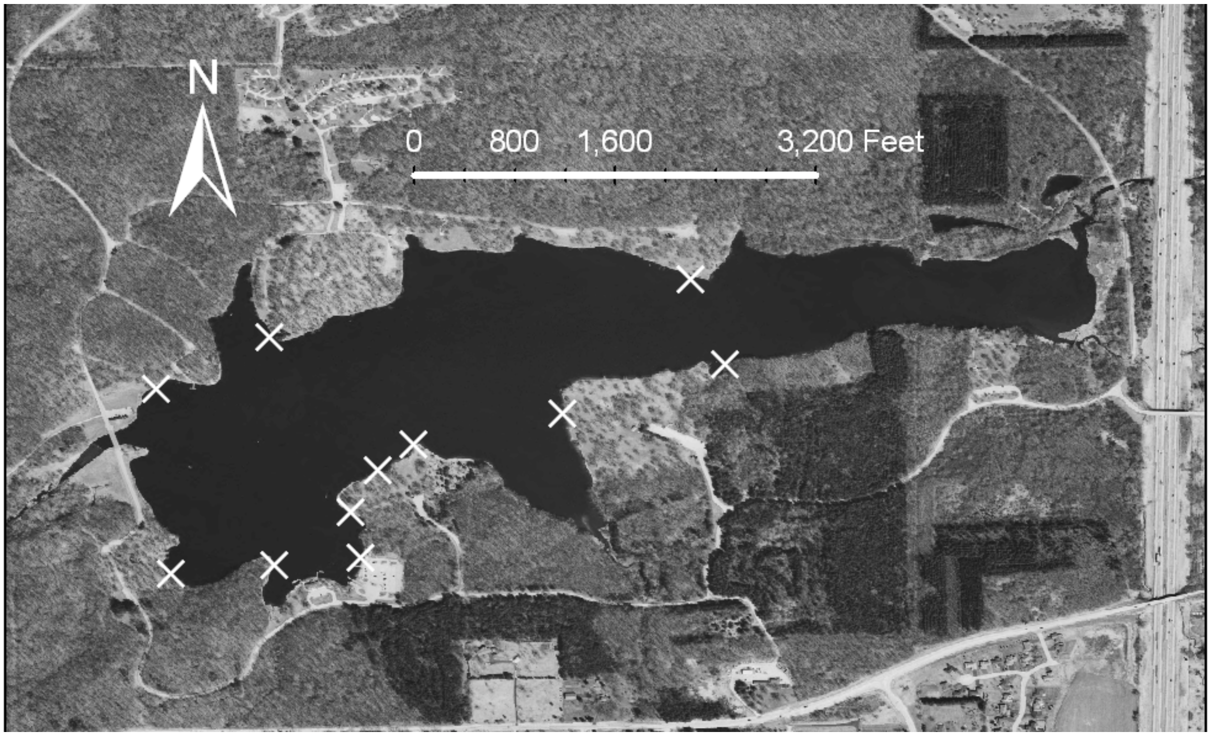

Figure 4. Mean daily growth rates (g/d, solid bars) and mean relative daily growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Pierce Lake during fall 2007. Growth is from the time of stocking through the following spring. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are Spirit Lake, Iowa progeny. Vertical lines represent ±1 standard error.

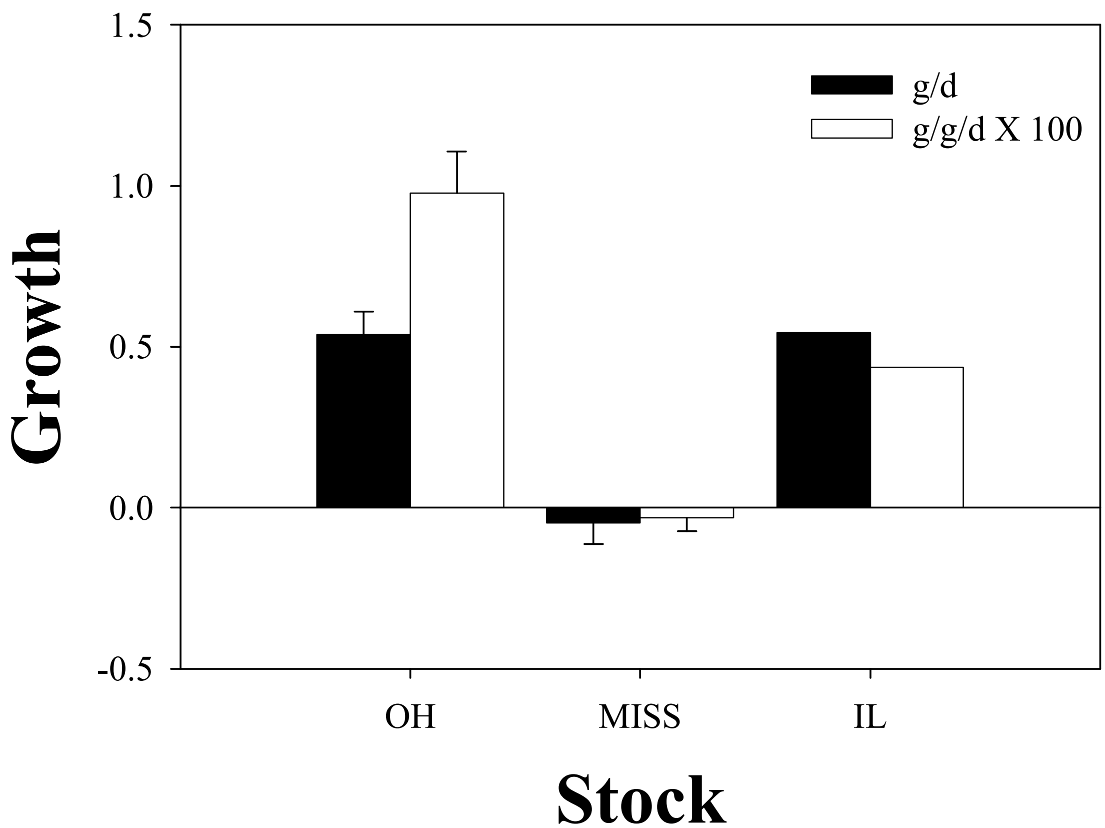

Figure 5. Mean daily growth rates (g/d, solid bars) and mean relative daily growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage, the Ohio River drainage, and North Spring Lake, IL introduced in Lake Mingo during fall 2007. Growth is from the time of stocking through the following spring. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Kentucky Cave Run Lake population, and the Illinois muskellunge are Spirit Lake, Iowa progeny. Vertical lines represent ±1 standard error.

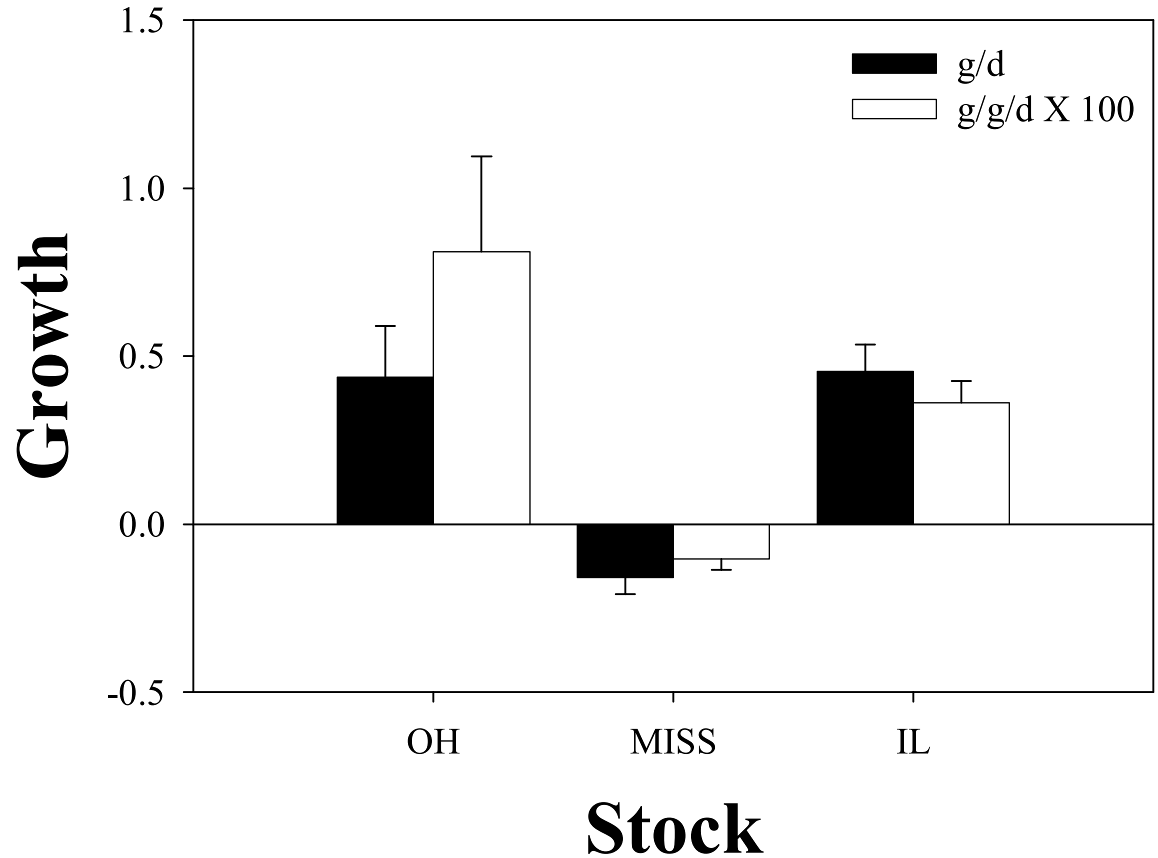

Figure 6. Mean daily growth rates (g/d, solid bars) and mean relative daily growth rates (g/g/d X 100, open bars) of muskellunge populations from the Upper Mississippi River drainage and Spirit Lake, Iowa introduced in Sam Dale Lake during fall 2007. Growth is from the time of stocking through the first spring (October 2007 through March 2008). The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population and the Illinois muskellunge are Spirit Lake, Iowa progeny. Vertical lines represent ±1 standard error.

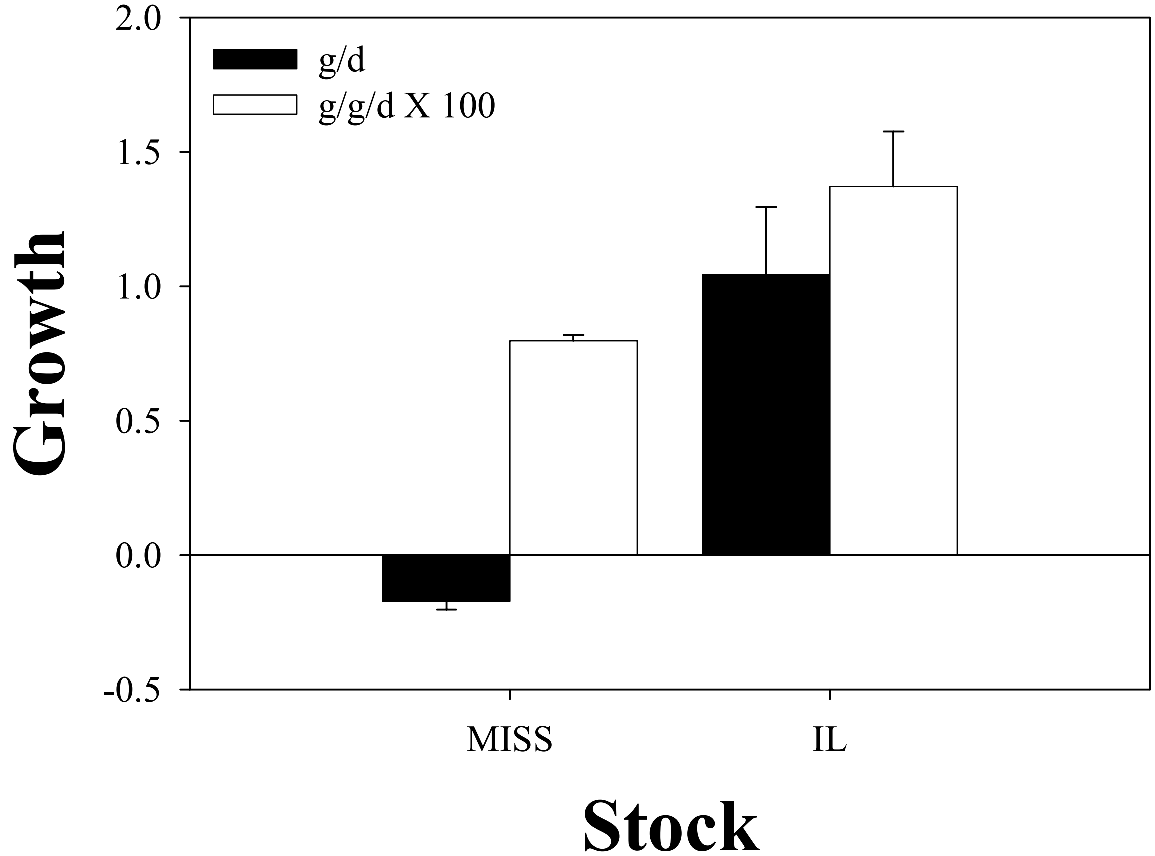

Figure 7. Mean total length (mm) at age and fitted von Bertalanffy growth functions for male muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Lake Mingo from fall 2002 through fall 2007.

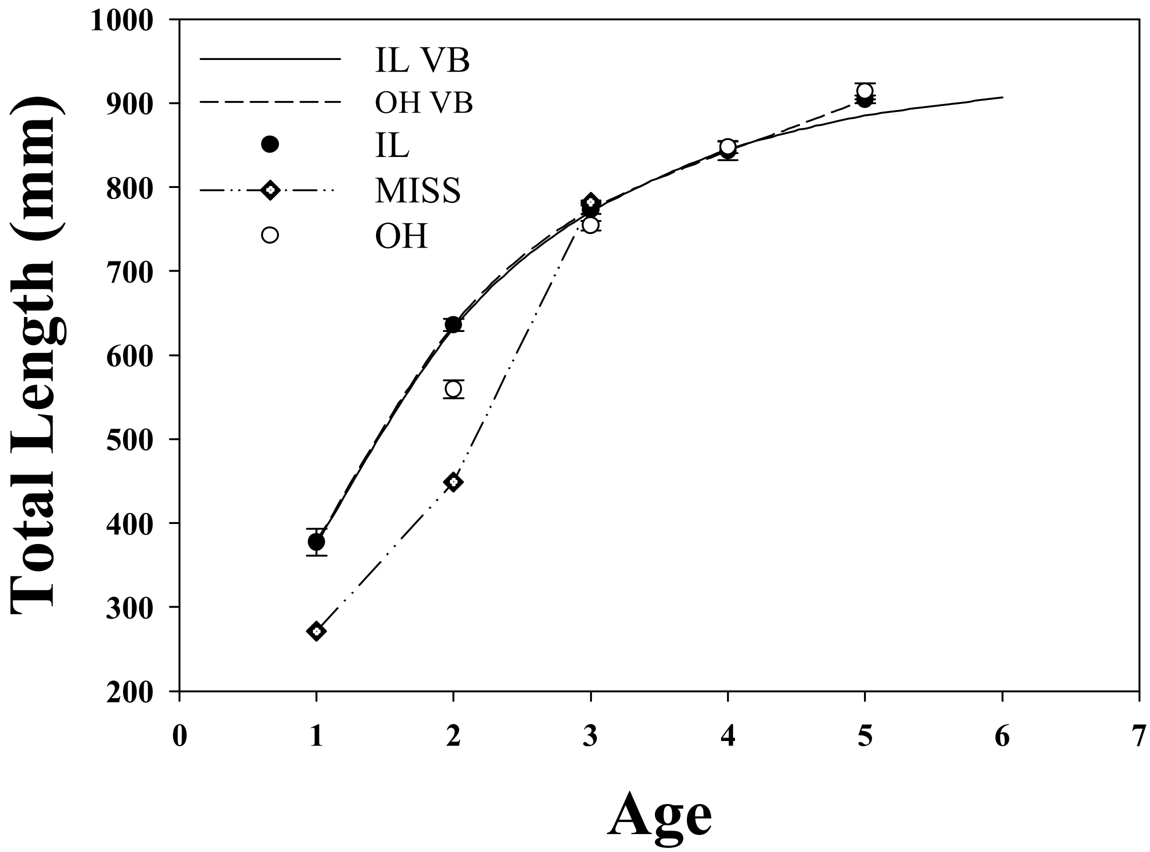

Figure 8. Mean total length (mm) at age and fitted von Bertalanffy growth functions for female muskellunge from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Lake Mingo from fall 2002 through fall 2007.

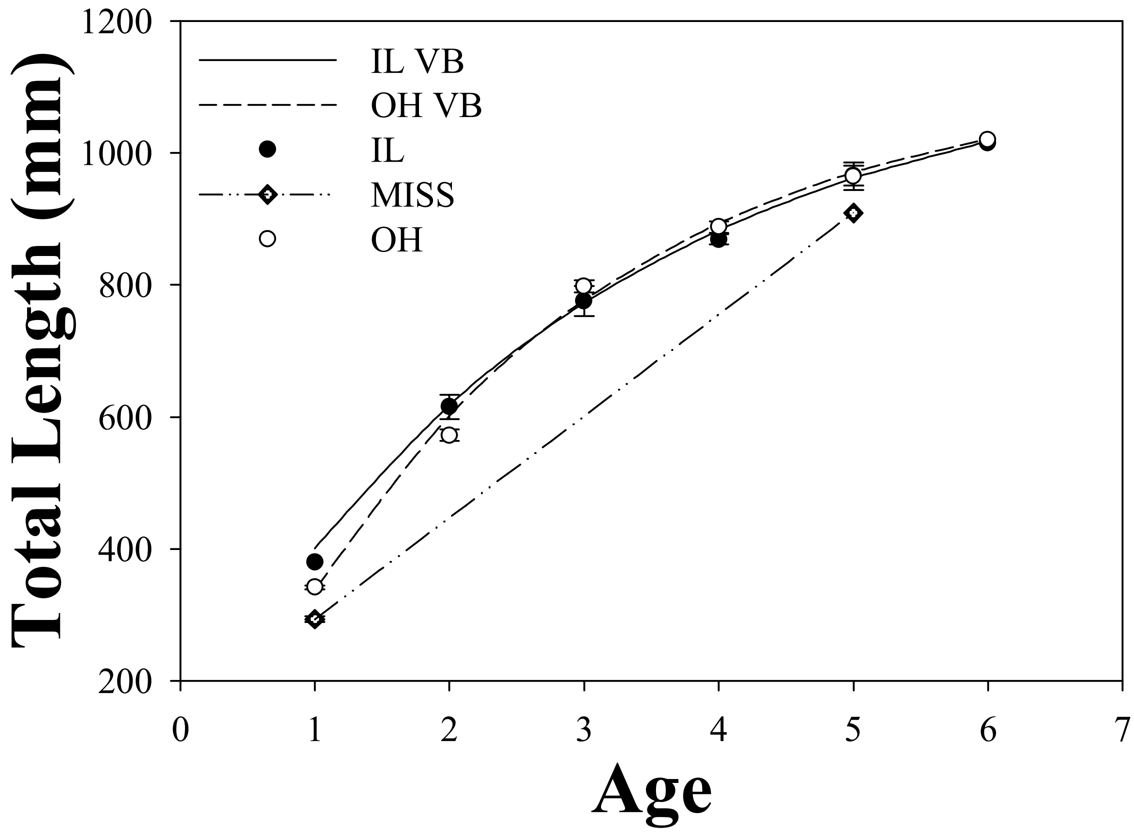

Figure 9. Mean total length (mm) at age and fitted von Bertalanffy growth functions for muskellunge (sexes combined) from the Illinois population (solid line) and the Ohio River drainage stock (dashed line) introduced into Pierce Lake from fall 2003 through fall 2007.

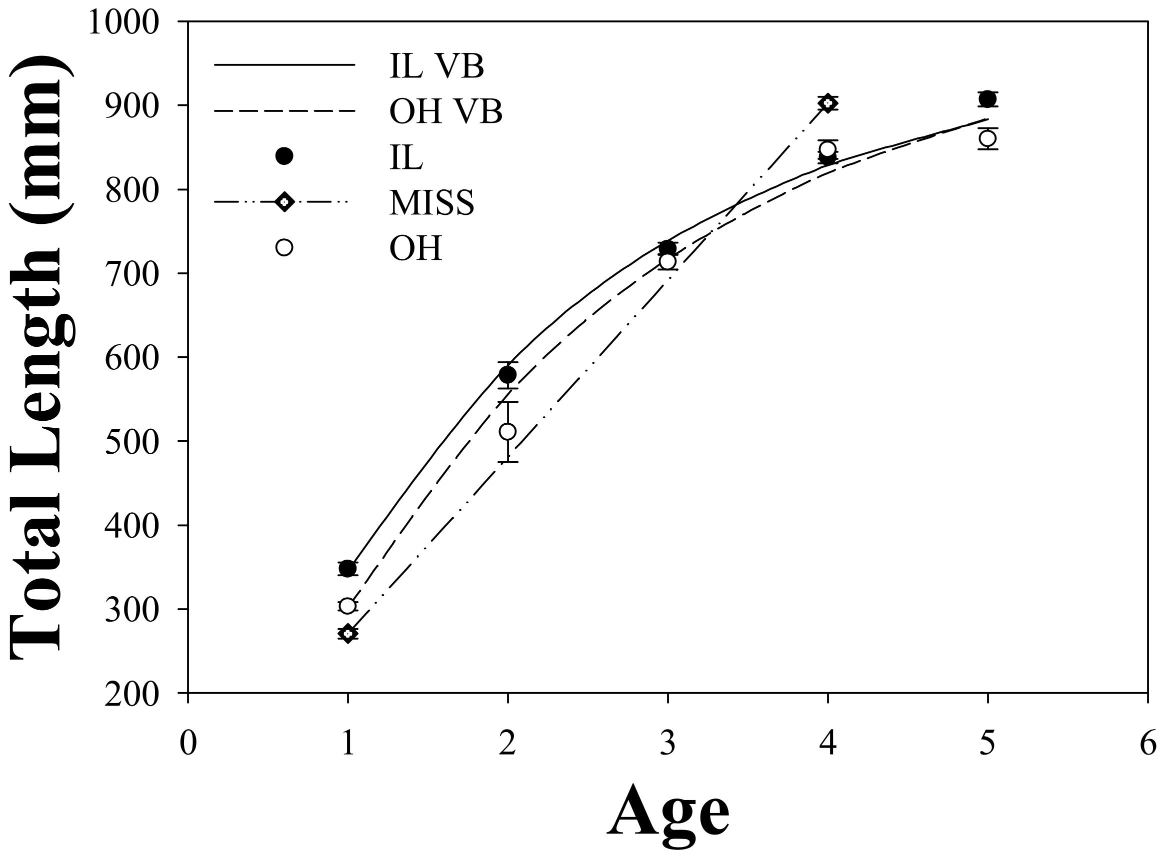

Figure 10. Diet composition of muskellunge sampled in Pierce Lake via shoreline electrofishing and modified fyke nets, June 2007-November 2007 and March-April 2008. Data are pooled across samples from each season (Spring-Fall). Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

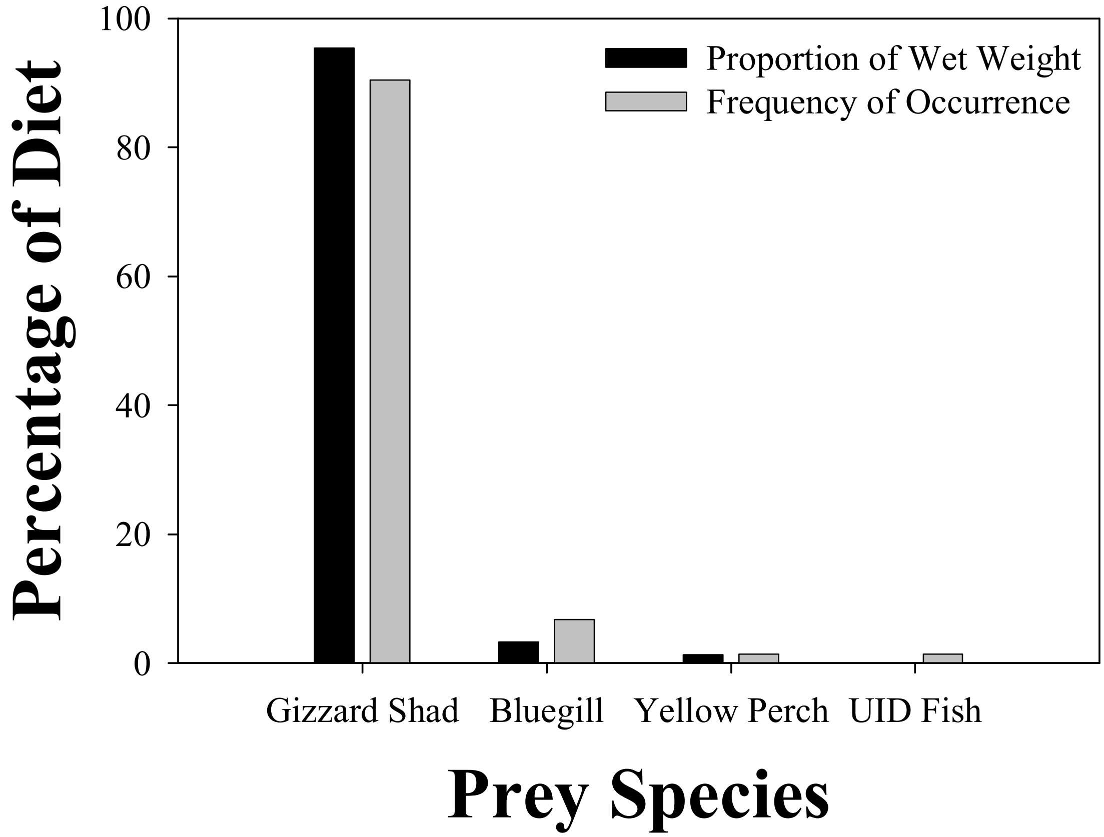

Figure 11. Diet composition of muskellunge sampled in Lake Mingo via shoreline electrofishing and modified fyke nets, June 2007-November 2007 and March-April 2008. Data are pooled across samples from each season (Spring-Fall). Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

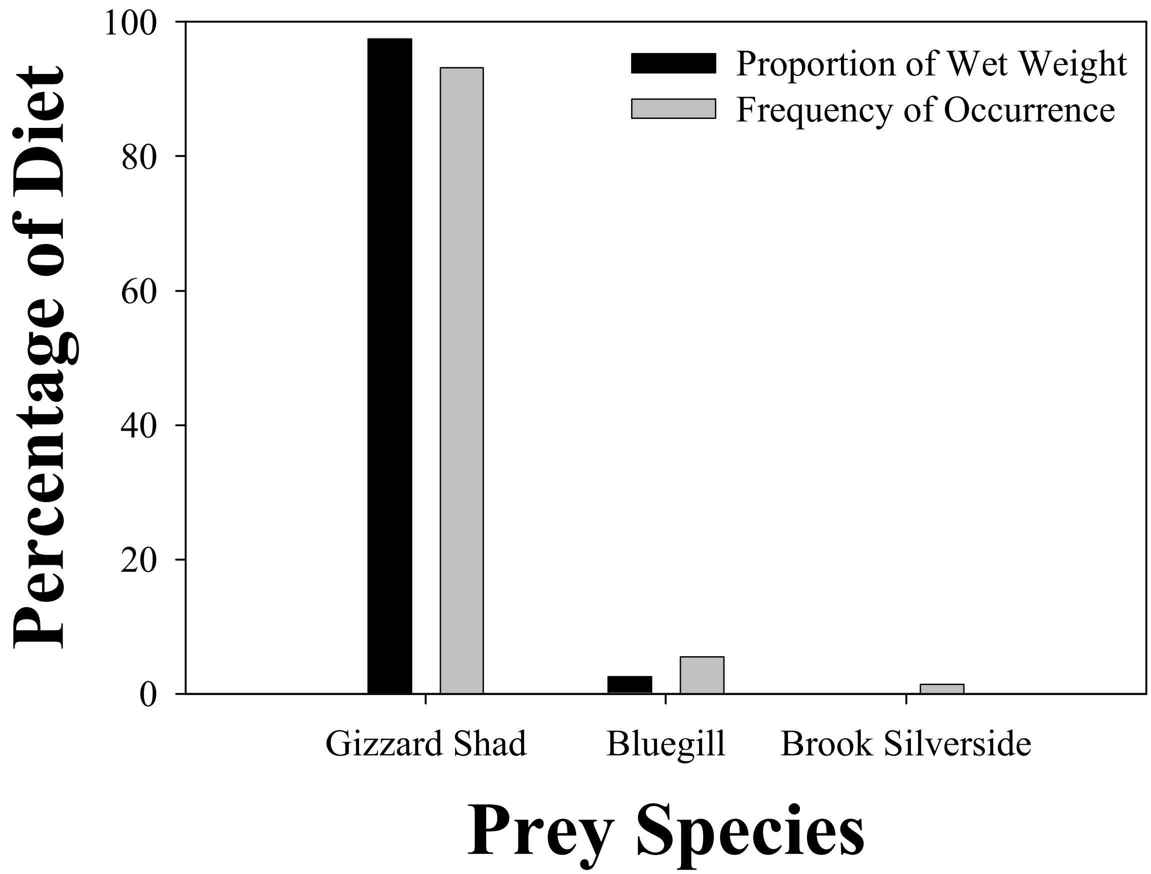

Figure 12. Diet composition of muskellunge sampled in Lake Shelbyville via shoreline electrofishing, June 2007-November 2007 and March-April 2008. Data are pooled across samples from each season (Spring-Fall). Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

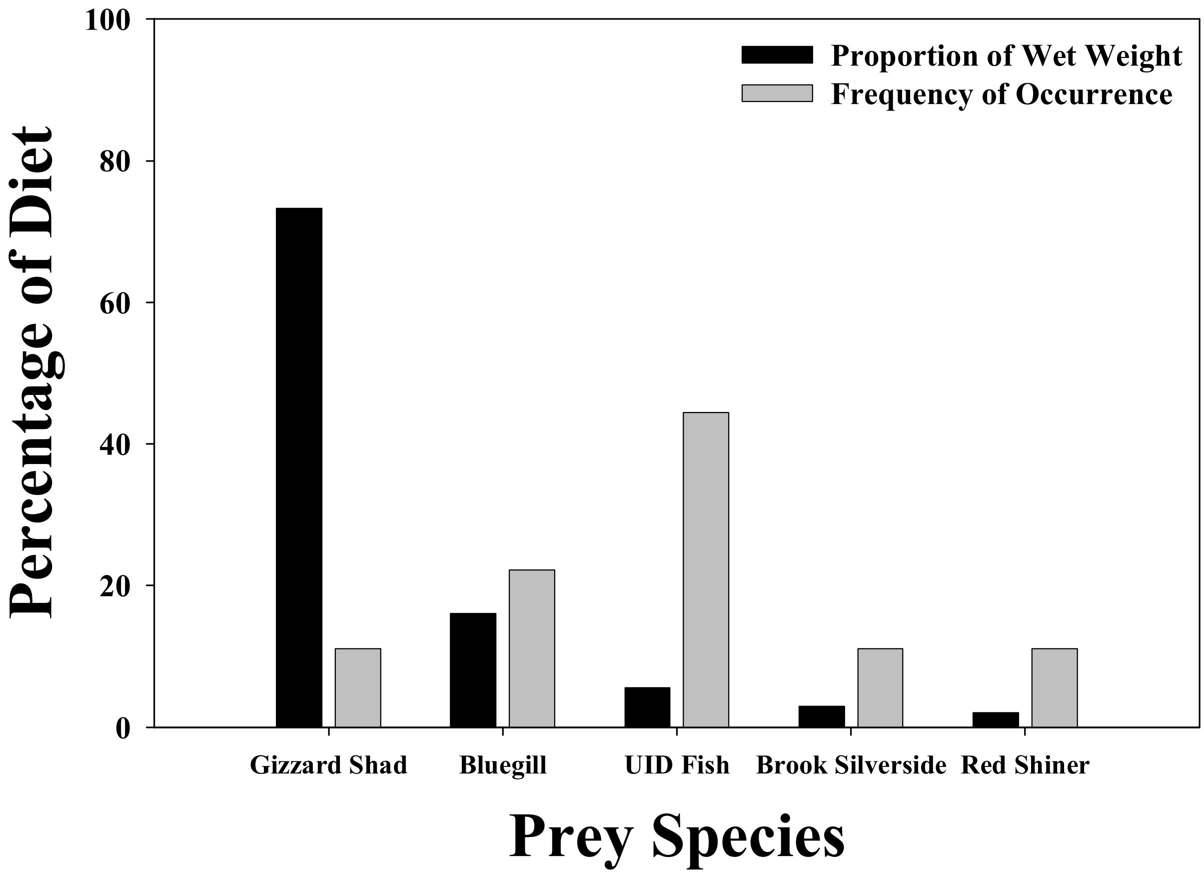

Figure 13. Diet composition of muskellunge sampled in Ridge Lake via shoreline electrofishing, and angler creel, June 2007-October 2007 and March-April 2008. Data are pooled across samples from each season (Spring-Fall). Proportions of diet by wet weight and frequency are transformed to percentages by multiplying by 100.

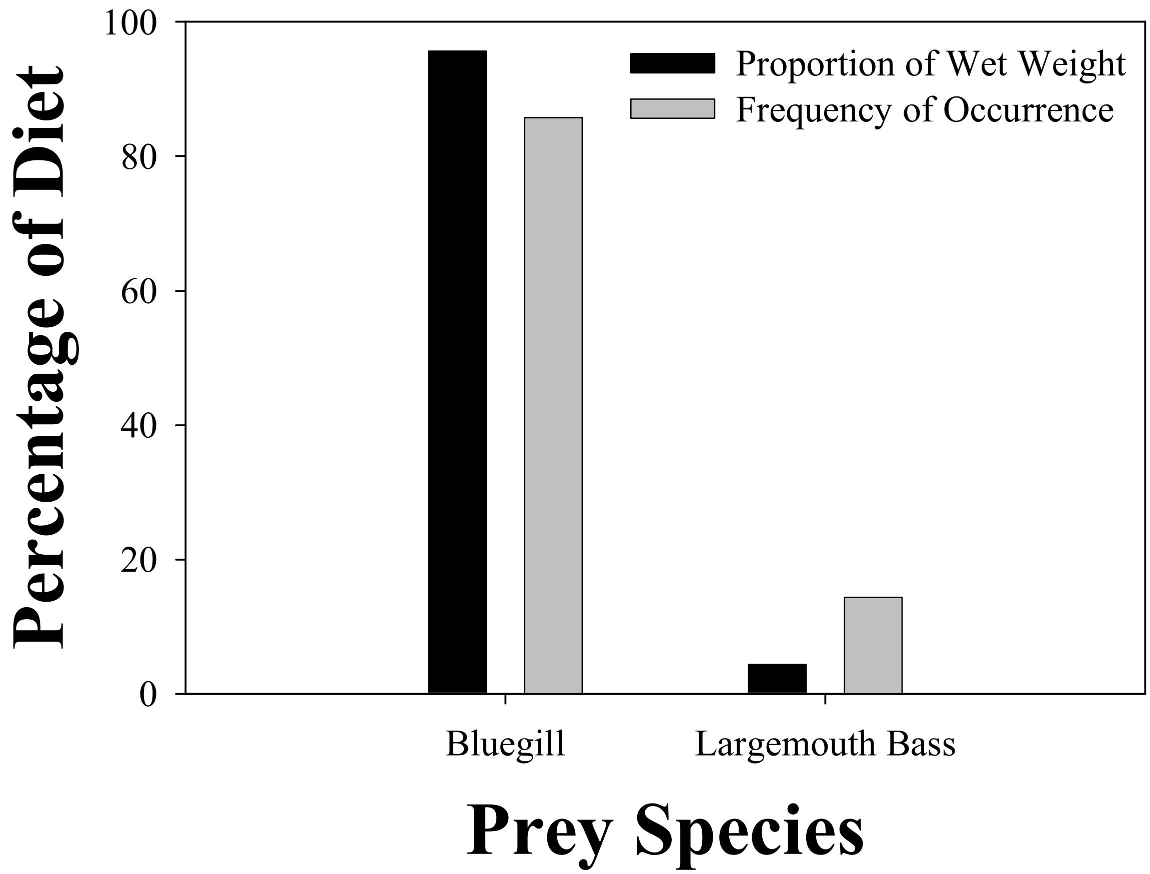

Figure 14. Mean catch per unit effort of largemouth bass in lakes Mingo and Homer 1998-2005. Date of initial muskellunge stocking (fall 2002) is denoted by black arrow.

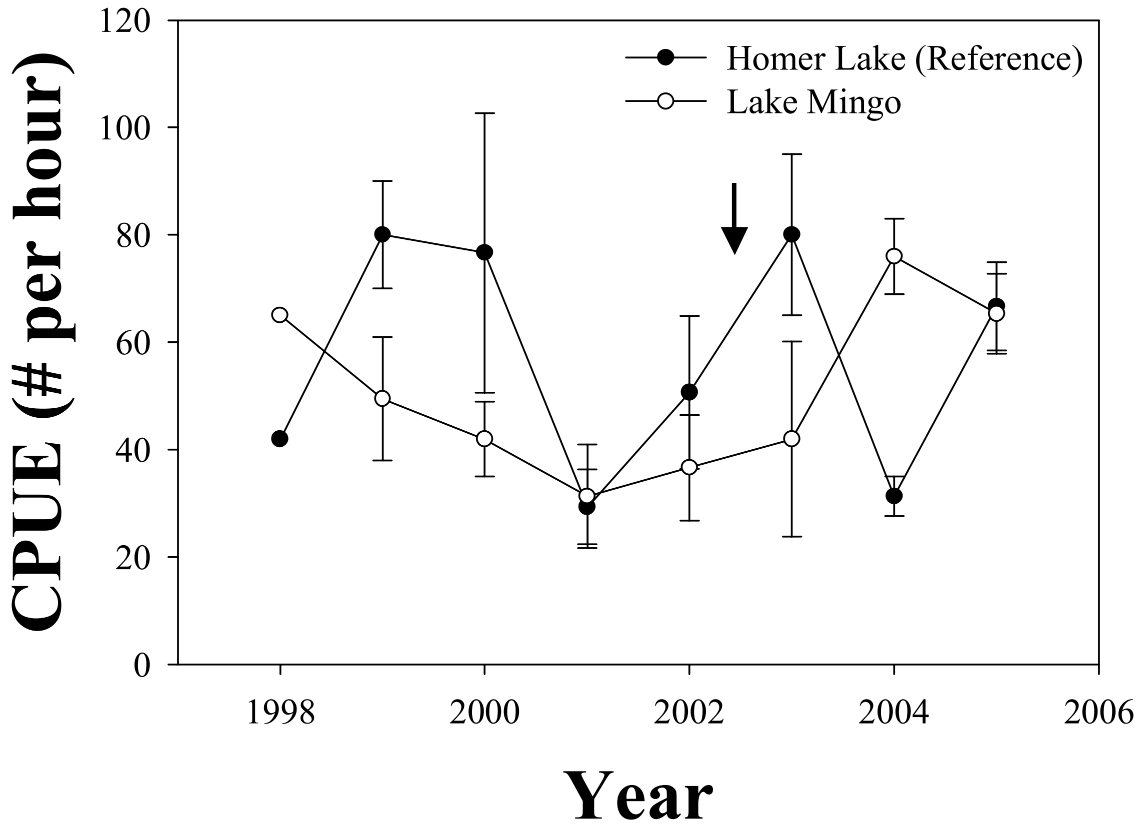

Figure 15. Mean length of gizzard shad collected during fall shoreline electrofishing samples in lakes Mingo and Homer 2001-2005. Date of initial muskellunge stocking (fall 2002) is denoted by black arrow.